Chapter 1

Introductory Chapter: Why Creep is Continuously Interesting for Science

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Additional information is available at the end of the chapter

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1. Introduction

The following study presents issues related to the broadly defined creep effect, which concerns not only the area of construction materials but also natural phenomena.

The advantage of the book is a very extended set of both theoretical and practical examples of creep testing for various categories of analysis of this process, carried out by scientists of renown in this field from a number of scientific and research centres all over the world. As presented in the book, the emphasis on the discussion of a new trend of experimental creep testing, which binds the classic creep methods to seek the correlation of parameters obtained in tests, deserves particular attention.

The technical progress observed for several years and a variety of interesting results of research, both with regard to the insight into the creep effect and methods for its analysis, have been enhancing the increase in requirements for the strength of new materials and development of new research methods. In particular, it concerns the construction elements and natural phenomena where creep effect that is generally understood as a process of deformation at a specific temperature takes place. Thus, creep is particularly important in many fields of science, such as power engineering, aviation, chemical industry, optical industry, earth sciences, etc., and the issues presented in the study are of great practical, and often utilitarian, significance.

The basic concept of creep defines a process that takes place under constant load, which ensures that stresses are within the Hooke's law range, and at elevated temperature. Therefore, the applied load causes stresses and strains whose values vary not only as a result of overload but also when loading remains unchanged, resulting in stresses lower than the yield strength.

The research carried out for the range of materials has revealed that creep has a significant impact in the event of an increase in the temperature of widely understood materials subjected to analysis. In steel elements creep intensifies even at approx. 400°C, while for materials with low melting temperature, the creep effect can already be observed at room temperature. Therefore, it can be concluded that the need to consider the creep effect in calculations depends on the material, temperature, time and existing load.

To sum-up the following study, it should be stated that the creep tests presented in individual chapters make a significant contribution to solving the issue of developing destructive and non-destructive methods. This concerns not only the creep methods but also the tools to provide information on a failure mode at a specific point of creep progress. Undoubtedly, this brings us closer to development of a set of research methods to ensure that failures and catastrophes in different industries can be avoided.

2. Outline of this book

To outline details of each chapter of the book, the concise summary of each of them is given below.

Whittaker et al. presented a modern philosophy for creep lifing in engineering alloys. The traditional view of creep in materials science is based on the derivation of a power law relationship between stress and the creep rate in the so-called secondary phase. A transition in the value of the exponent of the relationship, n, is often assumed to be representative of a change from dislocation to diffusional creep processes as applied stress levels decrease. However, in operational environments for high-performance alloys such as power generation plant and gas turbine engines, there is little evidence of significant contribution to the overall creep rate from diffusional creep. Furthermore, power law-based approaches have been shown to be flawed in many engineering alloys due to high and unrealistic exponent and activation energy values along with the breakdown of the power law at high stresses. However, modern philosophy, known as the Wilshire equations, is built around the dominance of dislocation activity in creep strain accumulation and has shown significant potential.

Golański et al. presented a study on degradation of the microstructure and mechanical properties of high-chromium steels used in the power industry. High-chromium martensitic steels are one of the basic creep-resisting construction materials used for the modernisation of the old and construction of the new power units. During the service under creep conditions, the metastable microstructure of martensitic steels undergoes gradual degradation. The rate of degradation mostly depends on the temperature of work, but it is also affected by the stresses. The changes in the microstructure of martensitic steels have an influence on the decrease in their mechanical properties, including creep resistance. The knowledge and description of the changes in the microstructure of steels working in creep conditions allow extending the time of safe operation of the elements of power systems. The paper presents and describes the main mechanisms of degradation of martensitic steels of the 9–12%Cr type on the basis of the independent studies and literature data.

Rękas et al. presented an article on the subject of high-temperature creep of metal oxides. This chapter presents a comprehensive review of the creep technique used for the study of defect structure and diffusion in metal oxides, both single crystals and ceramics. At high temperatures, the creep rate is proportional to the diffusion coefficient of the slowest species in solid compounds, whatever deformation mechanisms are present (Nabarro viscous creep, recovery creep or pure climb creep). The creep rate dependence on deviation from stoichiometry can be determined from this diffusion. In the case of metal oxides, the departure from stoichiometry is controlled by the oxygen activity which usually is identified with oxygen partial pressure (pO_2). The pO_2 dependence of the creep rate provides direct information about the nature of minority point defects. On the other hand, studies of the temperature dependency of the creep rate inform us about the activation energy of the diffusion coefficient.

