# **Non-Destructive Evaluation (NDE)**

Chapter 2

# Discontinuities origins and Classification

### Mohamad Fathi GHANAMEH



الجاوعــــــة الدوايــــــة للربـــــــ @∧₀⊔Հ+ +₀ⅩO₀∀೫₀I+ I QQ⊖₀E niversité Internationale de Rabat



Flaws or imperfections may be from the original material, caused by process used, created by human error or defects during operating life or combination of some of them.

A clear understanding of material, the process and the possible interaction between them is very important to determine any discontinuity/defects.





Discontinuity: An interruption (crack, forging lap, seam, inclusion, porosity, etc.) in the normal physical structure or configuration of an article, It may or may not be a defect

Defect: a discontinuity that interferes with the usefulness of a part or exceeds acceptability limits established by applicable specifications, Not all discontinuities are defects



الجاوعــــــــــة الدوايـــــــة للربـــــــا ⊙∧ه⊔Հ+ +هXOه۲۱۹۱+ I QQ⊖هE niversité Internationale de Rabat



# **Classification of Defects by Origin**

Typically grouped into 3 stages:

1. Inherent

Related to the melting and original solidification of metal in the ingot

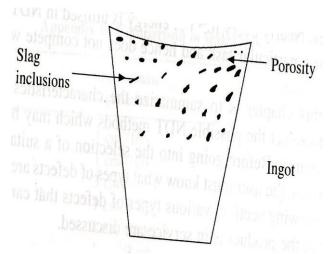
2. Processing

Formed by forming or fabrication operations (casting, rolling, forging, machining, grinding, heat treating, welding, plating)

Service-Induced (also call In-service)
Discontinuities caused by fatigue, corrosive environments, or overheating



- Related to the melting and original solidification of metal in the ingot (i.e. original steel-making process)
  - Inclusions
  - Porosity
  - "Pipe"





Non-Destructive Evaluation (AE5005) M. F. GHANAMEH 2018-2019



Porosity

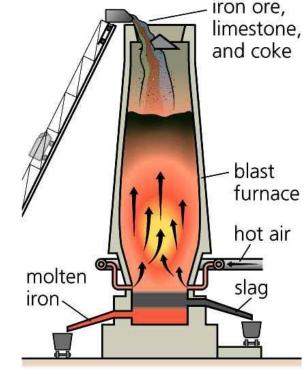
Porosity

#### **Example:** Steps in the Steelmaking Process

- Iron ore, coke, and limestone are fed into 1) the top of a blast furnace
  - Coke is a solid carbon fuel obtained from coal
  - Limestone is calcium carbonate
- 2) As the coke burns, the oxygen is removed from the iron ore
- The limestone reacts with the molten iron 3) to remove impurities
- The impurities form a slag which floats on 4) the surface of the metal pool. This slag is periodically removed from the furnace

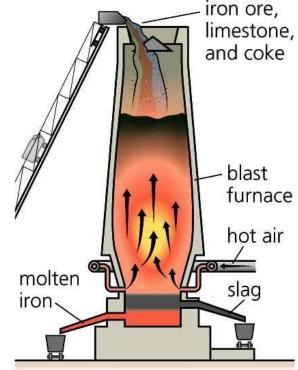






#### **Example: Steps in the Steelmaking Process**

- 5) The molten iron is drawn from the furnace and poured into ingot molds called "pig iron"
- 6) Pig iron contains 3-5% carbon; further refining is required to remove the excess carbon and improve the properties of the steel. Iron with less than 2% carbon is typically called a steel.







