Experimental studies on creep running at high temperatures over days and weeks

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Abstract. Experimental studies are helpful for both verifying existing theoretical predictions and finding new phenomena. Conducting long-term high-temperature experiments is subject to a number of difficulties. These difficulties are considered when conducting high-temperature tests for creep and long-term strength. The paper presents solutions to the most typical problems arising during the set-up and running of long-term tests. The problems of stabilization of the temperature in the furnace, measurement of the parameters of the heated specimen and fire safety are considered.

1. Introduction

Any theory requires experimental verification. Experimental studies help not only to verify existing theoretical predictions, but also to find new phenomena. All materials change their characteristics under the action of temperature. One of the changes of mechanical characteristics with increasing temperature is the appearance of a substantial creep of the material. Under these conditions, the loaded material increases deformation over time. The founder of this research area is Yu. N. Rabotnov [1]. In the literature there are many experimental studies of the creep of a material at elevated temperatures running for a relatively short time. The number of such experiments running over longer times (days and weeks) is very limited. Obviously, this is due to the complexity of these long-term experiments.

The work of Nadai [2] is one of the first significant publication that summarizes and describes the experimental studies on creep. This work provides data on numerous experimental studies on creep.

Long time experiments are given in [3]. For presented time (100000 h) in [3] is used recalculation for long-term strength from shorter-term experiments.

Long-term tests are properly set-up, when the deformation and stress are measured simultaneously. In [4], the studies of assessing the reliability of pavements due to cyclic impacts from traffic loads are presented. However, even in this case, the development of a measuring instrumentation is necessary.

2. Problem definition

The problem of conducting high-temperature tests for creep and long-term strength are considered. A fundamental factor required for carrying out such tests is a complicated equipment. Modernization of the experimental base for the preparation and conduction of the time-consuming tests at high temperature is an urgent and sought-after problem which solution would allow new experimental
This paper presents solutions to the most typical problems that arise during setting-up and running the long-term tests.

3. Solution

A creep testing is usually carried out as follows. The specimen is installed in a testing machine fixed in rods placed in a heating furnace. The furnace is heated to a predetermined temperature and the specimen is loaded with a given load. The specimen is deformed at this fixed load to failure. At some point in time, a narrowing (neck) appears in the working zone of the specimen where the deformation mainly concentrates further on. Furthermore deformation increases the neck area until the specimen is destroyed.

Many difficulties arise at a high-test temperature. They are associated with the need for, firstly, the temperature stabilization in the entire volume of the furnace over a long time, secondly, measurement of the parameters of the heated specimen, thirdly, fire safety, as well as others.

3.1. The measurement system

The well-known DIC method was originally planned to be applied for estimating the deformations of the specimen. However, after a series of preliminary tests, it turned out that this method does not work at high temperatures. The measurement of the parameters of the heated specimen is most convenient to obtain with a non-contact method [5]. In accordance with [5] we developed our own software package. The method is based on periodic photographing the specimen through a viewing window in the furnace wall. From the experiment, several hundreds of photographs are obtained, depending on the deformation of the specimen and the frequency of shooting. These files in the JPG or RAW format contain EXIF-data about the moment of shooting. The photographs are processed on a powerful workstation computer. We developed a software package that implements this processing. The whole instrumentation operates in a semi-automatic mode: for each frame, the boundaries of the working area of the specimen and pre-determined grid points in the vicinity of the area of appearance of the deformation are intelligently recognized. If the automatic module incorrectly recognizes an area then a manual adjustment is possible. This program creates a three-dimensional numerical model of the deformation of the specimen. According to these models, statistical data are collected from all experiments which reveal the patterns and criteria of interest.

