Pearson BTEC Level _ Higher Nationals in Engineering (RQF)

Unit 9: Material, Properties & Testing

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Material Failure

Contents

INTRODUCTION

Explain the relationship between the atomic structure and the physical properties of materials.

- *Material Failure:*
    - Reasons why engineered components fail in service
    - Working and environmental conditions that lead to material failure
    - Common mechanisms of failure for metals, polymers, ceramics and composites.
    - Preventative measures that can be used to extend service life.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

Figure 1.2: *Destructive Effect of Thermal Expansion*

1.1.2 Polymers

Many polymers will naturally degrade when exposed to sunlight and/or heat (either during production or use), in industry, many polymers use stabilisers which increase the resistance to degradation from UV radiation and heat. However, unlike many traditional products such as metals and woods, polymers do not usually corrode as readily when exposed to air and water (there are several notable exceptions to this, however).

Other factors can lead to the failure of a polymer product, fractures frequently occur when the polymer product is exposed to extremes or even at relatively low stress levels. There are four main reasons for failure at low stress levels and they are: fatigue, cyclic stresses, creep rupture and long-term stresses.

On occasion, a polymer product may be subject to chemical attack or 'solvation' which results in a weakening of the structure, some acids, alkalis and salts can have this damaging effect on polymer materials. Solvation is the process whereby the polymer is penetrated by corrosive elements which, in turn, cause softening, swelling and ultimate failure. A polymer subject to a chemical attack will deteriorate regardless of whether the corrosive substance has penetrated it or not and may not even swell or soften but simply dissolve, become brittle or degrade.

The life-expectancy of polymer products are generally shorter than other traditionally used materials and they are often used or installed improperly which usually leads to earlier than anticipated failure. If a polymer used as a sealant, for example, is utilised above its softening point then the sealant material will distort and cause failure in situ.

Commonly, in real life applications, polymer materials are over-exposed to heat and sunlight which causes discolouration and potential structural weakening of the material. If the polymer is not resistant to UV and heat or has not been imbued with additives to make it so, then it will inevitably deteriorate.

1.1.3 Ceramics

Often in ceramic materials, failure is due to crystallographic defects, which are difficult to detect, however before any plastic deformation occurs the material is likely to simply fracture, making it immediately obvious that failure is imminent or has occurred. Another feature of ceramics is their often-porous nature which leads to concentrations of stress occurring, resulting again in catastrophic failures.

1.2 Mechanisms of Failure

Failure mechanisms are the processes that occur, whether physical, chemical, thermodynamic or another, which result in failure. There are two main types of failure mechanisms, they are either classified as Overstress or Wearout. There is a key difference in these two mechanisms, overstress occurs due to a single load circumstance which surpasses the basic strength property of the component/system. Whereas wearout occurs when the component or system has been subjected to load stresses over a prolonged time period, leading to cumulative damage. These two mechanism types can be seen below:

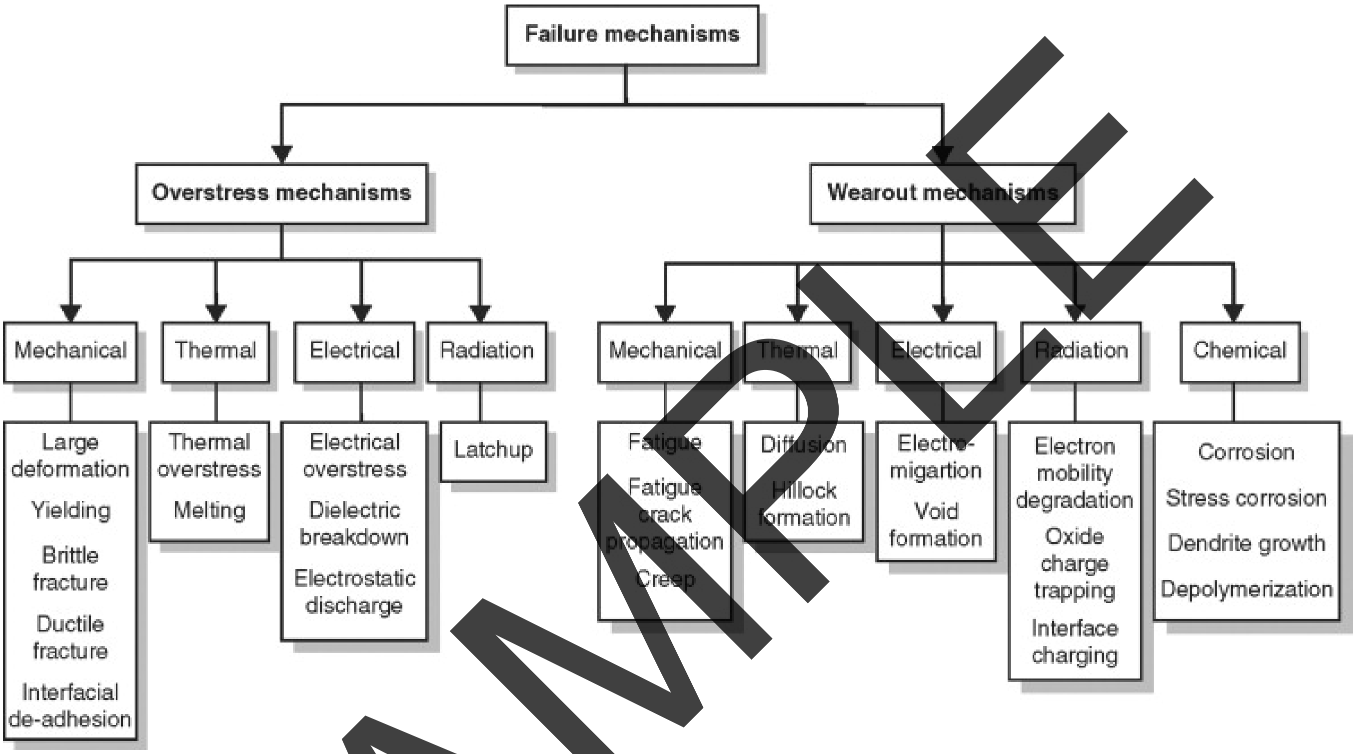

Figure 1.3: Failure Mechanism Tree

Often, more than one failure mechanism is combined to actually cause the component or system failure to occur.

Some examples of failure will now be explored.

- A plastic enclosure houses electrical components, this enclosure is kept in a humid environment which leads to moisture permeating the plastic. This absorbed moisture causes leaching of catalysts and other by-products of the polymer manufacturing process. This leaching reaches the internal electrical components and results in various failure mechanisms of resistors, electrical wiring, bond pads etc.
- A steel spring forms part of a car's suspension, over a period of 3 years the vibrations that occur from the car travelling over potholes, speed bumps and other uneven road surfaces, as well as vibrations transmitted from the engine through the car body cause fatigue. The accumulation of these vibrations of the time period leads to the spring fracturing. Other factors contributed to the failure, upon inspection, it was found that the material had inherent flaws as a result of manufacturing conditions.

1.3 Preventative Measures

All this talk of failure can be rather depressing; however, all is not lost! There are many ways in which service life can be extended and many components and systems do in fact outlast what was originally predicted. Georgian, Edwardian and Victorian buildings still stand today and function just as they were intended, some of the pyramids of ancient Egypt are over 2000 years old and still perform their function. Modern techniques help us to preserve and even extend service life, regular maintenance is of course important in ensuring smooth functioning of systems, as an obvious example: a car's lifespan is increased by regular servicing.

A structured approach is required to asses the causes of failure as well as to develop plans to reduce the likelihood of failures. Failure modes, mechanisms and effects analysis (FMMEA) is a logical methodology used for this purpose, which prioritises failure mechanisms according to their frequency and consequences.

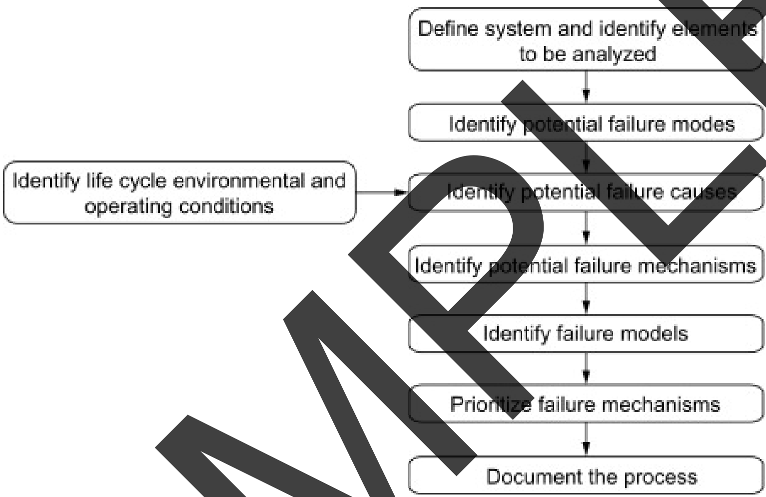

Figure 1.5: *FMMEA Methodology*

In order to inform future designs, information must be collated from previous failures and combined with calculations and computer modelling simulations. There are many different risk analysis tools and techniques that are commonly employed, examples include a Hazard & Operability Study (HAZOP), Fault Tree Analysis (FTA), Preliminary Hazard Analysis (PHA) and a variation of the FMMEA which is the Failure Mode & Effect Analysis (FMEA).

An example of a simple FMEA for the tyre of a car can be seen below: