Chapter 2
Mechanical Failure of Materials

Abstract This chapter describes the major causes of mechanical failure of the engineering components or structure. Various level of materials performance is introduced. Failures due to fracture, fatigue, creep, wear and corrosion have been explained in order to understand the common mechanical failure. A case study on the failure analysis of an electrical disconnector has been presented with the recommendation to prevent the failure.

Keywords Performance level of materials · Mechanical failure · Ductile–brittle fracture · Fracture toughness · Case study

Learning Outcomes
After learning this chapter student should be able to do the following:

Suggest the factors that influence the level of performance of a material
Explain the major causes of mechanical failure
Evaluate ductile-to-brittle transition phenomenon
Justify the safe use of materials for engineering application.

2.1 Introduction

Engineering materials don't reach theoretical strength when they are tested in the laboratory. Therefore, the performance of the material in service is not same as it is expected from the material, hence, the design of a component frequently implores the engineer to minimize the possibility of failure. However, the level of performance of components in service depends on several factors such as inherent properties of materials, load or stress system, environment and maintenance. The reason for failure in engineering component can be attributed to design deficiencies, poor selection of materials, manufacturing defects, exceeding design limits and overloading, inadequate maintenance etc. Therefore, engineer should

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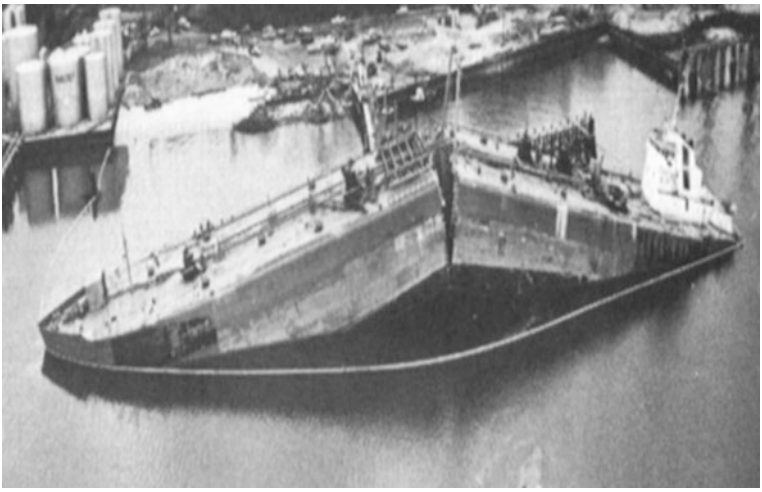

Fig. 2.1 An oil tanker that fractured in a brittle manner by crack propagation around its girth (Callister 1997, 4e) (This material is reproduced with permission of John Wiley & Sons, Inc.)

anticipate and plan for possible failure prevention in advance. Figure 2.1 shows a catastrophic failure of an oil tanker that fractured in a brittle manner by crack propagation at the middle of the tanker.

2.2 Mechanical Failure

The usual causes of mechanical failure in the component or system are:

- Misuse or abuse
- Assembly errors
- Manufacturing defects
- Improper or inadequate maintenance
- Design errors or design deficiencies
- Improper material or poor selection of materials
- Improper heat treatments
- Unforeseen operating conditions
- Inadequate quality assurance
- Inadequate environmental protection/control
- Casting discontinuities.

The design of a component or structure often asks to minimize the possibility of failure. The failure of metals is a complex subject which can only be dealt with fracture or other relevant phenomenon. Therefore, it is important to understand the different types of mechanical failure i.e. fracture, fatigue, creep, corrosion, wear etc.

The general types of mechanical failure include:

- Failure by fracture due to static overload, the fracture being either brittle or ductile.
- Buckling in columns due to compressive overloading.
- Yield under static loading which then leads to misalignment or overloading on other components.
- Failure due to impact loading or thermal shock.
- Failure by fatigue fracture.
- Creep failure due to low strain rate at high temperature.
- Failure due to the combined effects of stress and corrosion.
- Failure due to excessive wear.

2.3 Failure Due to Fracture

Fracture is described in various ways depending on the behavior of material under stress upon the mechanism of fracture or even its appearance. The fracture can be classified either as ductile or brittle depending upon whether or not plastic deformation of the material before any catastrophic failure. A brief description of both types of fracture is given below.

2.3.1 Ductile Fracture

Ductile fracture is characterized by tearing of metal and significant plastic deformation. The ductile fracture may have a gray, fibrous appearance. Ductile fractures are associated with overload of the structure or large discontinuities. This type of fracture occurs due to error in design, incorrect selection of materials, improper manufacturing technique and/or handling. Figure 2.2 shows the features of ductile fracture. Ductile metals experience observable plastic deformation prior to fracture. Ductile fracture has dimpled, cup and cone fracture appearance.

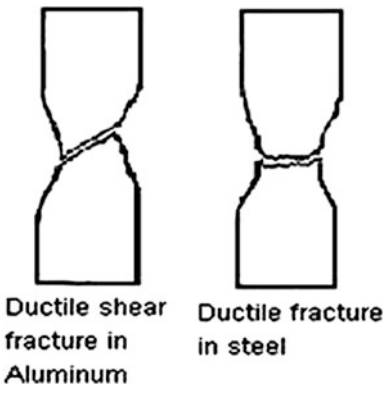

Fig. 2.2 Ductile fracture in aluminum and steel after tensile testing

The dimples can become elongated by a lateral shearing force, or if the crack is in the opening (tearing) mode. The fracture modes (dimples, cleavage, or intergranular fracture) may be seen on the fracture surface and it is possible all three modes will be present of a given fracture face.