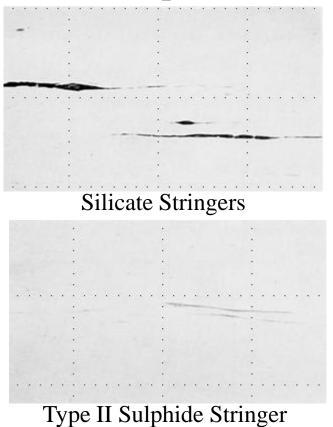
#### Inclusions

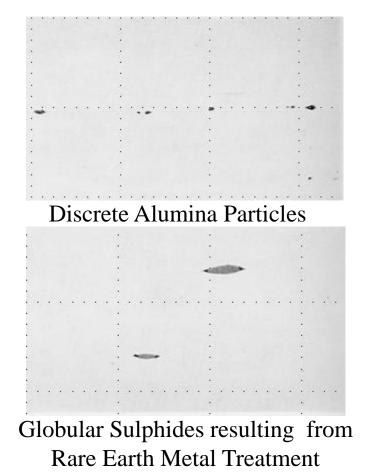
- Non-metallic impurities, such as slag, oxides, and sulfides that are present in the original ingot
  - Through rolling of raw material into billets or bar stock, these impurities form "stringers", or lines
  - Often irregularly shaped and in groups
  - Usually not objectionable, except when they occur in critical areas, on highly-stressed surfaces, or in unusual numbers





#### **Inclusion Example**

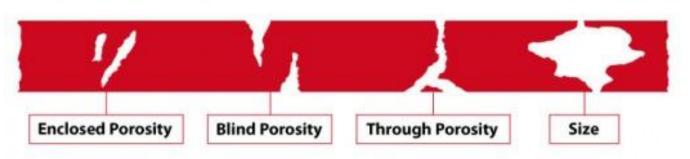






#### Porosity

- Due to gas bubbles being trapped in the material prior to solidification
  - Similar to bubbles in a carbonated drink
  - Bubbles generally round or spherical in shape









#### "Pipe"

- A discontinuity in the center of the ingot, caused by cavities formed during solidification
  - Becomes elongated in rolling operations
  - Not usually visible on the surface of the article





# **Processing Discontinuities**

- Formed by forming or fabrication operations
- Typically subdivided into:
  - primary processing discontinuities casting, rolling, forging
  - secondary processing discontinuities machining, grinding, heat treating, welding, plating

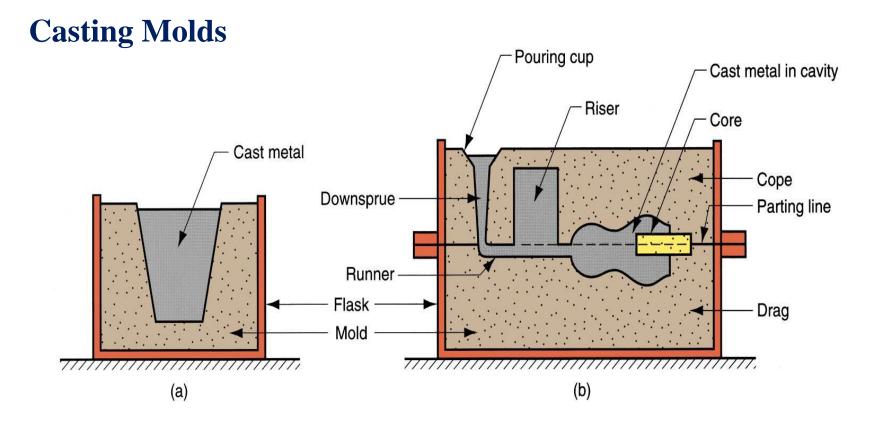




- Inclusions
- Porosity
- Cold shuts
- Hot tears
- Shrinkage cavities







• (a) Open mold and (b) closed mold.

الجائفـــــــة الدوليـــــة للربـــــاط +ه@٨هلا+ +هXOه/۲۱۱۰۱+ ا QQOهE Université Internationale de Rabat



Casting of metal involves pouring or injection of molten metal into a cavity.

