Biomaterials Journal
http://www.biomatj.com
Online ISSN: 2812-5045

Type of the Paper (Review Article)

Creep in dentistry: a review

Layla Bakir [1*]

[1] *Dental Biomaterials Department, Faculty of Dentistry, Cairo University, Egypt.*

* Corresponding author e-mail: *layla_bakiir@hotmail.com*

Citation: *Layla Bakir* . *Creep in dentistry: a review* . Biomat. J., 1 (7),9 – 15 (2022).

*https://doi.org/10.5281/*zenodo.5829408

Received: 15 June 2022

Accepted: 30 June 2022

Published: 31 July 2022

Abstract: Materials are often placed in service in the oral cavity at elevated temperatures and exposed to static stresses. Deformation under these conditions is called Creep. Creep is normally undesirable and limit the lifetime of the material.

Keywords: *Creep, Creep in dentistry, Creep mechanism, creep testing*.

Introduction

Creep is a viscoelastic property of the material. It's a time-dependent permanent plastic deformation of materials when subjected to a constant load below its yield strength at a temperature greater than 0.4 the melting temperature. [1]Creep is observed in all materials, it's observed at a temperature greater than 0.4 the melting temperature.
Creep rupture is the fracture of the material due to the creep process.[1]

Creep Curve:

Creep curve has insights into the relative elastic, viscous and inelastic response of the viscoelastic material. 2 Creep recovery curve is obtained from data collected during load removal. In this curve, after the load is removed, there is an instantaneous drop in strain and slower strain decay to steady-state strain. The instantaneous drop is the recovery of the elastic strain. The slower recovery is the inelastic strain, and the remaining permanent strain is the viscous strain2 (Figure 1)

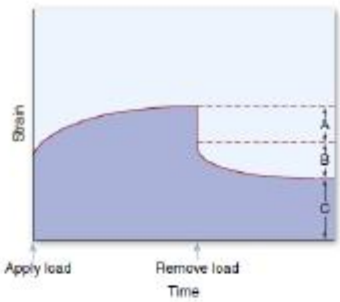

Figure 1: Creep recovery curve

Stages of Creep:

Creep consists of three regions; each has its own strain-time feature.

- Primary creep (Transient creep): In the primary stage, the strain rate is high, and it decreases with increasing time and strain. This is because of increasing the creep resistance or strain hardening.

- Secondary creep (Steady state creep): the creep rate is small and the strain increases slowly with time, so the plot is linear. This is the longest creep duration. Secondary creep is the dominant in most applications. This constancy is due to the equilibrium between softening and hardening.

- Tertiary creep: The strain rate increases rapidly until rupture, and the formation of internal cracks, cavities and voids.

Creep Mechanism:

1) Creep by dislocation slip

a) Glide

It occurs at high stresses and relatively low temperature. It involves motion of dislocation especially in metals where the density of dislocation is high. At stress below yield strength, no dislocation glide occurs. When the stresses are approaching the yield strength for long time, progressive dislocation occurs.

b) Climb

When dislocation glide reaches an obstacle, the stress is not enough for dislocation to overcome the obstacle, so dislocation climbs to a parallel slip plane. As the temperature increases, the atoms gain energy, so the vacancies in the metal increase. Vacancies should be at the site where climb is supposed to occur to allow vacancy-atom exchange.

2) Diffusion Creep

It occurs at high temperature and low stresses compared to the dislocation motion.

a) Grain boundary

The shape has changed from atoms becoming redistributed by diffusion. This type of dislocation occurs through the grain boundaries, it is referred to Coble Creep. Increasing the temperature increases the creep rate as the rate of diffusion become higher due to the high temperature. The activation energy for the grain boundary diffusion is low, and the cross sectional area for boundary diffusion is less than the bulk. So it occurs at low temperature and for samples with fine grain size.

b) Bulk diffusion

It occurs within the crystal lattice of the grain rather than the grain boundaries. It is called Nabarro-Herring creep. The cross sectional area via crystal lattice is high, especially if the grain is large. Bulk diffusion is temperature dependent, the activation energy is higher. This type of creep occurs at higher temperature and with large grains or single crystals.

c) Grain boundary sliding

In polycrystalline materials, the diffusion creep must be accompanied by grain-boundary sliding to reserve the material continuity. IR mainly occurs at grain boundaries in normal polycrystalline material undergoing diffusion creep.

How to measure Creep?

The major methods for testing creep are:

1) Tensile creep testing

2) Compressive creep testing

3) Flexural testing for creep

4) Impression (hardness) creep testing

5) Stress rupture test

The results of creep tests are plotted as strain-time curves. For metallic material, creep tests are conducted in a uniaxial tension having the same geometry as tensile test. However, for brittle materials, uniaxial com-

pression tests are conducted as no stress amplification and crack propagation.

1) Tensile creep testing:

The Creep test is performed by a tensile specimen to whom constant stress is applied by simple methods of suspending weights from it.