2.3.2 Brittle Fracture

Brittle fracture is characterized by rapid crack propagation with low energy release and without significant plastic deformation. Brittle metals experience little or no plastic deformation prior to fracture. The fracture may have a bright granular appearance. The fractures are generally of the flat type and chevron patterns may be present. Materials imperfection, sharp corner or notches in the component, fatigue crack etc. Brittle fracture displays either cleavage (transgranular) or intergranular fracture. This depends upon whether the grain boundaries are stronger or weaker than the grains. This type of fracture is associated with non-metals such as glass, concrete and thermosetting plastics. In metals, brittle fracture occurs mainly when BCC and HCP crystals are present.

In polymeric material, initially the crack grows by the growth of the voids along the midpoint of the trend which then coalesce to produce a crack followed by the growth of voids ahead of the advancing crack tip. This part of the fracture surface shows as the rougher region. Prior to the material yielding and necking formation, the material is quite likely to begin to show a cloudy appearance. This is due to small voids being produced within the material. Ceramics are brittle materials, whether glassy or crystalline. Typically fractured ceramic shows around the origin of the crack a mirror-like region bordered by a misty region containing numerous micro cracks. In some cases, the mirror-like region may extend over the entire surface. The difference between ductile fracture and brittle fracture is shown in Table 2.1.

2.3.3 Ductile-to-Brittle Transition

The temperature at which the component works is one of the most important factors that influence the nature of the fracture. Sharp ductile-to-brittle transition (DBTT) is observed in BCC and HCP metallic materials as shown in Fig. 2.3.

Table 2.1 The difference between ductile fracture and brittle fracture

	Ductile fracture	Brittle fracture
Plastic deformation	Extensive	Little
Process flow	Slowly	Rapidly
Crack	Stable	Unstable
Warning signal	Imminent	No
Shape	Cup-and-cone	V or chevron
Strain energy	High	Less

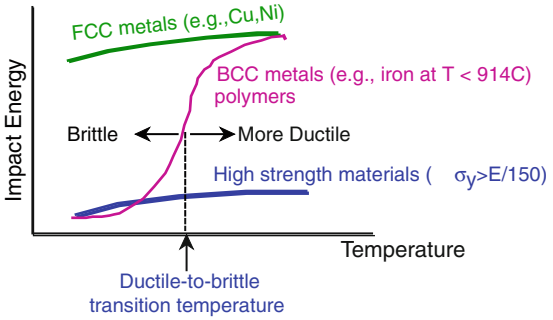

Fig. 2.3 Ductile–brittle transition temperature *curve* (Callister 2005)

2.4 Factors Affecting the Fracture of a Material

The main factors those affect the fracture of a material are:

- Stress concentration
- Speed of loading
- Temperature
- Thermal shock.

2.4.1 Stress Concentration

In order to break a small piece of material, one way is to make a small notch in the surface of the material and then apply a force. The presence of a notch, or any sudden change in section of a piece of material, can vary significantly change the stress at which fracture occurs. The notch or sudden change in section produces what are called **stress concentrations**. They disturb the normal stress distribution and produce local co-generations of stress. The amount by which the stress is raised depends on the depth of the notch, or change in section, and the radius of the tip of the notch. The greater the depth of the notch the greater the amount by which the stress is increased. The smaller the radius of the tip of the notch the greater the amount by which the stress is increased. This increase in stress is termed the **stress concentration factor**.

A crack in a brittle material will have quite a pointed tip and hence a small radius. Such a crack thus produces a large increase in stress at its tip. One way of arresting the progress of such a crack is to drill a hole at the end of the crack to increase its radius and so reduce the stress concentration. A crack in a ductile material is less likely to lead to failure than in a brittle material because a high stress concentration at the end of a notch leads to plastic flow and so an increase in the radius of the tip of the notch. The result is then a decrease in the stress concentration.

2.4.2 Speed of Loading

Another factor which can affect the fracture of a material is the speed of loading. A sudden blow to the material may lead to fracture where the same stress applied more slowly would not. With a very high rate of application of stress there may be insufficient time for plastic deformation of a material to occur under normal conditions, a ductile material will behave in a brittle manner.

2.4.3 Temperature

The temperature of a material can affect its behavior when subject to stress. Many metals which are ductile at high temperatures are brittle at low temperatures. For example, steel may behave as a ductile material above, say, 0 °C but below that temperature it becomes brittle. The ductile–brittle transition temperature is thus of importance in determining how a material will behave in service. The transition temperature with steel is affected by the alloying elements in the steel. Manganese and nickel reduce the transition temperature. Thus for low-temperature work, a steel with these alloying elements is to be preferred. Carbon, nitrogen and phosphorus increase the transition temperature.

2.4.4 Thermal Shocks

When hot water is poured into a cold glass it causes the glass to crack which is known as thermal shock. The layer of glass in contact with the hot water tends to expand but is restrained by the colder outer layers of the glass, these layers not heating up quickly because of the poor thermal conductivity of glass. The result is the setting up of stresses which can be sufficiently high to cause failure of the brittle glass.