#### **Non-metallic Inclusions:**

- Is a general term applied to sand, slag, oxide etc trapped in casting.
- Most of non-metallics generally lighter than the molten metal. Are mostly found on the top of the ingot. Nevertheless, there are some which are trapped at the bottom since they did not have sufficient time to reach the surface before molten metal above solidifies.
- Usually irregular in shape.



#### **Porosity**

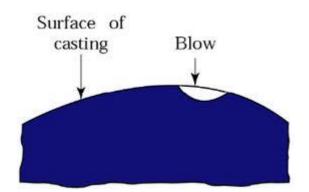
- Is caused by the entrapped gas in molten metal which get trapped in the solid casting.
- The size and amount depend on the gas content of the metal and the rate of solidification of the casting.
- May either be localized or throughout areas.
- Spherical/ nearly spherical in shape.





#### **Blow Holes**

- Are caused by trapping of air, mold, or core gases and water vapor in the casting during solidification.
- Smooth, round, elongated or oval shape of varying size.
- Sometimes extremely large gas holes appears.

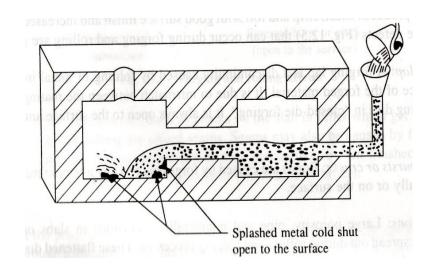






#### Cold Shut

- Is caused by the failure of the stream of molten metal to unite with a confluent stream/solid metal such as a pouring splash or chaplet.
- Usually look like a crack with a smooth and curved contour.
- Usually exposed to surface.

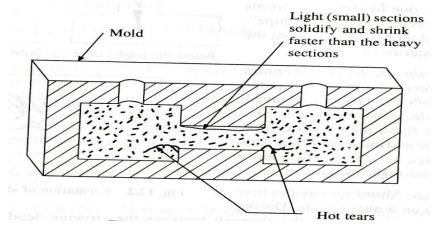






#### **Crack**

- This is a discontinuity which is due to fracture of metal during or after solidification.
- 'Hot tears' are cracks caused by stresses which develop near solidification temperatures when material has lowest strength.
- 'Stress cracks' also called as 'cold cracks' are formed when metal is completely solid.





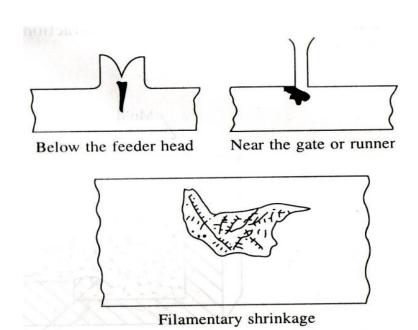


# **Casting Defects**

#### **Shrinkage flaws**

•These are cavities formed during liquid to solid contraction.

•Macro-shrinkage (piping defect): Solidification of molten material starts from surface and progresses to center of ingot. Since the center of ingot is the last to cool and solidify, most of the cavity due to shrinkage forms at center.





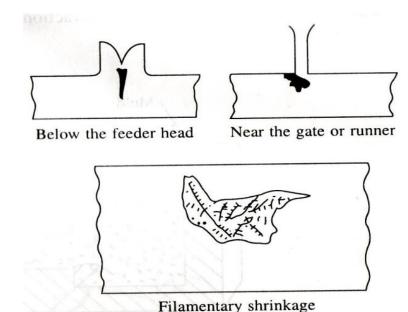


# **Casting Defects**

#### **Shrinkage flaws**

•Center line shrinkage (filamentary shrinkage): Occurs when solidification cannot be correctly controlled. It may be extensive, branched, dendritic and interconnected.

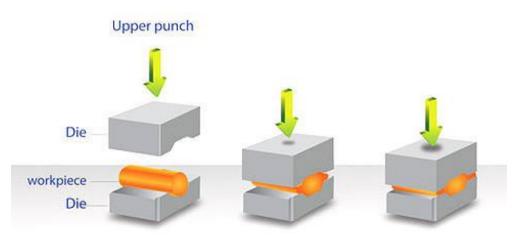
•Micro shrinkage: Shrinkage in microscale.