Around the specimen is a thermostatically controlled furnace. The temperature is controlled by a thermocouple attached to the specimen usually in the gage length.

The extension of the specimen is measured with an extensometer.The results of the creep test are plotted as strain versus time to obtain a curve.[3]

A constant tensile stress machine allows evaluation of tensile creep at 0-60°. A special loading arm, as the specimen lengthens by creep, and this reduces its cross section, the moment arm shortens. Temperature control is achieved by heated water bath controlled by thermistors.

The test specimen is based on a standard tensile specimen, it should be proportional, and it should be machined to a tighter tolerance than the standard tensile test.

The specimen should be smooth, scratch-free.[4]

Testing is carried out in the air at atmospheric pressure. If the material reacts with air, they are tested in a chamber contacting an inert atmosphere such as argon or vacuum.

Creep failure occurs in three phases, a rapid increase in length which is known as primary creep where the

creep rate decreases. Then it's followed by a period of constant creep rate known as secondary creep, and it is the longest period of the creep life. The third stage occurs when the creep life is exhausted, and the

cross-section has been reduced. This stage fasts until the specimen finally fails.

The creep test measures the rate at which secondary creep occurs. Increasing the temperature of the stress has the effect of increasing the slope. The results are presented as the amount of strain expressed as a percentage produced by

aplying a specified load.

2) Compressive creep testing

The creep test is performed by applying compressive loading to eliminate growth of cavities and their opening, so the creep rate in compression is slower than tension.

Creep tests are better to be performed under uniaxial conditions such as tension or compression because the analyses of the uniform stress results are simple.

According to ISO specification (ISO 1559), and ADA no.1 for amalgam testing creep refers to the deformation of amalgam under compressive stresses of 36 MPa of the specimen. The specimen of 4 mm in diameter and [7] mm in height were subjected to the compressive stress of 36 MPa for 4 hours at 37" C The change in length between one hour and four hours shall be recorded after they had been stored at 1, 2, 4, 7 days. The reduction in length was measured using a disc transducer. [5]

3) Flexural creep testing:

Many creep experiments employ flexure tests. There are two common testing methods, three and four-point bending tests.

The specimens are rectangular and without notches. The four points bend setup where the applied force in the lower part is tensile, while the applied force in the upper part is compressive. As a result, calculable bending develops. The machine used is the universal testing machine.

The flexural strength for three-point test of the rectangular bar is applied through force acting on a lever of size L/2, and the force is supported or balanced at the two supporting points marked by arrows near the end of the rectangular bar.

Three-point bending mode is a pure modification of deformation, as the specimen is freely supported by fulcrum without a clamping effect. Constant stress is applied to the surface as the upper arm contacts the specimen, and the resulting strain is measured over time. Once the stress is removed, the recovery strain is measured.[6]

In the paper below, the creep was measured using DMA in three-point bending mode. The specimen is freely supported by fulcrum, a constant stress is applied to the surface as the upper arm contacts the specimen, and the strain is measured overtime. The testing conditions of DMA with a small preload, a controlled temperature of 23°C.

In another paper, the creep was measured using DMA, it used flexural deformation for creep measurement.

The specimen was mounted as cantilever beam on two arms, that forms a predefined displacement. A computer was used for instrument control, data collection and data analysis. It uses a driver signal to generate the deformation. When the driver signal was active, the specimen was subject to a constant stress, and the arm position data was collected as a function of time to measure the creep deformation. When the driver signal was turned off, the arm position followed the material recovery and the arm position data was collected as a function of time to monitor the recovery.

As the computer signal was based on fixing the initial flexural amplitude of deformation for creep measurement, the amplitude corresponding the driver was determined.The creep measurement was done at temperature 37 C

Creep data was carried out for 120 minutes, and the recovery data was collected for additional 210 minutes until the driver signal reached a constant value. The analysis of the data was done using DMA.

4) Indentation (Hardness test)

Indentation creep is the percentage increase in indentation depth under constant loading over a while. Since conventional creep testing needs many specimens to establish stress and temperature, indentation hardness is used as a substitute. Many ways have been proposed to test the time- dependent hardness. The indentor is circular with a flat end. [7]

The indentation creep was measured using the indentation length plotted versus the indentation time at constant load.[8]

The indentation length increases with the loading time and the applied load. The curve consists of two stages similar to an ordinary creep curve. The first stage is the increase in the indentation length with the loading time, with a decreasing rate. Followed by a steady-state where the indentation size increases linearly with time. During the hardness test, no fracture of the specimen, so it is no possible to record the third stage of the curve to what happens in an ordinary creep test. [9]

$CIT = [(h2 - h1)/h1]*100\%$

Microhardness is measured by taking the depth of penetration of the indentor as the function of load. This allows the determination of the deformation under a load of indentations under increasing stable and decreas-ing load over time.A schematic diagram of the variation of the load over time is plotted. The load increase and the penetration

depth of the indentor was measure as a function of time (Δh). The load and the penetration depth were registered on the x-y graph. The measurement was made at the start of the creep, and after 10, 20, 30 and 60 seconds, and after 60 seconds up to 600 seconds.[9]

Indentation creep is used with the viscoelastic materials.

