SRINIVASAN ENGINEERING COLLEGE

AE2354 HIGH TEMPERATURE MATERIALS

TWO MARKS WITH ANSWERS

UNIT-1 CREEP

1. **Define creep**
   Creep is large plastic deformation of material on application of stress or elevated temperature or a combination of both applied for a prolonged time. A material subjected to a constant stress may fail well below its yield stress if load is applied for prolonged time.

2. **Define creep formation**
   It involves time-dependent deformation and high temperature creep cracking generally develops in an intercrystalline manner in components of engineering importance that fail over an extended time.

3. **What is meant by diffusion process?**
   At low stress and high temperature atoms diffuse from sides to the top and bottom.
   The grain becomes longer as the applied stress does work. Atomic diffusion in one direction is same as vacancy diffusion in opposite direction.

4. **Why the rate of creep is more at elevated temperature?**
   Creep is one of the most serious high temperature damage mechanisms. As temperature increases mobility of atom increases, frequently increasing the diffusion mechanism and has significantly influence on high temperature mechanical properties like creep and fracture. So the rate of creep is more at elevated temperature.

5. **What are the problems associated with materials used at elevated temperature?**
   Generally a material subjected to high temperature reduces the strength of the material and failure mechanisms affecting the functional life of components are totally different. At high temperature the strength of material has strong dependence on time.

6. **What are the factors influencing functional life of components at elevated temp?**
   1) Creep
   2) Corrosion
   3) High temperature fracture
   4) Thermo mechanical Fatigue
   5) Interaction of all above with each other
   6) Metallurgical ageing and metallurgical stability
   7) Micro structural changes

7. **Which types of materials are preferred for creep application?**

A material which posses the following features to avoid creep formation and get creep resistant at high temperatures.

1. Higher creep resistance is observed with metals having high melting point. Creep becomes significant above 0.4 T_m.
2. A coarse grain metal has high creep resistance than fine grained metals.
3. Single crystal have excellent creep resistance because they have no grain boundary.

8. **What are the deformation modes?**

    1. Dislocation climb and glide
    2. Vancancy diffusion
    3. Dislocation Creep
    4. Diffusion Creep
    5. Grain Boundary Sliding

9. **Draw typical creep curve, mark the various stages and mention the factors influencing each stage.**

1. Primary Or Transient Creep **– Strain or work hardening**
2. Secondary Or Steady State Or Recovery Creep**- Thermal Softening or Annealing**
3. Tertiary Creep **– Void Propagation and Grain boundary sliding**

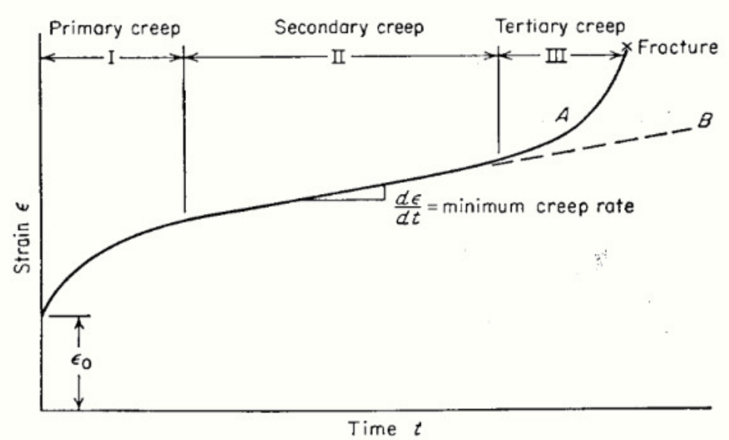

Figure 13-4 Typical creep curve showing the three steps of creep. Curve *A*, constant-load test; curve *B*, constant-stress test.

10. **Define super plasticity.**

Super plasticity is the ability to withstand very large deformation in without necking.