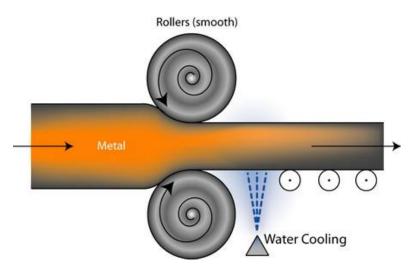
- Rolling Discontinuities
  - Laminations
    - Improperly fused layers of material
    - Can be seen from the cross-sectional view of rolled materials
  - Stringers, "pipe" also caused by rolling

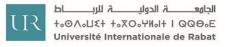






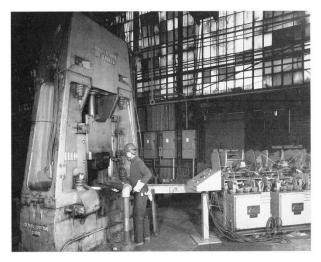
- Forging Discontinuities
  - Bursts surface or internal ruptures due to forging at improper temperatures
  - Laps folding of metal in a thin plate onto surface of forging







- Forging is the working of a material into an useful shape by hammering or pressing. Usually carried out at high temperature.
- The process of plastically deforming a material by passing it between rolls is known as rolling.





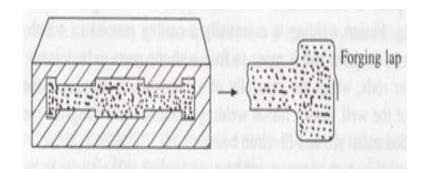


الجاوعــــــــــة الدوليــــــة للربـــــــا ۲۰۵۸۰۵۲۰ + ۲۰۵۵۲۰۲۰ ه Niversité Internationale de Rabat



#### Forging Lap

- Is a discontinuity caused by folding of metal in a thin plate on the surface of forged material.
- Is due to mismatch between the mating surfaces of die.

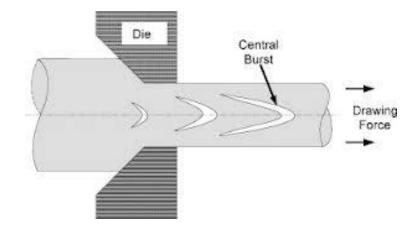






#### Forging Burst or Cracks

 Bursts are caused by forging at too low temperature. Can occur internally or on the surface.



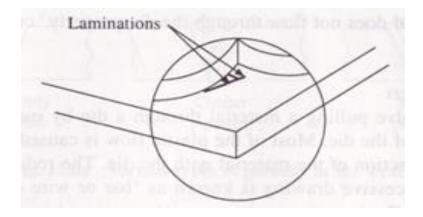


الجارعــــــــــة الدوليـــــــة للربـــــــاط +ه٢٥/٥٤ + ٩٥/٥٤ + ١ مراحه+ Université Internationale de Rabat



#### **Laminations**

 Large porosity, pipe and non metallic inclusions are flattened and spread out during rolling or forging.

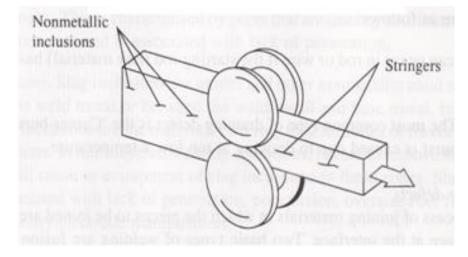






### <u>Stringer</u>

 Nonmetallic inclusions which get thinned and elongated in the direction of rolling.



