Non-Destructive Evaluation (NDE)

Chapter 4

Liquid Penetrant Inspection

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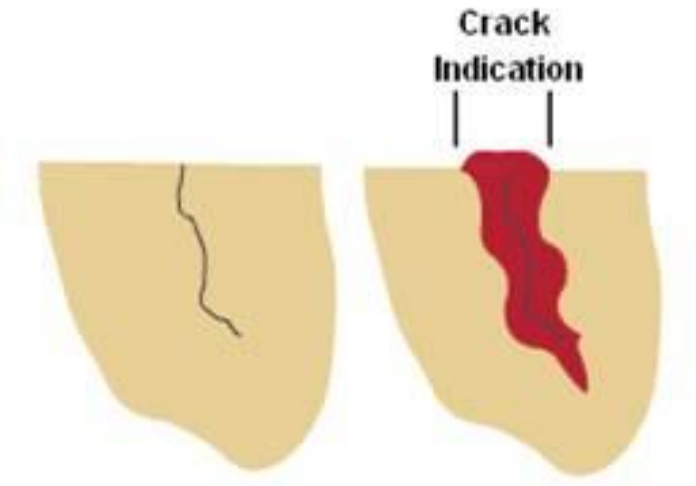
Liquid Penetrant Inspection

Penetrant Testing (PT): is a nondestructive testing method that builds on the principle of Visual Inspection, it increases the "seeability" of all discontinuities that the human eye might not be able to detect alone.

Dye Penetrant Inspection (DPI)

Penetrant Flaw Detection (PFD)

liquid penetrant inspection (LPI)



Liquid Penetrant Inspection

- is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics)
- The penetrant may be applied to all non-ferrous materials and ferrous materials, but for inspection of ferrous components magnetic-particle inspection is also preferred for its subsurface detection capability.
- PT is used to detect casting, forging and welding surface defects such as cracks, surface porosities, and leaks in new products, and fatigue cracks on in-service components.

Advantages of Penetrant Testing

- Relative ease of use and don't require great skills
- Can be used on a wide range of material types.
- Large areas or large volumes can be inspected.
- Can be used on non-ferrous metals, some plastics and glass
- Parts with complex geometries are routinely inspected.
- Indications are produced directly on surface of the part providing a visual image of the discontinuity.

Advantages of Penetrant Testing

- Initial equipment investment is low.
- Aerosol spray cans can make equipment very portable.
- Very sensitive
- No need power supply

Limitations of Penetrant Testing

- Defects open to the surface only can be detected
- Requires relatively smooth nonporous material.
- Surface preparation and precleaning is critical. Contaminants can mask defects, Do not applied to painted objects
- Requires multiple operations under controlled conditions.
- Chemical handling precautions necessary (toxicity, fire, waste).

Limitations of Penetrant Testing

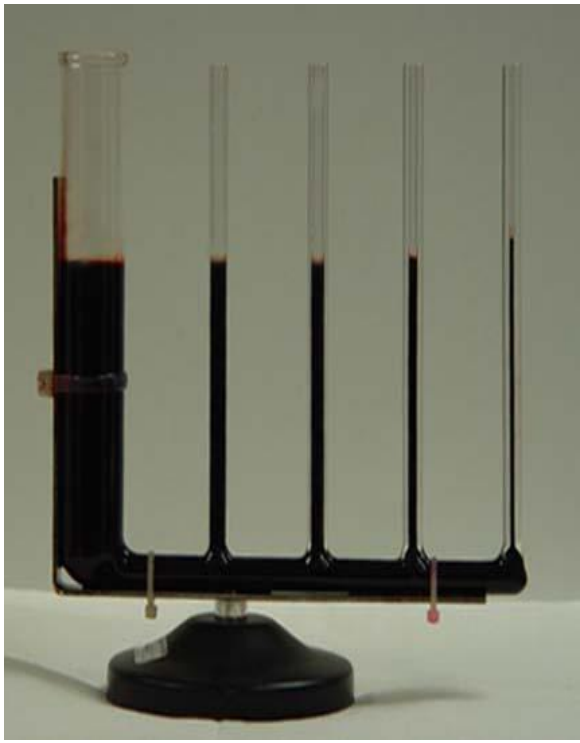
- Metal smearing from machining, grinding and other operations inhibits detection. Materials may need to be etched prior to inspection.
- Post cleaning is necessary to remove chemicals.
- The method takes time
- Interpretation sometimes difficult
- Effluent problem with waste

How Does PT Work?

- In penetrant testing, a liquid with high surface wetting characteristics is applied to the surface of a component under test.
- The penetrant “penetrates” into surface breaking discontinuities via capillary action and other mechanisms.
- Excess penetrant is removed from the surface and a developer is applied to pull trapped penetrant back the surface.
- With good inspection technique, visual indications of any discontinuities present become apparent.

How Does PT Work?

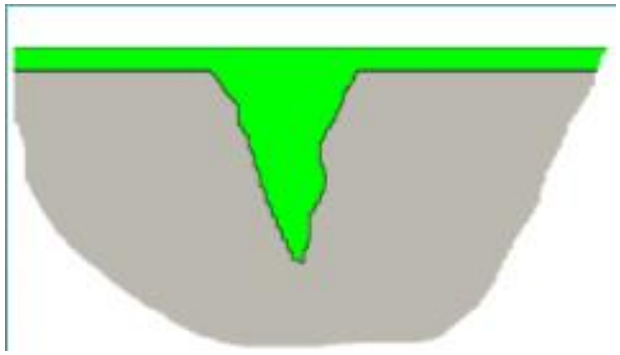
- Every step of the penetrant process is done to promote capillary action.
- This is the phenomenon of a liquid rising or climbing when confined to small openings due to surface wetting properties of the liquid.
- Some examples:
  - Plants and trees draw water up from the ground to their branches and leaves to supply their nourishment.
  - The human body has miles of capillaries that carry life sustaining blood to our entire body.