2.5 Griffith Crack Theory and Fracture Toughness

In 1920, Griffith advanced the theory that all materials contain small cracks but that a crack will not propagate until a particular stress is reached, the value of this stress depending on the length of the crack. Any defect (chemical, inhomogeneity, crack, dislocation, and residual stress) that exists is considered as Griffith crack, i.e. an in-homogeneity that can cause stress concentration which can be developed to failure at particular value of stress. *Fracture toughness* can be defined as being a measure of the resistance of a material to fracture, i.e. a measure of the ability of a material to resist crack propagation. *Stress intensity factor* (SIF) is another way of considering the toughness of a material in terms of intensity factor at the tip of a crack that is required for it to propagate. The parameter stress concentration factor, K_I (for mode I) is the ratio of the maximum stress in the vicinity of a notch, crack

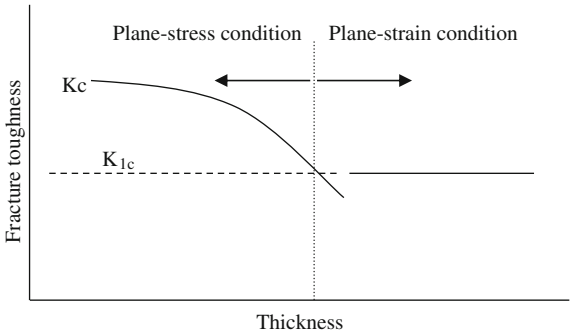

Fig. 2.4 Fracture toughness behavior: effect of material's thickness

or change in section to the remotely applied stress. The stress intensity factor, K is used to determine the fracture toughness of most materials which is a measure of the concentration of stress at crack front under some consideration.

Severe fracture occurs when this SIF reaches to a critical value as denoted by K_c. The relationship between K_I and K_c is similar to the relationship between yield strength and tensile strength whereby K_c is greater than K_I. Therefore, K_c is the maximum value that can withstand by the material without any final fracture and depends on both type of materials and its thickness. The smaller the value of K_c means the less tough the material. The critical stress intensity factor K_c is a function of the material and plate thickness concerned. The thickness factor is because the form of crack propagation is influenced by the thickness of the plate. The effect of thickness on the value of the critical stress intensity factor is shown Fig. 2.4.

At large thickness, the portion of the fracture area which has sheared is very small, most of the fracture being flat and at right angles to the tensile forces. This lower limiting value of the critical stress intensity factor is called the **plane strain fracture toughness** and is denoted by K_{1c}. This factor is solely a property of the material. It is the value commonly used in design for all but the very thin sheets; it being the lowest value of the critical stress intensity factor and hence the safest value to use. The lower the value of K_{1c} means the less tough the material is assumed to be. Table 2.2 shows difference between stress intensity factor (SIF) and fracture toughness (FT).

2.5.1 Factors for Fracture Toughness

Factors those affect fracture toughness are described as follows:

2.5.1.1 Composition of the Material

Different alloy systems have different fracture toughness. Thus, for example, many aluminium alloys have lower values of plane strain toughness than steels. Within each alloy system there are, however, some alloying elements which markedly reduce toughness e.g. phosphorus and sulphur in steels.

Table 2.2 Difference between stress intensity factor and fracture toughness

Stress intensity factor	Fracture toughness
Stress intensity factor, another way of considering the toughness of a material is in terms of the intensity factor at the tip of a crack that is required for it to propagate	Fracture toughness can be defined as being a measure of the resistance of a material to fracture
Material will fail at maximum stress	As the thickness increase fracture toughness will decrease and reaches a constant value
The stress intensity factor, K is used to determine the fracture toughness of most materials which is a measure of the concentration of stress at crack front under some consideration	Fracture toughness is a measure of the ability of a material to resist crack propagation
In a flawed material, as the stress is applied the crack will propagate	Fracture toughness depends on the materials geometry and properties

2.5.1.2 Heat Treatment

Heat treatment can markedly affect the fracture toughness of a material. Thus, for example, the toughness of steel is markedly affected by changes in tempering temperature.

2.5.1.3 Service Conditions

Service conditions such as temperature, corrosive environment and fluctuating loads can all affect fracture toughness.

2.6 Failure Due to Fatigue

Metal fatigue is caused by repeated cycling of the load. It is a progressive localized damage due to fluctuating stresses and strains on the material. Metal fatigue cracks initiate and propagate in regions where the strain is most severe. Figure 2.5 shows typical S–N curve for the fatigue strength of a metal.

The process of fatigue consists of three stages:

- Initial crack formation
- Progressive crack growth across the part
- Final but sudden fracture of the remaining cross section.