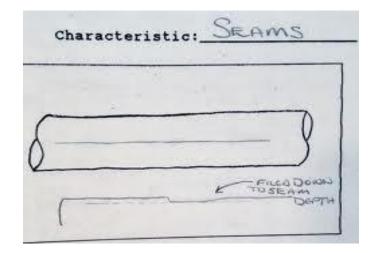


الجارعـــــــــة الدوليـــــــة للربـــــــاط +₀O∧₀LՀ+ +₀XO₀YH₀l+ I QQ⊖₀E Université Internationale de Rabat



#### <u>Seams</u>

 Seams are surface discontinuity. Surface irregularities such as crack get stretched and elongated during rolling are called seams.





الجائعـــــــة الدوليـــــــة للربــــــاد +₀O∧₀LՀ+ +₀XO₀YH₀l+ I QQ⊖₀E Jniversité Internationale de Rabat



 Extrusion is a process by which a block of material is reduced in cross section by forcing it to flow through a die under high pressure. Following defects generally formed:



#### Internal pipe or extrusion defect

• Trapping of oxidized outer skin of the billet into the central region of the extruded product.

#### <u>Cracks</u>

• If the material does not flow through the die properly, 'cracks' are generated.



الجاهعــــــــــة الدوايـــــــة للربـــــــاد ⊙∧ه⊔Հ+ +هXOه۲۱۵۱+ I QQ⊖هE Iniversité Internationale de Rabat



### **Machining Discontinuities**

- Tears - due to use of dull tools or cutting too deep



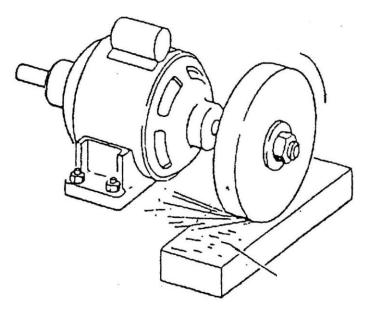
الجارعــــــــة الدوليـــــــة للربــــــاط +ه۵۸۵ها ا ۲۹۵۹ه-۲۷۱۰۲۲ Université Internationale de Rabat



### **Grinding Discontinuities**

#### **Grinding Cracks**

 Grinding cracks are caused by stresses which are build up from excessive heat generated between the grinding wheel and the material. Occurs on the surface of the material at direction of the grinding wheel rotation.







# **Heat Treating Discontinuities**

#### **Heat Treating Cracks**

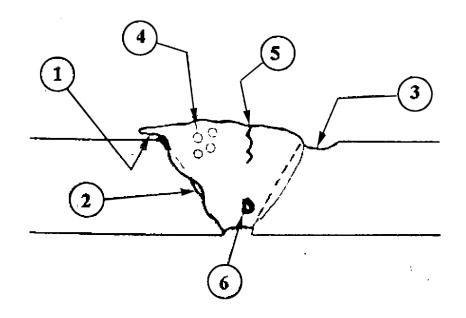
- Heat treating is basically a process of obtaining microstructure with desired properties like strength, hardness, ductility, impact strength etc. of a material by controlled heating and cooling.
- While heat treating, unequal cooling between light and heavy sections of a part results id build up of stress leading to cracking.
- This is called heat treating crack.





# **Welding Discontinuities**

- Lack of fusion
- Undercut
- Porosity
- Crater cracks
- Slag Inclusion
- Stress cracks
- Lack of penetration





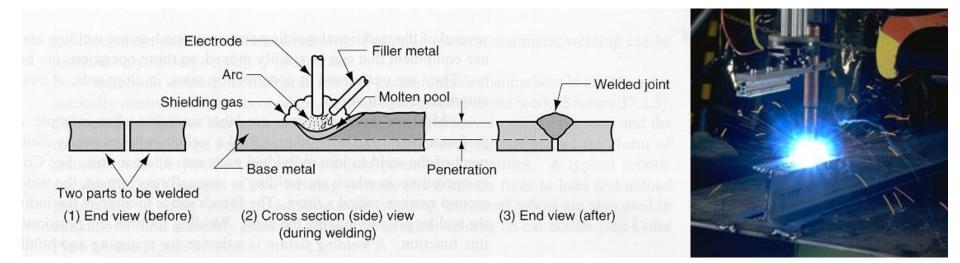
الجامعـــــــة الدوليـــــــة للربــــــاط +ه٥٨هلالاهه٨هها المالهه: المعامه المعامية Université Internationale de Rabat



