Liquid Penetrant Testing

Principles of Penetrant Fluid Mechanics & Inspection Applications

Liquid Penetrant (LP) Detection System

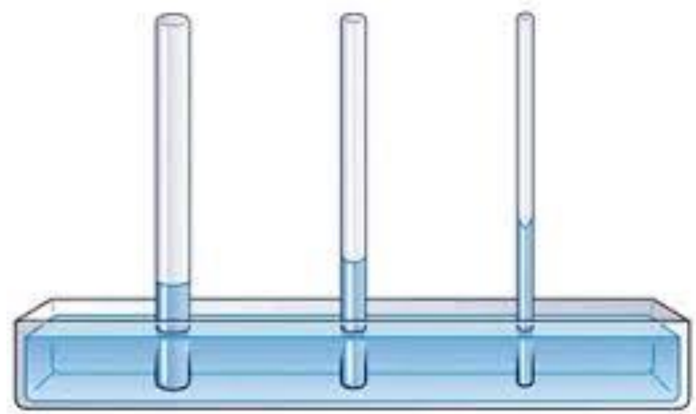
- Consists of:
  - Fluid mechanics on surface – accumulation of liquid at discontinuity
  - Recognition system – sufficient contrast between background and fluid

- Applies to non-porous materials

- Can only detect flaws open to a surface:
  - Cracks, seams, cold shut, porosity, etc.

Fluid Mechanics on Surfaces

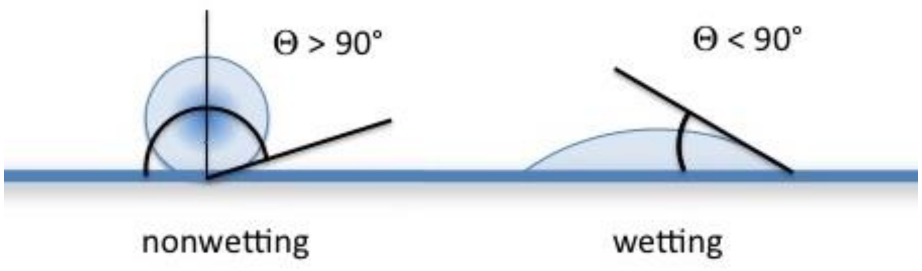
- Two main areas of focus
  - Surface Tension
  - Capillarity



Contact Angle

- Slope of a liquid relative to solid surface

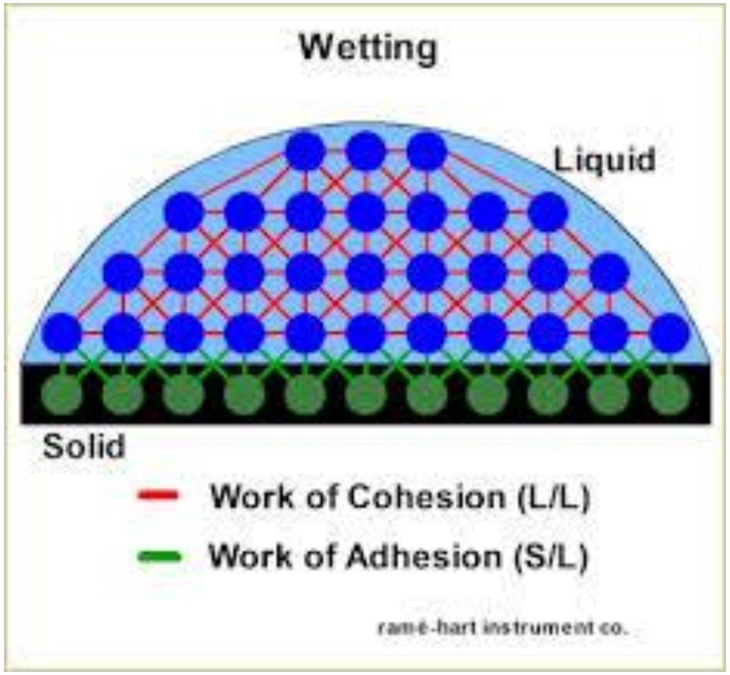
- Wetting Ability
  - Ability of a fluid to spread uniformly over another surface
  - Measured by the contact angle



  - As θ increases, wetting ability decreases

Cohesive & Adhesive Force

- Cohesive
  - Intermolecular forces within a liquid that resist separation (attraction between liquid particles of the same type)
- Adhesive
  - Attractive forces between unlike molecules (force that acts between the fluid particles and solid interface)
  - Caused by mechanical and electrostatic forces



Force Balance

- For adhesive forces >> cohesive forces
  - Contact angle < 90°
  - Molecules more attracted to surface than each other
  - Good wetting ability
- For cohesive forces >> adhesive forces
  - Contact angle > 90°
  - Molecules more attracted to each other than surface
  - Poor wetting ability

Viscosity

- A fluid’s resistance to deformation caused by shear stress
- Caused by friction between particles in a fluid that are moving at different velocities
- Plays a crucial role when it comes to LARGE cracks

Effect of Temperature on Penetrant

- Ideal temperature for LP inspection lies between 10 and 50°C (40 and 125°F)
- As temperature increases, surface tension decreases, which increases wetting ability

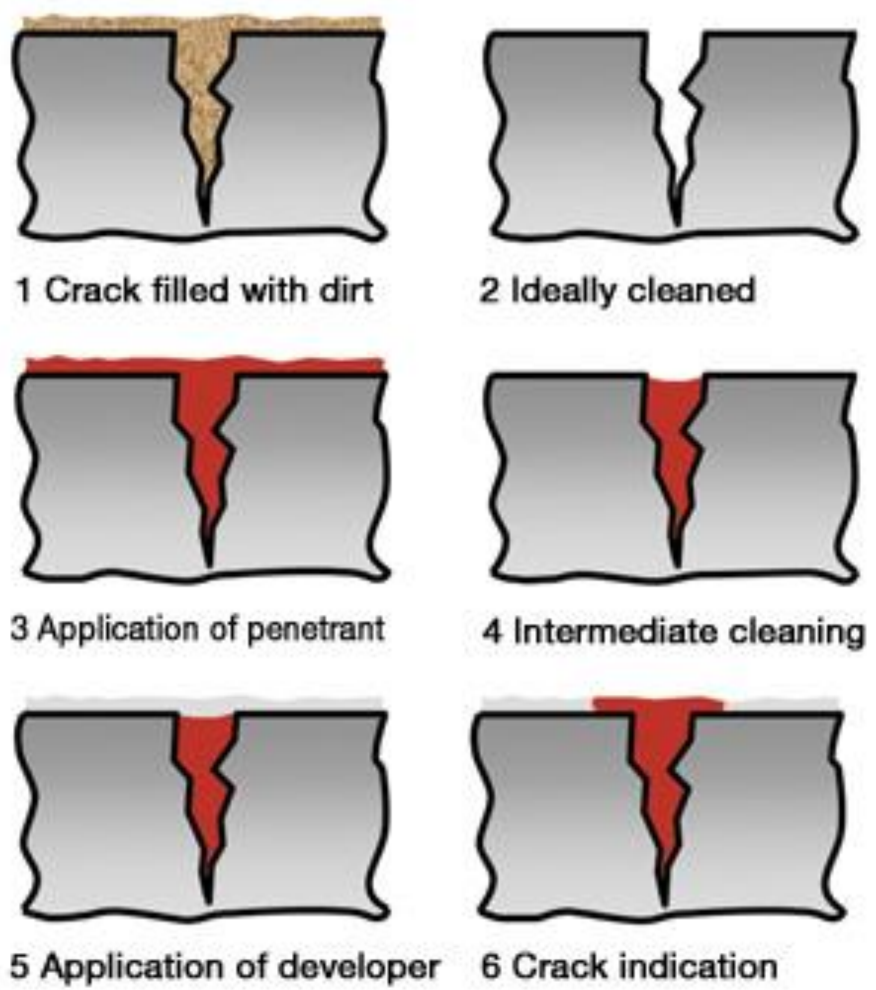
Fluid Mechanics Conclusions

- Satisfactory penetrant testing depends on:
  - Surface tension and density of fluid
  - Contact angle
    - Function of both fluid and material
    - Dependent upon cleanliness of part
  - Viscosity
    - Determines overall inspection time
  - Cavity size
    - Smaller width results in more penetrant drawn into cavity

Basic Steps in Penetrant Inspection

1) Pre-cleaning
2) Penetrant application
   - Dwell time
3) Penetrant removal
4) Developer application
   - Time
5) Inspection
6) Post cleaning

Basic Steps in Penetrant Inspection



Pre-cleaning

- Types of pre-cleaning processes
  - Alkaline
  - Steam
  - Vapor degreasing
  - Solvent wash
  - Acid etch
  - Paint stripper
  - Ultrasonic
  - Detergent
- Mechanical methods should be avoided as they smear and/or embed material in/on a flaw (sandblasting, grinding, etc.)
- Surface should be CLEAN and DRY before applying penetrant

Penetrant Application

- Penetrant can be applied via spraying, pouring, dipping, swabbing, brushing over entire surface
- Types of Penetrant:
  - Visible [Type I] – red indication on white background (developer)
    - Low sensitivity
    - Must have lighting
    - No power required

  - Fluorescent [Type II] – bright yellow-green indication activated by UV light
    - High sensitivity
    - Power is required for UV light
    - Dark conditions are a must

Penetrant Removal

Types and Methods:

- **Water-washable** (WW): Reference ASTM E-1209/1418
  - Temperature should not exceed 43°C (109°F)
  - Angle of spray should be between 45° and 70°
- **Post-emulsifiable** (PE): Reference ASTM E-1208/1210
  - Hydrophilic: reacts with oil-based penetrant – removable by scrubbing action and water rinse – can be reused
  - Lipophilic: oil soluble, diffuses into oil and breaks down structure – removable by water rinse
- **Solvent-removable** (SR): Reference ASTM E-1219/1220
  - Done by wiping with a cloth dampened with solvent
  - Good for "spot checks"

Comparison of Penetrant Examination Methods

- Water-washable
  - Least expensive
  - Low sensitivity
  - Not suitable for shallow flaws
  - Good for rough surfaces (threads)
- Post-emulsifier
  - Used only for Type II (fluorescent) penetrant
  - More expensive
  - Suitable for shallow flaws
  - Good for smooth surfaces
- Solvent-removable
  - Most expensive
  - Used for smooth, small-area surfaces

Developer Application

- Two requirements:
  - Developer must attract penetrant out of crevice by capillary action
  - Developer must create a viewing background that contrasts with the appearance of the penetrant

- Too thin of a layer and the developer will not absorb the penetrant
- Too thick of a layer and the developer will mask the penetrant

- 4 types of developers:
  - Dry powder
  - Aqueous (wet) powder-suspension
  - Water soluble
  - Solvent-suspendible (Nonaqueous)

Dry-Powder Developer

- Used for fluorescent penetrants
- High resolution
- Part must be dry
- Least sensitive
- Inexpensive
- Easy application

Aqueous Powder-Suspension Developer

- Applied right after washing step, before part is dried
- Not suitable for rough surfaces
- Used for high-volume inspections
- More sensitive to smaller cracks
- Requires drying system
- Must be stirred or agitated

Water Soluble Developer

- Contains water soluble crystalline substances that recrystallize into the developer film
- Applied directly after washing process, before part is dried
- Good sensitivity to small cracks
- Used for smooth surfaces
- Low resolution
- Must be dried quickly

Solvent (Nonaqueous) -Suspendible Developer

- High sensitivity
- May be applied to both fluorescent penetrant types
- Highest sensitivity
- Dries quickly on its own

Harmful Effects of Penetrants

- Chlorides are known to attack various high strength/high temperature alloys and cause crack initiation.
  - Nickel-based alloys
  - Austenitic stainless steels
  - Titanium

- Sulfur and Halogen – known to be present in penetrants
  - Initiate cracking if left in crevices of materials listed above
  - Levels of these elements must be closely monitored