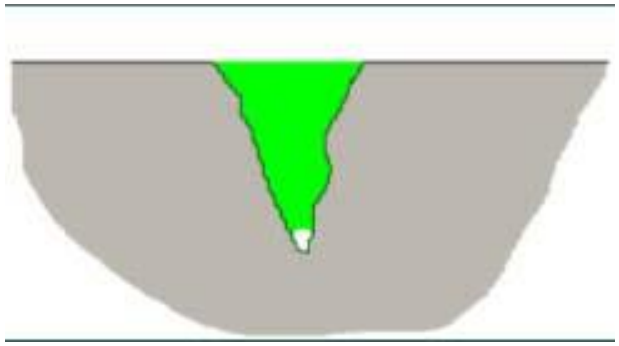
Basic Process of PT

1) Clean & Dry Component

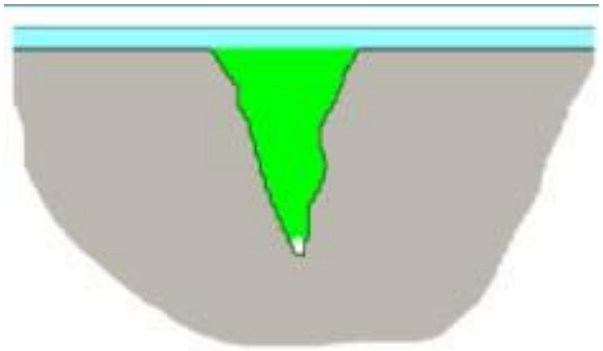
2) Apply Penetrant



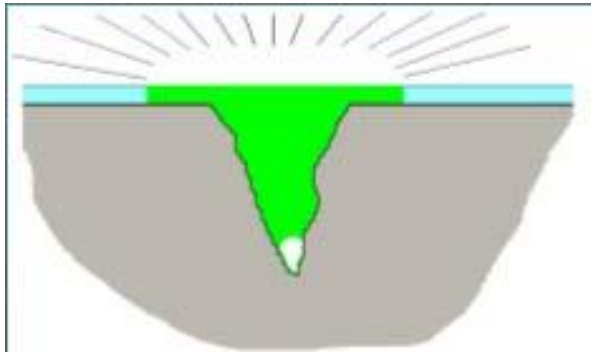
3) Remove Excess



4) Apply Developer



5) Visual Inspection



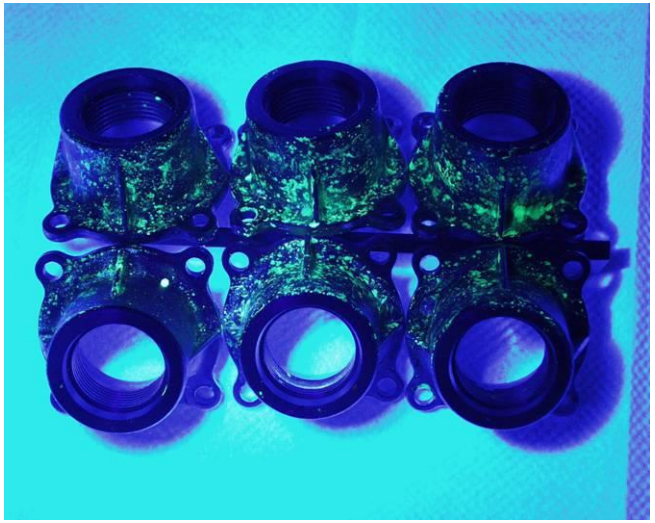
6) Post Clean Component

What Can Be Inspected Via PT?

Almost any material that has a relatively smooth, non-porous surface on which discontinuities or defects are suspected.

What Can NOT be Inspected Via PT?

- Components with rough surfaces, such as sand castings, that trap and hold penetrant.
- Porous ceramics
- Wood and other fibrous materials.
- Plastic parts that absorb or react with the penetrant materials.
- Components with coatings that prevent penetrants from entering defects.

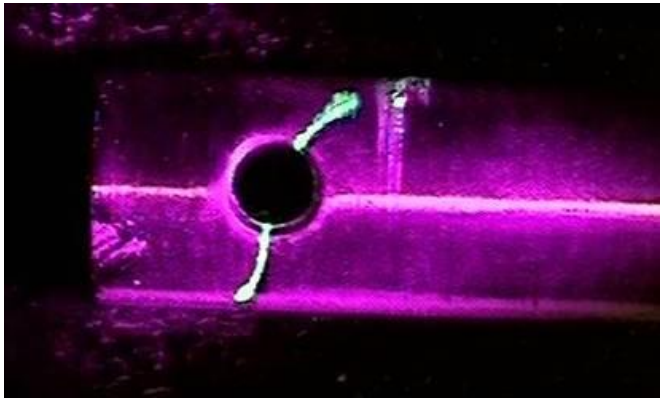


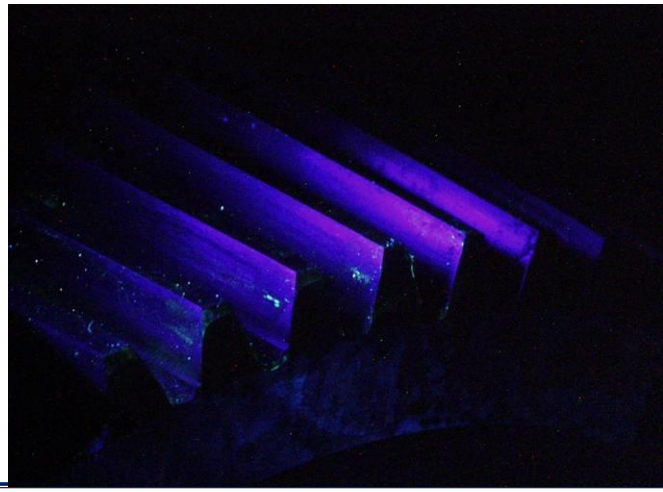
Defect indications become less distinguishable as the background “noise” level increases.

