Classification of Discontinuities

Classification of Discontinuities

Definitions

- **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
- **Surface discontinuity** – a discontinuity open to the surface
  - May be observed through VT, PT, or MT
  - More likely harmful to an article than a subsurface discontinuity

Classification of Discontinuities

More Definitions

- **Subsurface discontinuity** – a discontinuity that is not open onto the surface of an article
- **Nonrelevant indication** - indications that are not due to discontinuities
  - May be due to abrupt changes in article shape, surface roughness, etc.

Classification of Defects by Origin

Typically grouped into 3 stages:

- Inherent
- Processing
- Service-Induced (also call In-service)

Classification of Discontinuities

Inherent Discontinuities

1st stage of discontinuity

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

Classification of Discontinuities

Some reasons there are discontinuities and defects in metal?

Some of the reasons discontinuities and defects in metals are attributed to the processing of the ore to the casting process to the hot or cold working process. Take casting for example: there are several **casting defects** which are normally broken down into five main categories: *gas porosity*, *shrinkage defects*, *mold material defects*, *pouring metal defects*, and *metallurgical defects*. As further examples of some of the reasons discontinuities and defects in metals the processing of iron ore to make still is shown in the following slides. Imagine the many places that discontinuities and defects could be generated in this process.

Classification of Discontinuities

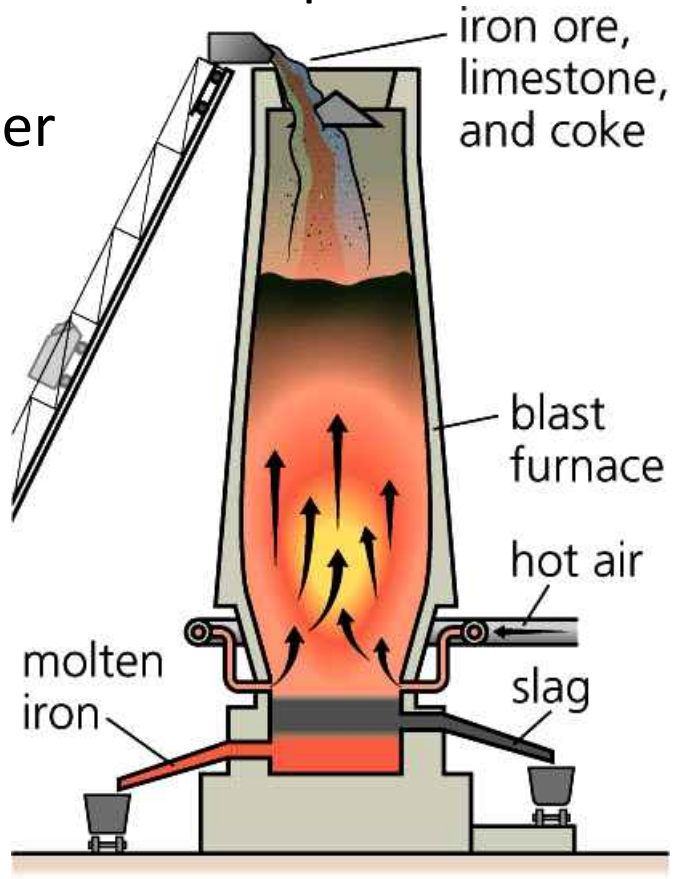
Example: Steps in the Steelmaking Process

1) Iron ore, coke, and limestone are fed into 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
3) The limestone reacts with the molten iron to remove impurities
4) The impurities form a slag which floats on the surface of the metal pool. This slag is periodically removed from the furnace

Classification of Discontinuities

Example: Steps in the Steelmaking Process

4) The molten iron is drawn from the furnace and poured into ingot molds called “pig iron”
5) 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.