![Figure 1. The modified door of a furnace: (a) – a model of a door (shortening) with an additional brick and hole (in center), (b) – a furnace photo (stretching) with viewing window (in center).](image-url)
3.2. The furnace modification

The temperature is stabilized by a furnace control unit. A common feature of industrial furnaces is location of the thermocouples near heating elements. This makes impossible to maintain the exact temperature of the specimen. The temperature of the specimen over a long period of time can be affected by drafts in the room, doors opened over a long time, a change in room temperature, etc. A more accurate temperature maintenance is possible by means of direct contact of the specimen with the thermocouple. For example, when each specimen is installed the thermocouples, connected to the control unit, are placed in contact with it.

For the contactless measurement method to work, it is necessary to have visual access to the specimen. This was done by means of the viewing windows made of quartz glasses (figure 1) that were made in the oven doors. In order to modernize the furnace door, a simulation was carried out on the specimen compression unit to determine the required dimensions of the additional brick, because insulating material does not allow to make a hole of the right size.

3.3. The lighting

One of the key features of the experimental set-up is the problem of lighting. For a clear photograph of the specimen in the process of deformation at 400°C, its illumination by heating elements is not enough. Therefore, a lamp is placed inside the furnace (figure 2). The lamp is fixed and powered with electricity through ceramic holders and nichrome wire. When the operating temperature increases from 400 to 600°C, the lighting lamp begin to burn out. Therefore the control system is modified so that the lamp is turned off most of the time between photographing and only shortly before a particular photograph is turned on. The lamp control is fully automatic.

3.4. The camera type

In order to register the process of deformation, a household and industrial video cameras were used, but the quality of their pictures (figure 3c) and high recording speed did not allow them to be used. The most appropriate for the creep tests is a digital camera.

For contactless motion measurement, a NIKON D300s camera with a NIKKOR 80-200 mm lens and a 12 mm extension ring is used for focusing at close distances. The focal length was set at 130 mm and the camera was set at a distance of 1 m from the furnace (figure 3d).
3.5. The camera control unit
The development of a narrowing in weakened place of the specimen occurs with velocities several orders of magnitude greater than the strain rates of the initial stage. Therefore, there is a need to create a device for controlling the shooting speed depending on the speed of the creep process in the automatic mode. Such a device was developed by the author. The device includes a linear resistive sensor connected via a rod to a moving machine, a housing and an electronic system with a display that converts data from a resistive sensor into control signals for the camera. The developed model is shown in figure 3a whereas the manufactured device is shown in figure 3b.

![Figure 3a](image1)

![Figure 3b](image2)

![Figure 3c](image3)

![Figure 3d](image4)

**Figure 3.** The model of the camera control unit (a), the real control device (b), a fragment of a photograph of the cylindrical specimen obtained with an ordinary camera (c) and adapted camera (d).

3.6. The reference lines
To study the deformations in the developing neck, a shallow grid is notched on the surface of a flat specimen, that is the reference lines, which are used in the computer processing (figure 4).

![Figure 4](image5)

**Figure 4.** Photograph of a specimen with the reference lines.

For drawing reference lines on specimens of small cross-section, the author created a table milling machine with digital control and a tool for applying the grid of lines on a flat specimen. A special
computer program was also developed for generation of the control program (written in G-code) for the milling machine.

3.7. The remote control
During long-term experiments with high temperatures running over several weeks, the fire safety is one of the main issues. In order to both control the course of the experiment is necessary and to have a video access, a remote control of the heating process was developed.

For remote control of the experiment, a video surveillance system is implemented using 4 webcams placed nearby the experimental installation, a mini-PC-based video server and free «iSpy» software (figure 5). The remote access from outside (via the Internet) is configured through a video server that allows to control the course of the long-term experiment from anywhere in the world.

An emergency shutdown of the heating can be implemented on the basis of TP-Link smart sockets.

![Figure 5. Schematic view of the remote control system.](image)

4. Conclusion
The solution of described problems allows us to carry out long-term (over the course of days and weeks) full-scale tests, from which, with the help of the created software package, we can obtain unique data for a high temperature creep. For long-term experiments, an integrated approach should be used when organizing tests. The most significant is the ability to remotely monitor and control the course of the experiment, as well as remote measurement of specimen parameters.

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