Types of discontinuities detectable by PT?

All defects that are open to the surface.

- Rolled products: cracks, seams, laminations.
- Castings: cold shuts, hot tears, porosity, blow holes, shrinkage.
- Forgings: cracks, laps, external bursts.
- Welds: cracks, porosity, undercut, overlap, lack of fusion, lack of penetration.





Choices of Penetrant Materials

Penetrant	Type	I Fluorescent
		II Visible
	Method	A Water Washable
		B Post-emulsifiable - Lipophilic
		C Solvent Removable
		D Post-emulsifiable - Hydrophilic
Developer	Form	Dry Powder
		Wet, Water Soluble
		Wet, Water Suspendable
		Wet, Non-Aqueous

Penetrant Materials

Penetrants are formulated to possess a number of important characteristics. To perform well, a penetrant must:

- Spread easily over the surface being inspected.
- Be drawn into surface breaking defects by capillary action or other mechanisms.
- Remain in the defect but remove easily from the surface of the part.
- Remain fluid through the drying and developing steps so it can be drawn back to the surface.
- Be highly visible or fluoresce brightly to produce easy to see indications.
- Not be harmful to the inspector or to the material being tested.

Penetrant Materials

- High surface tension
- Good wetting ability
- Specific gravity lower than 1
- Penetrant will not damaged the test piece
- Non-toxic
- High flash point
- Low volatility
- Visible in small quantities
- Post-cleaning should be easy

Sensitivity Levels

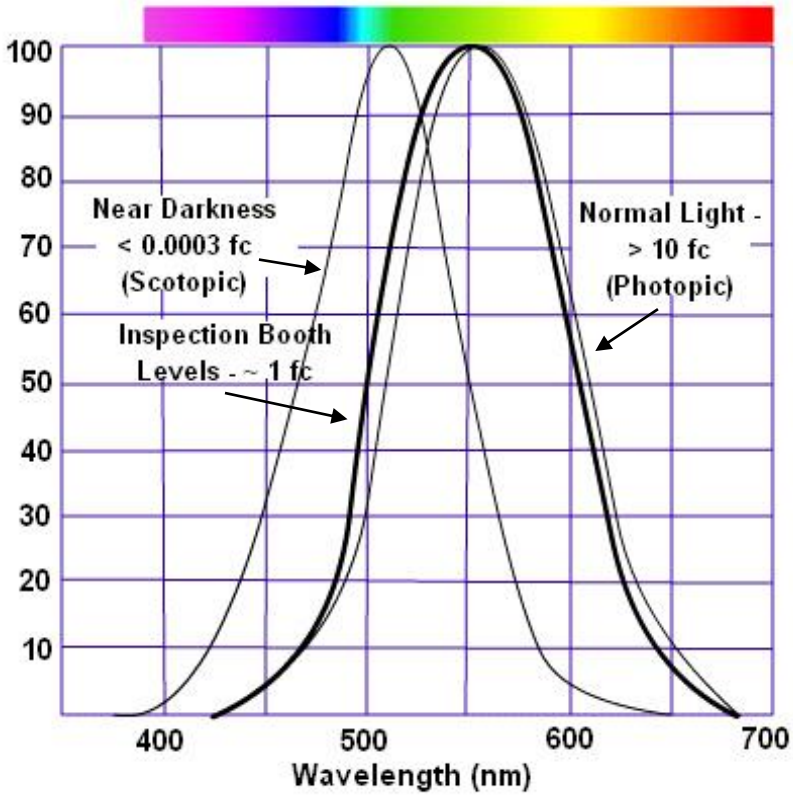
- Penetrants are also formulated to produce a variety of sensitivity levels. The higher the sensitivity level, the smaller the defect that the penetrant system is capable of detecting.
- The sensitivity levels are:
  - Level 4 - Ultra-High Sensitivity
  - Level 3 - High Sensitivity
  - Level 2 - Medium Sensitivity
  - Level 1 - Low Sensitivity
- As the sensitivity level increases, so does the number of non relevant indications. Therefore, a penetrant needs to be selected that will find the defects of interest but not produce too many non relevant indications.

Visible Vs Fluorescent PT

- Inspection can be performed using visible (or red dye) or fluorescent penetrant materials.
- Visible PT is performed under white light while fluorescent PT must be performed using an ultraviolet light in a darkened area. Sensitivity range 1 for both.
- Fluorescent PT is more sensitive than visible PT because the eye is more sensitive to a bright indication on a dark background. Sensitivity ranges from 1 to 4.

Why is Visible Penetrant Red and Fluorescent Penetrant Green?

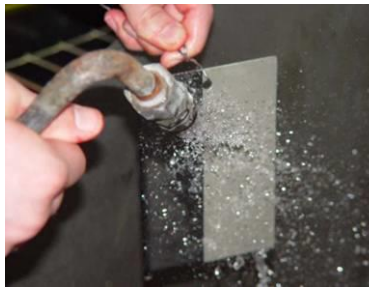
- Visible penetrant is usually red because red stands out and provides a high level of contrast against a light background
- Fluorescent penetrant is green because the eye is most sensitive to the color green due to the number and arrangement of the cones (the color receptors) in the eye.



