SIGNIFICANCE OF FLAWS IN PERFORMANCE OF ENGINEERING COMPONENTS

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It is a fact of life that any material or product produced after undergoing various manufacturing processes with utmost care does contain a flaw and material with a flaw is an acceptable norm in all the industries. Material is never free from flaws. Flaws affect structural integrity and have a considerable influence on the engineering application of the material. Flaws generated during some of the manufacturing processes and some are introduced as part of the design are considered to highlight the point under this topic. Various destructive and non-destructive testing methods are discussed to identify flaw tolerances in materials.

Assessment of Structural Integrity :

To assess the structural integrity of a component it is necessary to know the mechanical properties of the material used in fabrication of a structure, what are the stresses the material is subjected to and likely flaws which will be present in the material and how will these flaws grow during the service ?

- i) Mechanical properties : Basically a microstructure.
- ii) Stress applied : Service or applied and residual.
- iii) Flaws : Type, location and geometry of flaws.

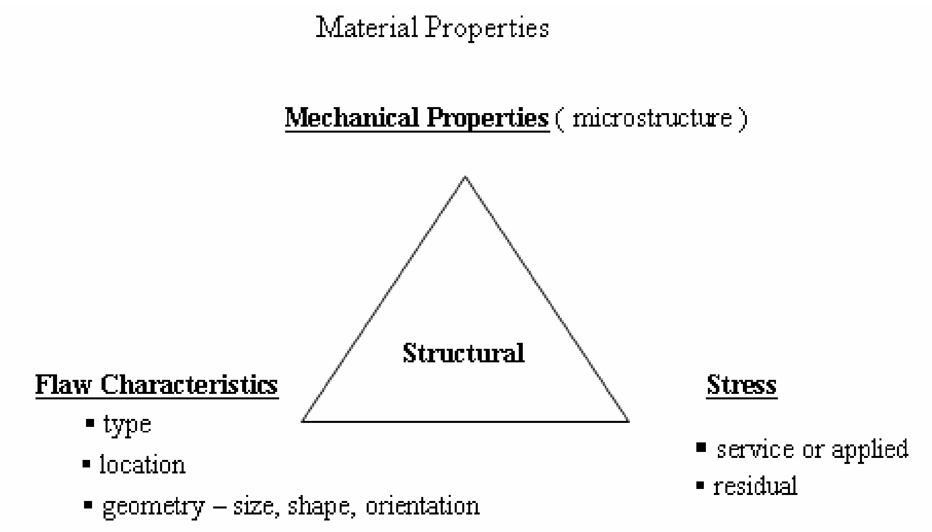

Fig 1

Structural integrity of a component primarily depends on three factors which have direct influence on its performance.

First the mechanical properties of the material from which the component is manufactured. It includes tensile strength, hardness, yield point, percentage elongation, impact resistance, creep, fatigue etc. These properties largely depend on microstructure of the material. Desired microstructure is obtained by employing suitable heat treatment.

Second factor is presence of flaws. When flaws are present, then nature and type of the flaws, location of the flaw and geometry of flaw, it includes size, shape and orientation of the flaw. A keyway is considered as a flaw with a desirable connotation because it is a part of a design of a component. Any interruption in material homogeneity is a flaw and has undesirable connotation. A flaw within an acceptable limit under given code may be acceptable but when it becomes unacceptable it makes component unfit for service. Third factor is the stress. It is of two types, one applied or service stress and the other is residual stress.

Classification of flaws :

1. Non-critical Flaws : Flaws which will not grow at all during service.
   A porosity or blow hole or shrinkage in a valve body. Such a discontinuity is not going to change in entire service life of the valve.

2. Not-critical Flaws : Flaws which will not grow to a critical size during life time. An excess penetration or excess fill is not going change in the weld joint or a lap on a forging during its service.

3. Sub-critical Flaws : Flaws which will grow to critical size in next inspection interval. Hard spots, arc strikes, notches may grow into cracks and heat affected zone may develop cracks of critical dimensions due to service conditions

4. Critical Flaws : Flaws which will grow to a critical size before next inspection. Existing flaws like cracks, overlap are likely to reach critical sizes.

Types of Inspection

Material undergoes inspection at various stages during manufacturing process. Inspections may be classifieds in following categories :

1. In Manufacturing Inspection (IMI). From raw material to final product and during each stage of production as material is progressively formed into desired shape, size and imparted mechanical properties is inspected to ensure quality of the product.

2. Pre Service Inspection (PSI). It provides a base line data for in service inspection. Presence of permissible discontinuities which may become cause of failure due to service conditions.

3. Base Line Inspection (BLI). Components undergoing dimensional changes for being in service for 2-3 years. This change in dimension is not to affect the performance of the product due dimensional change, eg. pipeline.

4. In Service Inspection (ISI). A routine inspection carried out at regular interval and some times in addition to this routine, to ascertain material integrity.

Flaws are present in the component but defect makes component unfit for service. Quality requirements necessitate to determine the properties of material by destructive testing as well as non-destructive testing.