### **Welding Discontinuities**

A concentrated heat source melts the material in the weld area; the molten area then solidifies to join the pieces together

Sometimes a filler material is added to the molten pool to strengthen the weld



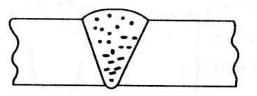


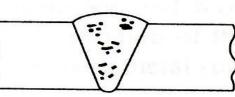
AOUX+ +OXOOHIOI+ I QQOOE niversité Internationale de Rabat

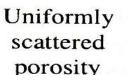


# **Welding Discontinuities**

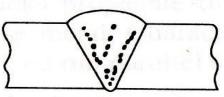
#### Gas Inclusions







Cluster porosity



Linear porosity

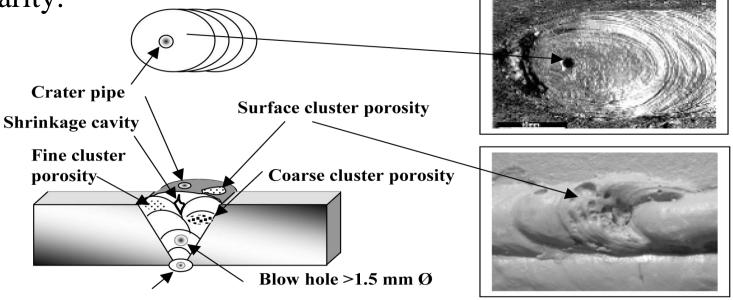
- Gas may be formed in molten weld metal for various reason and may get trapped if there is insufficient time for it to escape before solidification.
- Trapped gas is usually in the form of round holes termed porosity or blow holes or of an elongated shape called piping or wormholes.





#### Gas Inclusions (Porosity)

• Gas formation may be caused by chemical reaction during welding, high sulphur content in plate or electrode, excessive moisture in the electrode/plate, incorrect welding current or wrong polarity.

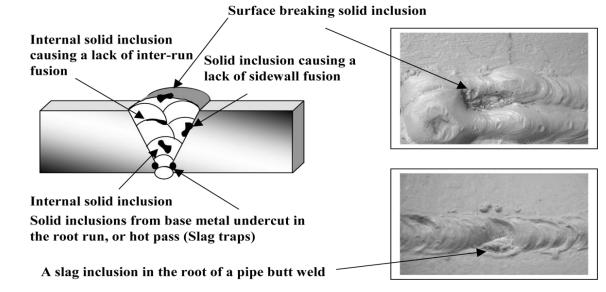






#### Slag inclusions (c)

- Are oxides and other nonmetallic solid materials that are entrapped in the weld metal or in between weld-base metal.
- Slag inclusions are frequently associated with lack of penetration, poor fusion or too narrow groove.



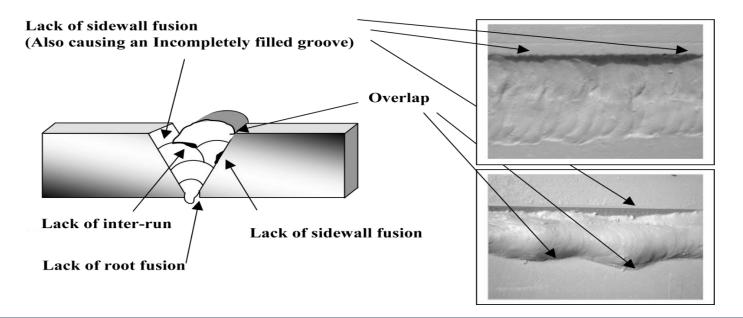


الجاهعــــــة الدوليــــــة للربــــــاد oO∧oLIՀ+ +oXOo+Hol+ I QQ⊖oE Jniversité Internationale de Rabat



#### Lack of Fusion (b)

• Is incomplete fusion caused by the failure of complete fusion of weld metal and base metal or inter-weld passes.