Penetrant Removal Method

Penetrants are also classified by the method of removing the excess penetrant.

- ✓ Solvent Removable
- ✓ Water Washable
- ✓ Post-Emulsifiable



Penetrant Removal Method

- **Solvent Removable** penetrants are removed by wiping with a cloth dampened with solvent. They are supplied in aerosol cans for portability and are primarily used for spot checks.

Description	Advantages	Disadvantages
1. Cleaned with a lint free cloth	1. Portability 2. No water supply required	1. Expensive 2. Not suited to batch Inspections 3. Hazardous

Penetrant Removal Method

- **Water Washable** penetrants are removed with a course spray of water. They are the easiest to employ and most cost effective when inspecting large areas.

Description	Advantages	Disadvantages
1. Contain emulsifier 2. Wash by course water	1. Useable on rough surfaces 2. Suitable for batch inspection 3. Cheaper	1. Easy to over washing 2. Least sensitive method 3. Required water source

Penetrant Removal Method

- **Post-Emulsifiable** penetrants are water-washable only after they have reacted with an emulsifier solution. A post-emulsifiable system is used when **washing the penetrant out of the defect is a concern.** The emulsifier is given time to reacts with the penetrant on the surface but not the penetrant trapped in the flaw.

  - *Post-Emulsifiable /lipophilic*
  - *Post-Emulsifiable / Hydrophilic*

Penetrant Removal Method

- *Post-Emulsifiable /lipophilic*

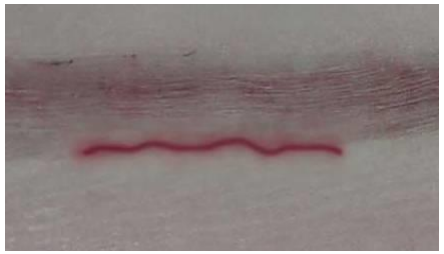
Description	Advantages	Disadvantages
1. Need to apply the emulsifier 2. Water supply also required	1. Used on high stress critical parts	1.Emulsification time is Critical

- *Post-Emulsifiable / Hydrophilic*

Description	Advantages	Disadvantages
1. Also known as detergents remover 2. Water supply also required	1. Maximum penetrating ability 2. Greater control over penetrant removal 3. Emulsification time not so critical 4. Wide shallow defects	1. Not suited to rough Surface 2. More expensive 3. More time consuming

Developers

- The role of the developer is:
  - to pull trapped penetrant out of effects and to spread it out on the surface so that it can be seen.
  - Also provides a light background to increase contrast when visible penetrant is used.
- Developer materials are available in several different forms
  - Dry Powder
  - Wet, Water Suspendable
  - Wet, Water Soluble
  - Wet, Non-Aqueous



Developers

- **Developer materials are available in several different forms**
  - **Dry Powder** is a mix of light fluffy powder that clumps together where penetrant bleeds back to the surface to produces very defined indications.

Application
• Light, fluffy, absorbent powder • Stick best at wet surfaces • Easy to remove but difficult to see if properly applied • Fine powders can be hazardous

Developers

- **Developer materials are available in several different forms**
  - **Wet, Water Suspendable** is a powder that is suspended in a water that covers the surface with a relatively uniform layer of developer when the water is evaporated. The solution is somewhat difficult to maintain as the powder settles out over time.

Application
• Not often be used • The powder will draws the penetrant out of defect when the water evaporates • Use as in concentrated in color contrast penetrant, thinner form in fluorescent

Developers

- **Developer materials are available in several different forms**
  - **Wet, Water Soluble** is a crystalline powder that forms a clear solution when mixed with water. The solution recrystallizes on the surface when the water is driven off. Indications sometimes lack definition and look milky. Not recommended for use with water-washable penetrants.

Application
• Solution of salts in forms of fine granules which dissolved in water • Suitably for fluorescent penetrant

Developers

- **Developer materials are available in several different forms**
  - **Wet, Non-Aqueous -** is supplied in a spray can and is the most sensitive developer for inspecting small areas. It is too costly and difficult to apply to large areas.

Application
• It is a suspension of inert white powder in a volatile solvent • The sovent evaporates leaving a fine white background • Most sensitive

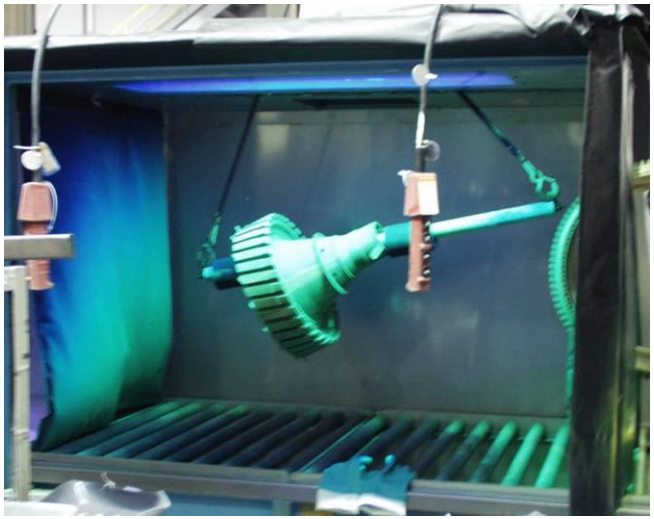
Developers

Essential features of developer

- Absorbent to draw penetrant out of defect
- Fine grained and not lumpy
- Able to mask the back ground but not thick enough to mask a defect
- Light and easy applicable
- Easily wet by penetrant
- Easily removed from the specimen
- Inert and non-toxic

