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MODELING AND STUDY OF NONLINEAR RHEONOMIC PROCESSES AT SMALL DEFORMATIONS (THE CONCEPT OF PERMANENT MEMORY)

ABSTRACT

of the dissertation in prtial fulfillment of the requirements
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Relevance of the research topic. Modern materials science requires a comprehensive study of the behavior of materials under long-term exposure to loads, as creep and stress relaxation processes significantly affect their durability and operational characteristics. The relevance of this work is determined by the need to predict the behavior not only of asphalt concrete but also of other rheonomic materials used in construction and machine engineering. This research performs a comprehensive analysis of experimental data, including both results from the author's own experiments and data presented in scientific publications by other authors. Using experimental data from various researchers allows the formation of a more accurate and justified model for describing material behavior under creep and stress relaxation conditions. The obtained results can be applied in the practice of creating more durable materials optimized for operation under prolonged load exposure, ultimately improving the quality and longevity of road and other engineering infrastructure.

Purpose of the work. To create a model describing the creep and stress relaxation processes of rheonomic materials to predict their deformation behavior at various temperatures and loading rates.

Research objectives:

1. Develop a model to describe the stages of creep and stress relaxation in asphalt concrete and other materials.
2. Study the influence of temperature and loading rate on the deformation properties of materials at different stages of creep.
3. Perform a comparative analysis of experimental data obtained both in the author's own research and from other sources to justify the applicability of the model to various materials.

The research object is various rheonomic materials and their behavior under creep and stress relaxation conditions, including the influence of temperature.

The research subject is the features of the manifestation of creep and stress relaxation in different rheonomic materials.

Research methods. The study is carried out according to the traditional approach of solid mechanics, based on the principles of continuum mechanics and experimentally observed facts. Nonlinear integral equations, the permanent memory hypothesis, and statistical methods are applied.

The theoretical and practical significance of the research lies in the development of approaches to describe the processes of creep and stress relaxation in rheonomic materials, such as asphalt concrete. The application of the permanent memory hypothesis and nonlinear integral equations deepens existing representations of the mechanics of deformable bodies and allows for more accurate modeling of material behavior under prolonged load exposure. The resulting models and conclusions can be used to predict the deformation behavior of materials under real operating conditions, which contributes to the optimization of material composition and conditions for their use in road construction and other industries. This research provides tools for increasing the durability and reliability of structures subjected to prolonged loads, which is especially important for creating sustainable and safe infrastructure.

The scientific novelty of the research lies in the development and justification of a new model that describes the processes of creep and stress relaxation in rheonomic materials, taking into account the permanent memory hypothesis and the use of nonlinear integral equations. A comprehensive analysis of the influence of temperature conditions on the behavior of various rheonomic materials under prolonged exposure has been conducted, which clarified the mechanisms of deformation and damage accumulation. The obtained results and the proposed dependencies expand existing representations of material behavior under prolonged loads and can serve as a basis for further research in continuum mechanics and rheology.

Formulation of research tasks

To achieve the goal of the research aimed at creating a model describing the creep and stress relaxation processes of rheonomic materials under small deformations at various temperatures and loading rates, the following tasks were set:

1. Develop a mathematical model to describe the stages of creep and stress relaxation in asphalt concrete and other rheonomic materials, taking into account the permanent memory hypothesis and nonlinear integral equations.

2. Study the influence of temperature and loading rate on the deformation properties of rheonomic materials, including asphalt concrete, polymer concrete, metal alloys, and other materials, at different stages of creep.

3. Perform a comparative analysis of experimental data obtained both in the author's own research and from scientific publications by other authors, to confirm the universality of the proposed model and its applicability to various types of materials.

4. Determine the similarity criteria of relaxation curves of rheonomic materials, such as similarity criterion, quasi-similarity criterion, and lack of similarity, to systematize and improve the prediction of material behavior under prolonged load exposure.

Research in the field of modeling nonlinear rheonomic processes began in the mid-20th century when the need arose for a more accurate description of complex materials that exhibit nonlinear and viscoelastic properties. Initially, models focused on linear rheological processes, but as the theory of elasticity and plasticity developed, scientists began to pay attention to material behavior under nonlinear deformations.

The concept of decaying memory, or memory with decay, refers to models describing the behavior of materials that are able to remember and partially retain information about past deformations, but with gradual loss of this data over time. This behavior is observed in a number of materials and systems, especially in viscoelastic materials, polymers, and biological tissues.

Key aspects of the concept of decaying memory:

1. **Phenomenology:** Unlike permanent memory, where a material or system "remembers" previous impacts for a long time or forever, decaying memory assumes that information about previous impacts gradually disappears. The longer the material remains unloaded, the weaker its "memory" of the previous state.