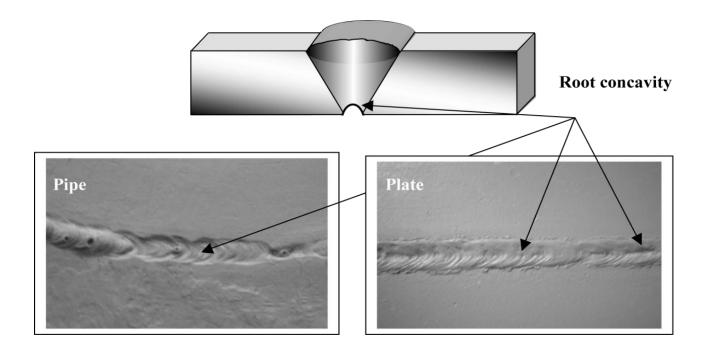






Lack of Penetration (a)

• The root of a weld will not be adequately filled with weld metal and void is left.

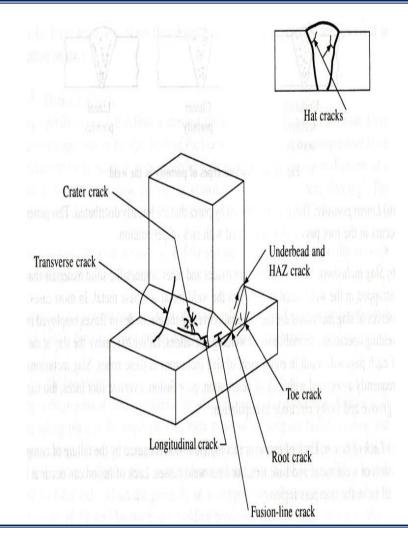






#### <u>Cracks</u>

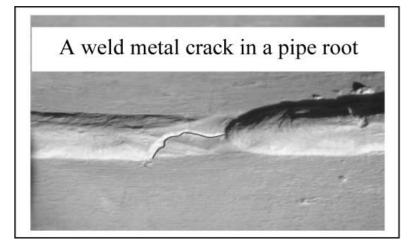
- Cracks are linear rupture of metal under stress. Cracks associated with welding may be categorized according to whether they originate in the weld itself or base metal.
- Generally 4 types of cracks occur in weld metal: transverse, longitudinal, crater and hot cracks.
- 7 types of base metal cracks: transverse cracks, underbead cracks, toe cracks, root cracks, lamellar tearing, delaminations and fusion-line cracks.

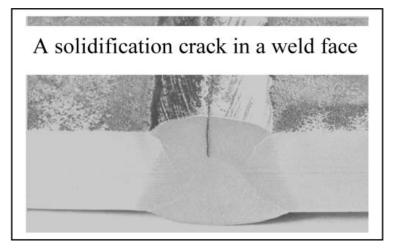




الجاوعـــــــــــة الدوايـــــــة للربـــــــاد ©∧ه⊔Հ+ +هXOه۲۷۵۱+ I QQOهE Iniversité Internationale de Rabat









الجاهعــــــة الدوليــــــة للربـــــاط +ه٥٨هالاه٥٢ه،كالاهه الالاهه: Université Internationale de Rabat



#### <u>Cracks</u>

- **Transverse cracks:** These cracks are usually open to the surface. They usually extend across the entire face of the weld and sometimes propagate into base material. It is the result of high residual stresses induced by thermal cycling during welding.
- Underbead cracks: Similar to transverse crack. It forms in the heat affected zone because of high hardness, excessive restraint and presence of hydrogen.
- Longitudinal cracks: Caused either build up of high contraction stress in weld joint. Root crack are the most common form of longitudinal weld metal cracks.