6 Steps of Penetrant Testing

1. Pre-Clean
2. Penetrant Application
3. Excess Penetrant Removal
4. Developer Application
5. Inspect/Evaluate
6. Post-clean



Pre-cleaning – Step 1

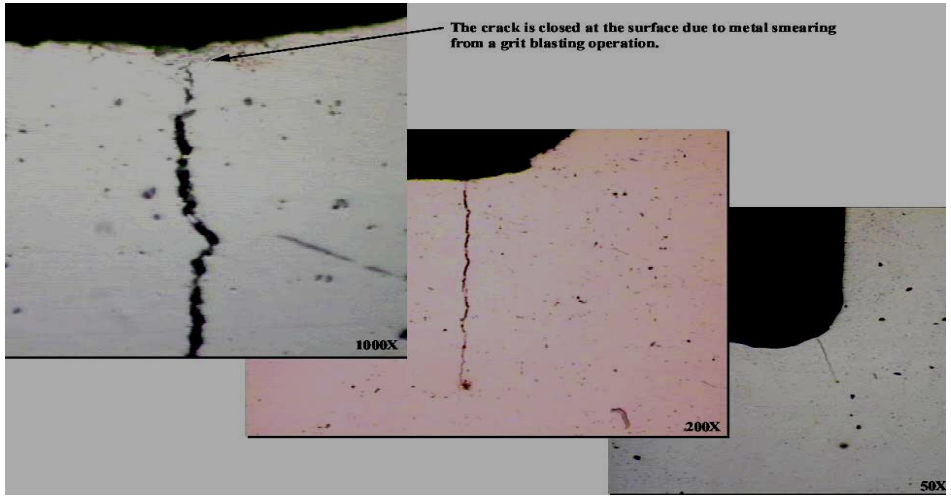
- Parts must be free of dirt, rust, scale, oil, grease, etc. to perform a reliable inspection.
- The cleaning process must remove contaminants from the surfaces of the part and defects, and must not plug any of the defects.
- Pre-cleaning is the most important step in the PT process!!!

Pre-cleaning – Step 1

Caution About Metal Smearing

Some machining, surface finishing and cleaning operations can cause a thin layer of metal to smear on the surface and prevent penetrant from entering any flaws that may be present.

Etching of the surface prior to inspection is sometimes required.

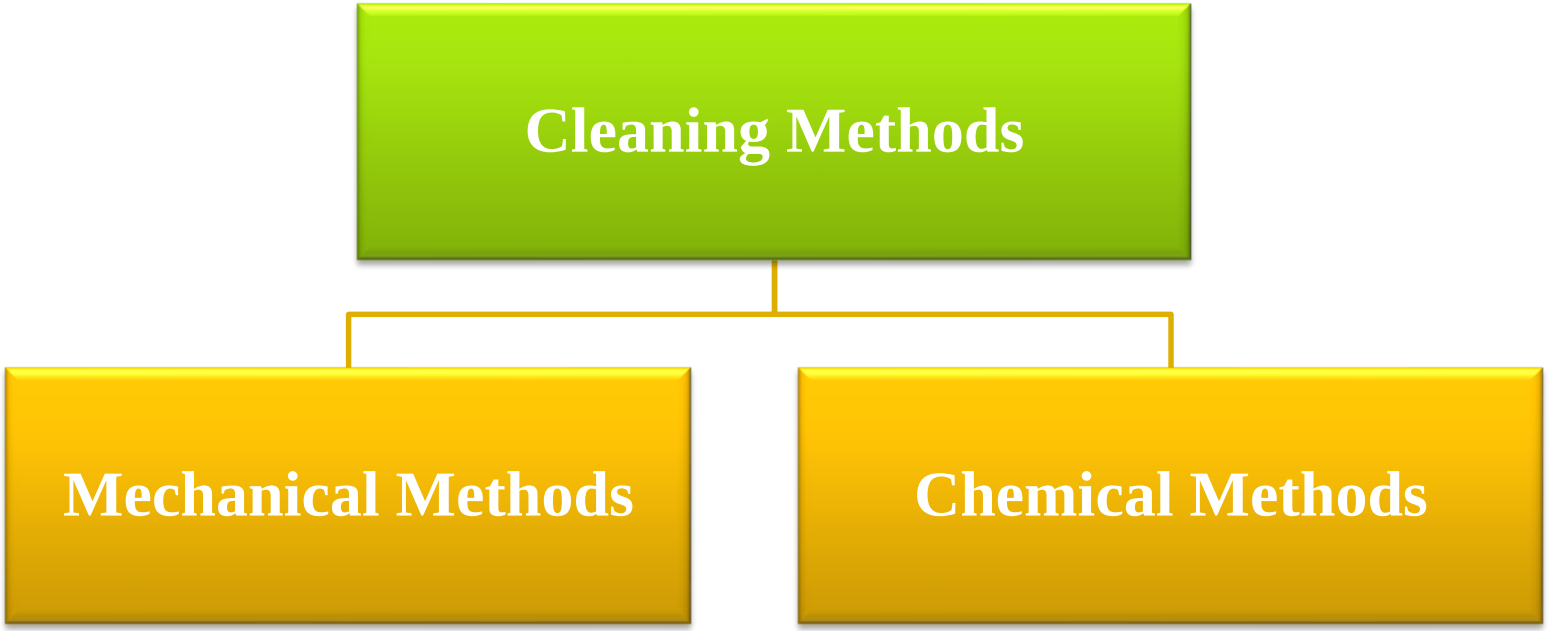


Pre-cleaning – Step 1

What will happen if cleaning is not been done properly ?

- ✓ The penetrant is not be able to wet the surface of the test object
- ✓ The penetrant is unable to enter a discontinuity due to a blockage
- ✓ The bleed out of the penetrant from a discontinuity is restricted

Pre-cleaning – Step 1



E.G BRUSHING,BLASTING

E.G HOT SOLVING
DEGREASING,ACID PICKLING

Penetrant Application – Step 2

Many methods of application are possible such as:

- Brushing
- Spraying
- Dipping/Immersing
- Flow-on
- And more

Dwell Time

- The penetrant solution must be allowed to “dwell” on the surface of the part to allow the penetrant time to fill any defects present.
- The dwell time vary according to penetrant type, temperature, material type and surface finish.

Excess Penetrant Removal – Step 3

The removal technique depends upon the type of penetrant used, as stated earlier…

- Solvent Removable
- Water Washable
- Post Emulsifiable

Liquid Penetrant Inspection

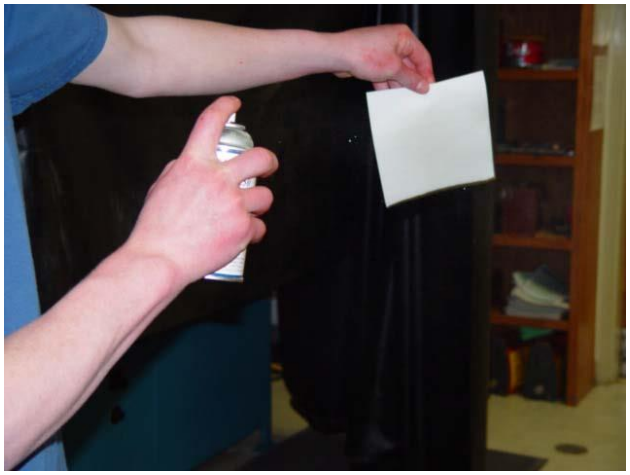
Water Washable

- A coarse water spray is used to remove the excess penetrant.
- The procedure used as a guideline for the inspection will specify water temperature (typically 50-100°F) and pressure (typically not more than 40 psi), etc.

Excess Penetrant Removal – Step 3

Solvent Removable

- The part is wiped with a clean dry cloth to remove the bulk of the excess penetrant.
- Then, a cloth lightly dampened with solvent is used to remove any remaining penetrant on the surface.



Excess Penetrant Removal – Step 3

Solvent Removable

Any time a solvent is used in the penetrant inspection process, a suitable flash time is required to allow excess solvent to evaporate.

Excess Penetrant Removal – Step 3

Post Emulsifiable

- When there is concern about removing much of the penetrant from the defect, a post emulsifiable system is used.
- This involves an additional step in which an emulsifier is applied to the surface of the part after the penetrant dwell time.
- The emulsifier is given just enough time to react with the penetrant on the surface to render it water washable but not enough time to diffuse into the penetrant trapped in the defects.

Developer Application – Step 4

The method of developer application is is dependent on the type of developer used. The primary methods for the following main developer types will be covered in the following slides.

- Dry
- Wet
- Nonaqueous Wet

Developer Application – Step 4

Dry Powder Developer

- Prior to applying a dry powder developer, the component must be thoroughly dried. Drying is usually accomplished in a hot air circulating oven.
- The developer is then applied by immersing the part in the powder or by dusting of the part with the powder.
- The part can also be placed in a developer dust cloud chamber.

Developer Application – Step 4

Wet Developer (water- suspended and water- soluble)

- Wet developers are applied by immersing or spraying the part while it is still wet from the penetrant removal process.
- The part is completely coated and the excess liquid allowed to drain to prevent pooling
- The part is then dried in a hot air circulating oven.

Developer Application – Step 4

Nonaqueous Developer (Solvent-Suspended)

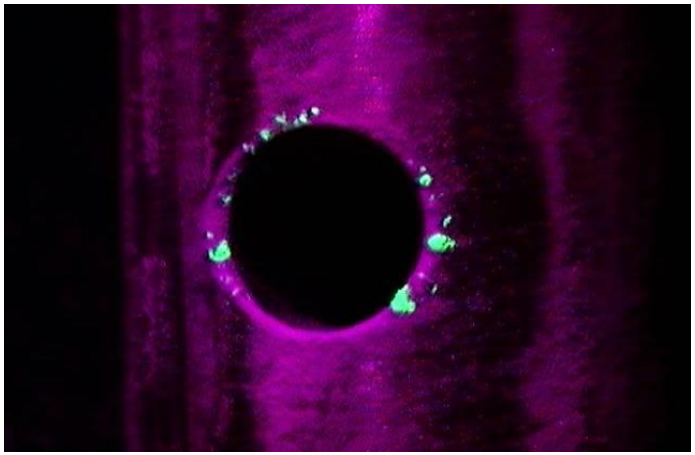
- Nonaqueous developer is applied by a aerosol spray to a thoroughly dried and cooled part.
- A thin even coating should be applied. The coating should be white but still slightly transparent when performing a visible dye penetrant inspection, and even thinner when performing a fluorescent penetrant inspection.

Inspection/Evaluation – Step 5

In this step the inspector evaluates the penetrant indications against specified accept/reject criteria and attempts to determine the origin of the indication.

The indications are judged to be either relevant, non-relevant or false.

Non-relevant weld geometry indications



Relevant crack indications from an abusive drilling process

Inspection/Evaluation – Step 5

A very important step of evaluation is to document findings on an inspection report form or other record keeping form.

This may be supported with drawings or photos of indications, etc.

Post Clean – Step 6

The final step in the penetrant inspection process is to thoroughly clean the part that has been tested to remove all penetrant processing materials.

The residual materials could possibly affect the performance of the part or affect its visual appeal.

Penetrant Inspection Systems

Penetrant systems can be highly portable or stationary.

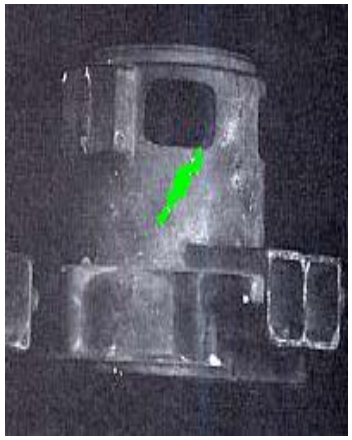
Portable Penetrant System

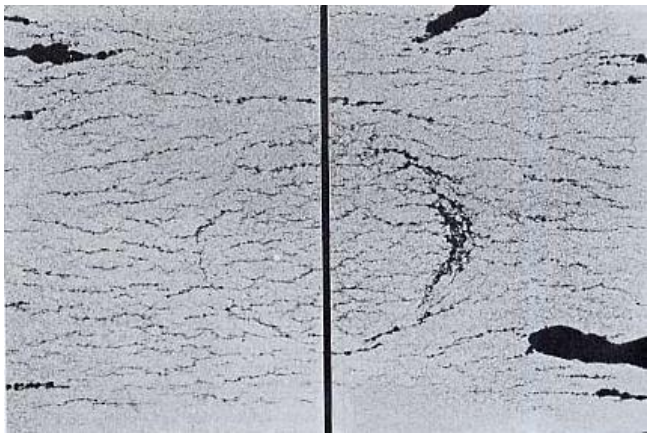
Stationary Penetrant System

Verification of Penetrant System Performance

Since penetrant testing involves multiple processing steps, the performance of the materials and the processes should be routinely checked using performance verification tools, which include:

- Quench cracked aluminium alloy block
- Chromium plated cracked test panel
- Cracked test piece



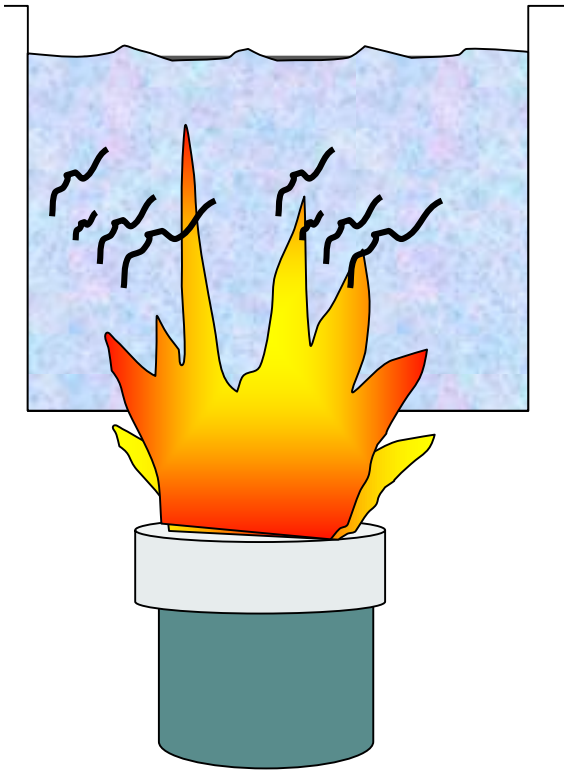


Overall System Performance

ARB BLOCK- Aeronautical Registration Board Block

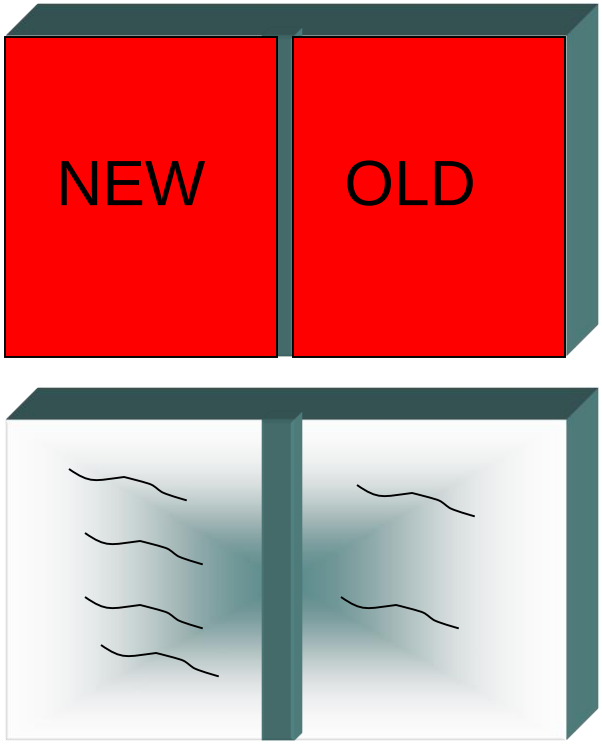
Two sided aluminum block which been quenched – to produce thermal cracks

May be used to check/compare performance of penetrant chemicals (penetrant, emulsifier, developer)



Overall System Performance

ARB BLOCK- Aeronautical Registration Board Block



Two different penetrant applied on each section of block

The excess penetrant is removed and developer applied

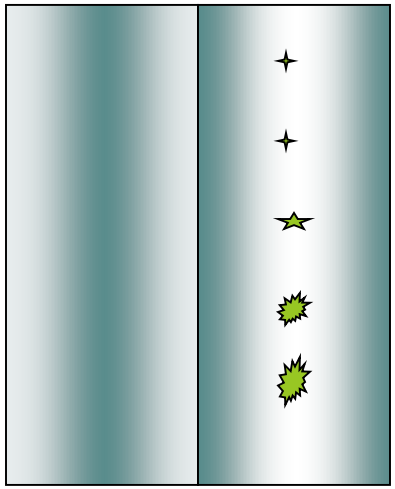
Indication are observed

Now process is repeat with the penetrant applied to different section

Overall System Performance

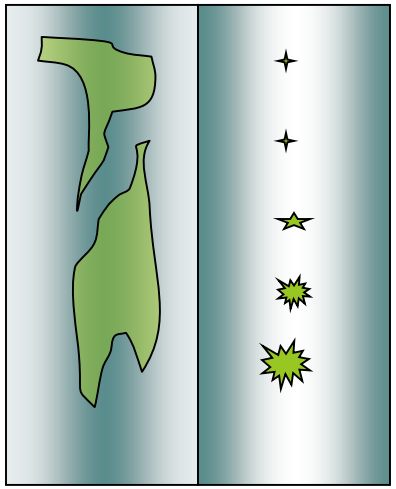
CHROMIUM PLATED BLOCK

TAM panel or SHERWIN panel

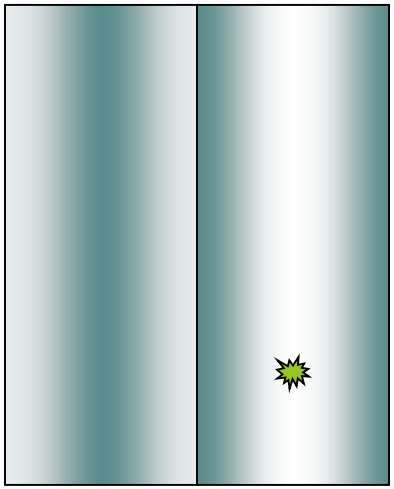


Section for checking effectiveness of cleaning

Section for checking sensitivity



Cleaning not effective



Less sensitive

Control Checks

- ✓ Overall system performance
- ✓ Water wash temperature and pressure
- ✓ Colour intensity
- ✓ Penetrant remover
- ✓ Developer
- ✓ UV lamp output
- ✓ UV monitor
- ✓ Water tolerance

Control Checks

Control Checks - Frequency

Overall system performance	Daily
Water wash temperature and pressure	Daily
Colour intensity	Weekly
Penetrant remover	Daily
Developer	Weekly
UV lamp output	Monthly
UV monitor	Annual
Water tolerance	Weekly

Maintenance Checks

- Tank levels
- Equipment cleanliness
- Airline cleanliness
- Processing units
- UV lamp maintenance
- Clean tanks

Selection of System

- Nature of discontinuities (size and type)
- Geometry and intricacy
- Surface condition

- Component material
- Size and position
- Equipment and expertise available
- Cost
- Number of components to be tested

Selection of System

- Inspection of a large number of threaded components

  What method will you select and why ?

  Fluorescent water washable with dry powder developer

  - Fluorescent for mass inspections
  - Water washable more suited than solvents to batch inspections
  - Post emulsifiable difficult to remove from threads

Selection of System

- Inspection of turbine blades for fatigue cracks

What method will you select and why ?

Fluorescent post emulsifiable with non-aqueous developer

- Fluorescent more sensitive than colour contrast
- Post emulsifiable more sensitive than water washable
- Non-aqueous developer most sensitive

Glossary of Terms

- **Capillary Action** - the tendency of certain liquids to travel or climb when exposed to small openings.
- **Contrast** - the relative amount of light emitted or reflected between and indication and its background.
- **Defect** - a discontinuity that effects the usefulness of a part or specimen.
- **Developer** - a finely divided material applied over the surface of a part to help promote reverse capillary action and thus bring out a penetrant indication.
- **Discontinuity** - any interruption in the normal physical structure of a part or weld. It may or may not affect the usefulness of a part.

Glossary of Terms

- **Dwell Time -** the period of time that a penetrant or developer must remain in contact with the surface of a part under test.
- **Emulsification Time -** the time allowed for the emulsifier to render the penetrant water washable and thus allow the part to be washed.
- **Emulsifier -** a material applied over a film of penetrant that renders it water washable.
- **Evaluation -** the process of deciding as to the severity of the condition after an indication has been interpreted.
- **False Indication -** an indication caused by improper processing; not caused by a relevant or non-relevant condition.

Glossary of Terms

- **Flash Time** - the time required for the solvent to evaporate from the surface of a part when used to preclean or remove excess penetrant.
- **Fluorescent Dye** - a dye which becomes fluorescent (gives off light) when exposed to short wave radiation such as ultraviolet light.
- **Indication** - the visible evidence or penetrant bleed-out on the surface of the specimen
- **Interpretation** - the process of evaluating an indication in an attempt to determine the cause and nature of the discontinuity.
- **Non-Aqueous Developer** - a developer in which developing powder is applied as a suspension in a quick drying solvent

Glossary of Terms

- **Penetrant** - a liquid used in fluorescent or visible dye penetrant inspection to penetrate into the surface openings of parts inspected via these methods
- **Relevant Indication** - an indication that has been determined not to be false or non-relevant - and actual discontinuity
- **Seeability** - the characteristic of an indication that enables it to be seen against the adverse conditions of background, outside light, etc.
- **Sensitivity** - the ability of a penetrant to detect surface openings. Higher sensitivity indicates smaller discontinuities can be detected
- **Ultraviolet Light** (or Black Light) - light energy just below the visible range of violet light (356 nanometers).

Glossary of Terms

- **Viscosity** - the resistance of a fluid to the motion of its particles
- **Washability** - the property of a penetrant which permits it to be cleaned from the surface of a part by washing with water