Nanoindentation creep test:

Nanoindentation provides a unique opportunity to measure the creep response of definite phases in complex microstructural materials that can't be measured with conventional bulk techniques.[10]

Understanding the fundamental relationship between creep and microstructure is a way to develop improved materials.High temperature creep resistance is important in many applications of high temperature materials. [11]

To measure the indentation creep accurately, the test instrument must displays ultra-low thermal drift across the entire measurement.

Nanoindentation creep experiment includes creep test that are mostly made with three-sided pyramidal indenter.

5) Creep rupture test:

Creep rupture test is also called the stress rupture test. These tests are continued until the specimen fractures.

Creep rupture test is a method of measuring the amount of creep material withstand until it ruptures. This includes given stress and temperature at a definite hour.

Creep rupture test requires:

1) Method of heating the specimen to a constant test temperature

2) Method of applying a constant load

3) Method for measuring the increase in length

The specimen is heated using a furnace with the temperature controlled device to ensure that the specimen temperature is maintained. As creep a temperature dependent property, there is a relation between the temperature and the creep rate, so a small increase in the temperature leads to a large increase in creep rate. The required load is applied by a system of dead weights. The length of the specimen is monitored using an extensometer attached to the specimen. [1]

Creep ductility of the material is obtained by comparing the length of the specimen after the rupture with the initial length. After a series of tests at different stresses, the time to rupture is measured as a function of the initially applied stress.

It is useful in specifying the design life of the components. Creep rupture test differs from other tests in that the creep test continues until rupture.

The material is fabricated to a known dimension. Then the material is placed under a load below yield strength. The temperature is elevated, and it reflects the temperature that presents in the application when the material is used.[4]

Factors affecting creep of materials:

1) Temperature

Creep is more pronounced at higher temperature. No creep occurs below 40% of the melting temperature

2) Time

Constant stress is maintained for long period of time.

3) Stress

Creep increases at higher load.

4) Alloy composition

Creep is dependent on grain size, and the grain size is dependent on the temperature.

a) If the material is exposed to high temperature (diffusion creep>dislocation creep): as it require coarse grain or single crystal. At high temperatures diffusion creep occurs.

b) IF material is exposed to low temperature function (dislocation creep>diffusion creep): fine grains are recommended to increase grain boundaries which act as obstacles, dislocations accumulate at the grain boundaries

(dislocation pile up), back stress is created that hinders any further movements, the material overcome theobstacles by the mechanism of climb.

References:

1) A Phenomenological Primary-Secondary-Tertiary Creep Model for Polymer-Bonded Composite Materials

2) Powers, J.M. and Sakaguchi, R.L.: Craig's Restorative Dental Material: 12th ed. Mosby, Elsevier Science Publishing Co., 11830 Westline Industrial drive, St, Louis, Missouri, 63146, p. 84, 2006.

3) Pelleg G, Solid Mechanics and Its Applications Creep in Ceramics Biomat. J., 1 (2),5 – 12 (2022)
15 of 11

4) Twi-global.com. 2022. Creep and Creep Testing. [online] Available at:<https://www.twi-global.com/technical-knowledge/job-knowledge/creep-and-creep-testing-081> [Accessed 15May 2022].

5) Espevik S. Flow and creep of Dental Amalgam. Acta Odontologica Scandinavica. 1975;33(5):239–42

6) Durgesh B, Alkheraif A, Abobaker, Musaibah S, Asiry M, Varrela J, Vallittu P, Creep Behavior of Resin Composite Interface Between Orthodontic Brackets and Enamel. J Adhes Dent. (2018),417-424, 20 (5)

7) S Chu, J Li, Impression creep; a new creep test (1977), 2200-2208

8) Hassan M, Zinelis s, Hersberger-Zurfluh M, Eliades T, Creep, hardness, and elastic modulus of lingual fixed retainer adhesives. Materials, (2019), 12 (4)

9) El-Bediwi A, Kashita E, Salman S, Influence of Annealing on Creep Indentation, Surface Properties and Electrochemical Corrosion Behavior of Ni-Cr Based Dental Alloy, International Journal of Applied Sciences and Biotechnology. (2017) , 366-374, 5(3).

10) Testing, C., 2022. | Micro-impact Testing | Micro-Fatigue | Coating optimisation. [online] Micro Materials. Available at: <https://www.micromaterials.co.uk/techniques/indentation/creep/> [Accessed 17 May 2022].

11) Ennis P, Creep and Stress Rupture Testing and Evaluation of Data. Reference Module in Materials Science and Materials Engineering (2016)