Types of Furnaces

- Blast Furnace (shown)
- Basic Oxygen Furnace
- Electric Furnace

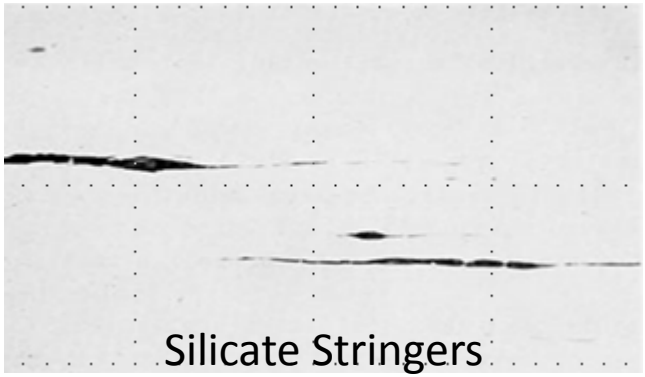
Classification of Discontinuities

Inclusions

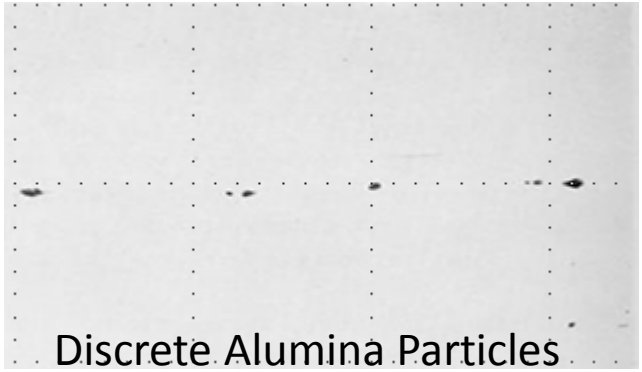
- Non-metallic impurities, such as slag, oxides, and sulfides that are present in the original ingot
  - Through rolling of raw material into billets or bar stock, these impurities form “stringers”, or lines
  - Often irregularly shaped and in groups
  - Usually not objectionable, except when they occur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