2.6.1 Prevention of Fatigue Failure

The most effective method of improving fatigue performance is improvements in design. The following design guideline is effective in controlling or preventing fatigue failure:

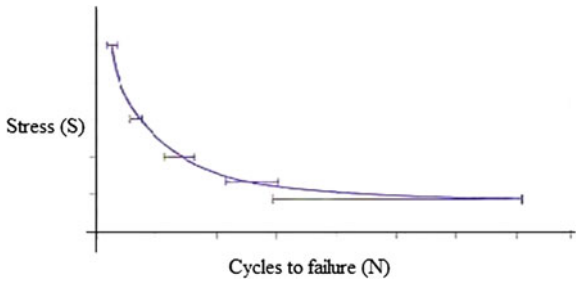

Fig. 2.5 Schematic of S–N *curve* showing increase in fatigue life with decreasing stresses

- Eliminate or reduce stress raisers by streamlining the part or component.
- Avoid sharp surface tears resulting from punching, stamping, shearing, or other processes.
- Prevent the development of surface discontinuities during processing.
- Reduce or eliminate tensile residual stresses caused by manufacturing.
- Improve the details of fabrication and fastening procedures.

2.7 Failure Due to Creep

Creep occurs under certain load at elevated temperature normally above 40 % of melting temperature of the material. Boilers, gas turbine engines, and ovens are some of the examples whereby the components experiences creep phenomenon. An understanding of high temperature materials behavior over a period of time is beneficial in evaluating failures of component due to creep. Failures involving creep are usually easy to identify due to the deformation that occurs. A typical creep rupture envelop is shown in Fig. 2.6. Failures may appear ductile or brittle manner due to creep. Cracking may be either transgranular or intergranular, if creep testing is done at a constant temperature and load, actual components may experience damage or failure at various temperatures and loading conditions.

In a creep test, a constant load is applied to a tensile specimen maintained at a constant temperature. Strain is then measured over a period of time. The slope of the curve, shown in Fig. 2.7 is the strain rate of the test during stage II or the creep rate of the material. Primary creep (known as stage I) is a period of decreasing creep rate. Primary creep is a period of primarily transient creep. During this period deformation takes place and the resistance to creep increases until stage II. Secondary creep (or stage II) is a period of approximate constant creep rate. Stage II is referred to as steady state creep. Tertiary creep (stage III) occurs when there is a reduction in cross sectional area due to necking or effective reduction in area due to internal void formation. Subsequently, increase in creep rate leading to the creep fracture or stress rupture.

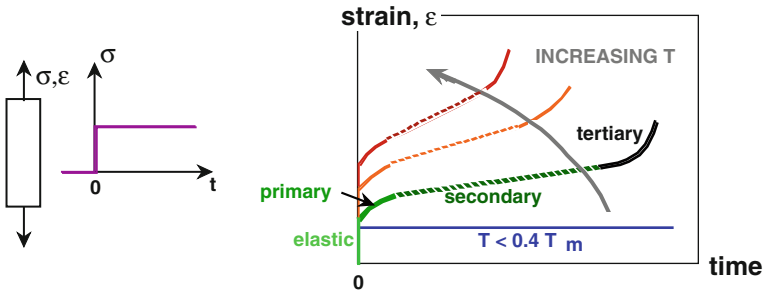

Fig. 2.6 Creep rupture envelop

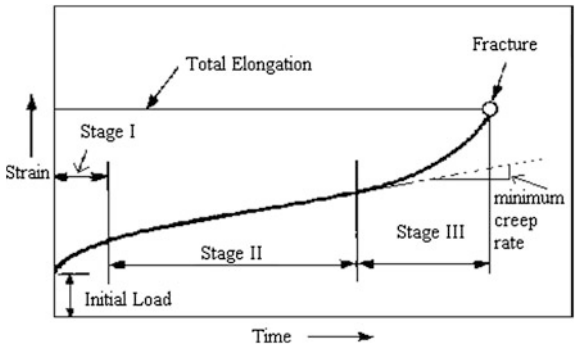

Fig. 2.7 Strain rate (typical creep *curve*) of material under creep test

Design Problem 1

The following data apply to extruded and cold rolled nickel alloy (Nimonic 80A) at 750 °C.

Given data:			
	Young's modulus = 140 GPa		
	0.2 % proof stress = 450 MPa (minimum)		
	Elongation to fracture = 25% (short term tensile test)		
	Mean coefficient of thermal expansion (20–750 °C range) = 15.8×10^{-6}		
	The stress to cause a (plastic) creep strain in 3,000 h is		
Stress (MPa)	110	130	160
Strain (%)	0.1	0.2	0.5

Estimate the coefficient n in a power law representation between stress and strain rate. What would be the total change in length of a bar of 50 mm initial length at 20 °C, when held at a stress of 150 MPa?

Solution

Strain (%)	Stress σ (MPa)	Strain rate $\dot{\varepsilon}$, (% h^{-1})	Log($\dot{\varepsilon}$)	Log σ
0.1	110	3.33×10^{-5}	−4.48	2.04
0.2	130	6.67×10^{-5}	−4.18	2.11
0.5	160	1.67×10^{-4}	−3.78	2.20

The creep rate is related to stress by $\dot{\varepsilon} = A\sigma^n \rightarrow \log(\dot{\varepsilon}) = \log(A) + n\log(\sigma)$. The slope of the plot in Fig. 2.8 provides n = 4.3.