11. **What are effects of stress and temperature on the creep curve?**

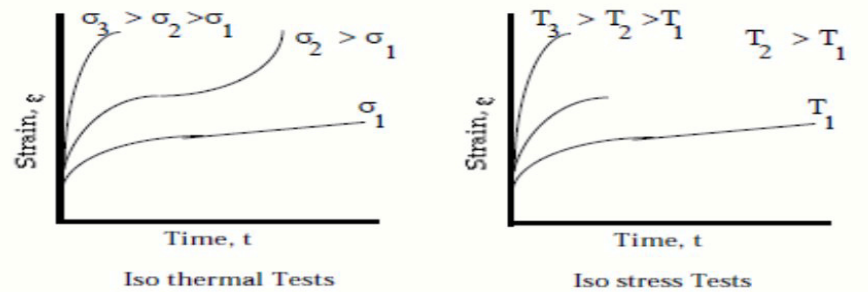

Figure 8.4 Effect of stress and temperature on strain time creep curves

12. Write any two high creep resistance materials.

1. Tungsten
2. Nickel based super alloys
3. Iron based super alloys
4. Cobalt based super alloys,
5. Molybdenum

13. Name two metallurgical factors that affect creep rate.

1. Work hardening
2. Thermal Softening
3. Grain boundary sliding
4. Diffusion and cavitation

UNIT-2: DESIGN FOR CREEP RESISTANCE

1. **What are Material aspects for creep resistance?**
   - Creep resistance improved if diffusion rates are decrease.
   - An increased modulus improves resistance to dislocation creep
   - When creep is controlled by dislocation climb and glide process, similarly material having high shear modulus display a better creep resistance.
   - Stress raises such as sharp corners are avoided so that the stress concentration diminish or vanish considerably and materials with finer grain size are utilized.
   - Surface irregularities and cracks are removed by polishing surface.
   - Compressive stresses are introduced at the surface by process such as short sand blasting.
   - Nitriding and carburising operations are performed to create strong surface layers.

2. **Define rupture life of creep?**

   Rupture life of creep is defined as the maximum stress that will allow the member to withstand creep without failure at the specified period of time. In creep testing the main goal is to determine the minimum creep rate in stage II. Once a designer knows the materials will creep and has accounted for this deformation a primary goal is to avoid failure of the component.

3. **Distinguish between Ductile material and brittle material.**

Ductile material	brittle material
Ductile materials undergo extend plastic deformation and absorb significant energy before fracture.	**Brittle material undergoes very low plastic deformation and low energy absorption prior to breaking.**
A crack, formed as a result of the ductile fracture, propagates slowly and when the stressis increased.	**A crack, formed as a result of the brittle fracture, propagates fast and without increase of the stress applied to the material.**

4. **Define Monkmann-Grant formula.**

   Monkman grant relationship predicts time of failure due to creep mechanisms.

Monk man grant relationship relates minimum strain rate and time to failure. Monk man grant relation is given as

$$\dot{\varepsilon}_{ss} = \dot{\varepsilon}_{min} = A\sigma^{n} \exp\left(\frac{-Q}{RT}\right) \qquad \dot{\varepsilon}_{min} t_f = C \approx \varepsilon_f$$

$$\dot{\varepsilon}_{min} t_f = C \approx \varepsilon_f$$

Where C is a constant

Minimum strain rate for a given stress and temperature is given by t he relation

5. **Define Transient creep time.**
   Creep deformation occurring in a component during the stress redistribution under steady load and temperature

6. **What is meant by strain hardening?**
   Work hardening or strain hardening phenomenon can also be explained from the intersection of various dislocations moving through the active slip planes. The resistance of the metal to deformation is increased to work or strain the metal in both the cases. This implies an increase in strength and hardness.