Classification of Discontinuities

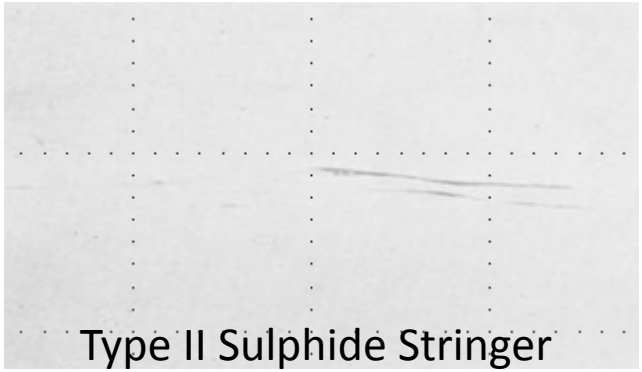
Inclusion Example



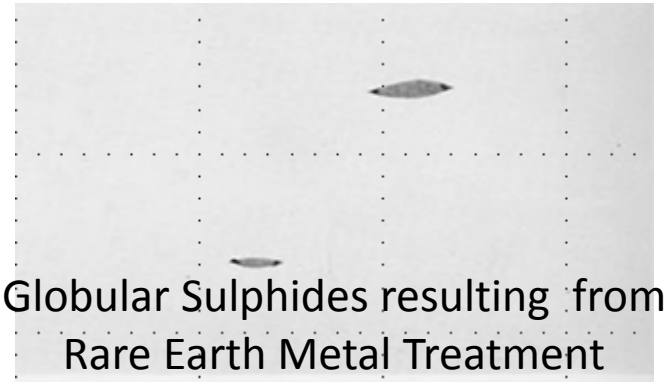
Silicate Stringers



Discrete Alumina Particles



Type II Sulphide Stringer

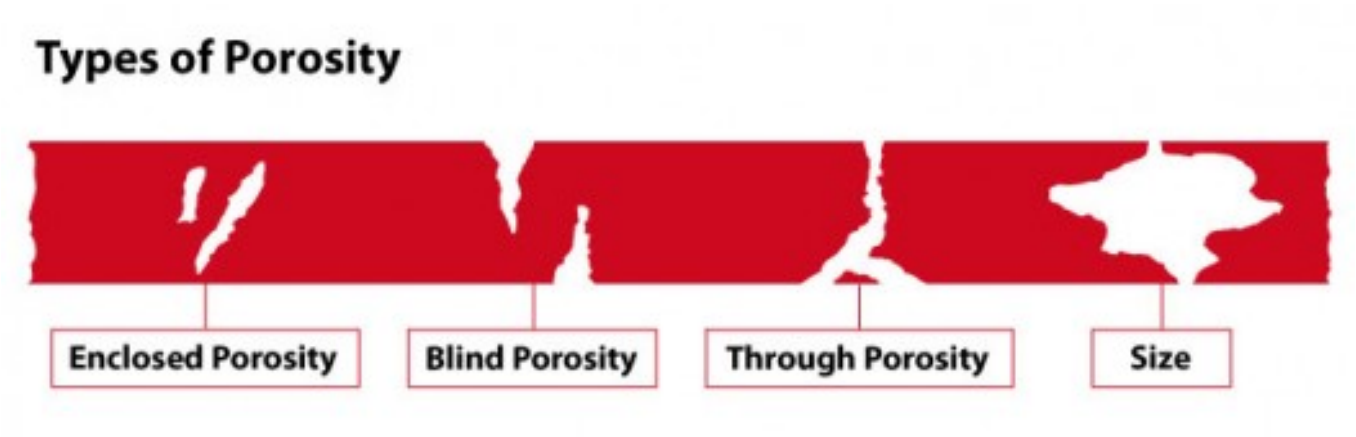


Globular Sulphides resulting from Rare Earth Metal Treatment

Classification of Discontinuities

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



Classification of Discontinuities

“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

Classification of Discontinuities

Processing Discontinuities

2nd stage of discontinuity

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

Classification of Discontinuities

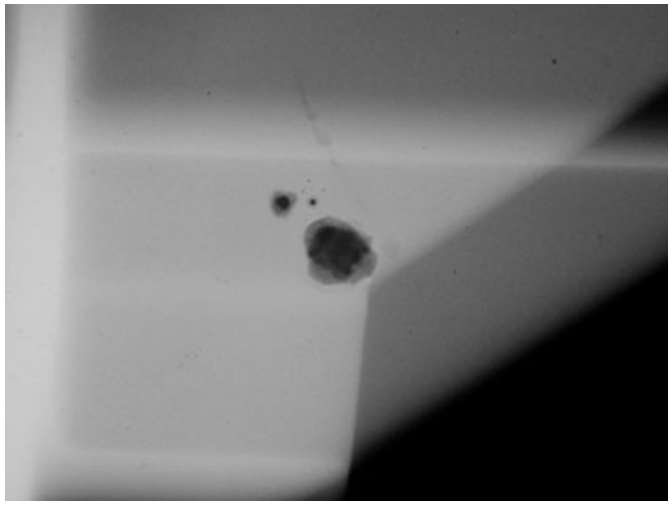
Primary Processing Discontinuities - Casting

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

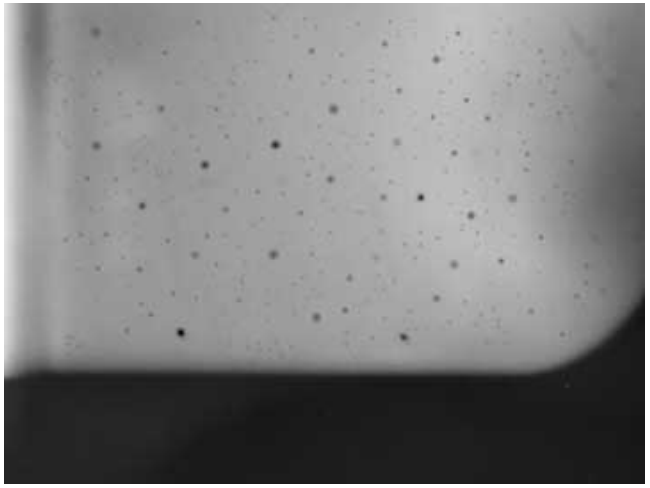
Classification of Discontinuities

Casting Discontinuity Examples

Sand Inclusion



Porosity

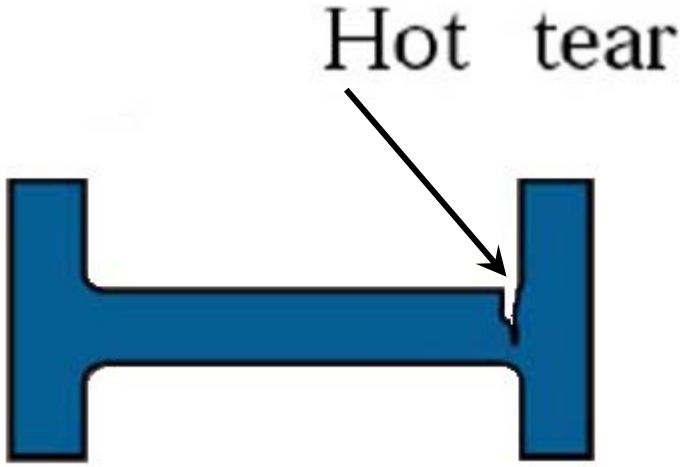


Classification of Discontinuities

Primary Processing Discontinuities - Casting

- Cold shut – due to lack of fusion between two streams of metal as it flows into the cast

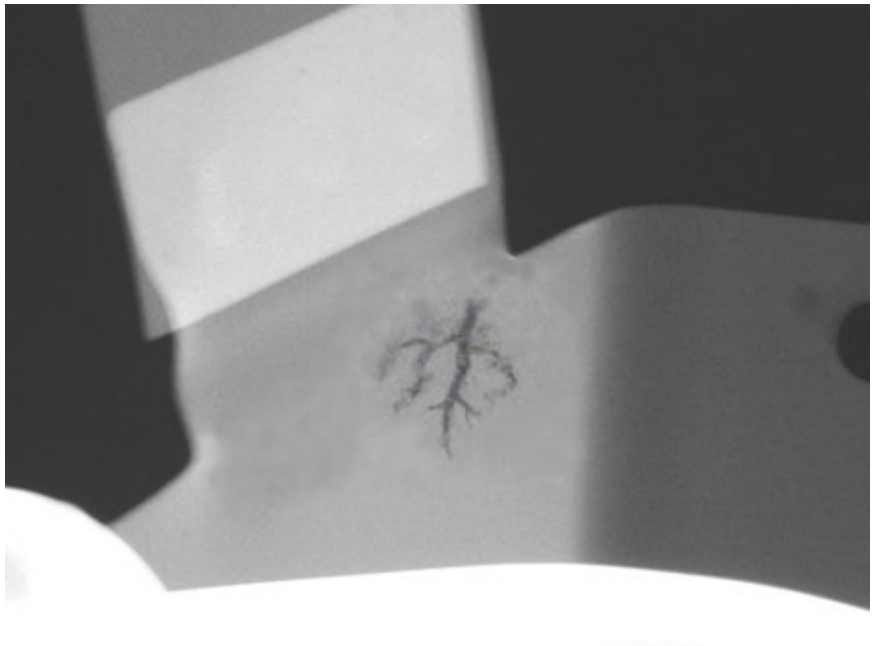
- Hot tear – due to difference in cooling rates between thin and thick sections (a crack formed while the casting is cooling)



Classification of Discontinuities

Primary Processing Discontinuities - Casting

- Shrinkage cavity – due to inadequate metal to fill the cast mold following shrinkage of the cast upon cooling



Classification of Discontinuities

Primary Processing Discontinuities - Forming

- 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

Classification of Discontinuities

Secondary Processing Discontinuities

- Machining
  - Tears – due to use of dull tools or cutting too deep
- Grinding
  - Cracks
    - Due to localized overheating
- Heat Treating
  - Stress cracks due to unequal heating or cooling

Classification of Discontinuities

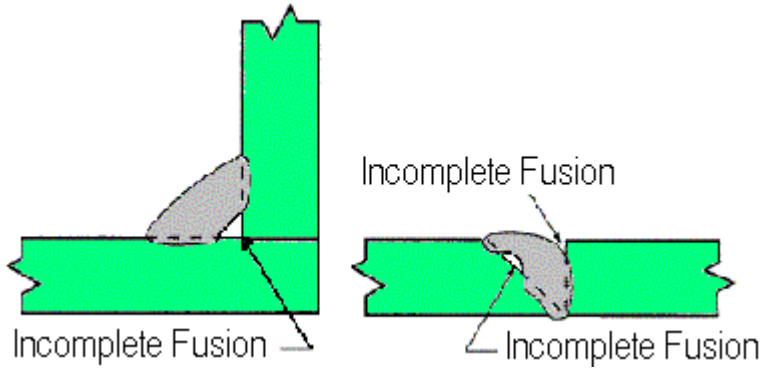
Secondary Processing Discontinuities - Welding

- Welding
  - Undercut
  - Lack of fusion
  - Lack of penetration
  - Inclusions
  - Porosity
  - Stress cracks
  - Crater cracks

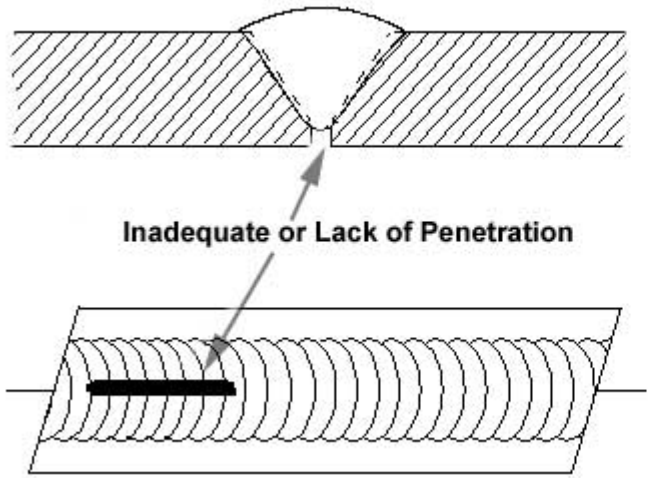
Classification of Discontinuities

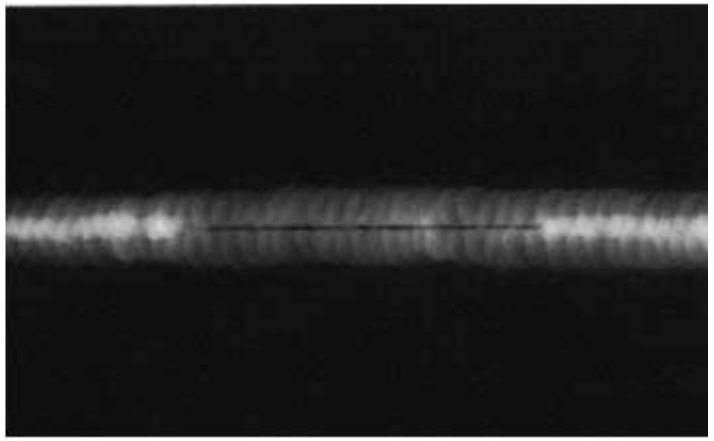
Secondary Processing Discontinuities - Welding

- Incomplete fusion



- Lack of penetration

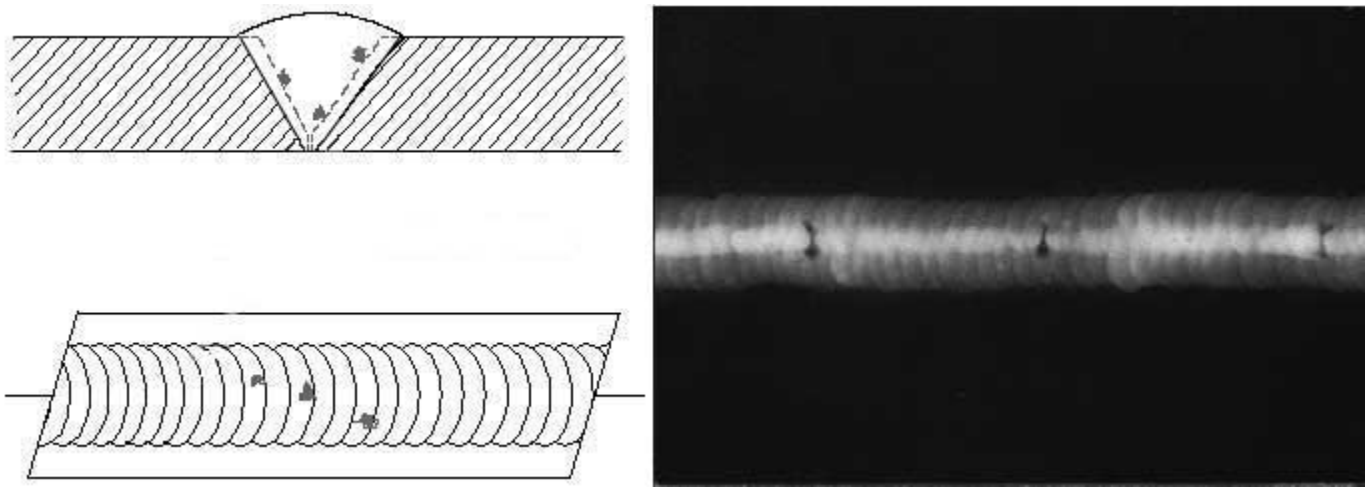




Classification of Discontinuities

Secondary Processing Discontinuities - Welding

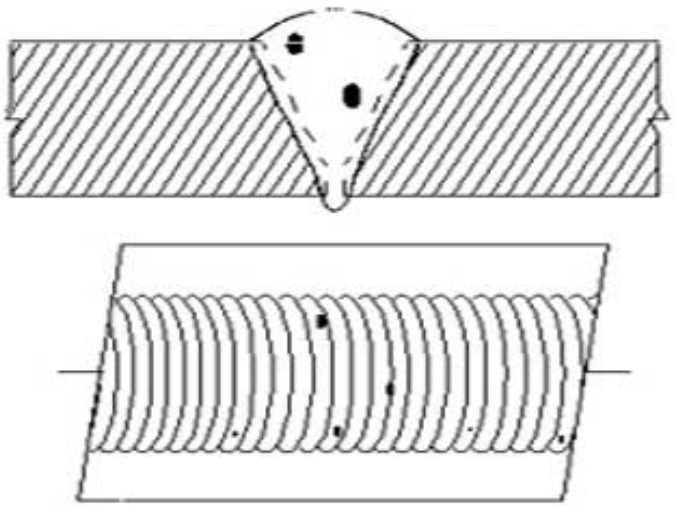
- Slag Inclusion

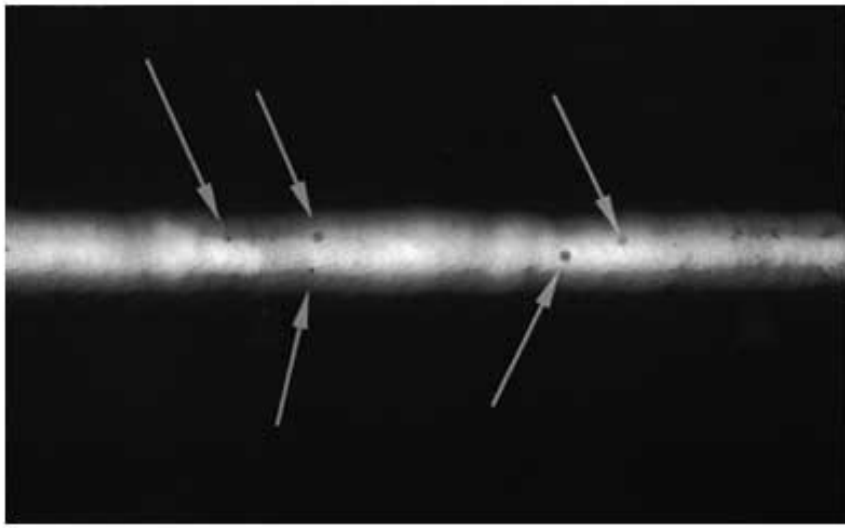


Classification of Discontinuities

Secondary Processing Discontinuities - Welding

- Porosity





Classification of Discontinuities

Service-Induced Discontinuities

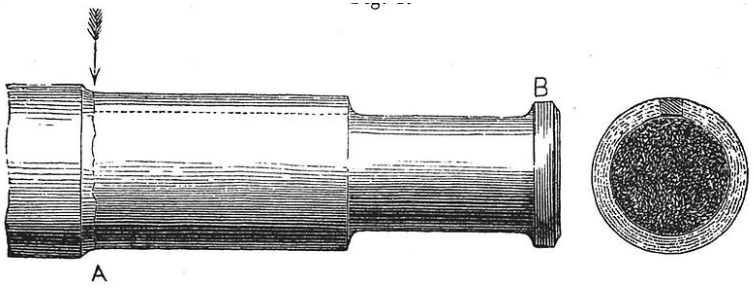
- Discontinuities caused by fatigue, corrosive environments, or overheating

- 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

Classification of Discontinuities

Mechanical Fatigue

- Failure of a part under repeated fluctuating stresses
  - Applied stresses are below the tensile strength of the material
  - Ex. Repeated loading and unloading of flow through a pipe
- 1842 - Versailles train wreck
  - Derailment due to broken locomotive axle
  - Crack growth occurred due to repeated loading in this area of high stress concentration



Classification of Discontinuities

Mechanical Fatigue

- 1954 – de Havilland Comet plane crashes
  - Two separate crashes due to metal fatigue caused by repeated pressurization and depressurization of the cabin
  - Failure occurred at cracks that started at riveted joints
  - Model was grounded and did not fly again until 1958

Classification of Discontinuities

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

Classification of Discontinuities

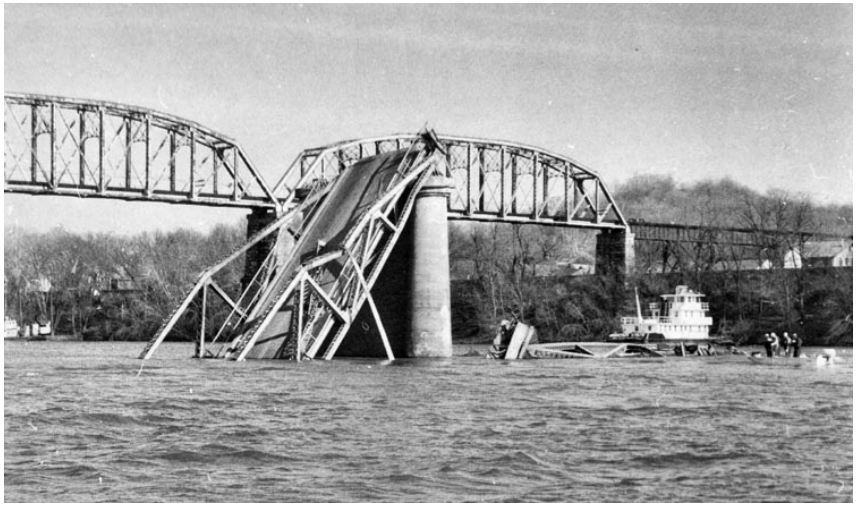
Corrosive Environments

- 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

Classification of Discontinuities

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



Classification of Discontinuities

Material Losses

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