



T4.2. Development of a practical VR course for PT NDT method

ERASMUS-EDU-2023-PI-FORWARD-LOT2



Co-funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.



VR-VET

Non-Destructive Testing

| Revision | Date | Author/Organisation | Description |
|-----------------|------------|---------------------|--|
| 1 st | 11.04.2025 | CESOL | 1 st Draft |
| 2 nd | 14.05.2025 | IPUNTO | Adapted to the latest standard version |
| 3 rd | 30.06.2025 | ISIM | Final approval |
| | | | |
| | | | |
| | | | |



INDEX OF THE DOCUMENT

| | |
|--|----|
| Introduction | 6 |
| Introduction to Penetrant Testing | 7 |
| General | 7 |
| Background | 7 |
| Capabilities of Penetrant Inspection | 7 |
| Basic Penetrant Process | 7 |
| Mechanism of Penetration | 8 |
| Leak Detection | 11 |
| Reasons for Selecting Penetrant Inspection | 12 |
| Personnel Requirements | 12 |
| Equipment Requirements | 12 |
| Advantages and Capabilities of Liquid Penetrant Inspection | 12 |
| Disadvantages and Limitations of Liquid Penetrant Inspection | 13 |
| Health and Safety | 14 |
| First Aid Treatment | 14 |
| Handling and Storage | 15 |
| Types of Penetrant | 15 |
| Methods of Removal | 16 |
| Developers | 18 |
| Sensitivity | 18 |
| Classification of Penetrant Materials and Processes | 20 |
| System (or Family) Concept | 20 |
| Penetrant Processes | 20 |
| Equipment Requirements | 25 |
| Inspection and Interpretation | 28 |
| General | 28 |
| Personnel | 28 |
| Lighting and Facilities | 28 |
| Black Light Sources | 29 |
| Generation of Black Light | 30 |
| Black Light Intensity Requirements | 33 |
| Visible Light Intensity Measurement | 33 |
| Ultraviolet Light Intensity Measurement | 33 |
| Black Light Intensity Variables | 34 |
| Black Light Hazards | 35 |
| Inspection Conditions | 36 |



| | |
|---|----|
| Inspection, Interpretation and Evaluation | 36 |
| Qualification Requirements | 37 |
| Classification of Discontinuities..... | 37 |
| Manufacturing Discontinuities..... | 38 |
| Service Induced Discontinuities | 41 |
| Evaluation of Indications | 42 |
| Photography of Indications | 42 |
| Pre-testing, Cleaning and Pre-cleaning, and Post-cleaning | 43 |
| General | 43 |
| Pre-testing..... | 43 |
| Cleaning | 43 |
| Types of Contaminants | 44 |
| Cleaning Processes | 45 |
| Mechanical Working Processes..... | 49 |
| Post-cleaning after Penetrant Inspection..... | 49 |
| Mechanism and Properties of Penetrants..... | 50 |
| General | 50 |
| Requirements of a Penetrant | 51 |
| Penetrant Physical Properties | 51 |
| Penetrant Chemical Properties..... | 52 |
| Application of Penetrant..... | 54 |
| Temperature Limitations | 57 |
| Penetrant Dwell..... | 57 |
| Penetrant Removal..... | 60 |
| General | 60 |
| Introduction..... | 60 |
| Factors Influencing Penetrant Removal | 60 |
| Methods of Removal..... | 62 |
| Water Washable Penetrant (EN ISO 3452-1 Method A): | 62 |
| Removal of Post-Emulsified Penetrant..... | 64 |
| Lipophilic Process (EN ISO 3452-1 Method B)..... | 65 |
| Hydrophilic Remover Process (EN ISO 3452-1 Method D) | 67 |
| Comparison of Lipophilic and Hydrophilic | 69 |
| Solvent Removal (EN ISO 3452-1 Method C)..... | 70 |
| Developers | 72 |
| General | 72 |
| Functions..... | 72 |
| Mechanisms of Developer Action..... | 72 |



| | |
|--|----|
| Solvent Action..... | 73 |
| Drying..... | 73 |
| Dry Developer (EN ISO 3452-1 form a) | 74 |
| Water Soluble Developer (EN ISO 3452-1 form b) | 76 |
| Water Suspensible Developer (EN ISO 3452-1 form c) | 76 |
| Solvent-based (Non-aqueous Wet) Developers | 78 |
| (EN ISO 3452-1 form d to Type I or form e to Type II/III) | 78 |
| Special Developers, eg. Plastic film Developers..... | 79 |
| (EN ISO 3452-1 form f)..... | 79 |
| When an indication requiring recording is detected by the penetrant inspection process, the following steps should be take: | 79 |
| Without Developer (EN ISO 3452-1 form g Type I only)..... | 79 |
| Developer Dwell | 79 |
| Comparison of Developers | 80 |
| Materials and Process Control..... | 81 |
| General | 81 |
| New Materials | 81 |
| In-use Materials | 81 |
| Causes of Materials Degradation..... | 82 |
| Frequency of Materials Verification and Process Control Checks | 83 |
| Materials Control | 83 |
| Process Control Testing | 84 |
| Penetrant System Monitor (PSM) | 84 |
| Penetrant System Monitor (PSM) Procedures..... | 84 |
| System Performance Testing | 85 |
| Storage of Panels | 85 |
| In-Process Penetrant Testing..... | 85 |
| Special Purpose Materials | 86 |
| General | 86 |
| Oxygen Compatible Penetrants..... | 86 |
| Low Sulphur, Low Chlorine Penetrant..... | 87 |
| High Temperature Penetrant Materials..... | 87 |
| Dye Precipitation Penetrant Systems..... | 87 |
| Reversed Fluorescence Method..... | 88 |
| Thixotropic Penetrant | 88 |
| Plastic Film Developers..... | 88 |
| Filtered Particle Penetrants | 88 |



Co-funded by
the European Union



Introduction

The VR-VET project purpose is to facilitate training of technical personnel by creating a VR platform with information and skills collected from teachers and trainers from existing vocational training centres, research institutes and universities for creating a penetrant liquid testing training course and making it ready available to experts from industrial companies from the non-destructive examination training sector in order to create an international training VR platform with possibility for additional training course development in order to support the creation of an European-wide knowledge / skills development ecosystem.

The project will develop innovative educational materials for VR training of specialists in liquid penetrant testing, supporting the green and digital transitions in the NDT sector. The platform will be used by a network of training centres from different countries to train specialists in non-destructive testing using the liquid penetrant testing method. The project will organize three pilot courses to test the VR training solution for NDT specialists in the field of liquid penetrant testing examination.

This deliverable aims to revolutionize Non-Destructive Testing (NDT) training methodologies through innovative pedagogical approaches and the development of an immersive virtual reality (VR) training platform.

The project encourages innovation, creativity and transnational cooperation through the transfer of innovation and a sustainable exploitation of the results obtained within the partnership. Thus, the project will develop and test a VR platform capable of improving the process of practical training of students and facilitating their access to education through an innovative, futuristic and attractive approach for students, based on VR and artificial intelligence. Currently, training in the field of welding is still very traditional and classroom based. Given that information and communication technology (ICT) has begun to govern social systems and that development in this field will not stop here and on this path, we will move towards a global society, digital training has become a priority. Thus, VET teachers and trainers, as well as their training methods must be adapted to the current labour market trend and they should continuously improve their professional skill, to develop of digital readiness, resilience and capacity to meet the needs of modern society. E learning is a digital technology that could be used for a proper teaching, learning and sharing of experience remotely, allowing the access to information of people with disabilities and especially in case of pandemic situations. Blending of classroom learning with e-learning and practical Work-Based Learning (WBL) has to be improved to facilitate a smoother and more flexible implementation within the non-destructive examination testing sector. In view of the above, in the project frame, the new teaching and training methodology and related educational materials will be designed to contribute to the implementation of the New European Bauhaus initiative and its values (sustainability, inclusiveness, and aesthetics), to accelerate the green transition in the welding sector, thus actively contributing to the European Green Deal, boosting innovation and technologies for an inclusive and sustainable European economy. In addition to the development of human resources, the project supports regional development through innovation and smart specialisation for the integration of SMEs and clusters into the value chains of the industrial ecosystem related to the non-destructive examination testing sector.



Introduction to Penetrant Testing

General

This chapter outlines the basic penetrant process. It describes the purpose and some reasons for selecting the penetrant inspection methods plus personnel qualification requirements. The equipment used is briefly discussed in general terms, along with some of the process advantages/capabilities and disadvantages/limitations.

Background

Liquid penetrant inspection is one of the oldest of modern non-destructive inspection methods. It originated in the railway maintenance shops in the late 1800s. Parts to be inspected would be immersed in used machine oil. After a suitable immersion time, the parts were withdrawn from the oil and the excess surface oil wiped off with rags or wadding. The part surfaces would then be coated with powdered chalk or a mixture of chalk suspended in alcohol (whiting). Oil trapped in cracks or flaws would bleed out causing a noticeable stain in the white chalk coating.

The oil and whiting method was replaced by magnetic particle inspection on steel and ferrous parts in 1930. However, industries using non-ferromagnetic metals, especially aircraft manufacturers, needed a more reliable and sophisticated tool than discoloured machine oil and chalk. In 1941, fluorescent dye materials were added to a highly penetrating oil to make a fluorescent penetrant material. Coloured dyes, primarily red, were produced a little later. Since then, a large number of penetrant systems or families have evolved. These include developments in the following:

- various types and concentrations of dye materials.
- types of penetrating oils and additives.
- materials and methods for removing the excess surface penetrant.
- various materials and forms of developing agents.

A generic listing or classification of penetrant systems is detailed later in this chapter.

Capabilities of Penetrant Inspection

Penetrant inspection is a simple, inexpensive and reliable non-destructive inspection method for detecting discontinuities which are open to the surface of the item to be inspected. It can be used on metals and other nonporous materials that are not attacked by penetrant materials. With the proper technique, it will detect a wide variety of discontinuities ranging in size from those readily visible down to the microscopic level, as long as the discontinuities are open to the surface and are sufficiently free of foreign material.

Basic Penetrant Process

The basic fundamentals of the penetrant process have not changed from the oil and whiting days. This introductory paragraph provides a simplified description of the fundamentals.



The figure below illustrates the basic principles of the penetrant inspection process:

Step 1. The parts are cleaned. Cleaning is not part of the penetrant process but is critical and emphasised because of its effect on the inspection results. Contaminants, soils or moisture, either inside the flaw or on the part surface at the flaw opening, can reduce the effectiveness of the Inspection.

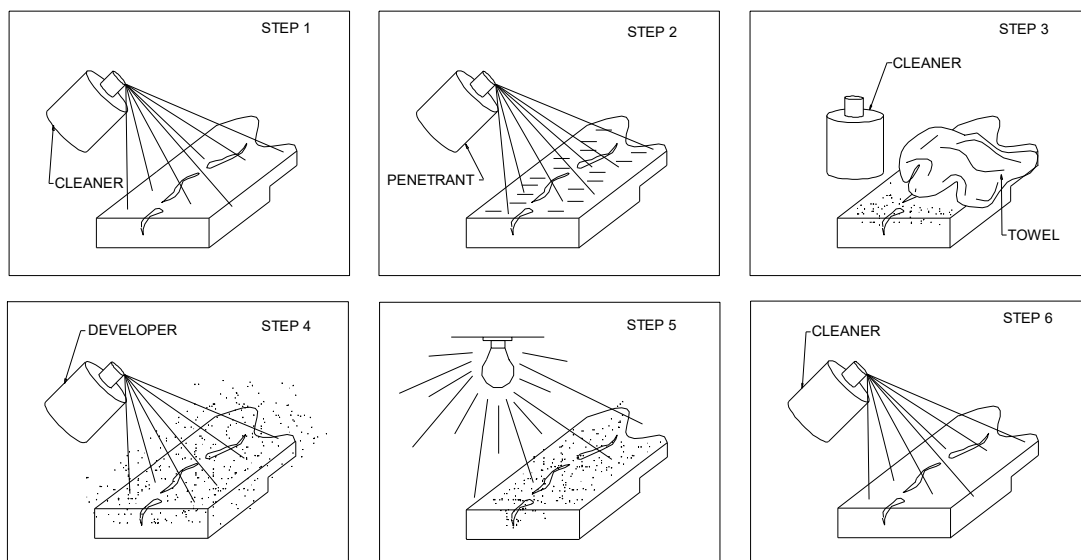
Step 2. A penetrating liquid containing dyes is applied to the surface of a clean part to be inspected. The penetrant is allowed to remain on the part surface for a period of time to permit it to enter and fill any openings or discontinuities.

Step 3. After a suitable dwell period, the penetrant is removed from the part surface. Care must be exercised to prevent removal of penetrant contained in discontinuities.

Step 4. A material called developer is then applied. The developer aids in drawing any trapped penetrant from discontinuities and improves the visibility of indications.

Step 5. The surface is viewed under correct lighting conditions. The type of penetrant used determines the required lighting conditions. Viewing often takes place using low level magnification. All relevant indications are noted at this time.

Step 6. The final step in the Penetrant process is to remove any traces of penetrant and developer by cleaning the part.



Sequence of Liquid Penetrant Tests

Mechanism of Penetration

The penetrant inspection process depends on a liquid that can flow over the surface. The discontinuities can be very small and difficult or impossible to see without magnification. The ability of a liquid to cover the surface of a part and enter any surface opening depends on the following physical factors - wetting ability, surface tension and contact angle. These three factors have the greatest influence on capillary action.

Wetting Ability:

When a liquid comes into contact with a solid surface, the cohesive force responsible for surface tension competes with or is countered by the adhesive force between the



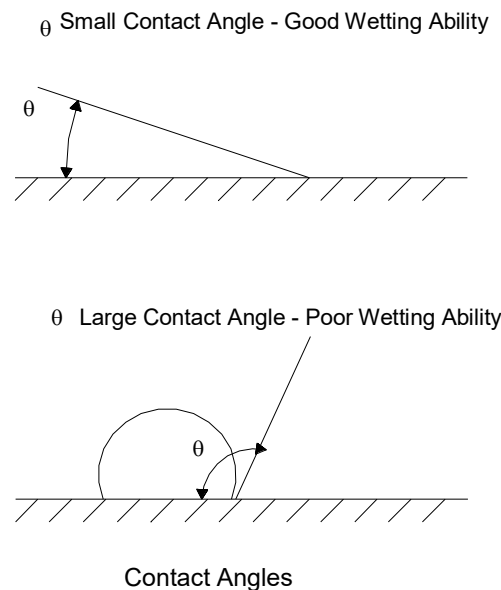
liquid molecules and the solid surface. These forces determine the contact angle which the liquid forms with the surface.

Surface Tension:

The surface of a liquid exhibits certain features resembling the properties of a stretched elastic membrane. These features are due to the cohesive forces holding the surface molecules together, hence the term "surface tension". As an example, one may lay a needle or safety razor blade upon the surface of water, and it will lie at rest in a shallow depression caused by its weight, much as if it were on a rubber air cushion.

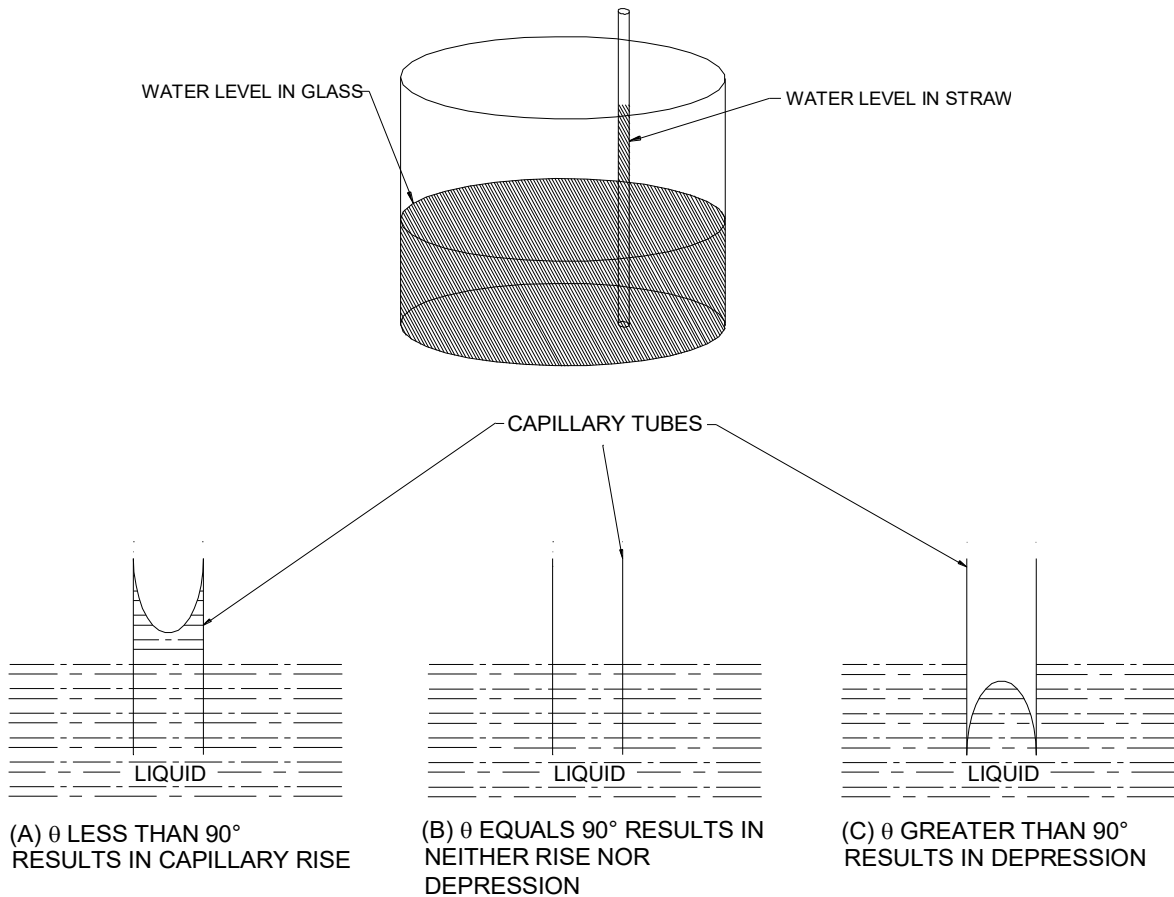
Contact Angle:

Contact angle is designated by the Greek letter "Theta" or θ . If the contact angle is less than 90° , the liquid spreads over the surface and is said to "wet the surface," or to have good wetting ability. Penetrants normally have wetting angles less than 5° . The figure below illustrates two contact angles.



Capillary Action:

Capillary action is associated with wetting ability. When a tube with a small inside diameter is inserted into a liquid, the liquid level inside the tubing may rise above, remain even, or be lower than the outside liquid level. If the contact angle between the liquid and the tubing wall is less than 90° (the liquid wets the tube wall), the liquid will be higher in the tube than on the outside. When the contact angle is 90° or greater (poor wetting), the liquid will not rise above the outside level and may even be depressed. The following figures illustrate the effects of contact angles and capillary action.



The Rise or Depression of Liquid in a Capillary Tube Depends upon the Contact Angle

Capillary Force:

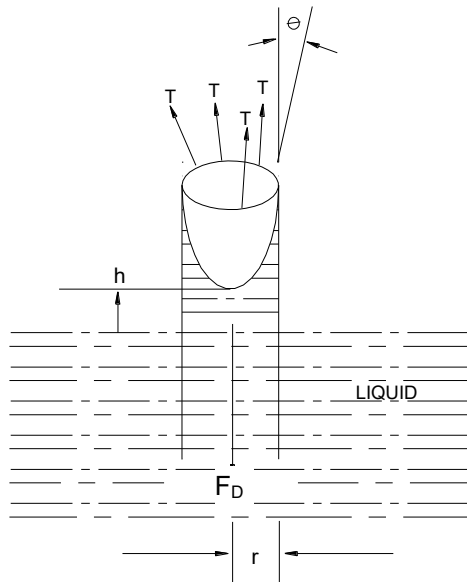
Capillary rise occurs when a liquid wets the inside of a tube and the surface tension draws additional liquid into the wetted area. The following figure (A) illustrates the forces involved. It is possible to calculate the height the column will rise. The upward force, figure (B) is the vertical component (Surface tension, T, times the cosine of the contact angle, θ) acting around the meniscus perimeter ($2\pi r$). The counter acting force, figure (A), is the weight of the liquid column. This can be calculated from the height of the column (h), the tube area (πr^2), density of the liquid (ρ), and the force of gravity (g). Since the upward force equals the downward force, the two equations can be used to calculate the column height:

The Simplified formula being:

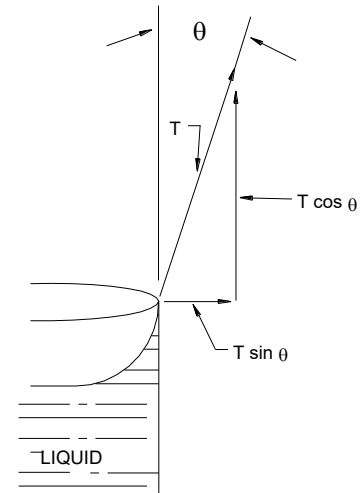
$$\text{Height} = \frac{2 \times \text{surface tension} \times \cosine \text{ of contact angle}}{\text{radius of tube} \times \text{density} \times \text{gravity}}$$

or:

$$\text{Height} = \frac{\text{Upward Force}}{\text{Downward force}}$$



(A) DOWNWARD FORCE =
WEIGHT OF LIQUID COLUMN
 $F_D = \pi r^2 \times \rho \times g \times h$



(B) UPWARD FORCE =
TENSION X MENISCUS PERIMETER
 $F_U = T \cos \theta \times 2\pi r$

Forces involved in Capillary Action

Penetrant Entry into Discontinuities:

The description of capillary action illustrates the basic principles by which a penetrant enters and exits a small surface opening. In actual practice, the equation is not used as the forces involved are more complex. The equation is based on an open capillary tube. If one end of the tube is closed, such as occurs in a flaw, the capillary rise is affected by compression of the air trapped in the closed end. In addition, flaws are not capillary tubes as the sides are not parallel and are not circular. These factors allow penetrant to enter a flaw even in an inverted position such as on a lower wing surface. The points to be remembered about the equation are:

- A high surface tension and small contact angle in a penetrant are desirable.
- Capillary force increases with smaller flaws.
- Viscosity is not a factor in penetrating ability.

Leak Detection

Penetrant inspection is also used to detect leaks in containers. The same basic fundamentals apply but the penetrant removal step may be omitted. The container is either filled with penetrant or the penetrant is applied to one side of the container wall. The developer is applied to the opposite side, which is inspected after allowing time for the penetrant to seep through any leak points. This method may be used on thin parts where there is access to both surfaces and the discontinuity is expected to extend through the material.



Reasons for Selecting Penetrant Inspection

There are a number of reasons for selecting penetrant inspection over other non-destructive inspection methods. Some of the reasons for choosing penetrant inspection are:

- Penetrant Inspection, under ideal conditions, can detect very small discontinuities. This is below the detection capabilities of many other non-destructive Inspection methods.
- Penetrant Inspection permits examination of all accessible surfaces of a part in one operation. Other non-destructive methods cover a specific area or location and must then be repeated to cover other areas or locations.
- Penetrant inspection magnifies the apparent size of discontinuities so the indications may be more readily detected without optical aids.
- Penetrant inspection indicates the location, orientation and approximate length of the indication directly on the part, making interpretation possible.
- The sensitivity level of penetrant inspection may be adjusted through selection of materials and technique. This allows suppression of indications from small, inconsequential discontinuities while indicating larger discontinuities of more concern.

Selection of a test method is complex and depends upon a large number of factors. A thorough knowledge of the capabilities and limitations of all non-destructive inspection methods is required. Whenever possible, the decision on which method to use, should be referred to the appropriate engineering department or body.

Personnel Requirements

The apparent simplicity of the penetrant inspection is deceptive. Very slight variations in performing the inspection process can ruin the inspection by failing to indicate serious flaws. It is essential that personnel performing penetrant inspection be trained and experienced in the penetrant process. All individuals who apply penetrant materials or examine components for penetrant indications should be qualified to recognised standards and certified as competent.

Equipment Requirements

The equipment used in the penetrant inspection process varies from spray or aerosol cans to complex automated systems.

Advantages and Capabilities of Liquid Penetrant Inspection

Liquid penetrant inspection can examine all the exterior surfaces of objects, even of complex shapes, in one operation. Other non-destructive inspection methods require the probing media to be directed to a specific surface or area, while penetrant coats the entire part. Parts that are too large for immersion can be processed by spraying the penetrant materials to provide complete surface coverage.



Liquid penetrant inspection can detect very small surface discontinuities. It is one of the more sensitive non-destructive inspection methods for detecting surface flaws.

Liquid penetrant inspection can be used on a wide variety of materials including ferrous and nonferrous metals and alloys, fired ceramics, powdered metal products, glass, and some types of organic materials. Restrictions on materials are covered in the limitations paragraph.

Liquid penetrant inspection can be accomplished with relatively Inexpensive, non-sophisticated equipment. If the area to be inspected is small, the inspection can be accomplished with portable equipment.

Liquid penetrant inspection magnifies the apparent size of discontinuities making the Indications more visible. In addition, the discontinuity location, orientation and approximate length are indicated on the part, making interpretation and evaluation possible.

Liquid penetrant inspection is readily adapted to volume processing permitting 100 percent inspection. Small parts may be placed in baskets for batch processing; specialized systems may be semi or fully automated to process as many parts per hour as required.

Liquid penetrant inspection may be adjusted to provide various sensitivity levels through the proper choice of materials and processing procedures or techniques. This selection can be used to suppress indications from small, Inconsequential discontinuities while indicating larger discontinuities of more concern.

Disadvantages and Limitations of Liquid Penetrant Inspection

Penetrant inspection depends upon the ability of the penetrating media to enter and fill discontinuities. Penetrant inspection will only reveal discontinuities that are open to the surface.

The surfaces of objects to be inspected must be clean and free of organic or inorganic contaminants that will impede the action of the penetrating media. It is also essential that the inside surface of the discontinuities be free of materials such as corrosion, combustion products or other contaminates, that would restrict the entry of penetrant.

Smear Metal:

Mechanical operations, such as shot peening, machine honing, abrasive blasting, buffing, wire brushing, grinding or sanding will smear or peen the surface of metals. This mechanical working closes or reduces the surface opening of any existing discontinuities. Mechanical working (smearing or peening) also occurs during service use when parts contact or rub against each other. Penetrant inspection will not reliably indicate discontinuities when it is performed after a mechanical operation or service use that smear or peens the surface.

Porous Surfaces:

Penetrant inspection is impractical on porous materials with interconnected subsurface networks. The penetrant rapidly enters the pores and migrates through the network. This results in an overall fluorescence or colour that would mask any potential discontinuity indications. In addition, removal of the penetrant may not be possible after the inspection.



Health and Safety

The penetrant inspection process is a chemical-based process. Many of the chemicals are hazardous to health and care must be taken to ensure all safety regulations and instructions are complied with.

Specific References:

For safety always obtain and take time to study the specific references found in Technical Information/Health and Safety Information Documents and Manufacturers Safety Data Sheets (MSDS). References included are typically:

- **Hazardous Ingredients.** Lists toxic ingredients of chemicals.
- **Physical Data.** Gives technical characteristics of chemicals.
- **Fire and Explosion Hazard Data.** Gives flash points, hazards, what fire extinguisher to use and any special procedures to fight fires.
- **Reactivity.** Describes any hazardous polymerization, incompatibilities and hazardous decomposition products.
- **Environmental and Disposal Information.** Details action for spills and waste and disposal.
- **Health Hazard Data.** Details changes of inhalation, skin contact, skin absorption, eye contact, digestion, systematic effect and aggravation of any existing medical condition together with any contained suspect cancer agents.
- **First Aid Information.** Details how to handle incidents described in the Health Hazard Data.
- **Handling Precautions.** Details items such as ventilation, need for gloves, respirators, goggles and any special equipment.
- **Storage and Handling.** How to store, freight, stack etc any special restrictions or requirements.
- **Department of Transport.** Regulations regarding air freight, and containers for transport are typically found in this part of MSDS.
- **Other Safety Information.** Special codes of usage or other factors not already covered in the previous sections would be addressed here.
- **Name of Preparer.** It is common to find a contact name, telephone number and address to satisfy the unanswered questions of any customer in this section.

First Aid Treatment

The various chemicals used in liquid penetrant testing constitute a health hazard. The following first aid treatment and precautions are to be observed, and where, due to local working conditions, additional protective measures are considered necessary, the advice of the area Health and Safety at Work Officer is to be sought and local safety procedures followed.

- **Contact with the Eyes.** If, due to location/orientation of the component being examined, a possibility exists of chemicals coming into contact with eyes, chemical proof goggles are to be worn. Should eye contamination occur, irrigate eyes with copious amounts of water. An industrial wash bottle should be provided where running water is not readily available. After first aid measures proper medical attention should be promptly sought.
- **Contact with the Skin.** Owing to the de fatting action of the chemicals, barrier cream is to be applied to the hands before commencement of work. Where



prolonged contact with chemicals is anticipated, protective PVC gloves are also to be worn. In all circumstances contact between skin and chemicals is to be kept to an absolute minimum. Should skin contamination cause dryness and irritation, thoroughly wash with warm soap and water, dry and apply a lanolin-based cream. If irritation persists, seek medical attention.

- Taken Internally. Do not consume food whilst carrying out penetrant techniques and wash hands thoroughly before eating food. Should chemicals be ingested, seek medical advice immediately. **DO NOT INDUCE VOMITING.**
- Inhalation. In confined areas, or where a high concentration of fumes and/or dry powders exist, face masks, fitted with filter cartridges, are to be worn. Penetrant bays, or areas where penetrant applications are commonplace, should be provided with forced air ventilation. Should nausea, dizziness, drowsiness or asphyxiation occur, remove victim to fresh air and seek medical advice. Use resuscitation methods if breathing has stopped.

Handling and Storage

- Fire Hazard. Certain vapours, which are emitted by volatile substances, will ignite when exposed to a flame. The lowest temperature at which these vapours ignite is referred to as the "flash point" of the substances. The higher a material's flashpoint the less fire hazard it presents so that penetrant materials having a very low flashpoint should be avoided. To ensure safety, it is recommended that penetrant materials in open tanks should have a minimum flashpoint of 93°C (200°F). Because most penetrant materials will eventually ignite, smoking, undue heat or open flames must be forbidden in or near penetrant work areas and as has been previously mentioned, the use of exhaust fans is essential in order to disperse potentially hazardous vapours. CO₂, foam and dry powder fire extinguishers are recommended, should be readily available and their operation understood by all employees.
- Storage. Store in sealed containers, in a dry area, away from heat and direct sunlight.
- Spillage. Soak up with absorbent material.
- Transport. Take appropriate precautions, dependent upon the flashpoint of the particular chemical concerned.
- Disposal. Should be treated as oily waste and not discharged into public sewers or waterways if large quantities are involved.

Types of Penetrant

The amount of penetrant material entrapped in discontinuities is usually very small. If the discontinuity is to be detected, the very small amount of penetrant must be highly visible. In the oil and whitening days, it was found that used or dirty oil was much more visible than clean machine oil, Present penetrants obtain visibility by dissolving highly coloured dyes in the penetrating vehicle or oil. The type of dye materials provides one means of classifying penetrants.

Fluorescent Penetrant (EN ISO 3452-1 Type I):

Some chemical compounds have the capability of emitting visible light when exposed to near ultraviolet or black light (energy with a wavelength of 320 to 400 nanometers/3200 – 4000 angstroms). This property is termed fluorescence, and the materials are called fluorescent. With the selection of proper fluorescent materials,



very small quantities of penetrant will emit highly visible indications when exposed to black light.

The unit of measurement for short wavelength electromagnetic energy is the nanometer (nm) [$1 \text{ m} \times 10^{-9}$]. It replaces the previously used Angstrom unit [$1 \text{ m} \times 10^{-10}$] with one nanometer being equal to 10 Angstrom units.

Colour Contrast Penetrant (EN ISO 3452-1 Type II):

Colour contrast penetrants contain a red dye dissolved in the penetrating oil. The visibility is further enhanced during the penetrant process by the application of a layer of white developer. The white developer provides a high contrast background for the bright red penetrant when viewed under natural or white light. This penetrant is not permitted for aerospace applications.

Dual Purpose (Fluorescent Colour Contrast) Penetrant (EN ISO 3452-1 Type III):

Dual Purpose (Fluorescent Colour Contrast) Penetrant contain dye materials that are both reddish in colour under white light and fluorescent under black light. However, both the intense, red visible colour and the fluorescent properties are compromised compared to the individual visible dye and fluorescent penetrants; the brilliance of colour and amount of fluorescence are reduced. This penetrant is not permitted for aerospace applications.

Methods of Removal

Penetrant materials are compounded or formulated for specific removal methods. The removal method provides another means of classifying penetrant materials. Each removal method has advantages and disadvantages, which are covered in later paragraphs.



Water Washable Penetrant (EN ISO 3452-1 Method A):

The usual liquid base or vehicle for a penetrant is a petroleum oil which is insoluble or immiscible in water. There are chemical compounds (usually, oil base liquids) that can mix with penetrant oils to form an emulsifiable mixture. An emulsified oil is one that can be removed with a water spray. The chemical compound forming the emulsifiable mixture is called an emulsifying agent or an emulsifier. Water washable penetrants contain an emulsifying agent when received from the manufacturer. This permits direct removal by a water spray immediately after the penetrant dwell.

Lipophilic Emulsifier (EN ISO 3452-1 Method B):

Penetrants used in the lipophilic emulsifier method are formulated to optimize their penetrating and visibility characteristics. They do not contain any emulsifying agent and cannot be removed with plain water. Removal is made possible by applying an emulsifier as a separate process step. This converts the excess surface penetrant into an emulsifiable mixture which can be removed with a water spray.

Solvent (EN ISO 3452-1 Method C):

The term "Solvent Removable" applies to the process rather than the material since all oil-based penetrants can be removed with solvents. Usually, the penetrants used in the solvent removable process are the standard post emulsifiable penetrants, however water wash penetrants can also be used.

Solvents used may contain aromatic, aliphatic, or halogenated compounds. Many are highly flammable while others may decompose at elevated temperatures. All solvents should be kept away from heat and open flame. Vapours may be harmful and adequate ventilation is required. Contact with skin and eyes should be avoided.

Hydrophilic Emulsifier (EN ISO 3452-1 Method D):

The hydrophilic emulsifier method uses penetrants without emulsifier. They are the same as, or similar to, the penetrants used in the lipophilic method. The difference between hydrophilic and lipophilic methods is in the materials and procedures used in the removal process. Hydrophilic removal is accomplished with a water base solution and a detergent, soapy surface action. Therefore, the hydrophilic method of penetrant removal is more correctly known as the hydrophilic remover method. The hydrophilic remover method is preferred over the lipophilic emulsifier method as it provides greater control over the removal process and produces less residual background.

Water Washable Penetrant and Solvent (EN ISO 3452-1 Method E):

You can use water first and then solvent to remove the excess of penetrant in the same terms combine both methods.



Developers

There are four forms of developers in general use. The four forms are:

- a. Dry Powder (EN ISO 3452-1 form a)
- b. Water Soluble (EN ISO 3452-1 form b)
- c. Water Suspendable (EN ISO 3452-1 form c)
- d. Nonaqueous (EN ISO 3452-1 form d) for fluorescent penetrant (Type I)
- e. Nonaqueous (EN ISO 3452-1 form e) for colour contrast penetrant (Type II)
- f. Special techniques
- g. Without developer (only Type I)

There are several methods of applying each form of developer, e.g., immersion, fog, air, electrostatic and pressure spray.

Sensitivity

The term "sensitivity", when used in conjunction with penetrant systems, refers to the ability of detecting small, tight flaws. Sensitivity is a relative factor in that it does not provide a measured numerical result. Sensitivity is determined by applying the penetrant system to a cracked panel, plate or block and comparing the resulting indications with those from a reference standard. Several factors influence the sensitivity of a given penetrant, and the type of developer can change the sensitivity level. Comparison of penetrants must be accomplished using the same type of developer.

Sensitivity Categories:

Penetrant systems (penetrant/emulsifier or remover) are often classified into four sensitivity levels, as follows:

- **Fluorescents penetrants (Type I)**

Sensitivity Level 1/2 - Ultra low

Sensitivity Level 1 - Low

Sensitivity Level 2 - Medium

Sensitivity Level 3 - High

Sensitivity Level 4 - Ultrahigh

- **Visible dye penetrants (Type II) or dual penetrants (Type III)**

Sensitivity Level 1 - Low

Sensitivity Level 2 - High

Definition of Sensitivity:

The term "low", used to describe Sensitivity Level 1 penetrant systems, is a contradiction. The sensitivity of Level 1 systems is low only when compared to higher



sensitivity penetrant systems. It is much higher than visual inspection and is acceptable for a large number of applications.

The most sensitive penetrant system for a given purpose is the one that most effectively finds flaws of the type sought under the circumstances involved.

Sensitivity Level Selection:

It is not necessary, nor is it always possible, to use the higher sensitivity materials. There are several factors governing selection of a sensitivity level.

Type and Size of Potential Flaws:

Large flaws, such as those caused by overstress, can be detected with low sensitivity materials. Small, tight fatigue cracks, such as those occurring on engine rotating parts, require ultrahigh sensitivity materials. The majority of flaws encountered in aircraft maintenance can be detected with medium or high sensitivity penetrant systems.

Surface Condition of the Part:

Parts with rough surfaces, such as casting, welds, forged and over etched parts, tend to retain some of the penetrant. The use of high or ultrahigh sensitivity penetrants on rough surfaces may produce an excessive residual background that could obscure potential flaws. Penetrant is very easily removed from smooth, polished surfaces. Low or medium sensitivity penetrants may not detect small flaws in smooth, polished surfaces due to the ease of over removal.

Material and Process Control Costs:

The higher sensitivity materials are considerably more expensive than lower sensitivity materials. This is due mainly to the increased amount of costly dyes. Also, the higher sensitivity materials require closer process control with a resulting increase in manhours. These increased materials and manhour costs are not justified if the higher sensitivity is not required.

Sensitivity vs. Penetrant Types:

Sensitivity varies with the type of penetrant and form of developer. In theory, the removal method does not affect sensitivity. However, some removal methods must be very closely controlled and slight process variations can significantly reduce sensitivity. The following generalizations can be made about various types of penetrants:

- Visible dye penetrants are less sensitive than fluorescent penetrants. Visible dye penetrants are only qualified to Sensitivity Level 1 (Low).
- Dual mode (Visible and Fluorescent) penetrants are qualified to Sensitivity Level 1 (Low).
- Sensitivity Level 1 penetrants are not permitted on aircraft parts.



Classification of Penetrant Materials and Processes

Industrial Classifications:

A number of professional and technical societies have developed classification systems covering penetrants. These are detailed in Appendix B.

System (or Family) Concept

Each penetrant inspection material's manufacturer has its own formulation for penetrants, lipophilic emulsifiers and hydrophilic removers. Penetrant and lipophilic emulsifier or hydrophilic removers are qualified as a system. This system consists of very specific materials from the same manufacturer. Additionally, the hydrophilic removers are qualified at a specific concentration. Therefore, only products that comprise a system may be used together and must be used at the concentration specified.

Mixing of manufacturers or components from the same manufacturer that are not part of the system will not provide for optimum performance and, in some cases, this practice will eliminate any chance of detecting defects, therefore, it is not done. Any manufacturer's developer can be used with combined penetrant and lipophilic emulsifier or hydrophilic remover system of another manufacturer. The condition in which developers can be used is the same for solvent removers.

Penetrant Processes

Abridged penetrant process flow charts illustrating the general process steps for the various penetrant methods are provided in the following paragraphs.

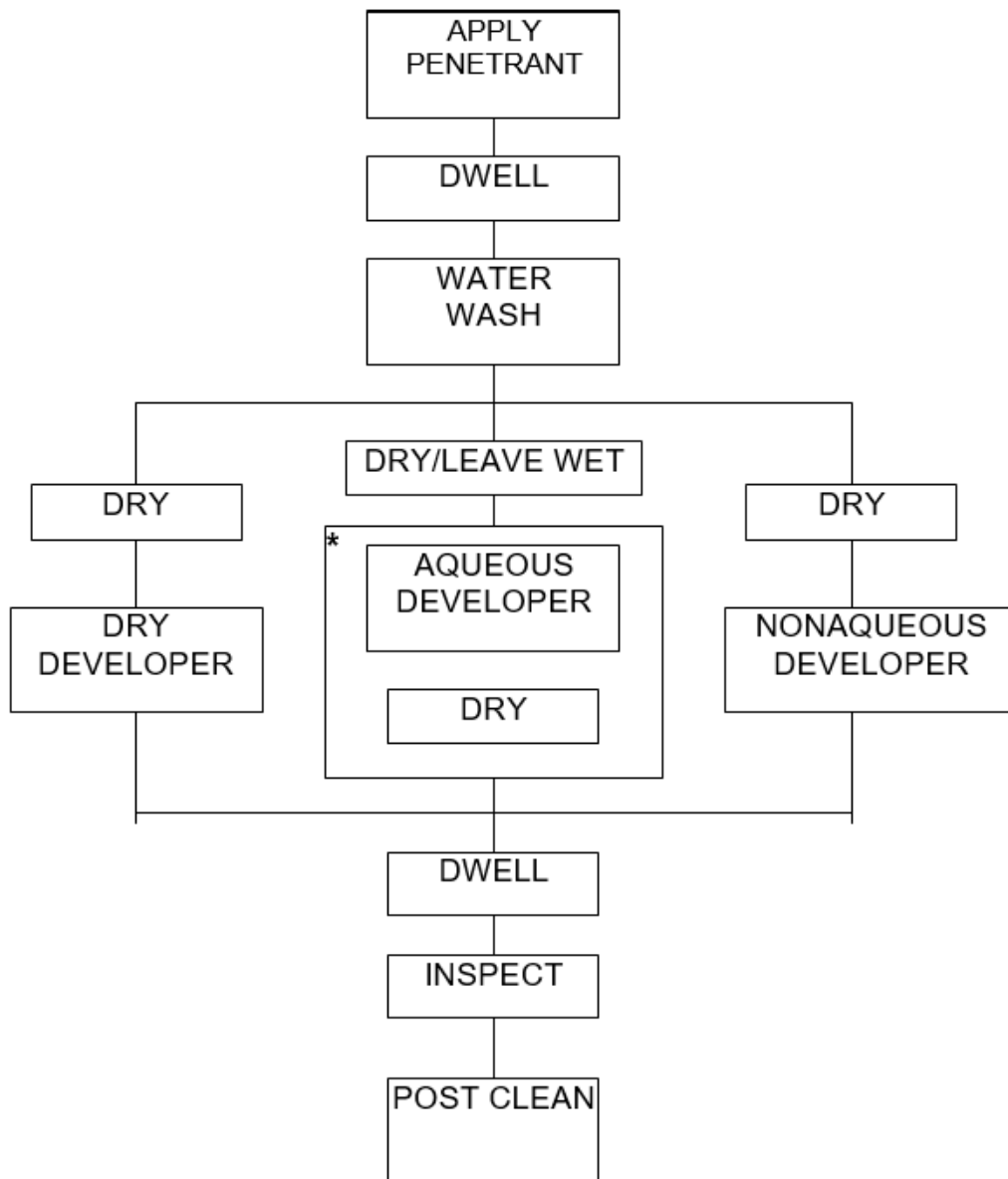
Fluorescent versus Visible Dye Procedures:

The application procedures for fluorescent penetrant and visible dye penetrant are similar. The process flow charts in the following paragraphs are applicable to both fluorescent and visible dye penetrants



Water-washable Penetrant Process (EN ISO 3452-1 Method A):

The flow chart shows the process steps involved in performing a water washable penetrant inspection.

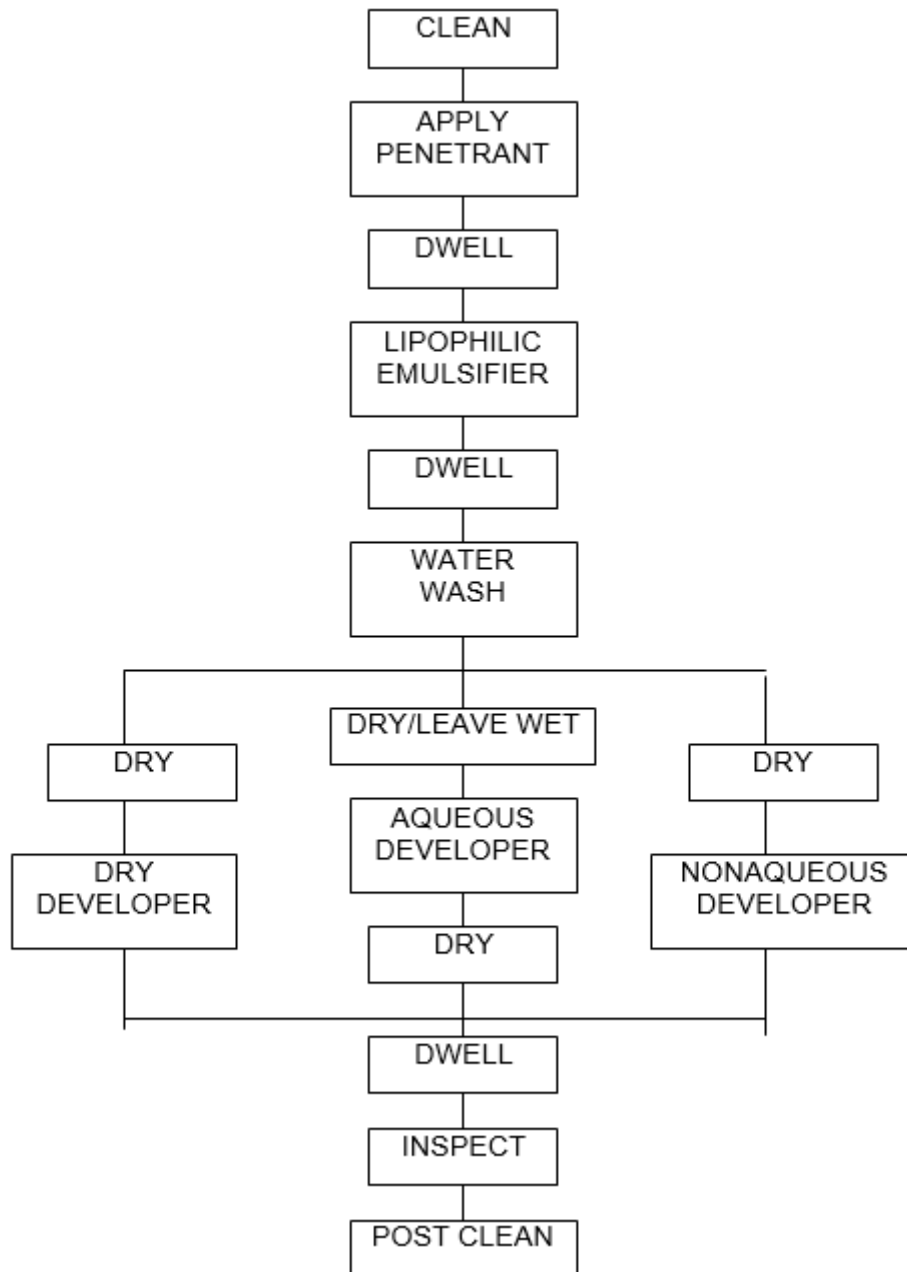


* Not normally permitted as water based developer will wash out indications from water washable penetrants!