7. **What are the types of Hardening (Strengthening) mechanisms?**
   1. Strain Hardening
   2. Hardening by grain refinement
   3. Solid solution strengthening
   4. Precipitation hardening

8. **Explain the term Creep Ductile Fracture and Brittle Fracture.**
   Ductile fracture:
   Ductile fracture is characterized by extensive plastic deformation and absorbs significant energy before fracture. A crack, formed as a result of the ductile fracture, propagates slowly and when the stress is increased.
9. **Brittle fracture:**
   Brittle fracture is characterized by very low plastic deformation and low energy absorption prior to breaking. A crack, formed as a result of the brittle fracture, propagates fast and without increase of the stress applied to the material.

10. **Define Monkman-Grant relationship and its significance as a Master curve.**
    Minimum strain rate is defined as the strain rate that is prescribed by the designer for creep resistance. It is specified by the designer for safe operation of the component without going to rupture stage. Once the minimum strain rate for creep design is specified, Monk man grant relationship relates minimum strain rate and time to failure.Monk man grant relation is given as

$$\dot{\varepsilon}_{min} t_f = C \approx \varepsilon_f$$

UNIT-3 - FRACTURE

1. **Define Fracture?**
   Fracture is a process of breaking a solid into number of pieces as a result of stress.
   Fracture denotes the complete destruction of the material, resulting separation of a portion of the material body.

2. **What are types of fracture?**
   Generally fracture can be divided into 2 types such
   - Brittle fracture (eg. Cast iron)
   - Ductile fracture (eg. Mild steel)

   Further it can e classified,
   Depends on the appearance as 1.shearing fracture and 2.cleavage fracture and crystallographic nature as1. fibrous and 2.granular fracture

3. **What is Brittle fracture?**
   Brittle fracture The word 'brittle' is associated with a ***minimum of plastic deformation,*** i.e. with a brittle fracture the material fractures with very rapid propagation of crack with very little or no plastic deformations like a ***china cup.***

4. **What is ductile fracture?**
   Ductile fracture: This signifies large plastic deformation, and occurs after extensive plastic deformation prior to and during the propagation of the crack. This requires considerable energy which is absorbed in forming dislocations and other imperfections (defects) in metals.

5. **Explain the terms Chisel Edge fracture and Point Edge fracture.**
   Chisel Edge fracture : An incomplete fracture of the head of the radius, in which the fracture line extends distally from the centre of the articular surface

6. **What is meant by Equicohesive Tempe rature (ECT)?**
   It is the temperature at which grain boundary strength and grain strength are equal
   Points to be noted about ECT
   1) It is not a fixed value
   2) It depends on stress, temperature and strain rate.

   Decreasing the strain rate lowers the ECT and encourages inter granular fracture.

7. **Distinguish between ductile fracture and brittle fracture?**

Ductile fracture	***Brittle fracture***
Materials fractures after plastic deformation and slow propagation of crack.	Materials fractures with very little or no plastic deformation, e.g. in a china clay, glass etc
Fractured surfaces are dull or fibrous in appearance.	Fractured surfaces are crystalline in appearance
Percentage elongation is about 30% prior to	Percentage elongation is about 0.5% or almost

fracture occurs.	nil prior to fracture occurs.
There is reduction in cross-sectional area of the specimen.	There is virtually no change in the cross sectional area.
Fracture takes place after necking with little sound.	Fracture occurs rapidly often accompanied by a Loud noise.

8. **Define cleavage fracture.**
   In brittle crystalline materials, fracture can occur by *cleavage* as the result of tensile stress acting normal to crystallographic planes with low bonding (cleavage planes). After the formation of micro crack described above, if the crack propagates along a weak crystallographic plane it is known as cleavage fracture.
   .
9. **Define Rupture?**
   Rupture is defined as the total destruction of material at loading conditions. When the applying load is relatively high enough to destructive the material at very short time.