(a) Raising temperature to 750 °C, Thermal strain = $15.8 \times 10^{-6} \times (750 - 20) = 1.15$ %

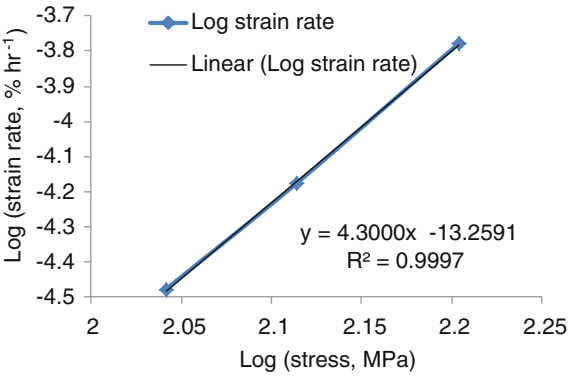

Fig. 2.8 Log strain rate versus log stress

Applying stress of 150 MPa and using $\sigma/E = \varepsilon \rightarrow$ Elastic strain $= 150/140 \times 10^3 = 0.1\,\%$

Increase in total strain = Thermal + Elastic component of strains = 1.15 + 0.1 = 1.25 %

For a 50 mm long bar, the extension = 0.63 mm.

(b)

$$\text{For stress} = 150\ \text{MPa} \quad Log(\sigma) = \log(150) = 2.18$$

Using graph or the linear regression $y = 4.3x - 13.2591$, $\text{Log}\,(\dot{\varepsilon}) = -3.9 \rightarrow \dot{\varepsilon} = 1.26 \times 10^{-4}\,\%\,\text{h}^{-1}$

After period of 3,000 h, material will creep and $\varepsilon = 1.26 \times 10^{-4} \times 3,000 = 0.38\,\%$

New total strain = 1.25 + 0.38 = 1.63 %

Extension = 0.82 mm

Design Problem 2 (Creep Life estimation)

The creep rupture properties of nickel alloy (Nimonic 105) are shown in Fig. 2.9. Using Fig. 2.9, estimate the maximum operating temperature of a gas turbine blade made out of this material which is to withstand a stress of 150 MPa for a duration of 10,000 h.

What would be the new design life if the turbine engine ran 40 °C hotter?

Solution:

Larson–Miller Parameter = 27.5 (when σ = 150 MPa)
T(20 + log t)/1,000 = 27.5
T(20 + log 10,000)/1,000 = 27.5
T = 1,146 K = 873 °C
New design life if operating T goes up by 40 °C

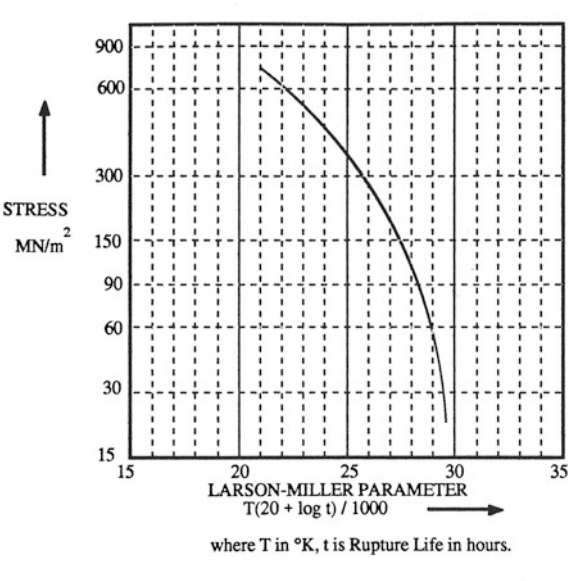

Fig. 2.9 Stress versus Larson–Miller parameters graph

$T = 1146 + 40 = 1186$ K
$1186(20 + \log t)/1000 = 27.5$
$20 + \log t = 23.2$
$t = 1539$ h

2.8 Failure Due to Corrosion

Corrosion of metallic materials occurs in a number of forms which differ in appearance. Failure due to corrosion is a major safety and economic concern. Several types of corrosion are encountered in metallic materials, among those: general corrosion, galvanic corrosion, crevice corrosion, pitting, intergranular, stress corrosion etc. This can be controlled using galvanic protection, corrosion inhibitors, materials selection, protective coating and observing some design rules.

Corrosion is chemically induced damage to a material that results in deterioration of the material and its properties. This may result in failure of the component. Several factors should be considered during a failure analysis to determine the effect of corrosion in a failure. Examples are listed below:

- Type of corrosion
- Corrosion rate
- The extent of the corrosion
- Interaction between corrosion and other failure mechanisms.

As the corrosion is a normal and natural process it can seldom be totally prevented, but it can be minimized or controlled by proper selection of material, design, coatings, and occasionally by changing the environment. Various types of metallic and nonmetallic coatings are regularly used to protect metal parts from corrosion.

2.9 Failure Due to Wear

Wear may be defined as damage to a solid surface caused by the removal or displacement of material by the mechanical action of a contacting solid, liquid, or gas. It may cause significant surface damage and the damage is usually thought of as gradual deterioration. Types of wear: abrasive and erosive wear, surface fatigue, corrosive wear, fretting etc. The main feature in wear failure:

- Removal of material and reduction of dimension as a mechanical action
- Wear takes place as a result of plastic deformation and detachment of materials over a period of time.

Adhesive wear has been commonly identified by the terms galling, or seizing. Abrasive wear, or abrasion, is caused by the displacement of material from a solid surface due to hard particles or protuberances sliding along the surface. Erosion, or erosive wear, is the loss of material from a solid surface due to relative motion in contact with a lubricant that contains solid particles. More than one mechanism can be responsible for the wear observed on a particular part.

2.10 Failure Analysis of an Electric Disconnector: Case Study

2.10.1 Introduction

This section will describe a case study result on the failure analysis of an electric power station disconnector (Maleque and Masjuki 1997). At the end of this section a recommendation is made to overcome the catastrophic failure of the component. At the initial investigation it was found that the fractured disconnector for a 500 kV substation (Fig. 2.10a) was failed during installation that cause of failure is unknown. Therefore, thorough destructive examinations were performed to elucidate the causes of the failure. An inspection was conducted for the evidence of failure on site which tells nothing promising about what could have caused the current failure of the Disconnector switch. However, the following features were observed:

- Detail specification of the break disconnector
- Driving mechanism of the disconnector
- Installation procedure of the disconnector.

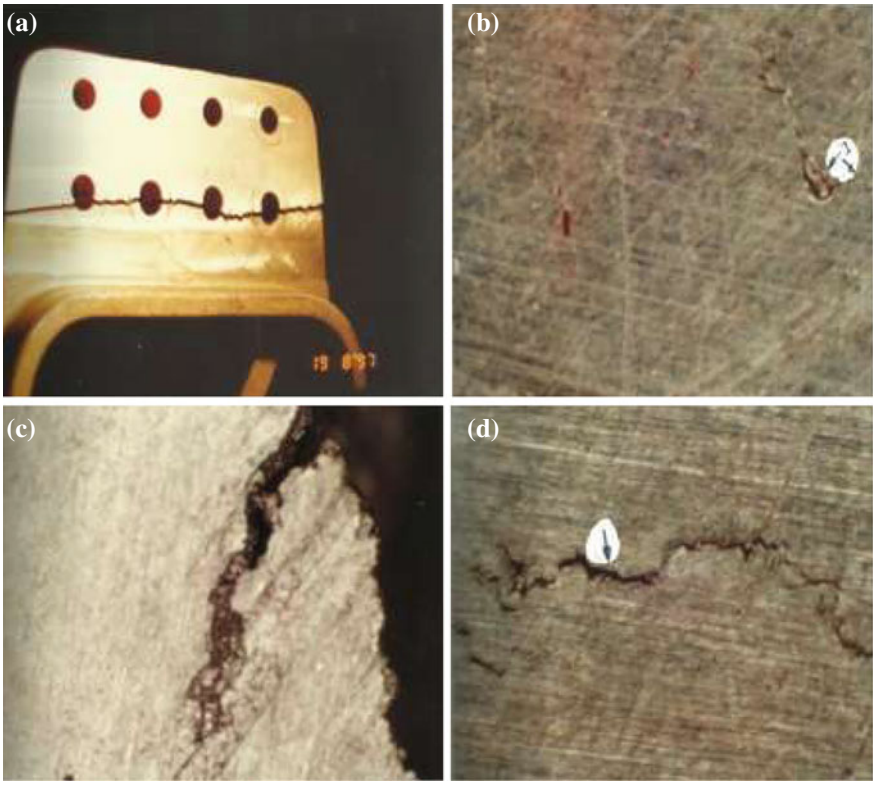

Fig. 2.10 **a** Fractured part of disconnector. **b** Crack pattern at the end of the fractured surface. **c** Extensive cracking at the bolt area. **d** Crack propagation at the inferior

2.10.2 Scope of Analysis

- Analysis of the failed components
- Determination of the cause and mode of failure
- Recommendation for corrective measure.

2.10.3 Visual Examination

The fractured part of the disconnector was cleaned properly and dye penetrant was applied. Cracks were found in various locations as follows:

- At the edge of the broken part as shown in Fig. 2.10a. In Fig. 2.10b, few cracks can be seen which were very close to the fractured surface, having extensive cracking.

- A wide and long crack nearby the fractured surface were found (as shown in Fig. 2.10c, d).
- Some voids or pored radiating from the surface of the part were also observed.

The nuts bolted with the hole had an interference fit where the bolts behave as integral parts. However, during installation or after installation, high force might acted on the component (such as base or blade) even if there is little movement or misalignment of the bushbar. Therefore, fracture or failure occurs towards downward direction.

From the nature and distribution of the cracks, and the appearance of the cracks surface of the disconnector, it can be suggested that:

- no plastic deformation
- rupture is downward
- surface is porous
- misalignment or mishandling of the component.

2.10.4 Metallographic Examination

The following sections were prepared for microstructural investigation:

- cross section of the blade of the disconnector
- two sections from the vicinity of the fractured part.

Before metallurgical examination, the specimens were polished and etched according to standard procedure and the microstructures were observed under optical microscope. In the photograph of the component (refer to Fig. 2.11) it can

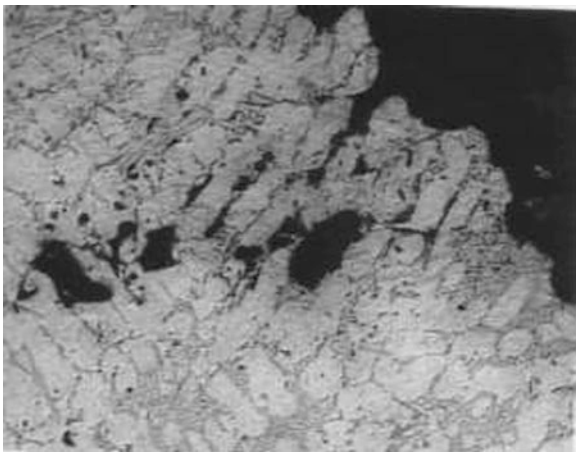

Fig. 2.11 Optical micrograph of materials. Showing α-aluminum dendrites, acicular silicon and primary silicon plates (×100)

be seen that the structure consist of α-aluminum dendrites, acicular silicon and primary silicon plates. Few inclusions and voids were noticed from the microstructure of the specimen which causes inferior mechanical properties of the disconnector material.