Destructive testing involves determination of crystal structure, dislocation density, microstructure and application of stress to determine fracture toughness, ductile and brittle fracture and other mechanical properties. Effect of artificial flaws both planar and volumetric like notches affect these values to a considerable extent. Suitable NDT methods must be adopted to locate planar and volumetric flaws in the material. Surface flaws can be detected by visual inspection. For internal flaws other NDT methods like ultrasonic testing, radiographic testing, eddy current testing may be used. Each method has its own principle of operation.

An engineering definition of crack is an imperfection in material in the form of a separation which has a length 100 μ (micron), ie. 0.08 to 0.10 mm, about 3 to 4 grains. Further a micro crack is less than 1 micron, and macro crack is greater than 100 μ (microns), or 1 mm.

Nature or type of flaw can be characterized if one knows its geometry, location and cause. In case of a weld joint, failure zone can be either a weld itself or a heat affected zone (HAZ). Weld is more prone to failure than heat affected zone. Weld pool is a molten metal solidified quite quickly similar to casting, so it will have varying microstructure and this is responsible for varying mechanical properties of the weld joint. Casting is always inferior in quality because of chemical in-homogeneity, varying microstructure, varying grain sizes and presence of physical discontinuities like pores and blow holes.

As per International Institute of Welding (IIW) in a weld joint there are 83 discontinuities out of which six are categorized as major ones.

Cold cracks are formed due to grain boundary segregation.
Hot cracks are formed due to hydrogen entrapment.
Intermediate temperature cracks are formed due to inter-granular precipitation.
Planar flaws are 2-dimensional flaws like crack, lack of fusion. To a great extent severity of these discontinuities induces brittle fracture. Volumetric flaws are 3-dimensional flaws like blow hole, porosity and inclusion.

Fracture is failure of material by breaking and separating. Macrostructure of the fractured surface reveals the nature of failure. A shiny surface at fracture is indicative of brittle failure (BF) where material did not deform before breaking. A dull surface at fracture is indicative of ductile failure (DF) where material yielded, deformed plastically before breaking. Notch produces tri-axial stress, high local stress, high local strain and high local strain rate. Planar flaw has high stress concentration and high stress intensity. Elastic failure takes place when material fails due to applied stress which exceeds yield strength (YS). Plastic failure takes place when material fails due to applied stress which exceeds ultimate tensile strength (UTS). Fracture toughness test is to determine conditional toughness of the material.

Assessment of a Fracture Mechanics.

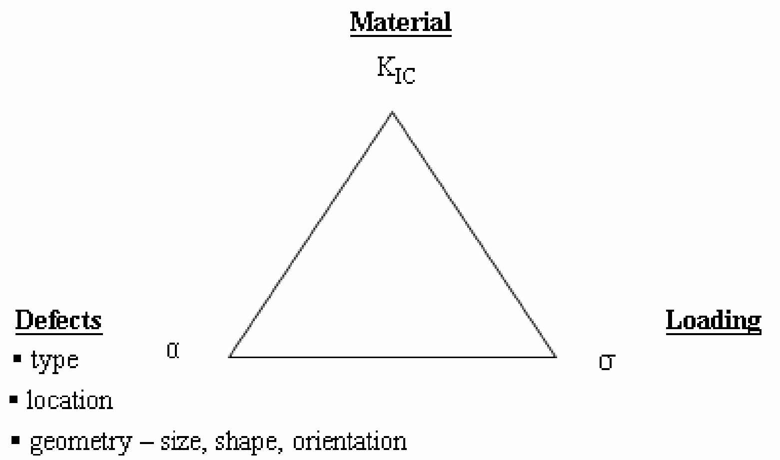

Fig 2

$K_{IC} = \alpha \cdot \sigma \cdot \sqrt{\pi . a}$

K_{IC} = material selection.
α = flaw geometry.
σ = design stress.
a = flaw size.

K_I at onset of fracture is K_C.
K_I = mode I stress intensity factor.
K is proportional to crack length and σ.

As strength increases, toughness decreases ie. material is less tolerant to presence of flaws. If toughness is high then the material tolerance to flaws is high. Material tolerances are high if applied pressure stress is low, stress – strain rates are low, material is a single phase, material has fine grain FCC crystal structure.

A material can be more tolerant to the flaws if it has high toughness value. A product or material when subjected to fabrication process, this fabrication process reduces flaw tolerance, it weakens the material and product further. Environment also contributes largely to this effect. Testing methods should be foolproof to ensure that no flaws are left undetected. Different materials have different limits of tolerances.

Welding has a considerable effect on flaw tolerance. Welding process modifies microstructure, reduces toughness so flaw tolerance is reduced. Introduction of flaws and residual stress weakens the material. Stress corrosion cracking which is result of simultaneous actions due to residual stress and corrosive environment, reduces toughness of material.

What location of flaw is more severe ?

Flaws which are open and likely to be found on surface are more severe than the flaws which are internal.

For detection of planar flaws on the surface as well as internal ones various NDT methods are used. For flaws which are open to surface can be detected by using magnetic particle testing and liquid penetrant testing. For detection of internal flaws radiographic testing may be used. In that case cracks may be missed if it is perpendicular to the surface and there is no depth indication. Ultrasonic testing is the best method.

Assessment of flaws is based on using different codes. Selection of a particular code depends on application of product in typical environment and working conditions. Design a code which is based on good workmanship, service experience and suitable NDT method. Different types of materials exhibit different tolerances.

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