Development of a Constant - Stress Creep Testing Equipment.

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ABSTRACT

The design and development of constant stress creep testing equipment has been undertaken in this work. It was discovered that the cost of purchasing laboratory testing equipment is huge due to the present foreign exchange rate in Nigeria, thereby depriving most of laboratories of this necessary equipment. This accounts for one of the reasons why many science and engineering graduates go through tertiary institutions without having adequate practical experience of some of these equipment which are either non functional or not available in most cases. The developed constant stress creep testing equipment is one of such equipment required in a materials testing laboratory. The materials used for the equipment development were locally sourced, therefore expected to be easily assessable and affordable as well as preserve foreign exchange. As of July, 2010, a unit cost less than N 250,000 Nigerian (approximately $1,700 U.S.).

(Keywords: development, constant stress creep, testing equipment, materials testing, laboratory, cost)

INTRODUCTION

In materials science, creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to high levels of stress that are below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near melting point. Creep always increases with temperature.

The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode. Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep is a "time-dependent" deformation.

The temperature range in which creep deformation may occur differs in various materials. For example, tungsten requires a temperature in the thousands of degrees before creep deformation can occur while ice will creep near 0 °C (32 °F)[1]. As a rule of thumb, the effects of creep deformation generally become noticeable at approximately 30% of the melting point (as measured on a thermodynamic temperature scale such as Kelvin or rankine) for metals and 40–50% of melting point for ceramics. Virtually any material will creep upon approaching its melting temperature. Since the minimum temperature is relative to melting point, creep can be seen at relatively low temperatures for some materials. McCrum, et al. (2003) stated that Plastics and low-melting-temperature metals, including many solders, creep at room temperature as can be seen markedly in old lead hot-water pipes.

Importance of Creep Test

In the Creep Test, loads below those necessary to cause instantaneous fracture are applied to the material, and the deformation over a period of time (Creep Strain) under constant load is measured. Ferdinand and Johnston (2006) asserted that creep deformation is important not only in systems where high temperatures are endured such as nuclear power plants, jet engines and heat exchangers, but also in the design of many everyday objects. In steam turbine power plants, pipes carry steam at high temperatures (566 °C or 1050 °F) and pressures (above 24.1 MPa or 3500 psi). In jet engines, temperatures can reach up to 1400 °C (2550 °F) and initiate creep deformation in even advanced-coated turbine blades. Hence, it is crucial for correct functionality to understand the creep deformation behavior of materials.

For example, metal paper clips are stronger than plastic ones because plastics creep at room temperatures. Aging glass windows are often erroneously used as an example of this phenomenon: measurable creep would only occur at temperatures above the glass transition temperature around 500 °C (900 °F). While glass does exhibit creep under the right conditions, apparent sagging in old windows may instead be a consequence of obsolete manufacturing processes, such as that used to create crown glass, which resulted in inconsistent thickness.[6][7]

BASIC THEORY

Stages of Creep

There are three stages of creep viz the Primary, Secondary and Tertiary. Figure1 shows the graph of strain as a function of time due to constant stress over an extended period for a viscoelastic material. It is used to explain the three basic stages.

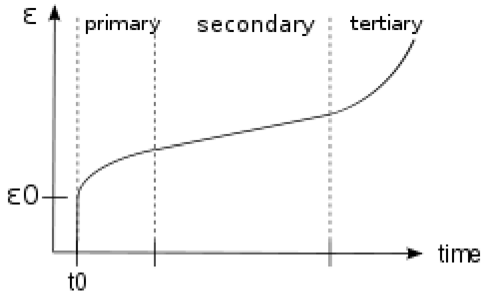

Figure 1: Strain as a Function of Time due to Constant Stress over an Extended Period for a Viscoelastic Material.

(Source:http://en.wikipedia.org/wiki/Creep%28deformation%29)

Primary Stage: In the initial stage, or primary creep, the strain rate is relatively high, but slows with increasing strain. This is due to work hardening.

Secondary Stage: Creep proceeds at a constant rate because a balance is achieved between the work hardening and annealing (thermal softening) processes.

Tertiary Stage: In tertiary creep, the strain rate exponentially increases with stress because of necking phenomena.

In terms of dislocation theory, dislocations are being generated continuously in the primary stage of creep. With increasing time, more and more dislocations are present and they produce increasing interference with each other's movement, thus causing the creep rate to decrease. In the secondary stage, a situation arises where the number of dislocations being generated is exactly equal to the number of dislocations being annealed out. This dynamic equilibrium causes the metal to creep at a constant rate. Eventually, however, the creep rate increases and the specimen fails due to localized necking of the specimen (or component), void and micro crack formation at the grain boundaries, and various metallurgical effects such as coarsening of precipitates.

When in service, an engineering component should never enter the tertiary stage of creep. It is therefore the secondary creep rate, which is of prime importance as a design criterion as suggested by Meyers and Chawla (1999). Components, which are subject to creep, spend most of their lives in the secondary stage, so it follows that the metals or alloys chosen for such components should have as small a secondary creep rate as possible. In general it is the secondary creep rate, which determines the life of a given component.

Mechanisms of Creep

The mechanism of creep depends on temperature and stress as asserted by Richard and Paul (2004). The various methods are:

- Bulk diffusion (Nabarro-Herring creep)
- Climb — here the strain is actually accomplished by climb

- Climb-assisted glide — here the climb is an *enabling* mechanism, allowing dislocations to get around obstacles
- Grain boundary diffusion (Coble creep)
- Thermally activated glide (e.g., via cross-slip)

General Creep Equation

The general creep equation is given in Equation 1:

$$\frac{d\epsilon}{dt} = \frac{C\sigma^{m}}{d^{b}} e^{\frac{-Q}{kT}} \qquad \textbf{(1)}$$

Where:

ϵ is the creep strain

C is a constant dependent on the material and the particular creep mechanism,
m and *b* are exponents dependent on the creep mechanism,
Q is the activation energy of the creep mechanism
σ is the applied stress
d is the grain size of the material
k is Boltzmann's constant
and *T* is the absolute temperature.

BASIC DESIGN

The aim of this work is to develop a constant stress creep testing equipment suitable for use in materials testing laboratories of tertiary institutions in Nigeria. The equipment designed was developed at minimum possible cost without compromising the expected efficiency. The designed equipment components include: the frame; Cam mechanism; and the furnace. The cam profile was developed using MatLab® software and modeling of the overall constant stress creep testing equipment was modeled using parametric 3-D design software- Pro/ Engineer®.

The Cam Profile

The cam was created through the development of a short code was written in MatLab using the equation below:

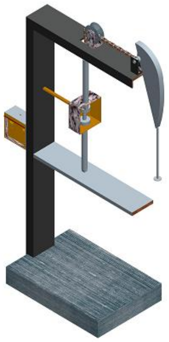

Figure2: Modeled Constant Stress Creep Testing Equipment.

The equation for the profile:

$$a = \frac{r_0 * l_0}{(l_0 - R*\theta)} \qquad \textbf{(2)}$$

$$b = \frac{R}{(l_0 - R*\theta_0)} \qquad \textbf{(3)}$$

$$x = \left(\frac{a}{l_0 + b\theta}\right) * \left(\cos\theta + \left[b * \frac{\sin\theta}{(l + b*\theta)}\right]\right) + R*\cos\theta \qquad \textbf{(4)}$$

$$y = \left(\frac{a}{lo + b\theta}\right) * \left(\sin\theta - \left[b * \frac{\cos\theta}{l + b*\theta}\right]\right) + R*\sin\theta \qquad \textbf{(5)}$$

With the above equations, a program was developed in MatLab® to generate the profile.

The Program was written to ask for the following value:

- lb = input ('Please enter the lower boundary for angle of rotation in Degrees = ');
- ub = input('Please enter the upper boundary for angle of rotation in Degrees = ');
- r_0 = input('Please enter length of moment arm(r0) = ');
- R = input('Please enter Radius of wheel(R) = ');
- l_0 = input('Please input initial Gauge length of specimen(l0) = ');
- theta0 = input('Please input initial angle in degrees = ');

The input data are as stated below;

- R= 25mm, r0 = 100mm, l0 = 35mm, a = 75mm, b = 10 OR 7, ø = 0

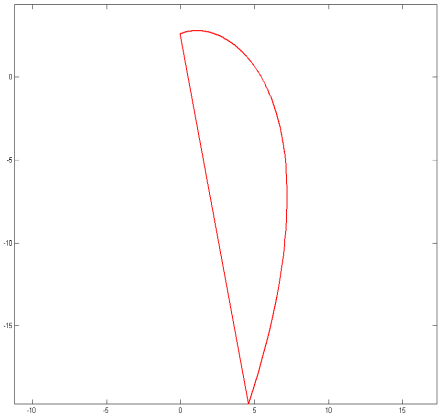

Figure 3: The Cam Profile Generated from MatLab®

Figure 4: The Modeled Cam Profile.

The Furnace

The furnace was modeled and designed using Computer Aided Design and Manufacturing (CAD/CAM). The modeled diagram is shown below. The inner part of the furnace was made with galvanized sheet while the other part was constructed with mild steel. It was designed to operate at a maximum temperature of about 1000^0C.

Table 1: Major Materials Specifications (Authors' Estimate; 2010).

S/N	Part Name	Specification
1.	Cam	2mm Mild steel sheet
2.	Furnace	Temperature of 800-1000^0C
3.	Control box	Lagged mild steel
4.	Frame	5" U-Channel (Mild steel)

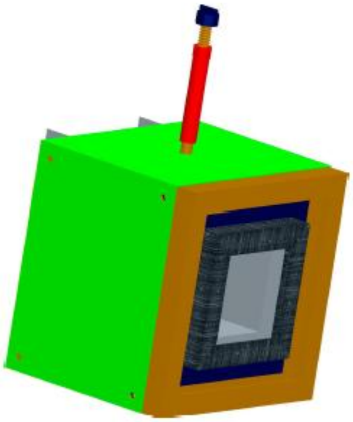

Figure 5: The Modeled Furnace without the Door.

Figure 6: The Developed Furnace.

Figure 7: The Developed Constant Stress Creep Testing Equipment.

CONCLUSION

The equipment was successfully designed and developed using Computer Aided Design and Computer Aided Manufacturing, at the lowest cost possible. The success recorded in developing the equipment coupled with the relatively low cost of production is expected to make the equipment available and affordable in materials testing laboratories across tertiary institutions in Nigeria. The developed equipment will also enhance the quality of teaching and learning of materials science and engineering in developing country like Nigeria.

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SUGGESTED CITATION

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