2.10.5 Mechanical Properties

2.10.5.1 Hardness Test Result

Tests were carried out using 10 kg_{fv} and 5 kg_f load. The hardness value of the material, close to the fractured edge, was around 40 HV_5. However at most of the places, the hardness was about 72 HV_{10}.

The microhardness test was carried out on polished surface specimen. The test result is shown in Table 2.3. For the area near to the fractured layer, its hardness is lower and the hardness increased as it when goes towards bulk area, at a distance around 4 mm from the fractured edge. Almost constant microhardness value was obtained away from the edge.

2.10.5.2 Tensile Properties

The tensile properties of the Disconnector switch are given in Table 2.4. The test was done according to BS18 (1987). From the test result it can be seen that some of the parameters comply with requirements given in Aluminium Standard and Data Hand Book (1984). The percentage elongation was about 4 which is quite below the requirements. This is possibly because of the very brittle nature of the material. The breaking load was 9.65 kN.

2.10.5.3 Compressive Strength

The compressive test result is also shown in Table 2.4. It can be noticed that the material compressed by 22.68 % when the applied load was 28,000 kg_f. At the transverse direction no remarkable change occurred when the same amount load was applied.

Table 2.3 Microhardness test results of 500 kV disconnector material

Distance from edge (mm)	Load (g_f)	VHN	Average VHN
1	100	67.07, 72.1, 67.07	68.75
2	100	74.04, 73.19	73.56
3	100	75.68, 68.58	72.13
4	100	78.84, 75.68	77.26

Table 2.4 Mechanical properties of 500 kV disconnector material

Specimen	Breaking load (kN)	Proof stress (0.2 %)	Tensile strength (MPa)	Elongation (%)	Reduction of area (%)	Young's modulus (MPa)	Compressive test	Charpy impact test (J)
1	9.59	65.4	121.54	4.06	1.72	5899.14	24.18	2.95
2	10.11	62.11	127.96	4.12	1.22	7673.42	21.18	3.03
3	9.25	56.34	119.74	3.82	2.15	6716.95	22.04	3.03
Average	9.65	61.28	123.08	4.00	1.70	6763.17	22.47	3.00

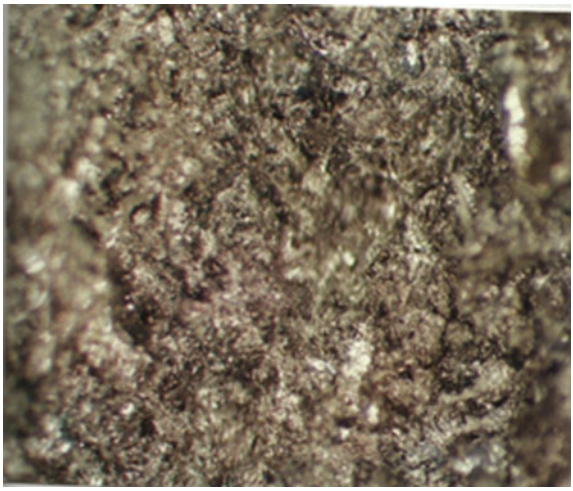

Fig. 2.12 Charpy fracture surface showing the shiny, granular surface which is the characteristics of brittle fracture

2.10.5.4 Fracture Surface

The charpy V-notch Impact Energy test results are shown in Table 2.4 (at the last colum). The average value of the change in potential energy was 3.00 J. From Table 2.4, it is obvious that the Disconnector head is below capacity of the absorbed energy as far as the impact energy is concerned.

The fracture surface was very shiny, having granural appearance (refer to Fig. 2.12). However, the resulting fracture surface was relatively flat without large undulation or gross irregularities.

2.10.5.5 Chemical Composition

From chemical analysis test the material of the Disconnector seemed to be AlSiMg alloy.

The analysis result is given in Table 2.5 and was obtained from optical emission spectrometry.

Table 2.5 Microhardness test results of 500 kV disconnector material

Element	Analysis (%)
Mg	0.55
Si	9.63
Fe	0.37
Cu	0.04
Mn	0.14
Zn	0.06
Al	Remainder

From Table 2.5, it can be seen that all the chemical contents are within specification except Si. The Si percentage is quite high (9.63 %) for this type of material and seemed to be decreased the ductility of the matrix and thus, enhanced the brittle characteristics of the material.

2.10.6 Discussion on the Findings

2.10.6.1 Mode of Failure

- failure of the disconnector occurred due to brittle fracture
- the major cracks on the vicinity of the fracture show that they were formed during installation and were not new cracks.