2. **Mathematical modeling:** Decaying memory is described by equations containing functions that decrease over time, such as exponential decay. One example is the use of integral operators with time-dependent kernels, allowing the modeling of the gradual fading of memory of deformations. Classical models, such as Maxwell's model, can also be adapted to account for decaying memory by adding nonlinear and time-dependent factors.

3. **Application in science and technology:** Models of decaying memory are important for analyzing materials where long-term memory is undesirable (for example, in structures subject to vibrations), as well as in biomedical applications, where tissues need to partially "forget" loads to restore their elasticity.

4. **Physical nature of decaying memory:** This phenomenon is related to relaxation processes in the material, where internal stresses and deformations are released and return to their original state. In polymers and biological materials, decaying memory may arise due to the rearrangement of molecular chains and changes in intermolecular bonds.

Examples of studies and models

Among the models studied that account for decaying memory, one can mention works on nonlinear viscoelasticity and mathematical models that use the superposition principle with consideration of temporal decay. Such approaches have been applied in the description of polymers and alloys, as well as in shape memory systems where controlled decay of deformation "memory" is required.

The process of creep testing at a constant load, as known, initially decreases the creep rate (first stage), then remains nearly constant for a while (second stage), and finally increases again (third stage). The third stage of creep precedes failure.

Currently, there is a relatively small amount of reliable experimental data describing the creep of rheonomic materials up to failure over a wide range of stresses. This is because tests under small stresses can last tens of thousands of hours. Therefore, such tests are often either not conducted to failure (i.e., long-term strength is not considered), or they are conducted to failure without measuring deformations during creep. The limited and fragmented factual material leads to the fact that the question of formulating a mechanical equation of state and kinetic equations that take into account the process of destruction remains largely open.

This chapter presents the results of creep tests under pure tension of asphalt concrete samples to failure, conducted at Kazakhstan Road Research Institute, and also proposes a model for describing uniaxial creep of rheonomic material up to failure.

This chapter provides and analyzes the results of experimental determination of deformation and failure characteristics of asphalt concrete at eleven loading rates ranging from 0.000563 MPa/s to 0.652 MPa/s, differing by a factor of 1158. For the study, a traditionally used hot fine-grained dense asphalt concrete of type B was selected, prepared with the use of viscous bitumen grade BND 100/130. The tests were carried out at a temperature of 22-24°C in a specially invented and assembled setup using a direct tension scheme. The asphalt concrete samples had the shape of rectangular beams with dimensions of 5x5x15 cm. It was found that from the beginning of loading to failure, asphalt concrete deforms nonlinearly. The degree of nonlinearity increases with increasing load. The loading rate has a strong influence on the deformation and failure characteristics of asphalt concrete: when the loading rate is increased by a factor of 1158 (almost 1200) from 0.000563 MPa/s to 0.652 MPa/s, the time to failure, the specific work of failure, and the deformation at failure decrease by a factor of 242, 160, and 3, respectively, while the strength increases by a factor of 5. The dependencies of the failure characteristics of asphalt concrete (time to failure, deformation at failure, specific work of failure, and strength) on the loading rate are described with high accuracy by a power function.

Basic information on creep is obtained from standard tension tests under constant load. The data from these tests are presented in the form of so-called creep curves. A typical creep curve is usually divided into three sections. In the first section (first stage), the deformation rate is variable and decreases over time, reaching a minimum value. In the second section (second stage), the creep rate is constant. In the third section (third stage), the creep rate increases again until sample rupture occurs. The creep process does not always follow this pattern. The first or third section may be absent, or the first section may transition directly into the third.

The reduction of the deformation rate in the first section is explained by the material strengthening, as the deformation of the sample is accompanied by structural changes that hinder creep. Transition to the second section means that the material's ability to strengthen is exhausted. The accelerated creep in the third section, according to Costa de Andrade, is related to a change in the cross-sectional area of the sample. Therefore, under constant stress, the third stage of creep should not occur. However, the third stage of creep under constant nominal stress exists for many materials. The destruction of material under prolonged load exposure occurs due to crack formation. The appearance of cracks reduces the effective cross-sectional area of the sample and, according to Workman, increases the effective stress. The effective stress is not equal to the nominal stress, which is why the third stage of creep results in an increase in creep rate. When the effective cross-sectional area approaches zero, the sample breaks. Rupture occurs when microscopic cracks merge and form a macrocrack.

The issue of the movement or equilibrium of a macrocrack in this setup is not of major importance; the main role is played by the kinetics of microcrack accumulation. When the density of microcracks reaches a critical level, failure occurs.

Failure of a solid body, in the literal sense, refers to its division into parts associated with the formation of new surfaces. The process of forming these new surfaces can be described as crack growth. Here, the term "crack" in

Workman's sense is used in its most general form and refers to changes in geometry.