Han-Yong et al. presented the review of long-term durable creep performance of geosynthetics by constitutive equations of reduction factors. The exact nature of the time dependence of the mechanical properties of a polymer sample depends upon the type of stress or straining cycle employed. During creep loading, a constant stress is applied to the specimen at t=0, and the strain increases rapidly at first, slowing down over longer time periods. In an elastic solid, the strain stays constant with time. In this case, the strain is held constant, and the stress decays slowly with time. The increase in strain is not linear, and the curve becomes steeper with time and also as the stress rate is increased. If different constant strain rates are used, the variation of stress with time is not linear. The slope of the curve tends to decrease with time, but it is steeper for higher strain rates. The variation of both strain and stress with time is linear for constant stress and strain rate tests upon elastic materials.

Liu et al. presented a unified creep-fatigue equation with application to engineering design. The chapter reviews the existing creep-fatigue equations. It then describes the principles of the unified creep-fatigue equation. This equation is then applied to a variety of materials: SS316, SS304, Inconel 718, GP91 and AL2024-T3 at multiple temperatures and cyclic times. Next, we assess the economy of this theory by evaluating the life prediction error with overall experimental cost. This leads to the presentation of a simplified form for the unified formulation, which has minimal testing requirements for material characterisation, hence good usefulness to design. Finally, a case study for a gas turbine disk is given, showing how the equation may be applied to material properties in finite element analysis (FEA).

Abdallah presented creep lifing models and predictions. The chapter will help researchers to employ such models on the various materials and alloys under varying conditions of stresses and temperatures under creep. This chapter presents novel methods that are able to model, simulate and reconstruct full creep curves based on short-term measurements. The chapter also shows to explore the creep behaviour of materials that are being used in the gas turbine aero engine. This work will also help researchers to understand the theory behind the long-term creep behaviour and predictions. The models will provide a tool through which physically meaningful interpolation and extrapolation of the creep data can be obtained.

Lancaster et al. presented the creep method—small punch creep (SPC). A thorough characterisation of the creep properties of any modern alloy designed for a structural application can be an expensive and timely process. As such, significant effort is now being placed in identifying suitable alternative characterisation techniques. The small punch creep (SPC) test is now widely regarded as an effective tool for ranking and establishing the creep properties of a number of critical structural materials from numerous industrial sectors.

Over recent years, the SP creep test has become an attractive miniaturised mechanical test method ideally suited for situations where only a limited quantity of material is available for qualification testing. Typically, the method requires only a modest amount of material and can provide key mechanical property information for highly localised regions of critical components. As such, SP creep testing offers a feasible option for determining the creep properties of novel alloy variants still at the experimental stage and the residual life of service-exposed material.

Xu et al. in the chapter, "Thermo-Mechanical Time-Dependent Deformation and Fracturing of Brittle Rocks," proposed a thermo-mechanical numerical model to describe the time-dependent brittle deformation of brittle rocks under different constant temperatures and confining pressures. The mesoscale model accounts for material heterogeneity through a stochastic local failure stress field and local material degradation using an exponential material softening law.

Importantly, the model introduces the concept of a mesoscopic renormalisation to capture the cooperative interaction between microcracks in the transition from distributed to localised damage.

Monfared showed the review on creep analysis and solved the problem. Creep in solids subjected to high stress, and temperature is one of the important topics in the scientific societies: therefore, the creep analysis becomes more significant in various industries. So, the creep analysis is vital and important for applications connecting high temperature and high stress. Therefore, a thorough knowledge of creep characteristics and deformation mechanisms of reinforced and non-reinforced materials is required to utilise the materials in high-stress and high-temperature applications.

Harrison et al. presented an article on advanced methods for creep in engineering design. Novel creep deformation and damage methods are considered for creep-resistant alloys and compared to existing methods. Focusing on the three candidate models, the theta-projection technique, a true-stress model and a new method based on the Wilshire equations, the merits of alternative approaches to full creep curve representation have been considered. The evaluation of parameters for these models has been investigated with respect to the micromechanical phenomenon. These models have been implemented in the commercially available finite element analysis software, Abaqus, and in doing so, an evaluation of creep hardening models has been made. An alternative approach to creep hardening is presented which relates creep rate to material state variables instead of the traditional approach of time or strain hardening. The ability of these models to represent transient creep has been assessed by comparing predictions to experimental test results at nonconstant creep conditions.

Sandström showed the fundamental models for the creep of metals. Analysis of creep properties has traditionally been made with empirical methods involving a number of adjustable parameters. This makes it quite difficult to make predictions outside the range of the original data. In recent years, the author has formulated basic models for prediction of creep properties, covering dislocation, particle and solid solution hardening. These models do not use adjustable parameters. In the present chapter, these models are further developed and utilised.

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The dislocation mobilities play an important role. The high-temperature climb mobility is extended to low temperatures by taking vacancies generated by plastic deformation into account. This new expression verifies the validity of the combined climb and glides mobility that has been used so far. By assuming that the glide rate is controlled by the climb of the jogs, a dislocation glide mobility is formulated.

The role of the mobilities is analysed, and various creep properties are derived. For example, secondary creep rates and strain versus time curves are computed and show good agreement with experimental data.

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