2.10.6.2 Contributory Factor

The macro and micro examination tests showed that some inclusions and voids are distributed throughout the matrix which seemed to be flattened. The macroscopic examinations also shows that the color of at the fracture surface and around it is shiny and having granular appearance. The fracture surface seems to be flat without large undulation or gross irregularities which show that brittle fracture had occurred. This is probably because of high percentage of silicon content in the alloy. The high amount of Si resulted in the aluminium wrought alloy becoming brittle.

Many cracks were found at the edge of the bolt which is an undesirable feature because it elevated the local stress level and might initiate and propagate crack. The presence of indentation mark closed to the fracture surface as well as edge of the bolt resulting from misalignment seems to be one of the probable cause of failure. Fracture occurred with no plastic deformation and proceeded along crystallographic planes.

2.10.6.3 Conclusion and Recommendation

The disconnector had failed by brittle fracture due to insufficient impact energy due to installation. The hardness of tensile properties and chemical composition (except silicon) are within specification. However, the Si percentage is quite high and contributes significantly to the brittle nature of the Disconnector material. The presence of inclusions, indentation mark at the edge of the bolt as aggravate the mechanical strength as well stress level at the point of fracture.

It is recommended that the percentage of Si of the alloy be reduced as it promotes brittleness of the material. Adopting some metallurgical strategy is important in order to avert or rather reduce brittleness of the material. It is also

suggested to handle the disconnector and other supporting components carefully during installation and refer to maintenance manual closely.

2.11 Summary

Engineering materials don't reach theoretical strength when they are tested in the laboratory. The usual causes of failure of engineering components can be attributed to: design deficiencies, poor selection of materials, manufacturing defects, exceeding design limits and overloading and inadequate maintenance. Flaws produce stress concentrations that cause premature failure in the component. Sharp corners in generally produce large stress concentrations leading to premature failure. Creep failure depends on both temperature and stress.

2.12 Tutorial Questions

2.1. What are the main factors that influence the level of performance of a part or component? What are the causes of failure of engineering components?
2.2. Explain the difference between stress intensity factor and fracture toughness.
2.3. Draw and explain the effect of thickness on fracture toughness behavior of materials.
2.4. Define and show both fatigue limit and fatigue strength using S–N diagrams.
2.5. Write down the common types of mechanical failures that encountered in engineering components or structures.
2.6. List down the differences between ductile and brittle fracture. Explain the ductile-to-brittle phenomenon. Support your answer with suitable diagram.
2.7. Ti–6Al–4V and aluminium 7075 alloys are widely used in making light-weight engineering structures. The fracture toughness of Ti-6Al-4 V and aluminium 7075 alloys are 55 MPa $m^{1/2}$ and 24 MPa $m^{1/2}$ respectively. The NDT equipment can only detect flaws larger than 3 mm in length. For the design of a structure that is subjected to a stress of 400 MPa,

    (1) Calculate the critical crack length of both materials.
    (2) Make a comment on the safe use of material for the structural applications.

2.8. AISI 4340 and Maraging 300 steels are being considered for making engineering structure. The fracture toughness of AISI 4340 and Maraging 300 steels are 50 and 90 MPa $m^{1/2}$ respectively. The NDT equipment can only detect flaws larger than 3 mm in length. For the design of a structure that is subjected to a stress of 600 MPa,

    (1) Calculate the critical crack length of both materials.
    (2) Make a comment on the safe use of material for designing a structural component.

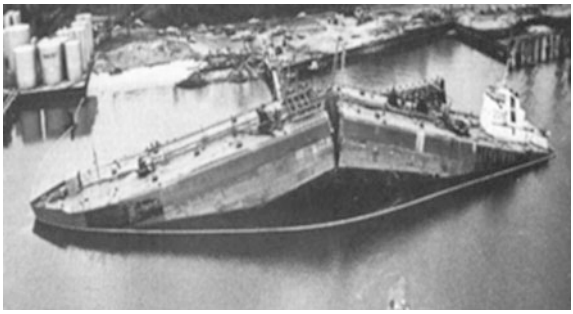

Fig. 2.13 Fracture of an oil tanker

2.9. Explain what is meant by fracture toughness. Explain the terms stress intensity factor K, critical stress intensity factor K_c and plane strain fracture toughness K_{1c}.
2.10. What factors can affect the values of the plane strain fracture toughness?
2.11. Secondary creep rate, where σ is stress, Q is activation energy, R is universal gas constant, T is temperature in degrees absolute, D and n are material constants. From laboratory tests on a Nickel alloy the value of n is found to be 3. The secondary creep rate is 3×10^{-10} s^{-1} at stresses of 18 and 4 MPa at temperatures of 627 and 777 °C respectively. Determine the values of D and Q. Use the equation to find the stress which will produce the same value of at a temperature of 727 °C.
2.12. Figure 2.13 shows the fracture of an oil tanker. Explain why and how such kind of fracture phenomenon occurs?
2.13. What do you mean by fracture toughness?
2.14. What are the main features of brittle material fracture surface? Discuss the ductile-to-brittle transition temperature (DBTT) with the help of diagram. Figure below shows a severe failure of the Titanic ship. What is your recommendation to overcome such kind of failure?
2.15. Explain the fatigue limit and fatigue life for safe-life fatigue of the engineering materials. Support your answer with diagrams.

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