10. **Define Transgranular fracture.**
    After the formation of micro crack and if temperature is high the grain boundaries are stronger than the grains and hence the crack propagates through the grains piercing the grain boundary and through the grains.
11. **What is Inte rgranular fracture?**
    After the formation of micro crack and if the temperature is low the grain stronger than grain boundaries and hence the crack propagates along grain boundaries

12. **What is fracture toughness?**
    Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for many design applications. The linear-elastic fracture toughness of a material is determined from the stress intensity factor (K) at which a thin crack in the materia l begins to grow.

13. **How micro void coalescence occurs?**
    MVC proceeds in three stages: nucleation, growth, and coalescence of microvoids. The nucleation of microvoids can be caused by particle cracking or interfacial failure between precipitate particles and the matrix. Microvoids grow during plastic flow of the matrix, and microvoids coalesce when adjacent microvoids link together or the material between microvoids experiences necking. Microvoid coalescence leads to fracture

14. **Analyse how micro void coalescence occurs.**
    Microvoids grow during plastic flow of the matrix, and microvoids coalesce when adjacent microvoids link together or the material between microvoids experiences necking. Microvoid coalescence leads to fracture.

UNIT-4:
OXIDATION AND HOT CORROSION

1. **Define oxidation process.**
Oxidation means the loss of electrons. The oxidation of a metal occurs when the metal loses one or more electrons, so that the atoms of the metal go from the neutral stateand become a positively charge ion. This commonly results in the formation of a metal oxide (in the case of iron that is known as rust).

2. **Define Pilling Bed worth theory.**
The Pilling-Bedworth ratio, (P-B ratio) R, of a metal oxide is defined as the ratio of the volume of the metal oxide, which is produced by the reaction of metal and oxygen, to the consumed metal volume:

$$R = \frac{V_{metal oxide\ produced}}{V_{metal consumed}} = \frac{Md}{amD}$$

M and D are the molecular weight and density of the metal oxide whose composition is (Metal)a(oxygen)b; m, and d are the atomic weight and density of the metal.

3. **What are the different stages of hot corrosion?**
    1. Type -1 hot CORROSION (Temp Range from 850-950'c)
    2. Type -1I hot CORROSION (Temp Range from 650-800'c)

4. **What are the Kinetic Laws of Oxidation?**
    1. Parabolic rate law
    2. logarithmic rate law
    3. Linear rate law

5. **What is meant by Fluxing mechanism?**
The process of non protective reaction product is formed to dissolute the oxide layer on metal surface is called fluxing mechanism.

6. **Define hot corrosion. What are the methods used for combat hot corrosion?**
Hot corrosion is defined as an accelerated, often catastrophic surface attack super alloy by hot-gas path component. This is severe in the temperature range 750-1000'c and has affected A/C engines and industrial gas turbines.

    There are three methods to combat hot corrosion such as
    1. Aluminide (diffusion) coatings
    2. Thermal barrier coatings
    3. Overlay coatings

7. **Name some oxidation resistance materials?**
Conventionally **Aluminium, chromium and copper** materials are majorly used towards corrosion resistance. Some metals have naturally slow reaction kinetics, these include such metals as **zinc, magnesium, and cadmium**. While corrosion of these metals is continuous and ongoing, it happens at an acceptably slow rate. An extreme example is **graphite**, which releases large amounts of energy upon oxidation, but has such slow kinetics that it is effectively immune to electrochemical corrosion under normal conditions.

8. **Define basic fluxing in hot corrosion.**
Basic fluxing: The term basic fluxing describes oxide dissolution, when O^{-2} contains with the oxide to form a soluble MO^{-2} radical. It is generally associated with temperatures > 900'C and termed as high temperature hot corrosion.
These results support a **basic fluxing** reaction, i.e. corrosive attack by forming a basic solute of the protective scale.
$4Ni + Na_2SO_4 = Na_2O + 3\ NiO + NiS$

9. **Define acidic fluxing in hot corrosion.**
Acidic Fluxing: It defines dissolution , when a soluble metal M^{2+} and O^{-2} are produced from oxide . The acidic fluxing is generally associated with temperature range of 650'C to 800'C and it is termed as low temperature hot corrosion. Acidic fluxing takes place when the O^{-2} activiyy in the molten salt is markedly lowered , it leads to much more severe oxidation compared to basic fluxing**.**

10. **What is the difference between n-type and p-type oxides?**
N-type : Zirconium oxide ZrO_2 contains an excess of four negatively charged electrons in place of two vacant anion sites. Zirconium oxide is termed as n-type semiconductor since it contains an excess of negatively charged electronic current carriers/ electrons.

P-type : nickel oxide NiO is a metal deficient oxide. For each nickel ion vacancy , there are two trivalent Ni ions in normal lattice positions. The trivalent ions can be considered as divalent ion and an associated "electron hole" (Absence of electron). This is called p-type oxides.

11. **Write any two methods to prevent corrosion.**
    1. Control or removal of aggressive impurities.
    2. Development of new alloys with higher resistance to hot gas corrosion and greater mechanical properties.
    3. Development of protective surface coatings.

12. **Define hot corrosion.**
Hot corrosion is an high- temperature analog of aqueous atmospheric corrosion. A thin film deposit of fused salt on an alloy surface in a hot oxidizing gas causes accelerated corrosion kinetics.

13. Comment on the various kinetic laws of oxidation.

The parabolic rate law assumes that the diffusion of metal cations or oxygen anions is the rate controlling step. The diffusivity of the oxide layer is also assumed to be invariant. This assumption implies that the oxide layer has to be uniform, continuous and of the single phase type.

UNIT-5:
SUPER ALLOYS AND OTHER MATERIALS

1. **Define Super alloys. What are the properties of super alloys?**
   Super alloys, or high performance alloys, are alloys that exhibit excellent mechanical strength and creep resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. They typically have an ***austenitic face-centered cubic crystal structure*** with a base alloying element of ***nickel, cobalt, or nickel-iron.***

2. **Why are super alloys preferred for high temperature application?**
   Super alloys, or high performance alloys, are alloys that exhibit excellent mechanical strength and creep resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. The development of super alloys has primarily been driven by the ***aerospace and power industries***.

3. **What are intermetallics?**
   Intermetallics are made up of two or more elements, producing a new phase with its own composition, crystal structure and properties. Intermetallics compounds are almost always very hard and brittle.

4. **What is Ceramic materials?**
   Ceramic materials are complex chemical compounds containing both metallic and non metallic elements. Alumina (Al_2O_3) is a ceramic composed of both metallic aluminum and non metallic oxygen atoms. Ceramics are formed because of ionic or covalent bonding, hence are usually hard, brittle and have high melting point.

5. **What are the strengthening mechanisms used for alloys?**
   i. Solid solution strengthening
   ii. Precipitation hardening by gamma prime
   iii. Grain boundary strengthening
   iv. Strain hardening.

6. **Name a few examples for super alloys applicable for high temperature applications.**
   Examples of superalloys are Hastelloy, Inconel (e.g. IN100, IN600, IN713), Waspaloy, Rene alloys (e.g. Rene 41, Rene 80, Rene 95, Rene N5), Haynes alloys, Incoloy, MP98T, TMS alloys, and CMSX (e.g. CMSX-4) single crystal alloys.

7. **Define precipitation strengthening.**
   Precipitation hardening, also called **age hardening**, is a heat treatment technique used to increase the yield strength of malleable materials, including most structural alloys of aluminium, magnesium, nickel, titanium, and some stainless steels. In super alloys, it is known to cause yield strength anomaly providing excellent high temperature strength.

8. **Define Embrittlement.**
   Embrittlement is a loss of ductility of a material, making it brittle. Various materials have different mechanisms of embrittlement. Hydrogen embrittlement is the effect of hydrogen absorption on some metals and alloys.

9. **What properties of ceramic compound offer high temperature applications?**
   General characteristics of ceramics:
   1. High melting point
   2. Low electrical and thermal conductivity
   3. Good chemical and thermal stability.
   4. High compressive strengths.

10. **Define corrosion fatigue.**
    Corrosion fatigue is fatigue in a corrosive environment. It is the mechanical degradation of a material under the joint action of corrosion and cyclic loading. Nearly all engineering structures experience some form of alternating stress, and are exposed to harmful environments during their service life. The environment plays a significant role in the fatigue of high-strength structural materials like steel, aluminum alloys and titanium alloys.

11. **What is grain boundary cracking? Give remedy for it**
    Intergranular fractures are cracks that take place along the grain boundary of a material. Straight edges of the grain and shiny surface may be seen. There are several processes that can lead to intergranular fracture. **Grain-boundary strengthening** is a method of strengthening materials by changing their average crystallite (grain) size. So, by changing grain size one can influence dislocation movement and yield strength.

12. **What are the types of Ni-base alloys?**
    Ni-base alloys are Hastelloy, Inconel (e.g. IN100, IN600, IN713), Waspaloy, Rene alloys (e.g. Rene 41, Rene 80, Rene 95, Rene N5), Haynes alloys, Incoloy,

13. **Define TCP phases and its significance in super alloys.**
    In some alloys, if composition has not been carefully controlled, undesirable phases can form either during heat treatment or, more commonly, during service. These phases affect the creep resistance; fracture strength, premature cracking, and yield strength. These precipitates are known as TCP phasesTopologically close-packed (TCP) type phases, which are plate-like or needle- like phases such as σ, and μ that may form for some compositions and under certain conditions. These cause lowered rupture strength and ductility.

14. **What are Super alloys and their applications?**
    Super alloys are generally in three ways such as Nickel base , cobalt base and iron base super alloys. These superalloys are majorly available in many industries such Aerospace, Turbine blades and jet/rocket engines, Marine industry, Submarines, Chemical processing industry, Nuclear reactors, Heat exchanger tubing, Industrial gas Turbines

15. **Define directional solidifications and its benefits.**
Directional solidification and **progressive solidification** describe types of solidification within castings. Directional solidification describes solidification that occurs from farthest end of the casting and works its way towards the sprue. Progressive solidification, also known as **parallel solidification.** Directional solidification can be used as a purification process. Since most impurities will be more soluble in the liquid than in the solid phase during solidification, impurities will be "pushed" by the solidification front, causing much of the finished casting to have a lower concentration of impurities than the feedstock material, while the last solidified metal will be enriched with impurities. This last part of the metal can be scrapped or recycled.

16. **Explain why the single crystal turbine blades perform better than directionally solidified and coarse grained cast products.**
Single crystal has the mechanical advantage of being able to operate at a much higher temperature than crystalline materials. Creep is a common cause of failure in turbine blades and is in fact the life limiting factor. When temperatures of a material under high stress are raised to a critical point, the creep rate quickly increases .The single crystal structure has the ability to withstand creep at higher temperatures than crystalline turbine blades due to the lack of grain boundaries present.

17. **Name two chemical composition of supe r alloys.**
Many **wrought nickel-base superalloys** contain 10 to 20% Cr, up to about 8% Al and Ti combined, 5 to 15% Co, and small amounts of boron, zirconium, magnesium, and carbon.

18. **Mention the name of two high temperature ceramics**
EXAMPLES OF HIGH TEMPERATURE CERAMICS:
Aluminum silicate, Alumina, Quartz, Porcelain

19. **Define and list various TCP phases and explain whether they are beneficial or detrimental for high temperature properties.**
The composition has to be carefully controlled in order to avoid topologically closepacked TCP) phases, for example σ phase, μ phase or Laves. These phases can be formed under certain conditions, usually during service. They are distinguished by their plate like or needle like shapes. Alloys containing transition metals, such as tantalum, niobium, chromium, tungsten or molybdenum, are the alloys the most vulnerable to the formation of TCP phases.