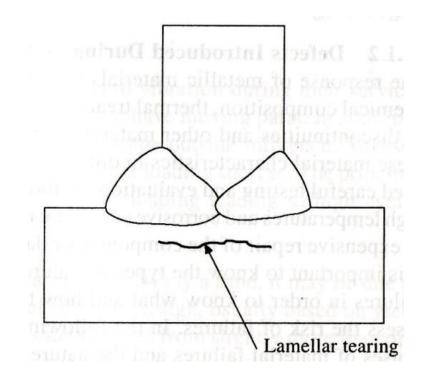
UR



#### <u>Cracks</u>

### • Lamellar tearing:

Phenomenon that occurs in T joints. The stresses developed by this configuration result in separation that takes place in the base metal between the roots of the two welds.

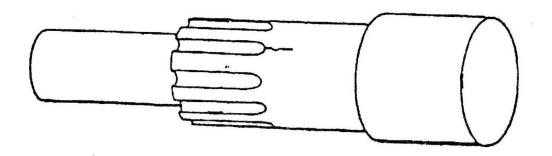






### **Service-Induced Discontinuities**

Discontinuities caused by fatigue, corrosive environments, or overheating





\_ة الدولا\_ +₀⊙∧₀⊔₹+ +₀ႿO₀ΨΝ₀I+ I QQ⊖₀E Université Internationale de Rabat



### **Service-Induced Discontinuities**

### **Cause of Material Failures**

- Products and structures may be subjected to a number of varying service conditions. Loads may be static loads (stationary or fixed) or dynamic loads (varying).
- The environment may also contribute.
- Mechanical failure is always a result of presence of stresses above some critical value, leading to deformation or fracture.
- Such excessive stresses are set up by combination of <u>material</u> <u>defect</u>, excess load, improper load application or design error.





### **Service-Induced Discontinuities**

• Discontinuities caused by fatigue, corrosive environments, or overheating





# **Fatigue Cracks**

- Fatigue Cracks
  - Develop at areas of high stress concentrations such as holes, fillets, keyways, etc.
  - May be due to mechanical or thermal fatigue
  - Once crack initiates, it can quickly propagate resulting in failure





# **Thermal Fatigue**

- Due to repeated heating and cooling of a part
  - Cracks resulting from large thermal gradients are usually multiple and often have an alligator skin appearance
- To reduce chance of failure, materials must be loaded below their fatigue strength





# **Corrosive Environments**

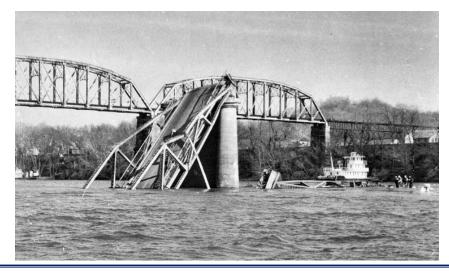
- Corrosive environments can lead to:
  - Embrittlement
    - When a material loses its ability to elastically deform it breaks rather than stretches
  - Stress corrosion cracking (SCC)
    - Combination of stress and a corrosive environment
    - Different materials react to different corrosives





### **Corrosive Environments**

- December, 1967 collapse of Silver Bridge at Point Pleasant, WV
  - Rust in an eye bar joint caused a stress corrosion crack
  - Initial crack 0.1" deep
  - High bridge loading and low temperatures caused crack to propagate to point of failure
  - 46 people killed





الجاوعــــــــة الدوايـــــــة للربـــــــا م∧ه⊔Հ+ +هTOه۲۷۵۲+ I QQ⊖هE niversité Internationale de Rabat



### **Material Losses**

- Service-Induced Discontinuities also due to loss of material
  - Wear
  - Erosion
  - Corrosion