Lipophilic Emulsifier Process (EN ISO 3452-1 Method B):

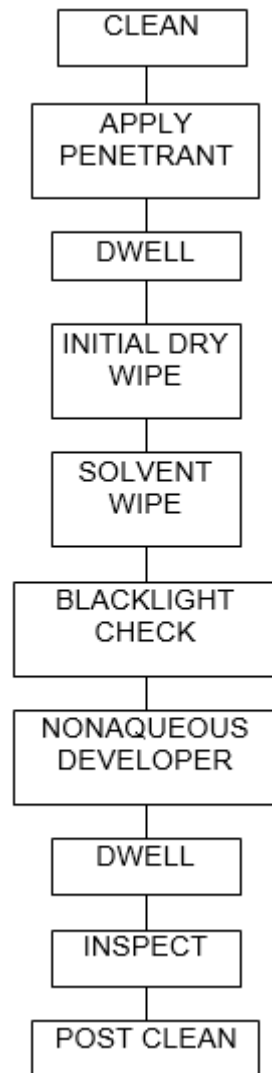
The flow chart shows the process steps involved in performing a post emulsified, lipophilic penetrant inspection.





Solvent (EN ISO 3452-1 Method C):

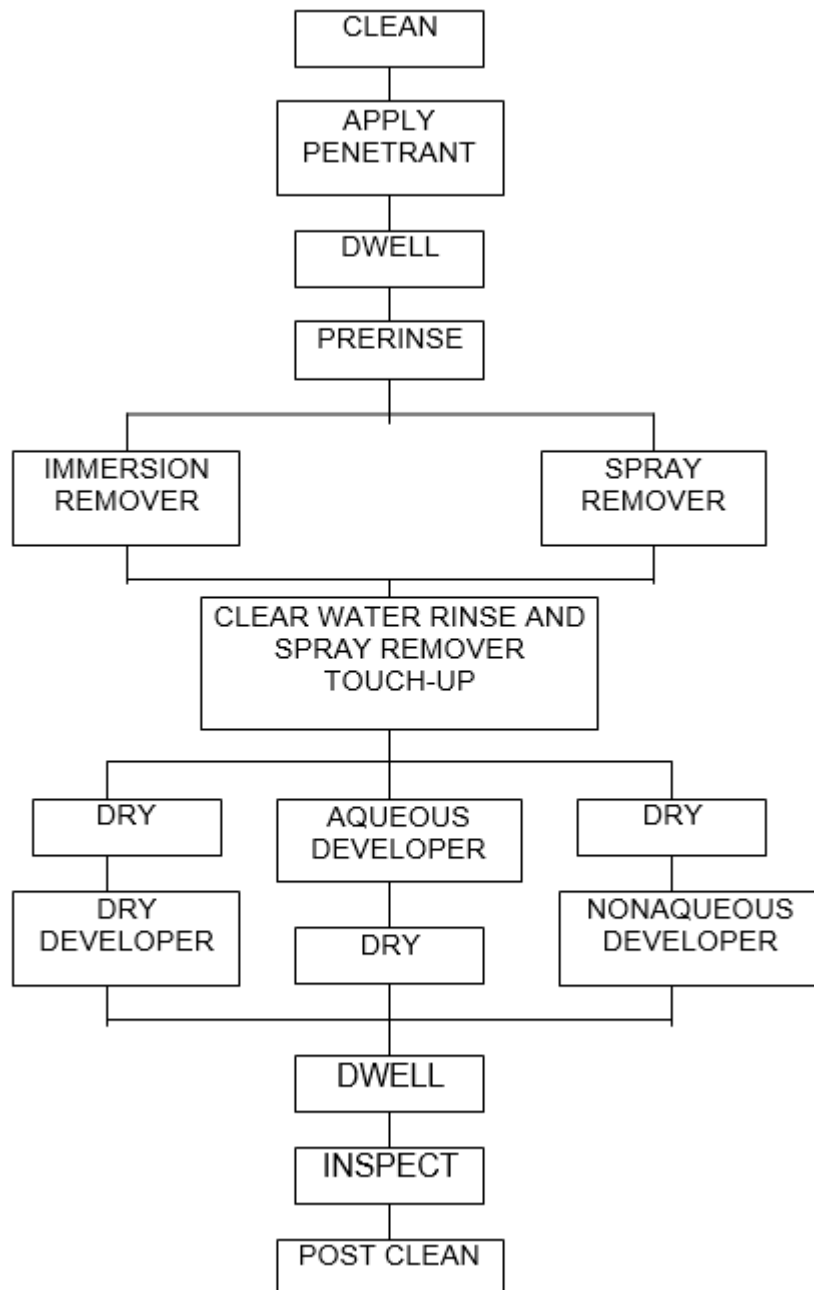
The flow chart shows the process steps involved in performing a solvent removable penetrant inspection.





Hydrophilic Emulsifier (EN ISO 3452-1 Method D):

The flow chart shows the process steps involved in performing a post emulsified, hydrophilic penetrant inspection.



Water Washable Penetrant and Solvent (EN ISO 3452-1 Method E):

You can use water first and then solvent to remove the excess of penetrant in the same terms combine both methods.



Equipment Requirements

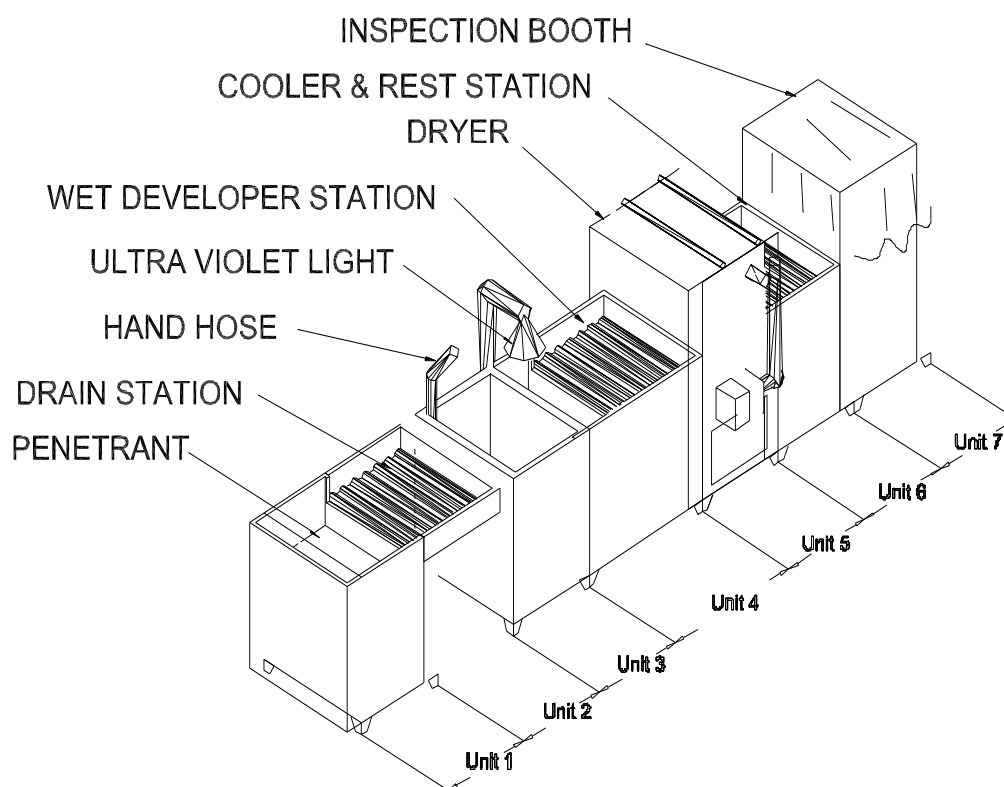
The equipment used in the penetrant inspection process varies from spray or aerosol cans to complex automated systems. Some of the more generally used types of equipment are briefly described in the following paragraphs.

Portable Equipment:

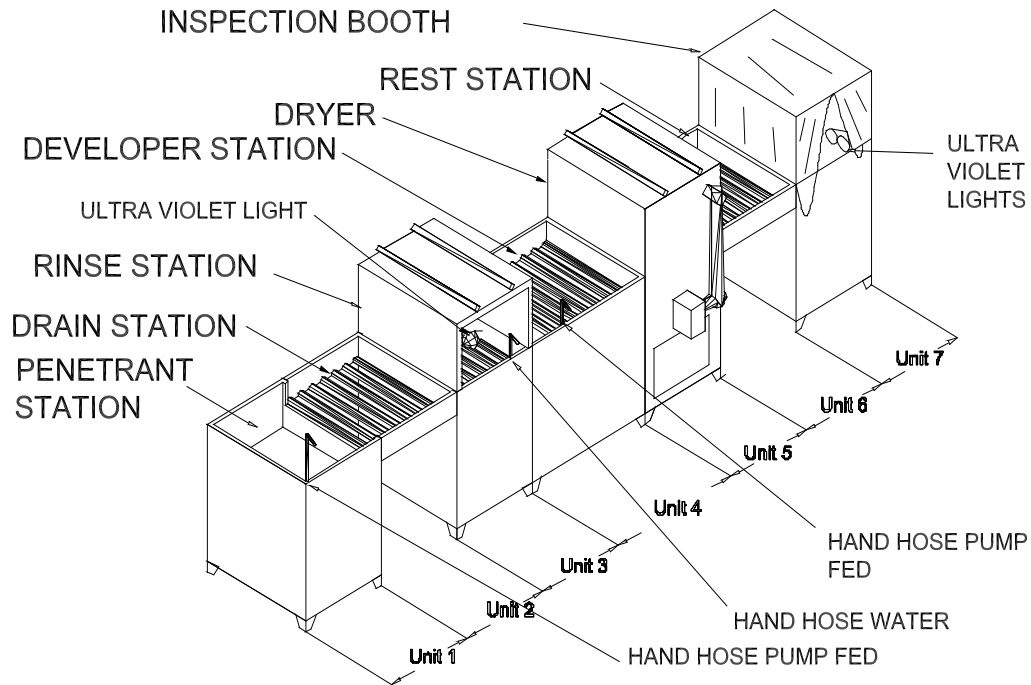
Penetrant inspection can be performed on installed parts (e.g. on aircraft) or on parts too large to be brought to the Inspection area. Penetrant materials are available in aerosol spray cans and in small containers for brush or wipe applications. Generally, portable penetrant applications are limited to localized area or spot inspections rather than entire part surfaces.

Stationary Inspection Equipment:

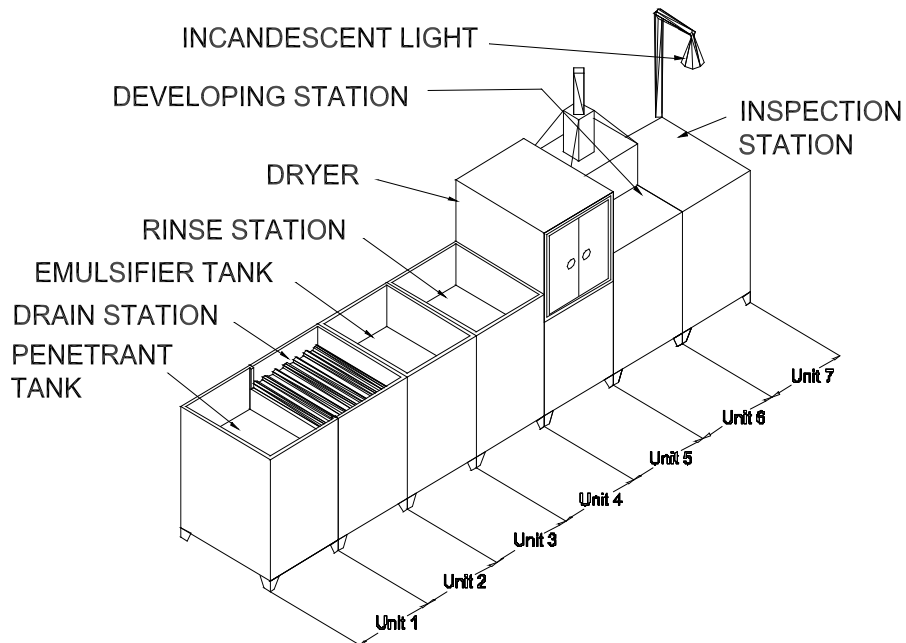
The type of equipment most frequently used in fixed installations consists of a series of modular sub-units. Each sub-unit performs a specific task. The number of sub-units in a processing line varies with the type of penetrant method used. The sub-units are: dip tanks for penetrant, remover or emulsifier, and developer, a number of drain or dwell stations; a spray wash station with a black light; a drying oven; and an inspection booth. The drain or dwell stations are roller top benches to hold the parts during the processing cycle. The usual arrangement is to position a drain or dwell station following each of the dip tanks, the wash station and the drying oven. The following figures show typical penetrant systems.



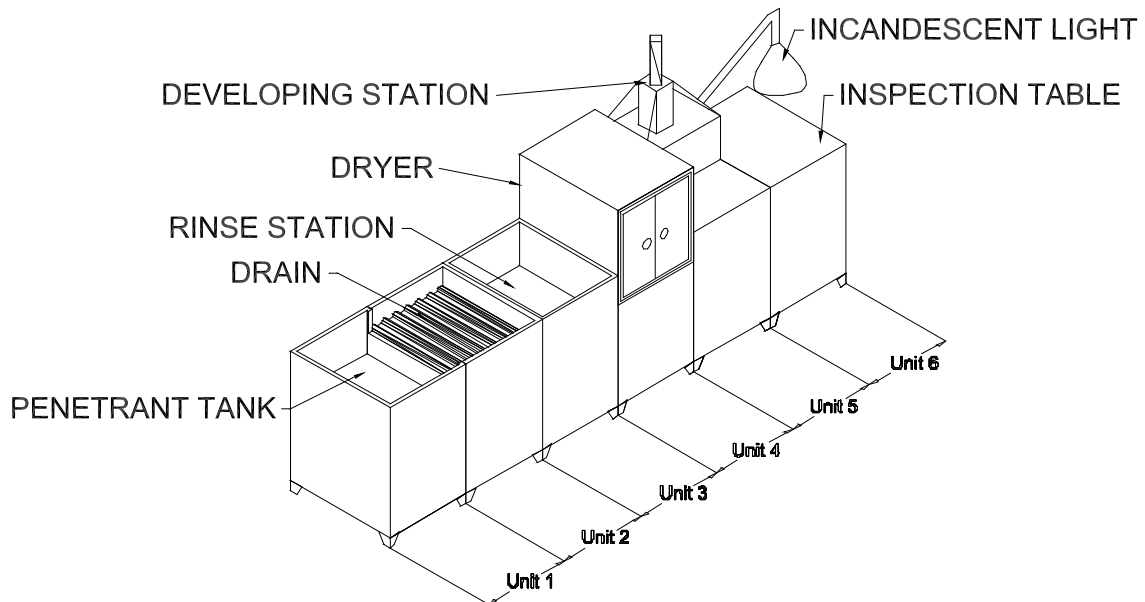
Typical Medium Size Parts Inspection Equipment



Typical Large Size Parts Inspection Equipment



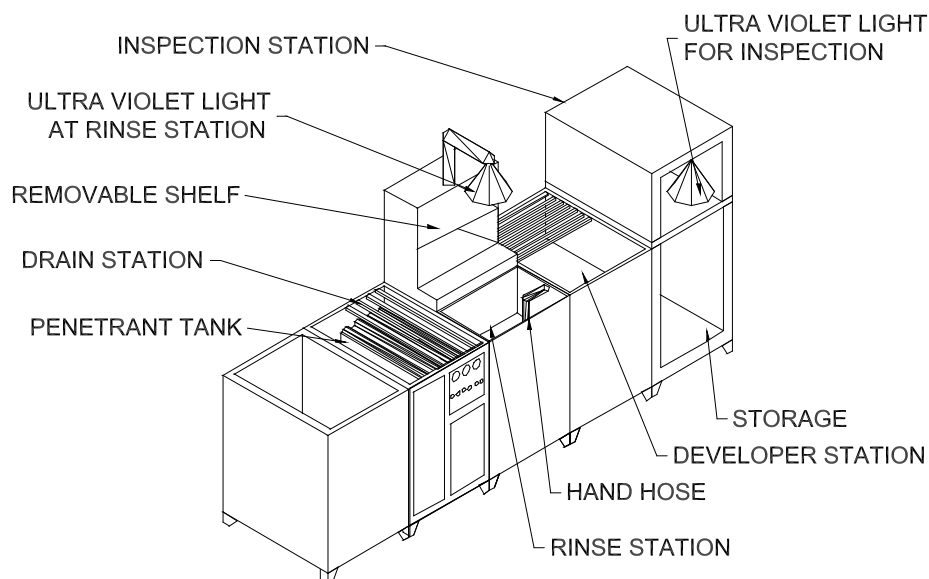
Typical Post-Emulsifiable Visible Dye Penetrant inspection Station



Typical Water-Washable Visible Dye Penetrant Inspection Equipment

Small Parts Inspection Unit:

There is inspection units designed for processing small parts. The units are smaller than the general systems described above and some of the stations serve multiple purposes. In use, the parts are loaded into wire baskets which are then batch processed through each of the stations. The wash station may contain a water-driven, rotary table with spray jets to supplement the handheld spray wand. The following figure shows a small part inspection unit.



Typical Small Parts Station



Automated Inspection Systems:

The penetrant inspection process lends itself to semi and fully automated processing equipment. Semi-automated systems consist of a conveyor transport for the parts with one or more of the processing steps, such as application of penetrant, emulsifier or remover, rinse, or developer, being manually accomplished. In fully automated systems, all the processing steps are mechanically accomplished without an operator. Automated equipment allows large numbers of parts to be rapidly processed with a minimum of man-hours. It also reduces the human variables and provides a uniform processing cycle.

Inspection and Interpretation

General

Detection of flaws by the penetrant inspection method depends upon the formation of an indication; an individual examining the part; observing any indications; and identifying them as flaws. Assuming the penetrant process has been properly accomplished, detection of flaws will be controlled by the ability of the technician and the quality of lighting during the examination. This section provides basic, intermediate and advanced information on the requirements for a reliable inspection and describes the appearance of indications from various types of flaws.

Personnel

Personnel who are responsible for processing of parts through one or more of the penetrant process steps, even though they do not inspect or interpret indications, should have a basic knowledge of the process theory, practical aspects and equipment operation. They should be aware of the process control requirements and of the effects of improper procedures or degraded materials on the formation of indications.

Personnel responsible for performing inspection and interpreting and evaluating penetrant indications should have a detailed knowledge of the theory, practical aspects, and application procedures for the major penetrant processes. They should be capable of performing all of the process steps, materials and process control tests, and providing technical guidance to operators and trainees. In addition, they should have knowledge of flaw formation, the appearance of penetrant indications, and experience in interpretation and evaluation of indications.

All personnel performing any of the penetrant process steps should be qualified.

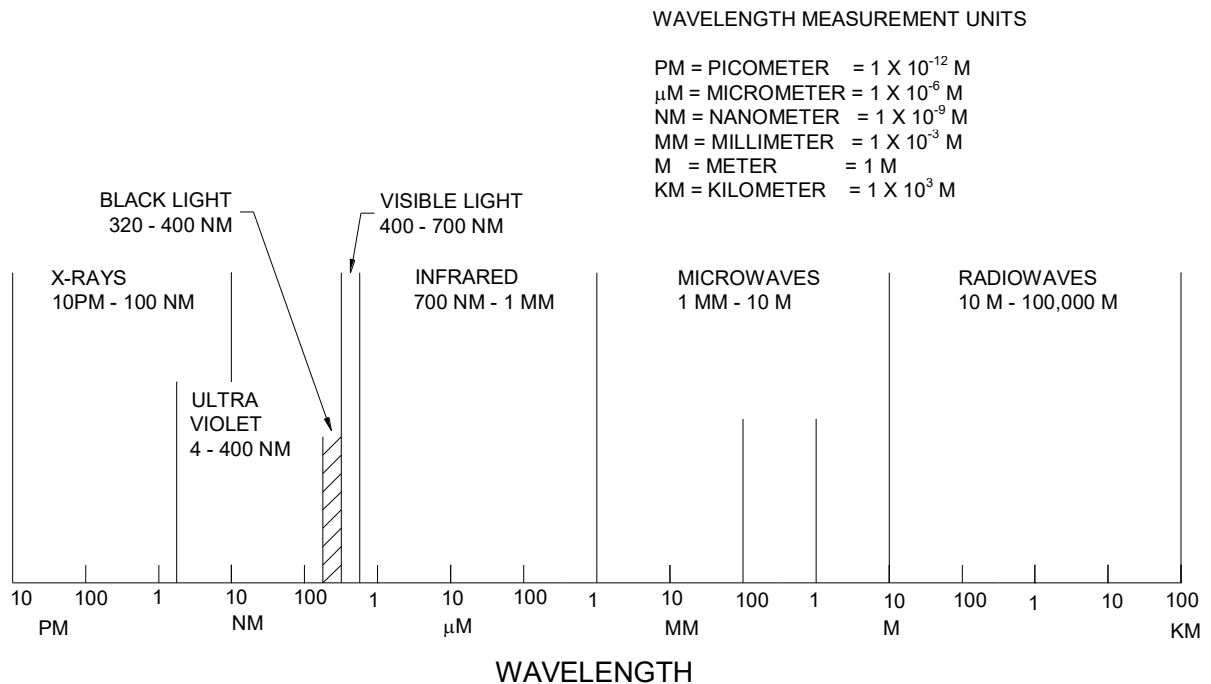
Lighting and Facilities

Ultraviolet is electromagnetic radiation with a wavelength ranging between X rays and visible light. The ultraviolet range is usually divided into three bands:

- Short wavelength, 4 to 270 nm, or hard ultraviolet which is used in germicidal or sterilizing lamps;
- Medium wavelength, 270 to 320 nm, which is used in examining minerals and suntan lamps;
- Soft ultraviolet or long wavelength, 320 to 400 nm, which is called black light. Wavelength 365 nm \pm 5 is used in Penetrant Testing.



Black light has the smallest bandwidth of the ultraviolet range and is just below visible wavelength light. The figure below is the electromagnetic spectrum showing the relatively small band of black light used in fluorescent penetrant. The eye is not too responsive to black light, especially if visible light is present. However, with reduced visible light, the sensitivity of the eye increases and with large amounts of black light, and the longer wavelengths (violet) may be visible.



Electromagnetic Spectrum shows the Relatively Narrow Band of Black Light:

When fluorescent materials are energized by ultraviolet radiation, they emit visible light. The quality or colour of the emitted light depends upon the material. Each type emits a specific wavelength ranging from violet (400 nm) to red (700 nm). One of the factors in selecting a dye for use in fluorescent penetrant is the colour emitted. The most frequently used dyes emit a yellow green in the wavelength band of 510 to 560 nm. This colour is chosen since the eye has its highest response to wavelengths in the 550 nm range.

Black Light Sources

There are three common sources used to generate ultraviolet energy. They are:

- Carbon arc systems.
- Low pressure fluorescent bulbs.
- High pressure, mercury vapour bulbs.

Carbon Arc Systems:

Electric current arcing between two carbon electrodes generates a high quantity of electromagnetic radiation. The radiation spans a range of wavelengths from about 10 nm to over 10 micrometers. Carbon arc systems are not used for fluorescent penetrant inspection.



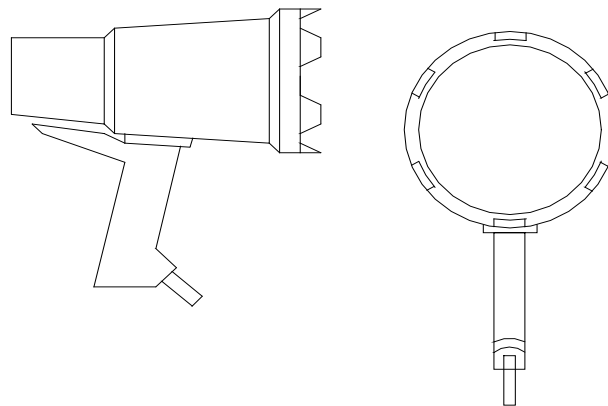
Low Pressure Fluorescent Bulbs:

Low pressure, fluorescent bulbs are similar to standard fluorescent tubes. When an electric current is applied they emit hard ultraviolet radiation with a wavelength of about 254 nm. This wavelength is not useful for fluorescent penetrant inspection. Therefore, the inside of the tube is coated with a phosphor that is activated by the hard ultraviolet and emits black and visible light in the wavelength range of 320 to 440 nm. The amount of useful black light at 365 nm is relatively small. In addition, fluorescent black light bulbs, because of their configuration, cannot be easily focused and their intensity per unit area is below that of other types of bulbs. Thus, fluorescent black lights must not be used for detecting fluorescent indications.

High Pressure Bulbs:

High pressure, mercury vapour bulbs are the most common sources for black light. They are preferred for fluorescent penetrant inspection because they have an acceptable output at a reasonable distance from the bulb. They can be focused to increase their intensity on a localized area. They are available in a wide range of sizes from a 2 watt pencil type to a 400 watt floodlight. The smaller sizes, less than 100 watt, must not be used for penetrant inspection.

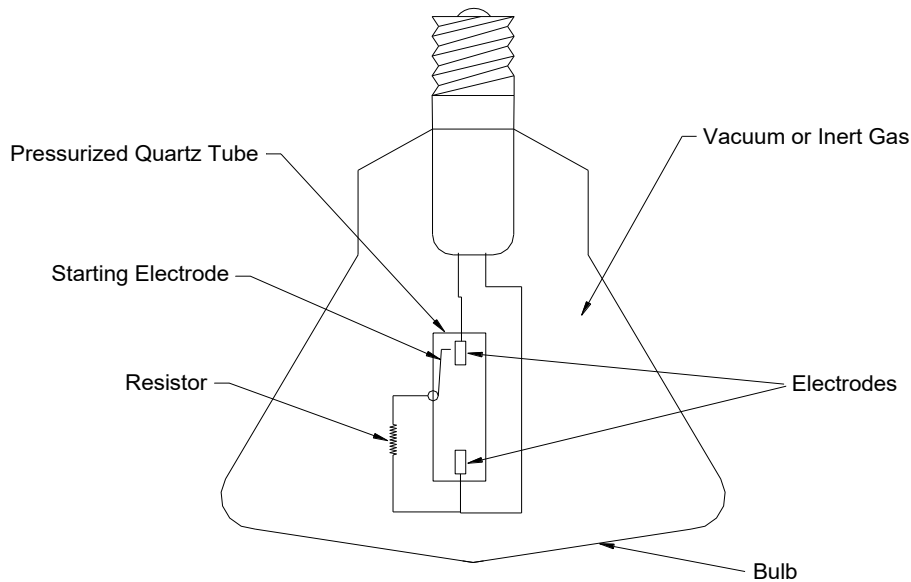
The most frequently used size is the 100 watt bulb which is mounted in a variety of fixtures or housings and are fairly portable. The bulbs are purchased from a lamp manufacturer and the fixtures or holders are provided by the penetrant supplier. Shown below is one supplier's black light source. All of the other suppliers have sources that are similar in configuration.



Black light source

Generation of Black Light

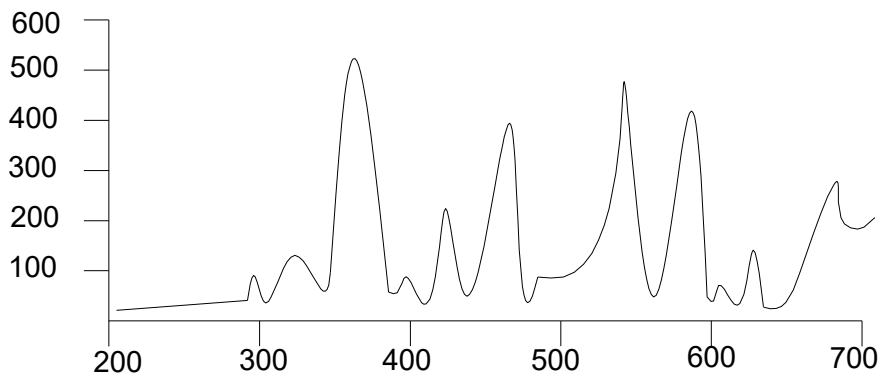
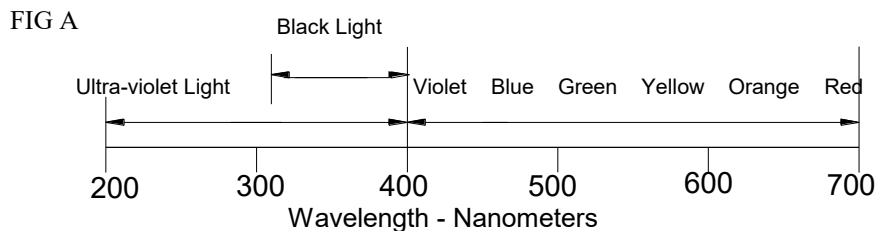
A cross-section of a typical mercury vapour arc discharge bulb is shown below. The high-pressure component is a quartz tube containing some mercury plus a small amount of neon gas. When the lamp is first turned on, the mercury is condensed as a liquid and an arc between the electrodes cannot be generated. This is the reason for the neon gas. A small amount of current, limited by the resistor, causes a discharge from the starting electrode through the neon gas. This glow is sufficient to vaporize the mercury which then allows the arc to pass between the main electrodes. This starting procedure requires from 5 to 15 minutes to fully vaporize the mercury and produce full output of black light. Black lights must be energized for 15 minutes before inspection is performed.



Cross Section of a Typical High Pressured, Mercury Vapour Arc Bulb

Black Light Filters:

Caution: Black light bulbs must not be operated without filters. Cracked, chipped or ill-fitting filters must be replaced before using the lamp as UV (B) and UV (C) together with white light is produced (see figure A below). High intensity "super" black lights that use bulbs with integral filters must have a splash guard attached to the front of the lamp housing to prevent accidental implosion of the bulb.



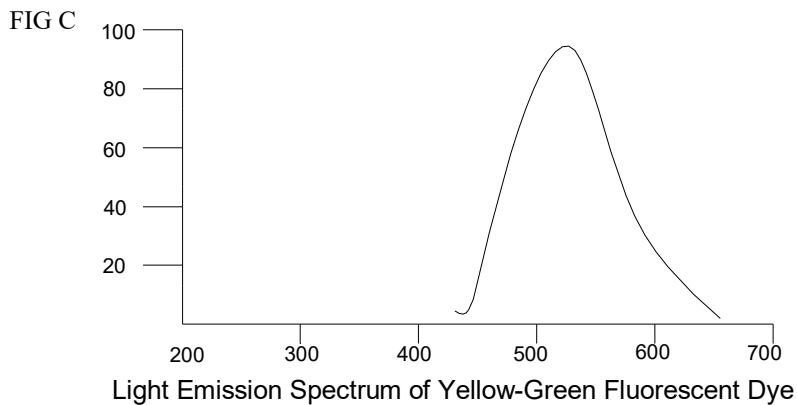
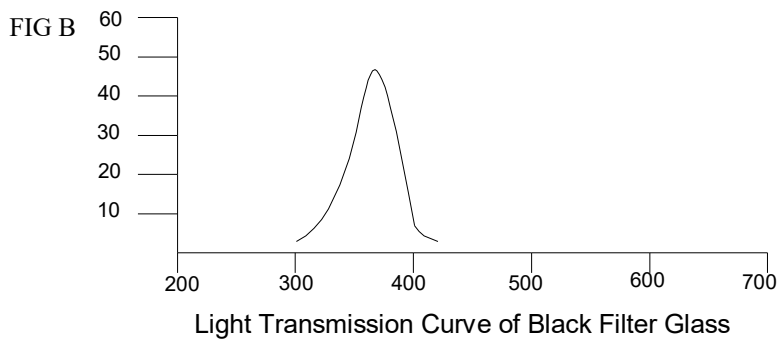
Spectrum of the Output of the High Pressure Mercury Arc

A high pressure, mercury vapour, black light bulb requires a housing, filter, regulating ballast or transformer and connecting cables or wires. The housing which may be metal or plastic, serves several functions:

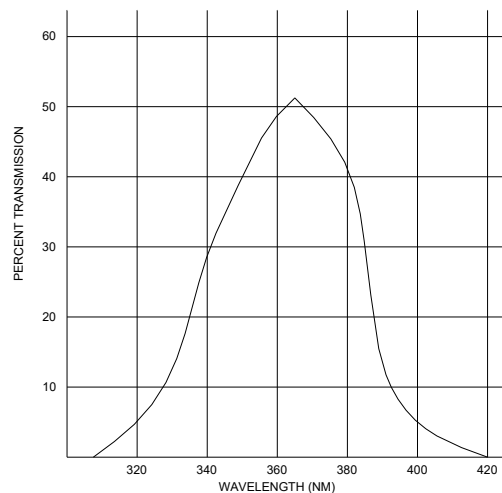


- Hold and protect the bulb.
- Hold and support the filter.
- Prevent leakage of unwanted visible light.
- Permit directing the beam on the surface to be inspected.
- Provide a means for handling the bulb.

The filter is a special cobalt glass that filters short wavelength ultraviolet and long wave-length visible light. The filter transmits ultraviolet between 320 nm and 400 nm as shown in figure B on next page. This energy wavelength causes maximum fluorescence of the penetrant dyes (figure C). Black lights used for penetrant inspection must have a peak wavelength between 340 and 380 nm. A current regulating ballast or transformer is required for proper functioning of the bulb.



The figure below shows the transmission characteristics of the filter glass. Filters for penetrant inspection can be either a smooth or fluted surface. The fluted surface provides a slightly larger focused spot than a smooth surface filter.





Black Light Intensity Requirements

Inspection of a part for fluorescent penetrant indications must always be done under the lowest possible level of ambient light. This increases the contrast between the light emitted from the indication and the background, hence the sensitivity of the inspection. At the same time, the black light intensity must be as high as possible since the brightness of the indication is directly proportional to the quantity of black light exciting it.

The adequacy of a black light source for fluorescent penetrant inspection is determined by measuring the intensity of the black light under working conditions on the test surface. In accordance with EN ISO 3059, this intensity must be at least $1000 \mu\text{W}/\text{cm}^2$ and sources providing less than this intensity must not be utilized.

The actual intensity needed at the surface of the part will vary depending upon the ambient light conditions and size of the suspected indication.

Ambient Light Restriction:

The ambient light levels within the inspection station of the fluorescent penetrant inspection unit must not exceed 20 lux. This includes any white light emitted from the black light source. When performing portable fluorescent penetrant inspection, a dark canvas or photographer's black cloth should be used to darken the inspection area of interest to the lowest possible ambient light level during the inspection.

Visible Light Intensity Measurement

The measurement of visible light is easily accomplished by using selenium cell photometers or light meters. The selenium cell is photosensitive and responds to electromagnetic energy with wavelengths of approximately 380-750 nm.

The units of measurements are lux. The commonly used conversion factor is 10 lux equals 1 foot candle. 1 lux is one candle at 1 metre; the foot candle being one candle at one foot.

Ultraviolet Light Intensity Measurement

Ultraviolet is electromagnetic energy and must be measured in units of energy, hence the watts per square meter or microwatts per square centimeter, where $1 \text{ w}/\text{m}^2$ equals $100 \mu \text{ w}/\text{cm}^2$. For measurement purposes, the ultraviolet spectrum is divided into three bands:

- UV C is very short wavelength, and ranges from about 4-180 nm
- UV B is the medium band, and ranges from 180-320 nm
- UV A called long wave, ranging from 320-400 nm.

Care must be exercised to assure the instrument is designed for the black light or 365 nm band. Meters are filtered to respond to 365 nm and come with a multiplier screen to extend the scale.

Application:

There are a few precautions to be observed in using black light intensity measuring instruments. Some instruments have selectable ranges and the proper range for the intensity being measured must be used. The range selector may be changed while under the black light. The sensing element should be at the location and orientation



of the part surface to be inspected. Some instruments have detachable sensors which may be placed directly on the part surface. White light does not affect the readings of the instruments.

Black Light Intensity Variables

The black light intensity may be affected by the following variables:

- Manufacturing Variations
- Service and Aging Variations
- Line Voltage Variations

Manufacturing Variations:

Black light bulbs are manufactured for other purposes than non-destructive testing, which uses only a small portion of the production. The primary users do not require a specific output or consistency between bulbs. Consequently, new bulbs can vary by as much as 50% in their initial output. This means that with two new bulbs, one may have an intensity that is double that of the other without either being defective.

New black light bulbs must be tested for output before being used. Intensity of new bulbs should be at least $1000/ \mu W/ cm^2$ at a working distance.

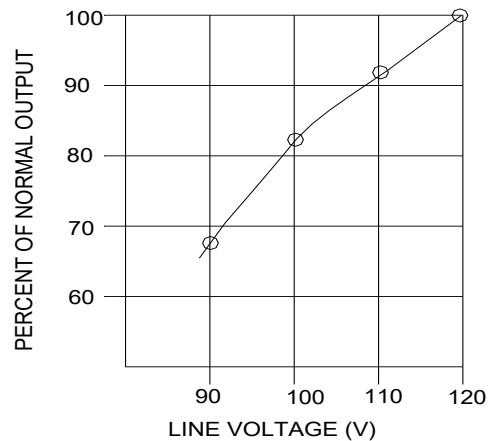
Service and Aging Variations:

During use, dust and dirt will collect on both the bulb face and filter. Even small amounts will reduce the intensity and if allowed to build up, can result in a 10-fold decrease. The bulb face and filter must be kept clean.

The output of black light bulbs will vary due to changes in operating characteristics. As the bulb ages, the intensity will gradually decrease. Operating hours will decrease output, but of greater significance is the number of bulbs starts. A single start can equate to 2 or 3 hours of continuous use on operating life. Black lights that will be used periodically during the day should be allowed to remain on until their last use of the day. This practice will extend the useful bulb life.

Line Voltage Variations:

Black light intensity varies almost linearly with line voltage. A common misconception is that the black light ballast or transformer will regulate line variations. This is not true, as shown in as shown in the next figure comparing black light output with line voltage variation. With low voltage, the lamps will not sustain the mercury arc and the lamp will extinguish. It will not restart until it has cooled. Black light lamps should be connected to stable power sources. If none are available and line voltage fluctuates, a constant potential transformer should be used.



Black Light Intensity as a
Function of Line Voltage

Black Light Hazards

Prolonged direct exposure of hands to the filtered black light main beam may be harmful. White cotton glove liners or other suitable glove should be worn when exposing hands to the main beam.

The temperature of some operating black light bulbs reaches 399°C or more during operation. This is above the ignition or flashpoint of fuel vapours. These vapours will burst into flame if they contact the bulb. These black lights must not be operated when flammable vapours are present.

The bulb temperature also heats the external surfaces of the lamp housing. The temperature is not high enough to be visually apparent but is high enough to cause severe burns with even momentary contact of exposed body surfaces. Extreme care must be exercised to prevent contacting the housing with any part of the body.

Black Light Physiological Effects:

Unfiltered ultraviolet radiation can be harmful to the eyes and skin. Black light bulbs must not be operated without filters. Cracked, chipped, or ill-fitting filters should be replaced before using the lamp.

Black light (long wavelength or near ultraviolet) under the proper conditions is not harmful.

Ultraviolet radiation below 320 nm can be hazardous and may cause permanent effects.

While black light does not cause lasting effects, some layers of the eye have a tendency to fluoresce when radiated. This can usually be corrected by positioning the lamp so the radiation is not directed or reflected into the inspector's eye. Yellow tinted glasses will reduce the eye fluorescence.

Sunglasses and glasses with photochromatic lens that darken when exposed to sunlight must not be worn when performing fluorescent penetrant inspection.



Inspection Conditions

Dark Adaptation:

The human eye becomes many times more sensitive to light under dark conditions. This increased sensitivity gradually occurs when the light conditions change from light to dark. Full sensitivity or dark adaptation requires about 20 minutes. A dark adaptation time of 5 minutes is usually sufficient for penetrant inspection with black light.

Cleanliness:

The inspection area, hands and clothing of the inspector must be clean and free of extraneous penetrant materials. Non relevant indications may be formed when parts contact extraneous penetrants. In addition, the fluorescence from the penetrant will raise the ambient light level, thus reducing sensitivity.

Colour Contrast Techniques:

EN ISO 3059 states that when using colour contrast techniques, the illuminance at the inspection test surface shall be 500 lux or greater.

Inspection, Interpretation and Evaluation

- Inspection is the process of detecting an indication.
- Interpretation is the process of determining whether an indication is relevant, non-relevant or false.
- Evaluation involves assessment of a relevant indication to determine: its cause and type; if it is a defect or flaw; and reporting its category, location, and approximate size.

A distinction must be made between relevant and non-relevant indications, discontinuities, and flaws or defects.

- A relevant indication is one resulting from a discontinuity.
- Non relevant indication is not associated with a part's structural condition or a discontinuity.
- A discontinuity is a non-intentional change in a part surface or physical condition such as tooling marks, scratches or gouges, cracks, seams, laps, and porosity.

Non relevant indications can result from an intentional change in part shape such as threads or small radii or may be caused by improper or careless processing procedures. The concern over non relevant indications is whether they mask or cover a true discontinuity indication.

A discontinuity may or may not affect the serviceability of the part. If the discontinuity reduces or interferes with the serviceability, it is classified as a flaw or defect. It is possible for a part to contain multiple indications.

The indication may be any combination of non-relevant discontinuities not affecting serviceability, and defects requiring further action. Such knowledge is gained only through experience. NDT personnel must be capable of interpreting indications and evaluating discontinuities. They are not normally responsible for disposition decisions on flawed parts, but report the type, location and approximate size of any flaws present. Acceptance, rework or repair, and rejection limits are contained in the repair manuals and are the responsibility of the applicable work center.



Qualification Requirements

The NDT inspector responsible for detecting and interpreting indications must be qualified. The individual must be familiar with the test method; know the potential types of discontinuities peculiar to the material; and be familiar with their effect on the structural integrity of the part.

Successful interpretation of penetrant indications requires recognition and identification of discontinuities from their surface appearance.

Classification of Discontinuities

There are a number of ways of classifying discontinuities, such as: by appearance of the indication; by its cause; by the material in which it occurs; and by its effect on the structural properties of the part.

The method of classification used depends upon the test method, the use of the parts, and the original designer. Many of the NDT application manuals, which are usually prepared by the original equipment manufacturer (OEM), contain several discontinuity classifications in the same manual.

Appearance of Indications:

The appearance of penetrant indications is influenced by the size and shape of the discontinuity, type of penetrant and developer, and the length of developer dwell. These factors hold true for all types and forms of material and apply to both large and small parts.

Continuous Line Indications:

Linear penetrant indications are caused by discontinuities such as cracks, seams, or laps. The width and brightness of the indication depend upon the volume of entrapped penetrant. The indication may be fairly straight or may have some curvature depending on how the discontinuity was formed. Also, the edges may be jagged or smooth, where the discontinuity meets the part surface. In the figure over (A) shows the surface appearance and a cross section through a large reservoir linear discontinuity and (B) is a narrow or tight linear discontinuity.

Intermittent Linear Indications:

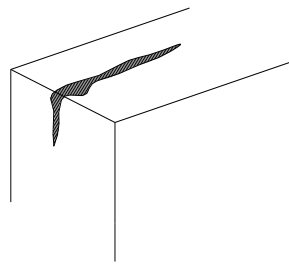
Intermittent linear indications are caused by the same discontinuities that form continuous linear indications. However, either a subsequent process or service use has partially sealed the surface edges. This occurs in forging laps or where the part has been subjected to a mechanical smearing on. A sub surface discontinuity that does not reach the surface for its entire length or a partially filled seam will also produce an intermittent linear indication as shown in figure (C).

Rounded or Dot Indications:

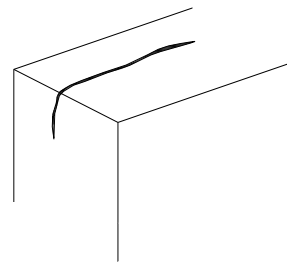
Rounded indications are characterized as having a length and width of approximately equal dimensions and are typical at porosity or relatively large areas of unsoundness in any form of metal. The indications appear rounded because of the volume of penetrant entrapped in the discontinuity; however, the actual surface opening may be irregular in shape. Deep discontinuities such as weld crater cracks may appear as rounded due to the large volume of entrapped penetrant. Figure (D) illustrates the appearance of large and small rounded indications.



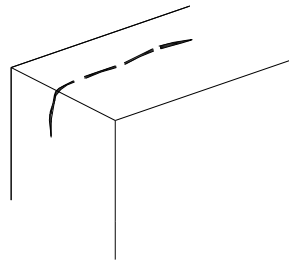
TYPICAL PENETRANT INDICATIONS



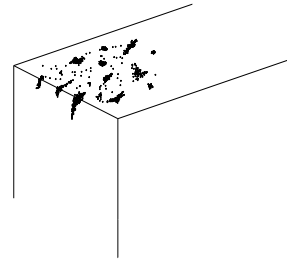
(A) LARGE RESERVOIR DISCONTINUITY



(B) NARROW OR TIGHT DISCONTINUITY



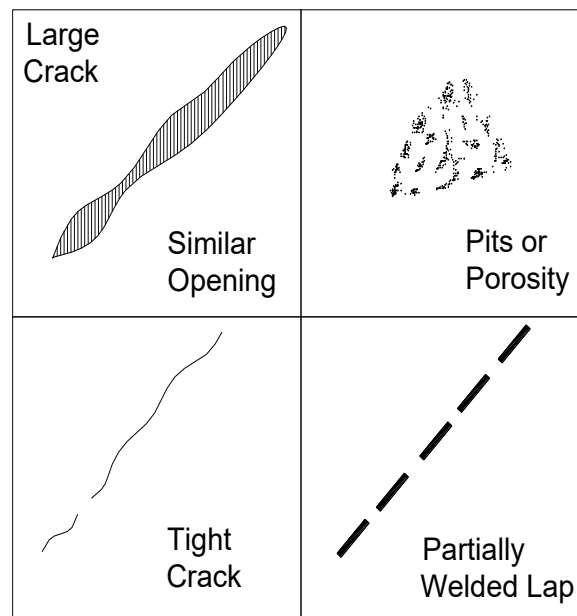
(C) PARTIALLY WELDED LINEAR DISCONTINUITY



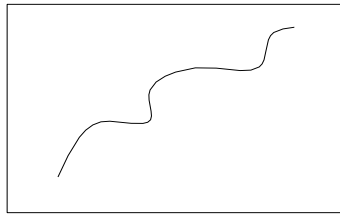
(D) ROUNDED (LARGE & SMALL) DISCONTINUITIES

Manufacturing Discontinuities

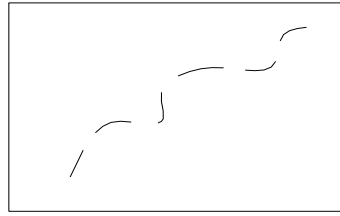
Many discontinuities result from the manufacturing and repair processes. These will probably be detected each time the part is re-inspected so the NDT inspector must be familiar with their appearance and cause in order to make valid interpretations of inspection results. Some of the common types of manufacturing discontinuities are described and illustrated in the following paragraphs.



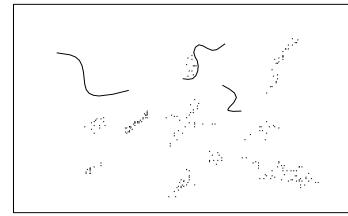
Types of Defect Indications



Continuous Line Indication



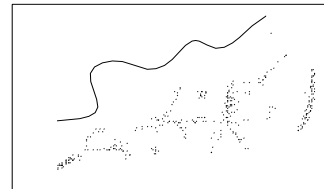
Intermittent or Broken
Line Indication



Small Dots and Rounded
Indications

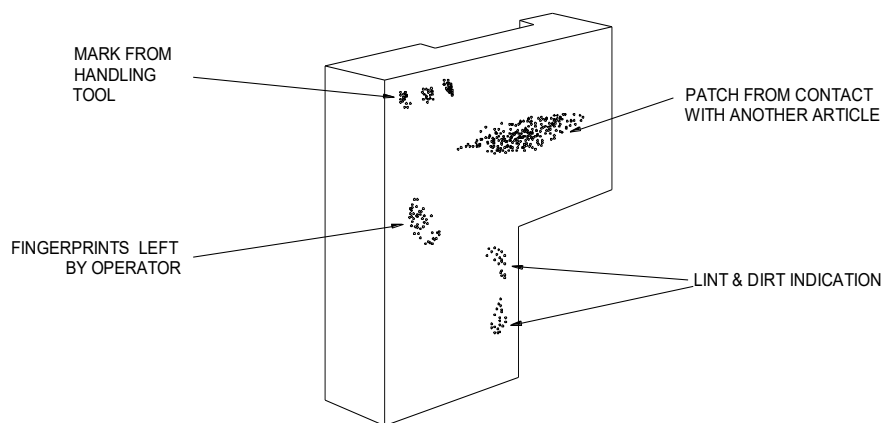
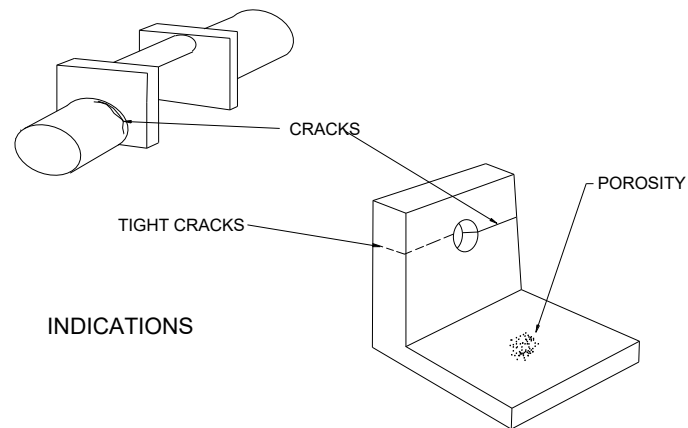


Faint Indications



Gross Indications

Typical True Indications



TYPICAL FALSE INDICATIONS



Porosity:

Porosity is common to all cast parts, particularly aluminium and magnesium. Porosity occurs when gases are entrapped in the molten metal during pouring and solidification and may also occur during welding. It does not always break the surface and internal porosity is not detected by penetrant inspection.

Porosity can be very small and distributed throughout the material in which case it is called microporosity. Microporosity may or may not result in a penetrant indication. When it does, it produces an overall background. The larger pores are called macroporosity.

Inclusions:

Inclusions are particles of foreign material, usually slag, oxides, sulphides or silicates, trapped in the metal during solidification. They are not usually at the part surface but may become exposed by subsequent machining. Since inclusions are solid foreign matter, they will not form penetrant indications unless the foreign material is porous.

Seams:

Seams occur in rolled bar stock or parts machined from bar stock. They are inclusions, porosity, or more commonly, metal folds that have been elongated by the rolling process during fabrication. They are long, straight discontinuities that run parallel to the direction of mechanical working. If the seams contain foreign material, they may produce no, or very faint, indications. They may be classified as defects depending on size and location.

Forging Laps:

Forging laps are formed when a portion of the metal is creased and folded over during the forging operation. They produce a wavy, irregular, linear indication. The indication may be faint or intermittent as the lap breaks the surface at an angle and the edges may be partially welded.

Flash Line Cracking:

Forging flash is the line of excess metal extruded into the space at the junction between the top and bottom dies. Cracking can occur when this excess metal is removed causing linear type indications. The cracking always occurs along and within the trimming marks.

Extrusion tears:

Extrusion involves forcing a metal through a die to produce a desired shape. The process is similar to squeezing tooth paste out of a tube. If the die lip has a nick, burr or lump of oxide, the die can produce tears in the extruded part. Extrusion tears are usually short linear defects perpendicular to the extrusion direction.

Thermal Cracks:

When metals are subjected to a high temperature, localized stresses can occur due to unequal heating or cooling, restricted movement within the part, or unequal cross section. Cracking will occur when the stresses exceed the tensile strength of the material. There are several types of thermal cracking depending upon the heating process.



Grinding Cracks:

Grinding of hardened surfaces frequently introduces surface cracks. These thermal cracks are caused by localized over heating due to insufficient or poor coolant, improper grinding wheel, too rapid feed, or too heavy a cut. The cracks are shallow and sharp at the root, generally occur at right angles to the direction of grinding, and usually but not always, occur in multiples.

Heat Treat Cracks:

Heat treats or quench cracks form from unequal heating or cooling within a part. The cracks are deep, usually forked and seldom form a pattern. These cracks are considered defects.

Weld Cracks:

Welds can contain a number of discontinuities detectable by penetrant. They may be due to lack of penetration, lack of fusion, heating or quenching cracks in the weld bead and heat affected zone and grinding cracks occurring during removal of the weld crown.

Service Induced Discontinuities

The most frequently encountered service discontinuities detected by penetrant inspection are fatigue cracks. Stress corrosion and overload cracking are also common. Overload fractures occur when the stress exceeds the tensile strength of the part. This is greater than the yield point and the fracture is accompanied by some distortion. Cracks caused by overloading are relatively large and are further magnified by the distortion, making them easy to detect visually without penetrant inspection.

Fatigue Cracks:

Fatigue cracks are caused by repeated or cyclic loads that are below the yield strength of the metal. They initiate after many load cycles usually at a surface imperfection such as a pit, scratch, tool mark, or at sharp change in cross section. The initial crack is very small and forms a quarter or half arc around the initiation point and then stops. After an additional number of load cycles, the crack grows slightly.

Fatigue cracks have many common features. They occur in regions of high stress, are perpendicular to the direction of principal stress at their origin and are transgranular. Trans-granular means the cracking progresses through the grains of metal rather than around them. Fatigue cracking occurs on a wide variety of parts and is considered a defect. It will continue to grow in service and the rate of growth increases as it becomes larger.

Stress Corrosion Cracks:

Stress corrosion cracking is caused by a combination of stress and corrosion action. The stress may be either from service loads or a residual stress inherent to the part. The residual stress can cause cracking of a part that has never been in service. Stress corrosion cracks have many of the characteristics of fatigue cracks: They occur in high stress areas; are perpendicular to the stress; and will grow in service.

Penetrant indications of stress corrosion cracks are almost identical to indications of fatigue cracks. It is not usually possible to distinguish between fatigue cracks and stress corrosion cracks from their surface appearance.



Corrosion Detection:

The penetrant inspection method is not used to detect corrosion except for the following:

- Stress corrosion cracking
- Special cases of inter-granular corrosion
- And following corrosion removal by grinding.

Detection of stress corrosion has been described previously. Inter-granular corrosion attacks the metallic grain boundaries and forms a network of very fine cracks. Penetrant indications of inter-granular corrosion appear as a residual background and are resolved only under magnification.

In monitoring corrosion grind out areas, a developer is not used, and following removal of excess surface penetrant, the area is examined using low power magnification.

Evaluation of Indications

Indications can be indistinct and blurred while still being highly visible. The following method may be used to verify and evaluate the type of indication. Carefully wipe the indication area once with a fast drying solvent such as solvent penetrant remover. After the solvent has evaporated, spray a very light layer of solvent developer over the area and watch the indication as it begins and continues to develop. If it does not reappear, wipe again with solvent and examine the bare surface with a 3X to 5X magnifying glass.

Evaluation of penetrant indications with a magnifying glass should be accomplished with the developer removed. Developer will blur and enlarge the indication.

The initial evaluation should be done at low magnification (3X to 5X) with higher magnification (10X) used only after the indication has been located. If no penetrant bleed out or surface imperfection can be seen, the original indication could have been non relevant and due to improper processing.

Photography of Indications

Photography is a good method of producing a permanent record of penetrant indications. Photographs provide a very descriptive record since they show both the indication size and location on the part. They are permanent, reproducible to some extent, and the required equipment is available.

Photographing penetrant indications is slightly different than normal photography and re-quires care, practice and a series of trial-and-error exposures to produce an optimum photograph. It is also very difficult to produce identical photographs when there is a time lapse between exposures. Photographs made at different times will vary due to a number of factors, such as changes in: part position; camera position; black light intensity; location of black light central beam; or changes in film processing or development.



Pre-testing, Cleaning and Pre-cleaning, and Post-cleaning

General

The treatment and condition of parts prior to inspection have a significant influence on the results of the inspection process. Non-destructive inspection personnel must be aware of the pretreatment processes and their effects on the penetrant process. This chapter provides the necessary information.

The paragraphs on cleaning are general in content and contain background information on the need for cleaning, the types of soils or contaminants and their effect on penetrant inspection, and how various cleaning processes remove specific types of soil. The paragraphs cover only fundamental principles. They do not contain enough information to permit selection of a cleaning process or to perform cleaning operations other than pre cleaning, such as vapour degreasing and solvent spray or wipe.

Pre-testing

Purpose of Pre-testing:

Some non-metallic parts, such as plastics, rubbers and acrylic plastics, may react with the oils and solvents contained in penetrant inspection materials, resulting in damage to the part.

The purpose of pre-testing is to ensure that parts to be inspected will not be damaged by penetrant materials. All non-metallic parts that have not been previously inspected, and which do not have approved written cleaning procedures, must be pre-tested.

Pre-testing Procedure:

To determine the corrosive properties of penetrant materials and their compatibility with the materials to be inspected, pre-testing should be performed in accordance with EN 3452-2:2000. This requires that all penetrant materials intended for use on metallic components the test shall be carried out on bare 7075-T6 aluminium, or equivalent, AZ-31B magnesium alloy, or equivalent, and 30CrMo4 steel, or equivalent. After the test there shall be no evidence of staining, pitting or any other corrosion when inspected under x10 magnification.

Cleaning

Responsibility for Cleaning:

Properly performing surface treatment operations such as paint stripping and cleaning of aircraft and engine metals and alloys requires skill and knowledge. Improper methods, materials or procedures can result in severe damage to surfaces and parts. Non-destructive inspection personnel are neither trained nor experienced in performing paint stripping or cleaning.

Need for Clean Surfaces:

The proper preparation of parts prior to inspection is critical. Successful detection of discontinuities by penetrant inspection depends upon the ability of the penetrant to enter and exit from the discontinuity and the resulting indication must be readily



distinguishable from the background. Surface conditions, such as coatings or soil contamination, can reduce the effectiveness of the inspection by interfering with the entry and exit process or producing a high residual background. Penetrant inspection is reliable only when the parts to be inspected are free of contaminants. Foreign material, either on the surface or within the discontinuity can produce erroneous results. Any interfering conditions must be removed by proper cleaning or surface treatment prior to penetrant application.

Factors in Selecting a Cleaning Process:

Improper cleaning methods can cause severe damage or degradation of parts. Selection and application of cleaning processes must be accomplished by qualified personnel.

The selection of a suitable cleaning process is complex and depends on a number of factors, such as:

- Type of soil(s) or contaminant(s) to be removed, since no one cleaning method is equally effective on all contaminants.
- Part material: some nonferrous metals, such as aluminium and magnesium, present problems because strong alkaline or acid cleaners attack the metals; steels, especially in the heat treated condition, are likely to become embrittled by acid cleaners; other metals, such as titanium and high nickel alloys can be attacked by cleaning compounds containing halogen and sulphur compounds,
- Part surface condition: rough surfaces tend to hold the soil, making it harder to remove.
- Part surface accessibility and geometry: complex shapes make it difficult to contact all the surfaces and soils lodged in restricted areas may escape the effects of cleaning.
- Required degree of cleanliness: determined by the surface treatment that will follow or what service conditions will be encountered by the cleaned part.
- Availability and adequacy of cleaning facilities: for example, a large part cannot be placed in a small alkaline or ultrasonic cleaning tank.

Types of Contaminants

Preservative, forming, machining or lubricating oils:

Most oils fluoresce under ultraviolet radiation. This fluorescence can obscure fluorescent liquid penetrant indications or produce false indications. Oily surfaces also tend to impair the action of the liquid penetrant. Oils can be removed by: vapour degreasing, hot tank alkaline cleaning, steam cleaning, solvent emulsion cleaning, water emulsion cleaning, solvent washing

Carbon, varnish or other tightly held soils:

Surface soils tend to adsorb or absorb penetrant, resulting in background colour or fluorescence. These contaminants may also obstruct penetration into discontinuities, impede wetting action or bridge discontinuities. These soils can be removed by: solvent type carbon remover, alkaline type remover, wire brushing, vapour or sand blasting. The removal process can be assisted by using ultrasonic cleaning.

Scale, rust, oxides and corrosion:

These contaminants also tend to adsorb or absorb penetrant, resulting in background colour or fluorescence. They may also obstruct penetration into discontinuities,



impede wetting action or bridge discontinuities. Rust, corrosion etc. can be removed by: alkaline or acid type removal procedures, wire brushing, vapour or sand blasting, electrocleaning

Paint coatings:

Paint coatings impede wetting and may also obscure or bridge surface discontinuity openings. Coating can be removed by: solvent type or alkaline type paint removers, abrasive removal procedures.

Water:

Water impedes wetting and penetration. Remove water by: air drying, force drying with dry air, oven dry at elevated temperature.

Acids and Alkalines:

Acids and alkalines impede wetting and penetration. They may also react with penetrant to decompose or degrade dyes or other constituents. Acids and alkalines are removed by: rinsing with fresh water, or using a neutralizing rinse, freshwater rinse and dry.

Surface roughness:

This reduces ease of rinsing and increases difficulty of hand wiping. Surface roughness can be treated by abrasive polishing or electropolishing.

Smear metal:

Smear metal is the resultant of performing operations of surface abrasion. These operations include: wire brushing, vapour or sand blasting, and other such abrasive removal procedures. These mechanical processes thatpeen or smear surface material may act to close opening into discontinuities so that liquid penetrant indications cannot form.

Such abrasive cleaning techniques are often prohibited or require a subsequent acid etch to reopen the discontinuity to the part surface so that penetrant can enter.

Effects of Previous Inspection Residues:

If the post inspection cleaning is inadequate, the residues must be considered as contaminants during a subsequent re-inspection:

- Developer residues on the part surface will retain penetrant causing a high residual background which can obscure valid indications.
- Developer residues also absorb and retain moisture (hygroscopic).
- Penetrant residues, if not removed from discontinuities, will dry, forming a varnish like material in the flaw. This entrapped residue may not fluoresce and will reduce or prohibit entry of additional penetrant.
- The red dye in visible dye penetrant acts as a filter to black light radiation. When red dye residues mix with fluorescent penetrant in a discontinuity, the fluorescent brightness can be reduced or destroyed.

Cleaning Processes

The success of any penetrant inspection procedure depends upon the part surface and discontinuities being free of any contaminants or soils that might interfere with the penetrant process. There is a variety of cleaning methods that may be utilised.



The methods are generic and are used principally for corrosion prevention and preparation of items for surface treatments. There are no special methods used exclusively to prepare parts for penetrant inspection. Some of the cleaning methods are discussed in the following paragraphs.

Paint Removal:

There is a large variety of paint coatings and finish systems in use on parts and surfaces. Some conventional coatings are readily removed using standard methods. However, advances in paint technology have resulted in finishes that can only be removed with unique materials and techniques.

Care must be taken to ensure the area to be inspected is free of paint and remover residues as they interfere with the penetrant inspection process.

Solvent Cleaning:

This type of process removes such soils as oils and greases, waxes, sealants, paints and general organic matter by dissolving them. The resulting solution may leave a thin film or residue of an oily nature. This oily film must be removed with fresh solvent, vapour degreasing, alkaline or detergent cleaning prior to penetrant inspection. Solvent cleaning may be accomplished by tank immersion but is more often applied by spraying or hand wiping when alkaline, detergent or vapour degreasing is impractical.

Solvent Cleaning with Aerosol Spray Cans:

Portable penetrant kits contain aerosol spray cans of penetrant, developer and cleaner/remover. The cleaner/ remover is used in three ways:

- it serves as a cleaner before penetrant application;
- it removes the last of the excess penetrant after completion of the penetrant dwell,
- and serves as a post cleaner to remove entrapped penetrant when the inspection has been completed.

The method of applying spray cleaner/remover as a pre-cleaner is different than when it is used to remove penetrant following penetrant dwell. When used as a pre-cleaner, the solvent may be sprayed directly on the test surface. Spraying the solvent directly on the surface is not permitted when removing penetrant. As a pre-cleaner, a liberal amount of solvent should be applied and the excess solvent and contaminants wiped from the test surface with a dry, lint free cloth or paper towels. The spray and wiping operation should be repeated until a clean surface is obtained. Following the application of spray solvent, a dwell period must be allowed to permit evaporation of any residual solvent before applying penetrant.

Aerosol Can Hazards:

The hazards in the use of aerosol cans are annotated in the Manufacturers Safety Data Sheets.

Vapour Degreasing:

Vapour degreasing is the preferred method of removing oily and grease type soils from part surfaces and discontinuities. It provides a strong dissolving action plus a



mild mechanical action as the vapours condense and drain from the part surface. After the inspection, it is an excellent method of removing penetrant residues following developer removal.

Ultrasonic Cleaning:

This method adds ultrasonic agitation to solvent or detergent cleaning. Agitation increases the action of the cleaning solution and decreases cleaning time. It is particularly effective in removing contaminants trapped in discontinuities. However, its effectiveness is dependent upon the cleaning medium.

Alkaline Cleaning:

It is important to remember that some alkaline cleaning compounds will attack aluminium parts and components. Care must be used in selecting the proper cleaning process for the materials to be cleaned.

Steam Cleaning:

Steam cleaning is a form of alkaline or detergent cleaning.

Detergent Cleaning:

Detergent cleaners are water base chemicals called surfactants, which surround and attach themselves to particles of surface soil.

The particles of soil and detergent are then washed away by solution agitation, pressure spray, or hand wiping.

Emulsion Cleaning:

Emulsion cleaners employ a two-phase medium, composed of an organic solvent and a detergent in a water-based solution. The organic solvent may be a petroleum base liquid.

The soils are removed through a combination solvent detergent action.

Chemical Cleaning – Salt Bath:

Molten salt baths are used in removing heavy, tightly held scale and oxide from alloy steels, nickel and cobalt base alloys, and some types of stainless steel. It cannot be used on aluminium, magnesium, or titanium alloys.

Chemical Cleaning – Acids:

Solutions of acids or their salts are often used to remove rust, scale, corrosion products, and dry shop soils. The type of acid and its concentration depends on the part material and contaminant to be removed.

Acid cleaning requires very careful control of procedures and solution to prevent damage to the parts.

Chemical Etching:



Chemical removal or etching of deformed or disturbed surface metal is necessary if flaws are to be detected by penetrant inspection. There are a number of mechanical processes that deform the surface of a part.

The deformation is a thin layer, surface metal flow that seals or reduces the opening of any discontinuities. The smeared metal over the surface opening prevents or severely restricts the penetrant entry into any discontinuities.

Chemical etching restores the effectiveness of penetrant inspection by removing the smeared metal.

Removal of Cleaning Process Residues:

Cleaning process residues are removed by rinsing with fresh water. The use of warm water and agitation followed by repeated immersions in fresh water assist in complete removal.

Summary of Cleaning Processes:

The following table provides a summary of chemical cleaning processes that may be used prior to penetrant inspection.

| CHEMICAL CLEANING METHODS | |
|---------------------------|--------------------|
| SOLVENT | NON-SOLVENT |
| Immersion | Alkaline cleaning |
| Spray | Steam cleaning |
| Vapour degreasing | Detergent cleaning |
| Ultrasonic cleaning | Emulsion cleaning |
| | Paint removal |
| | Carbon removal |
| | Salt bath |
| | Acid cleaning |
| | Chemical etching |



Mechanical Working Processes

Mechanical working processes involve displacement or removal of metal on the part surface.

| MECHANICAL WORKING PROCESSES | |
|------------------------------|---------------------|
| METAL REMOVAL | ABRASIVE BLASTING |
| Filing | Sand |
| Sanding | Aluminium Oxide |
| Scraping | Glass bead |
| Milling | Plastic media beads |
| Drilling | Ligno-cellulose |
| Reaming | Shot peening |
| Grinding | Metallic grit |
| Liquid Honing | Organic media |
| Vibration/tumble deburring | |

Effects of Mechanical Working:

Severe mechanical working processes, such as metal removal, shot peening, or grit blasting, can seal or close the surface openings of large discontinuities which prevent the formation of penetrant indications. Penetrant inspection must be accomplished prior to mechanical work processes.

Post-cleaning after Penetrant Inspection

Effects of Inspection Residues on Subsequent Service:

Penetrant inspection residues can have several adverse effects on subsequent processing and service. Developer and penetrant residues, if not removed, have detrimental effects on the application of surface finishes such as painting, plating, and anodizing. Parts that will contact liquid oxygen must be given special attention. Traces of oil can cause an explosion when contacted by liquid oxygen.

Developer residues can interfere with the functioning of the part if they involve a moving or wear surface. In addition, developer materials can absorb and retain moisture (hygroscopic) resulting in corrosion of the part.

Developer Residue Removal:

Developers are the last material applied in the penetrant process and may be one of several forms. The form of developer applied (dry powder, nonaqueous, wet suspended or water soluble) greatly influences the method and difficulties of removal. One point common to most developers is the increase in adherence with time on the part. The longer a developer remains on a part, the more difficult it is to remove. Removal of the developer coating must be done as soon as possible after completing the penetrant inspection. The method of removal depends upon the form of developer.



Removal of Dry powder Developer:

Dry powder developer is the easiest form of developer to remove and can be removed with a plain water wash.

Removal of Nonaqueous Developer:

Nonaqueous developer is removed by initially hand wiping the surface with a dry cloth or paper towel to remove most of the developer. The remaining traces of developer can then be removed with a water moistened rag or paper towel. A water spray may be needed to remove developer from inspected areas having threads, crevices and surface recesses.

Removal of Water-soluble Developer:

Water soluble developer is easy to remove. The developer coating is thin, the particles are not adherent, and the developer readily re dissolves. Water soluble developer should be removed by immersion or spraying with water.

Removal of Water Suspended Developer:

Water suspended developer is the most difficult to remove of all the developer forms. The developer layer is relatively thick and hot air-drying following application tends to bake the coating on the part. The best method of removal is immersion and pressure spraying with a hot detergent solution. It can also be removed with a plain water spray and hand scrubbing with a fibre bristle brush.

Removal of Penetrant Residues:

The amount of residual penetrant is small, consisting of penetrant retained in discontinuities, crevices and part surface irregularities. Some of the developer removal processes, such as detergent or alkaline cleaning, only remove some of this entrapped penetrant. Penetrant residues generally can be removed by vapour degreasing, liquid solvents, detergent or alkaline cleaning.

Protection of Parts following Penetrant Inspection:

The penetrant inspection process and subsequent removal of inspection residues leave the parts with a chemically clean surface. These surfaces, especially ferrous materials, are highly reactive and may corrode from the moisture in air. Parts should receive a corrosion protection treatment as soon as practical, following penetrant inspection.

Mechanism and Properties of Penetrants

General

describes the physical and chemical properties of penetrants and discusses their effects on the inspection process; describes methods and provides instructions on applying penetrants; and presents information and guidance on the penetrant dwell process.

The description of capillary action illustrates the basic principles by which a penetrant enters and exits a small surface opening. In actual practice, the equation in chapter 1 is not used as the forces involved are more complex. The equation is based on an open capillary tube. If one end of the tube is closed, such as occurs in a flaw, the capillary rise is affected by compression of the air trapped in the closed end. In



addition, flaws are not capillary tubes as the sides are not parallel or circular. These factors cause a large difference between the theoretical and actual penetration forces acting on a true crack. This permits penetrant to enter a flaw even in an inverted position such as on a lower wing surface. The points to be remembered about the equation are:

- Good wetting ability, achieved by a high surface tension and small contact angle, in a penetrant is desirable.
- Capillary force increases with smaller flaws.
- Viscosity is not a factor in penetrating ability.

Requirements of a Penetrant

Surface tension and wetting action are only two requirements of a penetrant. Formulation, selection and application of penetrant materials require consideration of many physical and chemical properties. Some of these properties, other than surface tension and wetting ability, are discussed in the following paragraphs. The four primary requirements are:

- It must be capable of entering and filling surface openings even though they may be very small.
- It must resist removal and remain in the discontinuity during removal of the excess penetrant material on the surface of the part.
- It must exit from the discontinuity after the surface penetrant has been removed.
- It must present a readily visible or noticeable indication of the discontinuity.

The primary requirements listed do not include the factors of being economical, safe and practical to use. The primary requirements combined with the additional factors complicate the formulation of a penetrant material. They are controlled by a number of physical and chemical properties, many of which are conflicting. As a result, commercial penetrants are a complex mixture of chemicals which are formulated for specific performance characteristics. Unfortunately, there is no simple rule for formulating a penetrant material, nor is there a set of characteristics which, if provided, will ensure a final material that is completely satisfactory for all applications.

Penetrant Physical Properties

Viscosity:

Viscosity is a measure of a liquid's resistance to a change in physical shape and is related to internal friction. Viscosity varies with temperature, decreasing as the temperature is raised and increasing with lower temperatures. Viscosity has no effect on penetrating ability. However, from an application viewpoint, viscosity affects the speed with which a penetrant enters a discontinuity.

Viscosity also determines how much penetrant will remain on a part surface during the dwell period. High viscosity penetrants cling to the surface requiring increased effort for removal and result in high drag out losses. Very thin penetrants (low viscosity) may drain from the part surface so quickly that insufficient penetrant remains to permit entry into discontinuities.



Specific Gravity:

Specific gravity has no direct effect on the performance of a penetrant. Most commercial penetrants have a specific gravity of less than one.

Flash Point:

Flash point is the temperature at which sufficient flammable vapour is given off the liquid to form an explosive mixture in air over the liquid. The flash point does not affect the performance of a penetrant. High flash points are desirable to reduce the hazard of fire.

Volatility:

Volatility is characterized by the vapour pressure or boiling point of a liquid. It is associated with the evaporation rate of liquids and in penetrant materials and it is desirable to have a material with a low volatility, i.e., a high boiling point. However, in the case of petroleum products, viscosity increases as the boiling point goes up. For penetrants a lower viscosity is preferred as they require less penetrating time.

In addition, a highly volatile material will dry on the part during the penetrant dwell, leaving a film which is difficult to remove. Entrapped penetrant would also have a tendency to dry or lose its liquid properties, thus resulting in failure to indicate discontinuities.

Thermal Stability:

The dyes used in fluorescent and colour contrast penetrant lose their brightness or colour when subjected to elevated temperature. Heat stability is an important consideration during hot air drying before or after developer application.

Storage Temperature Stability:

Storage temperature stability is a penetrant's ability to resist physical and chemical changes at operating and storage temperatures.

Penetrant Chemical Properties

Chemical Inertness:

Penetrant materials should not react with the materials to be inspected. It is necessary that the penetrant, emulsifier and developer material be chemically inert relative to the parts being inspected.

Chemical reactivity of penetrant materials must be considered whenever a new application is encountered. Some rubber (natural and synthetic) and plastic (transparent and opaque) parts are susceptible to attack by the solvents and oils in the penetrant materials. Some metals can be degraded by the trace amounts of sulphur or chlorine in conventional penetrants.

Toxicity:

Toxicity is the measure of adverse effects on humans resulting from contact with the material. It is essential that penetrant materials be nontoxic. In qualifying penetrant, the manufacturer must submit a certified statement identifying each ingredient in the product by a recognizable chemical or trade name. This information is evaluated for toxicity by Environmental Health Laboratories before listing the material.

Solvent Ability:



The visibility of indications depends upon the fluorescent or visible dye dissolved in the penetrant oils. The oils used in penetrants must have good solvent properties to dissolve and hold the dye in solution.

Removability:

This term describes two conflicting requirements for a penetrant: the ease of removing the surface penetrant leaving little or no residual background; and not removing penetrant entrapped in shallow discontinuities.

To meet the first requirement, the penetrant must maintain the dyes in solution even when in the form of a thin film on the surface of a part and without its more volatile components that have been lost during the dwell time. This requirement is more difficult for water washable penetrants than post emulsifiable penetrants because the water washable penetrant does not receive the additional solvent or surfactant during the removal process.

The second requirement is met by the penetrant resisting the removal process. For water washable penetrants and post emulsified penetrants used with a lipophilic emulsifier, this is accomplished by the formation of a gel with the penetrant/water mixture during washing that protects the penetrant in discontinuities from removal. For post emulsifiable penetrants used with a hydrophilic emulsifier, this is done by the lack of diffusion of the surfactant into the surface penetrant layer, this making only the thin layer emulsifiable and not the penetrant in discontinuities beneath the layer. For solvent removable penetrants this can only be done by controlling the amount of solvent used during the removal process.

Water Tolerance:

When penetrants are used in open tanks, it is inevitable that some water contamination will occur. Water is the most common contaminant of penetrants. Post emulsified penetrants are inherently tolerant to water intrusion as any extraneous water will settle to the bottom of the tank. However, water washable penetrants contain emulsifiers and will combine with water. It is important that they tolerate the addition of some water without losing their properties.

Mechanism of Fluorescence:

The mechanism of fluorescence involves two factors: the atomic structure of the fluorescent material and the energy level or wavelength of the radiation source. When a photon of electromagnetic radiation from an X ray, ultraviolet or black light impacts an electron in an atom of fluorescent material, some of the photon energy is transferred to the electron which displaces it from its natural energy level. This is an abnormal condition, and the displaced electron quickly returns to its natural energy level. In returning to equilibrium, the electron releases the excess energy as electromagnetic radiation. The released electromagnetic energy always has a longer wavelength than the exciting radiation. The released energy in fluorescent materials has a wavelength of 400 to 700 nm which is visible (yellow) light.

Brightness:

One of the more important factors responsible for the effectiveness of the penetrant process is the visibility of the indication. Penetrants containing fluorescent dyes are not especially visible under white light. However, when subjected to near ultraviolet (365 nm) radiation or black light, the dyes emit visible or white light. Some dyes emit more visible light per unit of black light energy than others. In addition, the amount of light given off is proportional to the amount of dye in the penetrant. Summarizing,



brightness is the amount of visible light given off when fluorescent dye is exposed to black light. It is controlled by the particular dye's efficiency in converting black light into visible light and by the quantity of dye dissolved in the penetrant.

Ultraviolet Stability:

Fluorescent dyes lose their ability to fluoresce after prolonged exposure to black light. Resistance to this loss is termed ultraviolet stability. For this reason, tanks should always be covered when not in use to minimise ultraviolet light even from daylight.

Penetrant Sensitivity:

The term "sensitivity" when used to describe a penetrant performance characteristic, is the ability to produce indications from very small, tight cracks. This ability involves both penetrating ability and brightness. The flaw opening is usually restricted and the void volume is such that only a very small amount of penetrant can be entrapped. The penetrant must enter and exit the flaw with enough dye to produce a noticeable indication.

The test for sensitivity depends upon visual comparison of the indications produced by a penetrant system (penetrant and emulsifier, penetrant and remover) versus the indications produced by a penetrant system designated as a standard. The test panels for penetrants of Sensitivity Level 1 Low, are thermally cracked aluminium blocks. The test panels for the rest of the sensitivity levels are a series of titanium and nickel alloy panels containing various sizes of laboratory generated fatigue cracks. There is only one set of qualification test panels and it is not presently possible to duplicate fatigue cracks with identical penetrant performance characteristics. Therefore, non-qualification comparison tests are often accomplished with cracked chrome plated panels.

Selection of the sensitivity level to be used depends on a number of factors:

- potential flaw size
- width of opening and volume
- part size
- shape
- surface finish and residual stress
- intended service of the part.

The rule is to use the lowest sensitivity that will reveal the flaws. Difficulties can be experienced if the sensitivity level is either too low or too high. Low sensitivity levels may not reveal the potential flaws while excessive sensitivity can result in a residual background that would obscure any discontinuity indications.

Application of Penetrant

Penetrant can be applied by any of several methods:

- Immersion or dipping
- Spraying
- Brushing
- Swabbing
- Flowing

The method to be used depends on several factors, including size, shape and configuration of part or area to be inspected, accessibility of the area to be inspected,



and availability of inspection equipment. All methods of application are acceptable provided the surface or area to be inspected is completely coated with penetrant. However, there are certain conditions that must be met for each method.

Immersion:

Immersing or dipping is the preferred method of applying penetrant when the entire surface of a part must be inspected. The method is limited by the size of the tank or penetrant container. Parts can be immersed one at a time or, if small, can be batch processed by placing them in a basket or rack. When batch processing parts in a basket, they must be separated from each other during the immersion and dwell period. Contact between parts interferes with the formation of a smooth, even coating of penetrant.

Certain part conditions require special attention during application of penetrant by immersion. Parts containing concave surfaces can trap an air bubble or pocket when immersed. Air bubbles or pockets will prevent the penetrant from contacting the part surface. Complex shaped parts should be inverted or turned over while immersed to dislodge any entrapped air.

Precautions must also be taken when immersing parts with air cooling or oil passages and blind holes. During immersion, the passages and holes will fill with penetrant which will bleed out during development and obscure any discontinuities in the area. In addition, it is difficult or impossible to completely remove penetrant from passages and blind holes following inspection. Oil or air-cooling passages and blind holes should be plugged or stopped off with corks, rubber stoppers or wax plugs prior to immersion in penetrant. These devices must be removed immediately after the inspection process.

Spraying:

Penetrant may be applied by any of several hand or automated spray methods. Spray application is especially suitable for parts too large to be immersed; automated systems; on aircraft inspections (portable); and when only a portion or local area of a large part or component requires inspection. In applying penetrant by the spray method, the requirement is to apply a thin layer that completely covers the area to be inspected. Spraying has several advantages over the immersion method: it is usually more economical since less penetrant is applied, pooling of penetrant in part cavities is reduced and it reduces contamination as the penetrant is pumped from containers and is not usually recovered.

Air or Pressure Spray:

Penetrants can be applied from most types of spray equipment liquid pressure only, air aspiration only, or a combination. The equipment used is similar to that used in spraying paint. The air applied to the gun converts the stream of penetrant into a spray. The air pressure controls the size of the spray droplets. Too low a pressure produces nearly a solid stream of penetrant. Too high a pressure can atomize the penetrant into a fine fog with poor covering ability and which drifts away from the part.

Electrostatic Spray:

The equipment required for electrostatic spraying is similar to that used in air spraying. In addition, a high voltage power supply is connected to the gun. This puts a positive electrical charge on the penetrant particles as they leave the gun. The part is electrically grounded and attracts the charged penetrant particles. The attraction



is strong enough to pull the particles to surfaces not in front of or perpendicular to the spray. This ability makes electrostatic spray a preferred method for automated lines where complex shaped parts are to be coated. However, throw or coverage inside cavities is limited.

An advantage of the electrostatic spray method is the large savings resulting from reduced material requirements. Electrostatic spraying deposits a thinner layer of penetrant on the part than air spraying and greatly reduces penetrant loss due to overspray.

Aerosol Spray:

Penetrant packaged in aerosol containers provides a convenient method of application when portability is required. Packaging in sealed containers also eliminates contamination and evaporation of penetrant. Another advantage is that special exhaust equipment, such as used in pressure spray booths, is not normally required as the amount of penetrant involved is small.

There are disadvantages:

- Material cost is increased by the special packaging.
- Not used on large areas due to small spray pattern and high material cost.
- Overspray coats adjacent surfaces and complicates penetrant removal.
- Cans lose propellant and remaining penetrant must be discarded.

Aerosol Spray Application:

Penetrants, unlike non-aqueous developers, do not settle out of solution. Therefore, a mixing ball in the container is not essential. However, some manufacturers buy only a single type of aerosol can which is then used to package penetrant, solvent remover, or nonaqueous developer. Whether the can does or does not contain a mixing ball, it is good practice to shake the can once or twice before spraying. This ensures an even distribution of penetrant and propellant.

The propellant pressure is directly proportional to the ambient temperature. At temperatures below 15.6°C (60°F), the pressure may be too low for proper spraying. On the high temperature side, the pressure becomes excessive and may burst the container when the temperature reaches 49°C (120°F). When applying penetrant from an aerosol container, the nozzle should be held 75 to 150 mm (3 to 6 inches) from the part surface and the can moved in a line to completely cover the area to be inspected.

A thin, even coating with no breaks or non-wetted areas is necessary. Excessive penetrant is not desirable as it tends to run or drain off the area and complicates removal. Holding the can motionless or moving it too slowly while spraying will result in an excessive layer of penetrant. Short distances between the can nozzle and the part reduce the size of the spray pattern and produce a thick layer of penetrant in the small area. Long distances increase the size of the spray pattern and reduce the penetrant layer thickness. There is also an increase in over-spray and the possibility of non-covered areas.

Brush or Swab Application:

Penetrant can be applied to large parts by brushing, wiping or even pouring from a container. However, one of the most frequent applications of the brush or swab method is to coat a small area of a large structure. Brushing or swabbing provides control over the placement of penetrant on the desired area, improves the ability to



regulate the quantity or thickness of the penetrant layer, and eliminates over-spray. A common field practice, when small containers are not readily available, is to spray a small quantity of penetrant into the cap of the aerosol can and use a cotton bud.

Temperature Limitations

Penetrants may be applied over a range of ambient temperatures. However, certain limits must not be exceeded as the inspection process may be degraded. The operating range for conventional penetrants is 4°C (40°F) to 49°C (120°F). There are special penetrants formulated for hot applications exceeding these limits.

Low Temperature Limitations:

Penetrant inspection must not be performed when the test part temperature is less than 4°C (40°F). There are several reasons for this restriction:

- At 0°C (32°F) or less, any moisture, even from the inspector's breath, will form ice crystals on the part, which will interfere with the penetration process.
- The propellant in aerosol containers is affected by temperature because the gas volume or pressure decreases with lower temperatures.
- The evaporation rate of solvent cleaners and nonaqueous developers is reduced at lower temperatures.
- The viscosity of the penetrant increases as the temperature decreases. When temperatures are below 15.6°C (60°F) and above 4°C (40°F), the penetration dwell time must be increased due to the increased viscosity.

High Temperature Limitations:

Sensitivity is improved slightly when test part temperatures are 49°C (120°F) to 65.5°C (150°F). The higher temperature evaporates some of the liquid which increases the dye concentration and improves the visibility of indications. The elevated temperature also reduces viscosity which speeds penetration. However, the disadvantages of elevated temperatures outweigh the advantages. At temperatures of 49°C (120°F), the volatile components of penetrants are rapidly evaporated.

Modern penetrants are very carefully compounded, and the loss of any constituents can reduce the effectiveness of the process. During penetrant dwell, the layer of penetrant is very thin and with a part temperature of more than 49°C (120°F), the loss of volatile constituents will drastically change the composition. Elevated temperatures also reduce visible dye colour and fluorescence (heat fade), making indications less visible. Penetrant inspection must not be performed on parts whose temperature exceeds 49°C (120°F), unless special high temperature penetrants are used. Part temperature can be estimated by handling, as above 49°C (120°F), parts become too hot to hold.

Penetrant Dwell

Penetrant dwell is the total length of time from the initial application of penetrant until its removal. This includes immersion, soak, and drain times. The purpose of dwell is to allow the penetrant to seep into and fill any surface openings.

Factors Influencing Penetrant Dwell:

There are several interacting factors that influence the length of time required for penetrant to enter and fill a surface void. Some of the factors are:



- Width and depth of the void
- Type and sensitivity of penetrant
- Part material and form
- Type of discontinuity
- Penetrant viscosity
- Cleanliness of the discontinuity

Width and Depth of the Void:

The time required for a penetrant to enter and fill the surface void depends largely on the width of the surface opening and depth of the void. Penetrant enters and fills voids with wide openings more rapidly than those with narrow openings, very narrow or tight flaws, such as those associated with fatigue cracking may require 2 to 5 times the length of time needed for a wider flaw caused by over stressing. The void depth is simply a matter of volume with more time required to fill a deep void.

Type and Sensitivity of Penetrant:

The type and sensitivity level of penetrants affect the length of penetrant dwell. The differences in dwell times are due to the differences in surface tension, contact angle and viscosity of the various penetrant types and sensitivities. While viscosities between manufacturers of the same type and sensitivity level vary, the combination of factors tends to stabilize dwell time for each type and sensitivity. This allows penetrants within each of the sensitivity levels to have equivalent dwell times.

Part Material and Form:

The effect of part material (steel, magnesium, aluminium, etc.) and form (castings, forgings, welds, etc.) on penetrant dwell relates to the width of the surface opening of the discontinuities. For example: cold shuts in steel casting tend to have tighter openings than cold shuts in magnesium castings. Therefore, the penetrating dwell time for cold shuts in steel castings is longer than the dwell time in magnesium and aluminium castings. Discontinuities occurring in forgings are tighter than in castings and require more penetrating time.

Type of Discontinuity:

The various types of discontinuities differ in the width of the opening. Laps are tighter than porosity and fatigue cracks are tighter than either laps or porosity. The length of penetrant dwell increases as the discontinuity width decreases (surface opening becomes tighter or narrower).

Penetrant Viscosity:

Viscosity has been previously defined as a liquid's resistance to changing shape. This resistance controls the flow characteristics of a liquid and is a major factor in the time required to enter and fill a void.

The part temperature range for applying penetrants is 4°C (40°F) to 49°C (120°F). Nearly all operating instructions or procedures specifying dwell times, are based on penetrant application at the 21.1°C (70°F) part temperature. Penetrant dwell times which are normally based on application at room temperature must be adjusted to compensate for viscosity changes at other temperatures. The evaporation rate of penetrant is increased at temperatures above 37.2°C (100°F). Care must be taken to prevent the penetrant from drying.

Cleanliness of the Discontinuity:



Penetrant dwell times are based on clean parts without entrapped contaminants. Inspection of parts that have been in service can be complicated by the difficulty of removing all of the entrapped soil from the discontinuities. The effect of the entrapped soil on the penetrant dwell time depends upon the type and amount of soil involved.

If the discontinuity is full of soil that is not soluble in penetrant, penetration cannot occur. A change in penetrant sensitivity or dwell time will not help since penetrant inspection will not detect such flaws. A discontinuity that is only partially filled with insoluble soil will produce a smaller and less visible indication. Increasing the dwell time will not improve the indication. However, a more sensitive penetrant with its higher dye content will produce a more visible indication.

In summary, when a flaw is partially filled with an insoluble soil, an increase in dwell time will not improve the visibility of the indication. However, if the soil is soluble in the penetrant, the visibility will improve with increases in dwell time. In both cases, insoluble and soluble soil contamination, a higher sensitivity penetrant will improve the results.

Penetrant Dwell Characteristics:

There are two basic penetrant dwell modes:

- Immersion dwell
- Drain dwell

Immersion Dwell:

Where the part remains submerged in a tank of liquid penetrant for the entire dwell period.

Drain dwell:

Preferred where the part is first covered with penetrant by spraying, brushing, or immersion. Once coated, the part is placed on a rack or rest and allowed to drain during the dwell period. Laboratory tests have demonstrated the improved performance of drain dwell mode compared to that of immersion dwell mode.

During the drain dwell period, the lighter weight liquids evaporate which increases the concentration of the dye material entrapped in discontinuities. The increased dye concentration enhances the visibility of the indication. The drain dwell mode is also more economical than immersion dwell mode as the excess penetrant drains from the part and is recovered. The saving with drain dwell is twofold. The drained penetrant is recovered and since the remaining penetrant layer is much thinner than an immersion dwell layer, less emulsifier is required during removal.

Minimum Penetrant Dwell Times:

The number of factors influencing the entry of penetrant into a discontinuity complicates setting uniform minimum penetrant dwell times. Most dwell times are based on past experience with similar parts, materials and potential flaws.

Effects of Under Dwell:

When the dwell time is too short to allow the penetrant to completely fill the discontinuity, the visibility of the resulting indication will be reduced. The amount of



reduction depends upon the amount of penetrant that enters the void, which is a function of void volume and tightness and length of dwell. If the void is very small or if the dwell time is much too short, there will be no indication. If it is suspected that a part has not had an adequate dwell, the part must be completely cleaned and then reprocessed through the entire inspection process.

Effects of Over Dwell:

Once the penetrant has completely filled a void, extending the dwell time will not improve the indication, except for contaminated flaws. However, very tight fatigue cracks, flaws in surfaces under compressive loading, and stress corrosion cracks may require dwell times measured in hours instead of minutes. It is good practice to apply fresh penetrant at 60 minutes intervals when long dwell times are required.

Application of fresh penetrant improves the rate of penetration and makes it easier to remove the excess surface penetrant at the end of the dwell period. The penetrant must not be allowed to evaporate to the tacky or dry state while on the part.

If for some reason the penetrant is allowed to become tacky, the part must be subjected to a complete reprocessing through the pre cleaning and penetrant inspection cycle.

Penetrant Removal

General

This section provides basic, intermediate and advanced information on the theory, methods and procedures used in removing the excess surface penetrant. The first portion of the section contains general information applicable to all removal methods. The second portion is devoted to the water washable penetrant processes and water washing or spray rinsing. The remaining portions cover the theory and procedures used in the lipophilic emulsifier, hydrophilic remover, and solvent removal penetrant processes.

Introduction

After the penetrant has been applied and has filled any open discontinuities, the excess penetrant on the surface must be removed. Removal of the excess surface penetrant is a critical step in the inspection process. Improper removal can lead to misinterpretation and erroneous results. Excessive or over removal will reduce the quantity of penetrant entrapped in a flaw resulting in either a failure to produce an indication or an indication with greatly reduced visibility. Incomplete or under removal produces a residual background which may interfere with the detection of flaw indications.

Factors Influencing Penetrant Removal

- Part surface condition
- Part shape or geometry
- Flaw size and shape
- Type of penetrant

Part Surface Condition:



The surface condition of the part has a direct effect on removability. Smooth, polished surfaces such as chromium plated panels can be easily processed by any of the removal methods with no residual background. As the surfaces become rougher, such as chemically etched or sand blasted, the removal of surface penetrant becomes more difficult. Rough surfaces reduce removability in two ways: the roughness restricts the mechanical force of the spray rinse in the indentations or low points; and, also prevents the emulsifier from evenly combining with the surface penetrant. It is not always possible to produce a background free surface on rough parts. The wash or emulsification time required for a completely clean surface may remove some of the penetrant entrapped in flaws. In this case, the wash or emulsification time must be shortened, leaving some residual background. The amount of residual background must be limited to allow any flaw indications to be visible through the background.

Part Shape or Geometry:

The part shape and geometry affect removability in two ways:

- accessibility of the test surface by the spray rinse;
- and thickness of penetrant layer following the dwell period.

One of the factors involved in removing excess surface penetrant is the mechanical action or force of the spray rinse. When parts contain surfaces where the spray cannot directly strike the surface, such as concave or recessed areas, holes, and screw threads, the removal time is increased in these local areas. Also, the thickness of the penetrant layer in these inaccessible areas is usually greater than that on the adjacent surfaces. This is due to the tendency of the penetrant to drain and collect in these areas.

Care must be exercised to prevent over removal on the accessible, thinner penetrant coated surfaces, while trying to adequately clean the thicker penetrant layer from the inaccessible surface.

Flaw Size and Shape:

Flaw size and shape complicate the removal process. Narrow, deep flaws, while requiring long penetrant dwell times, provide a relatively large reservoir to hold entrapped penetrant. The narrow surface opening reduces both the diffusion rate of emulsifier into the flaw and the mechanical force of the spray rinse on the entrapped penetrant. The result is that narrow, deep flaws produce highly visible indications with a minimum of removal problems.

The removal process becomes slightly more critical when narrow, shallow flaws are present. Narrow, shallow flaws do not have a large reservoir to hold entrapped penetrant. The visibility of an indication depends on the amount of penetrant that exits from the flaw. If the flaw is shallow, only a small amount of penetrant is available, and the indication may be faint. Removal of any entrapped penetrant (over removal) will reduce the visibility of an already faint indication. In addition, a small amount of residual background (under removal) will obscure faint indications.

Broad, shallow flaws are classified as flaws where the surface opening is equal to or greater than the depth. They present the most critical case of penetrant removal. The opening does not reduce the force of the spray rinse nor does it restrict the emulsification rate and entrapped penetrant is easily removed. Extreme care must be used during penetrant removal if broad shallow flaws are likely to be present.

Type of Penetrant:



Penetrant materials vary widely in their ease of removal. There are differences in removability between the various penetrant types, classes, and sensitivity levels. Also, similar penetrants provided by different manufacturers vary in removability. One penetrant characteristic affecting removability is the viscosity. High viscosity (thick) penetrants are more difficult or more slowly removed than low viscosity (thin) penetrants.

The penetrant sensitivity level also affects removability. High sensitivity penetrants contain more dye per volume and trace quantities of residual penetrant will produce a higher background than the same quantity of low sensitivity penetrant. It is necessary to remove more of the residual high sensitivity penetrant to produce an equivalent background.

Methods of Removal

There are four principal methods of penetrant removal. Each method has detailed characteristics affecting the removal and total penetrant process. The following paragraphs provide information on the theory, effects and required application procedures for the four removal methods.

Water Washable Penetrant (EN ISO 3452-1 Method A):

Water washable penetrants must not be used on aerospace systems or aerospace system components except when directed to do so by the appropriate engineering activity or by written and approved inspection procedures.

Water washable penetrants are penetrants that contain an emulsifying agent, and the excess surface penetrant is removed with a water spray following the penetrant dwell period. The water washable penetrant is converted into small suspended oil droplets by the mechanical force of the water spray. High performance water washable penetrants approach the capabilities of post emulsified penetrants and some have been qualified to "High Sensitivity".

Removal Procedure:

Water washable penetrant is removed after penetrant dwell by subjecting the part to a water spray wash. The spray wash may be a handheld nozzle, a semi-automatic system, or a fully automated system. Care must be exercised to prevent over removal as the penetrant entrapped in discontinuities contains an emulsifying agent and is easily removed. Removal is controlled by length of wash time and the wash must be stopped when an acceptable background is reached. Water washing of fluorescent penetrant must be accomplished under black light.

Advantages of Water-Washable Penetrant:

Water washable penetrants offer several advantages. Two of the advantages are:

- The emulsifiable mixture is easily removed from complex shaped parts making it advantageous for use on threads and key-ways.
- The variables associated with controlling emulsifier dwell time are eliminated.

Disadvantages of Water-Washable Penetrant:



The water washable process has a number of disadvantages or limitations. Two of the disadvantages are:

- There is no control over the diffusion or emulsified layer. Penetrant entrapped in flaws contains emulsifying agent making it susceptible to removal by over washing. It is also easily removed from broad, shallow flaws.
- The penetrant emulsifying agent mixture is susceptible to water contamination.

Water Washing or Spray Rinsing

Water washing or spray rinsing is usually accomplished in a stationary rinse tank which is provided with a hose, nozzle, drain and, in the case of fluorescent penetrant, a black light. The rinsing procedures used for removal of water washable penetrant and post emulsified penetrant (after emulsification) are almost identical. The difference is in controlling the rinse time. Rinse times for water washable penetrants are very critical as the entrapped water washable penetrant can be removed from discontinuities if the time is not controlled.

Entrapped post emulsified penetrants that have not been diffused with emulsifier, resist removal and rinse times are not as critical. The conditions and procedures described in the following paragraphs are applicable to both water washable and post emulsifiable penetrants.

Factors Influencing Spray Rinse:

- Size of Water Droplets
- Water Pressure
- Water Temperature
- Spray Angle
- Recommended Procedure

Size of Water Droplets:

Removal of excess surface penetrant depends upon the mechanical force of the water impacting the part surface. The impact force consists of the droplet mass and velocity at impact. The two factors are related and increasing either will produce a higher mechanical force. There are limits on both size and pressure. If the droplet is small or the pressure is too high, the result will be a fog or mist with little removal ability. A solid stream of water is not desirable as it covers only a small area at one time.

Water Pressure:

The effect of water pressure is straightforward. Increased water pressure increases the speed of removal.

Water Temperature:

The temperature of the rinse water may or may not affect the washability. The effect of temperature on washability depends upon the formulation which varies between suppliers.

Spray Angle:



The angle of spray may be varied over a wide range with only slight effects on the removal time. When the angle is close to perpendicular, 80° to 90°, the droplets will rebound into the oncoming water, diverting the fresh droplets which reduces the scrubbing action. The scrubbing action is also reduced when the spray is close to parallel with the part surface, 10° to 20°, as there is little energy transfer at the point of impact. Generally, an angle of 45° to 70° is most effective.

Water nozzles that are capable of producing spray patterns such as solid streams or a fine mist must not be used. Rinsing dye penetrant from surface parts must only be accomplished with a fan shaped, coarse spray.

Recommended Procedure:

Washing is best accomplished with a fan shaped, coarse spray with a temperature range of 15.5°C (60°F) to 37.8°C (100°F) and line pressure water not to exceed 40 psig. The wash time will depend upon the surface roughness of the part. Water washable penetrant can easily be over washed and wash time must be closely controlled. Washing of fluorescent penetrant must be done under a black light in a semi-darkened area and the washing stopped when a low background level is reached. If small defects must be detected in parts with rough surfaces, some residual background may be necessary.

Removal of Post-Emulsified Penetrant

The post-emulsified penetrant is a general term combining the Lipophilic emulsifier and hydrophilic remover processes. Post emulsified penetrants are oil-based vehicles containing highly visible colour or fluorescent dyes. They are formulated to optimize their penetration and visibility capabilities. They differ from water washable penetrant as they resist removal by water washing since they do not contain an emulsifier. A separate process step of emulsification is required for removal.

Lipophilic and Hydrophilic:

The words, "lipophilic" and "hydrophilic", like many other chemical and medical terms, have their basis in Greek work elements: "Lipo" comes from the Greek word for oil or fat. "Hydro" is from the Greek word for water. "Philic" means a fondness or affinity for, borrowed from the Greek word "philos" for loving. Thus, lipophilic is an oil or fat-based material and hydrophilic is a water-based solution. In this chapter, the word "emulsifier" will be used when referring to lipophilic material and the word "remover" will be used when discussing hydrophilic material. This is a practice generally used by industry.

An understanding of the hydrophilic process and the difference in mode of action between lipophilic emulsifiers and hydrophilic removers requires a brief review of each process. Chapter 1 describes both the eleven steps in the lipophilic process, and the eleven steps in the hydrophilic process. However, there is more similarity between the two processes than the number of steps. The pre clean, penetrant, dwell, developer, dry, dwell, inspect and post clean steps are identical for both processes.

The materials, procedures, and equipment used in each of these process steps are the same. Any post emulsifiable penetrant can be used with either the lipophilic or hydrophilic removal methods. Where the two processes differ is in the emulsifier, dwell and rinse steps in the lipophilic method and in the pre rinse, remover, and rinse steps in the hydrophilic methods.

Emulsification:



Certain chemicals have the ability to combine with oily materials to form an easily emulsifiable mixture. This is the case with penetrants and emulsifiers. The penetrant is an oil that repels water and resists removal. However, when combined with an emulsifier, the resulting mixture can be removed with a water spray.

Lipophilic Process (EN ISO 3452-1 Method B)

Application of Emulsifier:

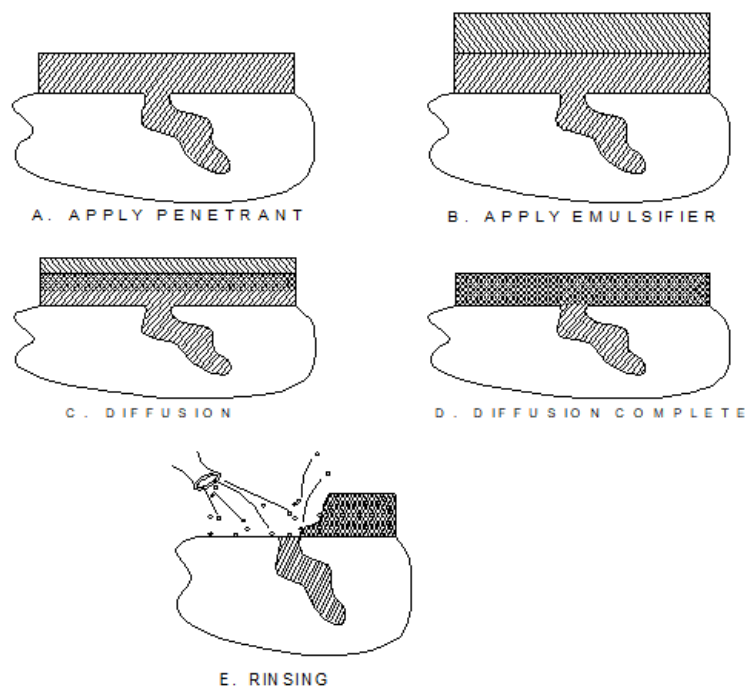
Lipophilic emulsifier is usually applied by dipping or immersing the part in a tank of emulsifier. Parts can be immersed one at a time, or placed in a basket for processing. Application by spraying or flowing the emulsifier is not recommended. The problem with spraying is the difficulty of applying enough emulsifier without the mechanical force of the spray scrubbing the penetrant layer. There are a few automated systems where the emulsifier is applied as a fog. Emulsifier must not be applied by brushing or wiping. Brushing or wiping produces an uncontrolled and uneven mixing action.

Emulsifier Drain:

When the part surface has been coated with emulsifier, the part should be removed from the liquid and allowed to drain. As the emulsifier drains, the movement carries with it considerable surface penetrant. This scrubbing or mechanical action reduces the amount of penetrant to be emulsified and also initiates the chemical or diffusion action. Without this mixing action, emulsifier dwell time might be as long as ten or twenty minutes.

Diffusion:

Diffusion is the intermingling of molecules or other particles as a result of their random thermal motion. After a period of time, the entire quantity of liquid will reach a nearly uniform concentration.



Diffusion of Emulsifier into Penetrant during the Lipophilic Emulsifier Dwell Step

Emulsifier Dwell:



After emulsifier has been applied, a period of time is allowed for diffusion. This is the emulsifier dwell time and is one of the most critical factors in the lipophilic process. It is important to stop the diffusion when the emulsifier has just reached the part surface and before it diffuses into any penetrant entrapped in a discontinuity. If the dwell time is too long, the emulsifier will diffuse into entrapped penetrant which is easily removed resulting in missed flaws. If the time is too short, the thin layer of surface penetrant not emulsified will cause an excessive background which can obscure a discontinuity indication.

Factors Influencing Dwell Time:

There are a number of factors which influence the dwell time and are discussed in the following paragraphs.

- Part Surface
- Flaw Type
- Emulsifier Types
- Effect of Penetrant Dwell Time
- Effect of Penetrant Contamination
- Emulsifier Dwell Time
- Water Rinsing the Emulsified Layer
- Under or Over Emulsification

Part Surface:

Very smooth, polished surfaces retain only a thin layer of penetrant which require, a relatively short emulsifier dwell period. Rough surfaces such as sand castings retain a thicker layer of penetrant, plus the need for the emulsifier to diffuse to the bottom of the indications. Longer emulsifier dwell times are required for rough surfaces.

Flaw Type:

Tight flaws with some depth, relative to flaw width, are more tolerant to longer emulsification dwell time than are wide, shallow flaws. When shallow flaws must be detected in parts with rough surfaces, some under emulsification or residual background may be necessary.

Emulsifier Types:

There are at least two general types of emulsifier. The two general types are similar in composition with the principal difference being viscosity. However, viscosity and diffusion rates are related, and viscous materials diffuse slowly, while thinner, less viscous emulsifiers diffuse more rapidly.

Effect of Penetrant Dwell Time:

Long penetrant dwell times permit more penetrant to drain from the part, resulting in a thinner surface layer. Since diffusion rate is constant, the emulsifier dwell time is proportional to the thickness of the penetrant layer i.e. thicker layers require more emulsification dwell time and thinner layers less time.

Effect of Penetrant Contamination of the Emulsifier:

As parts are processed, the emulsifier becomes contaminated with penetrant from both the initial immersion and the drain cycle. While penetrant and emulsifier are



soluble in all combinations, the gradual increase of penetrant in the emulsifier slows the emulsification action.

Emulsifier Dwell Time:

It should be remembered that when a number of parts are being inspected they must be processed one at a time through the emulsifier, emulsifier dwell and wash steps. Over dwell will occur when emulsifier is applied to a number of parts and they are then individually washed.

Although emulsifier dwell time is critical for most defects, the large number of influencing factors makes it impossible to develop a general dwell timetable. Optimum emulsifier dwell time must be determined on each part by experiment.

Water Rinsing the Emulsified Layer:

When diffusion of the emulsifier has reached the desired end point, further diffusion is stopped by spraying with water. The same water spray is then used to remove the emulsified penetrant surface layer. Post emulsified penetrant entrapped in flaws and not diffused with emulsifier is relatively resistant to water spray and rinse time is not critical. However, excessive spray pressure or hot water can remove entrapped penetrant and must be avoided.

Under or Over Emulsification:

The part must be completely reprocessed if during or after the rinse step, it is suspected that a too short (under emulsification) or too long (over emulsification) dwell time has occurred. Correction of dwell time cannot be made by immersing in penetrant or emulsifier. The part must be cleaned to remove all residual penetrant and reprocessed through the entire process.

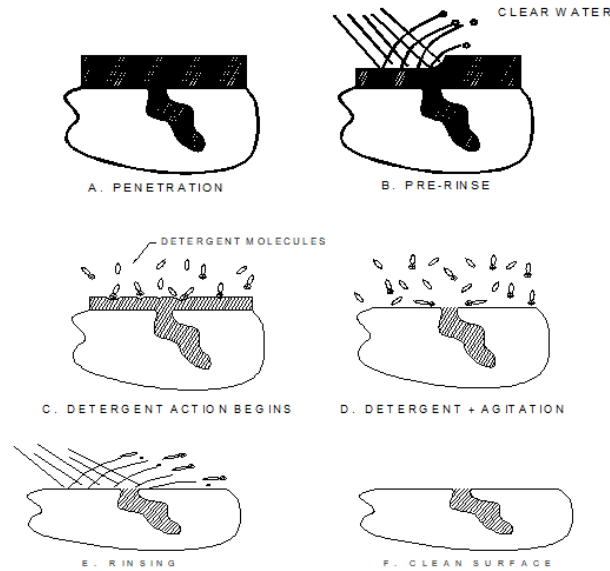
Hydrophilic Remover Process (EN ISO 3452-1 Method D)

The hydrophilic method is completely different from the lipophilic method. The differences are in the materials, mechanism or mode of action, and the procedures used. The removal of excess surface penetrant using hydrophilic removers can be accomplished using immersion or spray techniques. A combination of both techniques is most often used in manual processing on lines.

Mechanism or Mode of Action:

Hydrophilic removers consist of water-soluble chemicals. They are supplied as concentrated liquids and are mixed with water either before or during the removal process. The surface-active agent in the remover displaces a small quantity of penetrant from the surface and prevents it from recombining with the remaining penetrant layer. Unlike lipophilic emulsifier, hydrophilic remover is immiscible in penetrant and diffusion does not occur. All of the removal action takes place at the exposed surface and penetrant just below the surface is not involved until it becomes exposed. Agitation of the liquid removes the displaced penetrant and allows fresh remover to contact the remaining penetrant layer.

The next figure illustrates hydrophilic remover action.



Action of Hydrophilic Process

Pre-rinse:

The clean, pre clean, penetrant and penetrant dwell steps are identical in both the lipophilic and hydrophilic methods. However, the processes diverge with the pre rinse step in the hydrophilic method. The part is subjected to a plain water spray following the penetrant dwell when using the hydrophilic method. The mechanical action of the water spray removes over 80% of the excess surface penetrant, leaving only a very thin layer on the part.

Application of Remover:

The removal of excess surface penetrant using hydrophilic removers can be accomplished through the use of either immersion or spray techniques.

Immersion Technique:

The primary advantage of the hydrophilic immersion technique compared to the spray technique, is its effectiveness on hollow or complex geometry parts where the configuration interferes with the spray impinging on the part surface. In use, the part or parts are immersed in the remover tank while still wet from the pre rinse. The principal mode of action is a detergent mechanism. A slight agitation is necessary to bring fresh solution in contact with the surface. Agitation can be movement of the part through the solution but is most usually produced by an air manifold in the bottom of the tank. Excessive agitation which is evidenced by foaming should be avoided. Time of immersion depends on a large number of factors and will vary between 30 seconds and two minutes. The maximum time of two minutes is seldom necessary except on very rough surfaces or when remover is depleted.

Concentration:

A wide range of bath concentrations, from 5 to 35 percent may be used. All concentrations are effective, but the contact time must be adjusted. Remover concentration must not exceed 35 percent. Each penetrant manufacturer has its own formulation which varies in aggressiveness and caution must be exercised when



changes in suppliers are involved. Penetrant and remover are included in the system (family) concept and must not be interchanged.

Penetrant Tolerance:

One of the disadvantages of the hydrophilic immersion technique is the remover's limited tolerance to penetrant contamination. As parts are processed, the amount of penetrant in the remover gradually increases. If the removal process is closely timed, penetrant contamination will reach a point where a distinct performance change occurs, particularly longer removal time. The amount of penetrant causing this performance change is called the remover's penetrant tolerance point or level.

Bath Appearance:

A freshly mixed remover bath is a transparent or clear, pink solution. During use, as penetrant is removed from the parts and retained, the bath becomes turbid or cloudy with distinct colour change. When the penetrant tolerance point is reached, the penetrant will remain floating on the surface and this will deposit on the part as it is withdrawn from the bath.

Hydrophilic Spray Technique:

Hydrophilic remover can be applied by spraying the part with a mixture of water and re-mover. This method of application has several advantages: it does not require a separate tank; works well on simple contoured parts; and can be easily. The recommended concentration for more critical (e.g. aviation) manual spray operations is 1% by volume

Equipment:

A practical and efficient way of handling the low remover concentrations is by continuously metering the remover directly into the stream of water. This can be done with an aspirator device which employs the water flow to create a vacuum, Bernoulli effect, drawing up the concentrate directly from the container. The method is inexpensive, requires a minimum of equipment and permits intermittent, on/off operation.

Removal Mechanism:

The modes of action are the same for both hydrophilic immersion and spray remover techniques.

Water Rinse:

Following the penetrant removal step, the part must be subjected to a plain water rinse or wash. The purpose is to remove any remover residues that could contaminate the developer or interfere with the development process. The rinse step is a simple water spray in the station or tank used for the pre rinse. The process step is not critical and requires very few controls. Rinsing of fluorescent penetrants must be accomplished under a black light.

Comparison of Lipophilic and Hydrophilic

A comparison of the physical, chemical and application differences between the lipophilic and hydrophilic techniques is shown in the following table.

| HYDROPHILIC | LIPOPHILIC |
|-------------|------------|
|-------------|------------|



| | |
|--|---|
| Supplied as a concentrate | Supplied as a ready to use fluid |
| Water base when mixed | Oil base |
| Low viscosity 9 to 12 cs | High viscosity 120 cs, 35 cs |
| Limited penetrant tolerance | Miscible with penetrant in all concentrations |
| Miscible with water in all concentrations | Limited water tolerance |
| Applied as dip or spray | Applied as dip |
| Action: Dip-detergent with minor scrubbing | Action: Diffusion activated by scrubbing |

Comparison of Hydrophilic versus Lipophilic Methods

The hydrophilic method has the ability to remove surface penetrant with reduced effect on entrapped penetrant. This ability results in several benefits compared to the lipophilic method. A major advantage of hydrophilic removers is the increased process tolerance, i.e., removal time is not as critical as emulsification dwell.

Another advantage of hydrophilic remover is its relative insensitivity to removal of penetrant entrapped in a discontinuity. This permits complete removal of fluorescent background in most cases. In contrast, when using lipophilic emulsifier on slightly rough surfaces, it is desirable to leave a faint residual background when maximum sensitivity is required. The reduction of background fluorescence with the hydrophilic technique improves the contrast, making faint indications easier to see. The hydrophilic method also allows spot or touch up removal on local areas during the final clear water rinse. This cannot be done with the lipophilic method since the oil base emulsifier will not tolerate water.

In summary, when environmental concerns of Lipophilic oils are taken into account and the simpler spot or touch up process permitted with Hydrophilic are seen, it is not surprising that Hydrophilic Systems are much preferred to Lipophilic.

Solvent Removal (EN ISO 3452-1 Method C)

All oil-based penetrants are soluble in a large number of organic liquids. However, post emulsified penetrants are most frequently used in Method C. The solvents are usually volatile mixtures of either chlorinated hydrocarbons or aliphatic petroleum. They are closed containers, i.e., aerosol or pressure can because of their high evaporation rate. Removal is accomplished through dissolving and dilution.

Most removers may be used to pre clean the surface and to remove the excess penetrant.



The selection of a suitable solvent remover depends on a number of factors and is much like choosing a precleaning method. The advantages and disadvantages of each type of remover are also dependent on many factors. A general rule is to not use chlorinated (halogenated) solvents on parts containing crevices. Halogenated solvents may cause damage to some metals such as titanium especially if left in the crevices when the part is returned to service. Some general advantages and disadvantages are listed in the following table.

| | Advantages | Disadvantages |
|-------------------------|---|--|
| Halogenated Solvents | Nonflammable Usually no residue Can be used as a precleaner | Toxic Not for use on some materials Can be expensive |
| Nonhalogenated Solvents | Inexpensive May be water miscible May not be toxic May be used on most materials | Flammable May not be used as a precleaner May have very low flash point Need a final wipe |

Comparison of Halogenated and Nonhalogenated Solvents

Application Procedure:

The use of high sensitivity, post emulsified penetrant with the solvent removal method will produce indications from small, tight flaws. However, improper application procedures will seriously degrade the indications. The use of excess solvent will remove or dilute entrapped penetrant resulting in a failure to produce a visible indication.

After pre-cleaning and following the penetrant dwell period, the surface must be wiped with a clean, dry rag or paper towel to remove the major portion of surface penetrant. The proper procedure is to make only a single pass and then fold the rag or towel over to provide a fresh surface for each succeeding wipe. When the surface penetrant has been reduced to a minimum with dry rags or towels, any residual penetrant is removed with a fresh rag or towel moistened with solvent. The amount of solvent applied to the rag or towel is critical. The cloth or towel should only be lightly moistened. This is normally accomplished by the application of a mist of solvent to the cloth. The cloth must not be saturated either by immersion in liquid solvent or sprayed on solvent.

For fluorescent penetrants a black light must be used to examine the part surface during the intermediate and final wiping stages.

Confirmation of cleaning is achieved by examination of the part surface and rag after the final solvent wipe. Finally, a dry clean wipe should be used to accelerate the drying of the solvent cleaner prior to the next stage. With colour contrast penetrant dyes, defects will show as bright red lines in white developer background.



Developers

General

This section covers the development process. Development follows penetrant application, dwell and removal of excess surface penetrant. The section contains basic, intermediate and advanced information on the process theory, materials and application procedures. The first portion is introductory in nature, discussing the functions and required properties of developers. The second portion is devoted to the mechanisms and theory of developers. The third portion covers drying of the part after surface penetrant removal or application of a water base, aqueous, developer. The fourth portion describes the materials and application procedures for dry, aqueous and non-aqueous developers. The section concludes with a comparison of the various types of developers.

Functions

The basic function of all developers is to improve the visibility of the entrapped penetrant indication. The improvement in visibility is achieved through a number of mechanisms that include the following:

- Assist in extracting the entrapped penetrant from discontinuities.
- Increase in the surface layer thickness of exuded penetrant thereby increasing the apparent brightness of the indication.
- Spread or disperse the exuded penetrant laterally on the surface thus increasing the apparent size of the indication.
- Improve the contrast between the indication and the background.

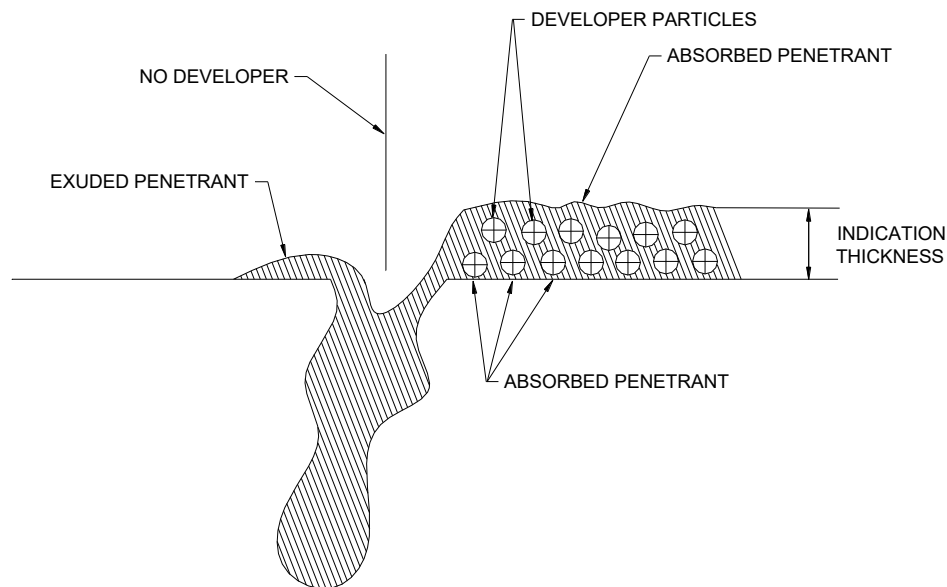
Mechanisms of Developer Action

Self-Development:

Self-development is the formation of an indication without the application of a developer material. All penetrants are capable of some degree of self-development as they will exude from a discontinuity and spread over the surface. The critical factor is the size and volume of the discontinuities that must be detected. A relatively large volume of entrapped penetrant is required and self-development is not reliable in detecting small tight flaws. Some procedures may use self-development to detect processing flaws during manufacture. Self-development should not be used in aircraft and engine maintenance inspection where service incurred flaws must be detected,

Adsorption versus Absorption:

One of the principal modes of developer action involves adsorption and absorption. Adsorption refers to the collection of a liquid on the outer surface of a particle due to adhesive forces. Absorption refers to the blotting action that occurs when a liquid merges into an absorbent particle. The mechanism of development is a combination of both adsorption and absorption.



The Effects of Developer

Contrast Enhancement:

Developers improve the visibility of indications by providing a contrasting background. They reduce reflections and appear blue black under black light. The blue-black colour provides a high contrast with the fluorescent yellow green penetrant indications. Water suspendable and non-aqueous developer produce a white coating which provides contrasting background for red visible dye penetrant.

Solvent Action

Non-aqueous developers contain solvents which hold the developer particles in suspension. When sprayed on the part, the solvent combines with any entrapped penetrant, diluting it, and reducing its viscosity. This increases the volume of penetrant that exudes from the discontinuity thus improving the visibility of the indication. Non-aqueous developers provide the highest sensitivity of any of the developer forms.

Drying

Purpose and Methods:

After removal of excess surface penetrant, the parts must be dried before applying dry developer. When aqueous developers are used, the drying is done after application of the wet developer. Drying can be accomplished in a number of ways:

- Ambient or room air
- Warm air blowers
- Recirculating air ovens

Ambient or room air:

Parts can be dried by allowing the parts to set in still air, The length of time required for this method depends upon the humidity of the air and is usually too long to be used for drying wet developer.



Warm air blowers:

Warm air blowers are often used on large parts which cannot be oven dried. The method may not properly dry wet developers.

Re-circulating air ovens:

The most frequently used method of drying parts is with a re-circulating hot air oven. It provides a rapid means of properly drying parts and wet developer; is adaptable to production; and, permits control of the temperature.

Time-Temperature Effects:

When drying test parts in a re-circulating oven, both time of exposure and dryer temperature must be carefully controlled. The minute quantity of penetrant entrapped in discontinuities can be subject to dye degradation and/or large evaporation losses. Fluorescent dyes experience a heat fade or permanent loss of fluorescence at elevated temperatures.

Another serious effect of elevated temperature is the evaporation loss of volatile liquids in the penetrant. This can decrease the small amount of penetrant entrapped in a discontinuity to such a low level that it will not contact the developer on the surface and an indication will not form.

Aqueous or wet developers are applied before heat and may retain contact with the penetrant during the drying cycle. When nonaqueous developers are used the part must be free of water prior to developer application. The base vehicle of the developer tends to mix with the penetrant in the defect. The evaporating action of the base vehicle helps to draw the penetrant from the defect to form the indication.

Procedure:

It is easy to monitor and control oven temperature, but almost impossible to monitor test part temperatures. Another complicating factor is the rate at which parts heat. Thin areas will dry and reach oven temperature before thick sections become warm. The procedure is to set the oven temperature at 60°C or less and to remove the parts from the oven as soon as they are dry. Parts must be separated with an air space between them. If the part temperature reaches and remains at 60°C for over ten minutes, the inspection sensitivity can be reduced. A guide is to remove the parts while they are warm but can still be handled with bare hands. This is a temperature of about 49-52°C.

Dry Developer (EN ISO 3452-1 form a)

Dry developers are characterised by their fluffy nature and low bulk density. Dry developers can be used with any type of fluorescent penetrant. They are loosely held on the part surface by adhesion. They do not adhere well on smooth, polished or mirror surfaces and require some penetrant at the surface to hold them in place. Dry developers are very effective on macrocracks and midrange size cracks which exude enough surface penetrant to catch and hold the dry particles. However, the effectiveness of dry developer is reduced on micro-cracks (cracks visible only under microscopic enlargement) since the amount of exuded surface penetrant is small.

Dry developer particles are generally white, not colourless. However, when the dry developer is applied to part surfaces, the coating layer is very thin and gives the impression of being colourless. In fact, dry developers leave almost no visible trace



and it is often not possible to determine if developer has been applied to a test part. Dry developers must not be used with visible dye penetrants since they do not provide adequate contrast.

Application:

Dry developer particles are not toxic materials. However, like any solid foreign matter, they should not be inhaled. Air cleaners, face masks, or respirators may be required.

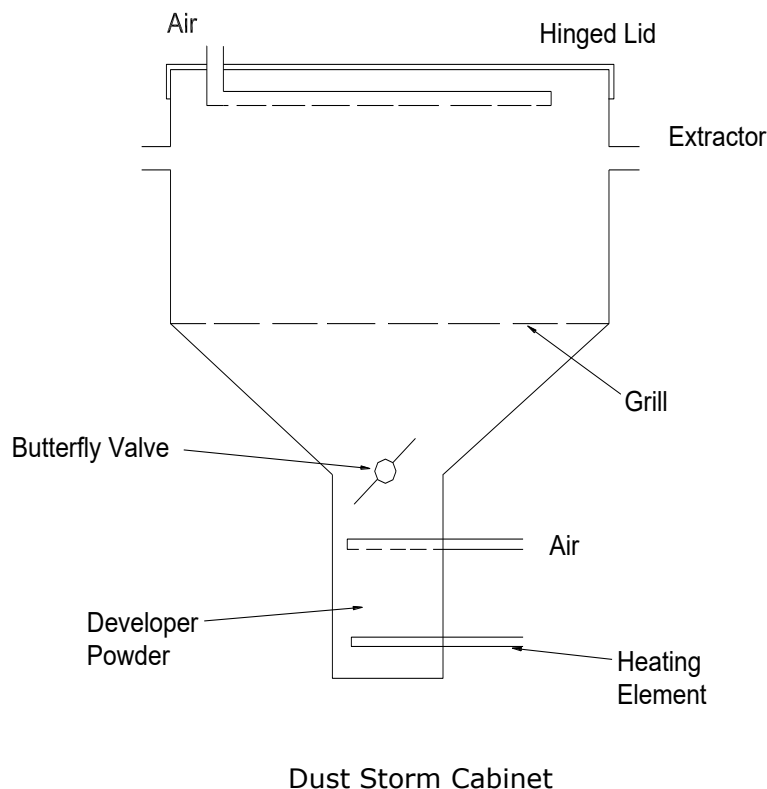
Dry developers must not be applied to a part until the surface and any discontinuities are thoroughly free of moisture. The presence of even a little moisture will interfere with the developer action and small flaws may be missed.

Dry developers can be applied in a number of ways:

- Blowing the powder on with a bulb type blower.
- Immersing the part in a container of dry particle powder.
- Pouring the powder over the parts.
- Using a dust storm cabinet, see figure on next page, where the particles are blown into an air suspension. This is also known as a fluidized bed.
- Spraying with an electrostatic system or a low-pressure flock gun.

After application, the excess developer should be shaken off or removed with a hand air bulb or squeeze blower. Wiping, brushing or compressed air in excess of 5 psi must not be used.

The two most frequent contaminants are water or moisture and penetrant. Water in dry developer comes from parts that have not been completely dried or from careless splashing during the wash step. Water or moisture contamination will cause the dry developer to form lumps or to cake, thus reducing its effectiveness. Penetrant contamination occurs when particles of penetrant soaked developer fall from poorly washed parts or heavy indications.





Water Soluble Developer (EN ISO 3452-1 form b)

Water soluble developer's contain developer particles, wetting agents and corrosion inhibitors. They differ from water suspendable developer since the particles dissolve in water to form a clear solution. During the drying process, the developer particles crystallize out of solution as the water evaporates. The resultant coating is translucent and is not readily visible. The dry layer is thinner than water suspendable developer coating, but much thicker than dry developer layers.

Application:

Water soluble developers are supplied as dry powders and must be dissolved in water before use. Since the developer particles are dissolved in the solution, agitation is not required after the developer has been initially mixed with water.

The developer may be applied by spraying, flowing or immersion. If the immersion process is used, the part should not remain in the solution any longer than required to provide complete coverage. The developer may be applied to parts while they are still wet from the water wash after penetrant removal. Care must be exercised to prevent entrapment of soluble developer in the part cavities or concave surfaces (pooling). The developer should wet the part surface with no water break areas after application. After developer is applied the parts must be oven dried since room temperature evaporation is too slow. The developing action does not start until the developer crystallizes and is dried out.

Advantages:

The advantages of water soluble compared to water suspendable developer are:

- The elimination of the need for agitation to keep the particles in suspension.
- The developer layer is thinner and translucent and will not mask or hide indications.
- The coating does not produce streaks or runs that often occur with water suspendable developers.
- The developer particles, being soluble in water, are much easier to remove during post cleaning than a water suspendable developer coating.

Disadvantages:

The disadvantages of water soluble compared to water suspendable developer are:

- Water soluble developers contain wetting agents which can act as penetrant removers and must be carefully used. This removal action is accelerated with water washable penetrants.
- The transparency of soluble developer coatings is an asset with fluorescent penetrant, however it does not produce an acceptable background contrast for visible dye penetrant indications.
- Water soluble developers are not recommended to be used with Type II penetrants or Type I, Method A penetrants.

Water Suspendable Developer (EN ISO 3452-1 form c)

Water suspendable developers consist of inert particles in a water suspension. The particles are insoluble in water and when dry are highly adsorptive and absorptive. When applied, water suspendable developers evaporate very slowly at room temperature and require a hot air oven for proper drying.



Note: Developing action in water suspendable developers will not start until all the absorbed and adsorbed water has been driven off. Developer dwell time must not begin until the part is completely free of moisture.

Application:

Although permissible, it is not recommended to apply a water suspendable developer when water washable, Method A, penetrant has been used, as further removal of penetrant will occur from shallow discontinuities.

Water suspendable developers are applied by spraying, flowing, or immersion. Spraying is the preferred method. Water suspendable developer is always used in stationary systems due to the requirement for a drying oven. Wet developer, since it has a water base, can be applied to parts still wet from penetrant removal. When the part has been thoroughly covered with the developer solution, it is allowed to drain for a short time (water suspendable developer drain must not exceed 30 seconds) and then placed in a drying oven.

Advantages:

Water suspendable developers have several attributes which produce greater sensitivity than possible with dry developer:

- The coating is in more intimate contact with the part surface and the layer is thicker than that of dry powder resulting in increased extraction and the formation of brighter indications.
- Water suspendable developers produce a visible coating which shows the extent of coverage and the presence of any voids.
- Water suspendable developers do not give off any solvent vapours or obnoxious dust and do not require expensive exhaust and ventilating equipment.

Disadvantages:

There are a number of disadvantages with water suspendable developers. They are:

- Water suspendable developer particles being insoluble and heavier than the water, rapidly settle to the bottom. Frequent agitation or stirring is required to maintain a uniform concentration.
- The dried coating thickness of water suspendable developer is critical. If the coating thickness is excessive, the layer can reduce or mask the visibility of flaw indications. The thickness of the dried developer layer depends upon the concentration of developer in the water.
- The wetting agent in the developer can act as a detergent and remove penetrant entrapped in flaws. Parts should not be immersed any longer than necessary. This detergent action is accelerated with water-washable penetrant.
- The liquid developer is mobile on the part surface before drying and it may flow into and collect in cavities or recesses leaving an excess of developer. This local build up can be reduced by careful handling and positioning of the part.
- Dried water suspendable developer coatings can be the most difficult to remove when the inspection has been completed. The difficulty of removal increases when the developer remains on the part for any length of time as the coating sets up or hardens. Water suspendable developer must be removed as soon as practical following the inspection.



Solvent-based (Non-aqueous Wet) Developers (EN ISO 3452-1 form d to Type I or form e to Type II/III)

Solvent-based (Non-aqueous Wet) developers are supplied in the ready to use condition and contain particles of developer suspended in a mixture of volatile solvents. The solvents are carefully selected for their compatibility with the penetrants. Solvent-based developers also contain surfactants and dispersants whose functions are to coat the particles and reduce their tendency to clump or agglomerate.

Solvent-based developers are the most sensitive form of developers due to the solvent action contributing to the adsorption and absorption mechanisms. In many cases where tight, small flaws occur, the dry and aqueous developers do not contact the entrapped penetrant. This results in the failure of the developer to create the necessary capillary and surface tension forces that serve to pull the penetrant from the flaw. The non-aqueous developer solvents enter the flaw and dissolve into the penetrant. This action increases the volume and reduces the viscosity of the penetrant.

The manufacturer must carefully select and compound the solvent mixture. Either excessive or inadequate volatility and solubility will adversely affect the performance of the developing action. High volatility reduces the time for the developer to function before it evaporates, while low volatility increases the drying time. Low solubility reduces the penetrant dissolving action and the improvement in exuding the penetrant from the defect.

Application:

Solvent-based (Non-aqueous Wet) developers are always applied by spraying. Proper spraying produces a thin, uniform layer that is very sensitive in producing indications. Non-aqueous developer must be applied only as a fine spray or mist.

Spraying of non-aqueous developer is most often done with pressurized, aerosol containers. Like dry powder developers, solvent developers must not be applied to a part until the surface and any discontinuities are thoroughly free of moisture.

Prior to spray application, the container must be agitated. Non-aqueous developer is usually a suspension and the particles settle out in a matter of minutes. The spray can or gun must be held far enough from the surface to produce a light, moist film. Liquid flow on the part surface must be avoided. This is usually achieved at a distance of 12" -18" (30 - 45cm).

The recommended technique is to apply a very thin, dry layer and build up the thickness with several passes rather than applying a single, wet pass. The optimum coating thickness cannot be measured but must be judged from its appearance. The luster or surface texture of the part surface should not be completely hidden. If the metallic luster cannot be seen, the developer layer is too thick and small indications may be masked or too widely spread to be easily seen. At the thin end of the optimum thickness range, there should be sufficient developer on the part surface to be clearly visible. Coatings that are too thin may not extract the sufficient amount of entrapped penetrant. Also, thin coats do not allow the penetrant to spread and magnify the indication.

Advantages:

Non-aqueous wet developers produce the highest level of sensitivity of any of the developer forms due to their solvent action. They are also convenient to use in portable applications for two reasons:



- They are packaged in portable aerosol containers.
- They are volatile and fast drying in the air, thus eliminating the need for a drying oven.

They are sealed in their containers and are not recovered after their initial use which eliminates any degradation by contamination. When proper techniques are used, they provide a smooth, even layer of developer whose thickness can be controlled by the operator.

Non-aqueous wet developers are recommended for use with both fluorescent and colour contrast penetrants.

Disadvantages:

Nonaqueous wet developers contain solvents which can be relatively flammable, and when used in confined locations, present a health hazard. Caution must be exercised to prevent ignition and to avoid inhalation of the vapours.

The developer particles are suspended in the solvent and tend to rapidly settle out. Agitation prior to and during application is required. The portable aerosol containers have a small spray coverage which makes coating of a large surface very time consuming. The inspection is limited to small, local areas.

There is a gradual loss of pressure over a period of time and occasionally there are leaks due to improper sealing. When the pressure is lost, the can and its remaining contents must be discarded. Aerosol spray patterns are not uniform and if the nozzle is not free of dried developer particles, can be very erratic. It is necessary to clean the nozzle after every use.

Special Developers, eg. Plastic film Developers (EN ISO 3452-1 form f)

When an indication requiring recording is detected by the penetrant inspection process, the following steps should be take:

- Remove the developer with a clean, dry, lint-free cloth.
- Apply the same penetrant by any appropriate means, then continue exactly same process used initially until the developer is applied.
- After removing the excess penetrant and drying the part, apply the peel developer as recommended the manufacturer.
- When the recommended development time has elapsed, carefully remove the developer coating. The indications appear on the side of the coating that was in direct contact with the part.

Without Developer (EN ISO 3452-1 form g Type I only)

The penetrant testing can be performed without using a developer, if all parts are in compliance and the level of sensitivity is not affected.

Developer Dwell

Extraction of the penetrant entrapped in a flaw is a function of time and volume of available penetrant. Time must be allowed for the developer to assist in drawing some of the entrapped penetrant from the flaw and spreading it on the part surface to form the indication. The length of developing time varies widely with a number of influencing factors and must not start until part is completely free of moisture.



Maximum Developer Dwell Time:

Over development, i.e., too long a development time, is possible and must be avoided. Developer action starts when the developer is completely dry and continues until all of the available penetrant is extracted. An indication will gradually form, reach a maximum resolution point, and then begin to degrade. The lateral diffusion of penetrant over a period of time can be so great that the indication becomes indistinct. Medium size or large discontinuities will appear as a smear or blob of penetrant. Small indications are especially critical since the small amount of penetrant may not be observed when it diffuses.

Comparison of Developers

The relative sensitivities of penetrant inspection with various forms of developer are influenced by a number of factors. The method of applying the developer produces a range of sensitivities for each of the developer forms.

It is recognized that solvent-based developers applied by spraying produces the highest sensitive penetrant system. Industry agreement on the developer sensitivity order ends at this point.

The type of test sample, type of flaw, flaw size and shape, type of penetrant, method of removal and drying procedures will affect the sensitivity of the penetrant system.

The table below lists some of the common forms of developer, plus the application method, arranged in a decreasing sensitivity order. This is the sensitivity order most generally accepted.

| | | |
|------------------------------------|-------------------------|------------------------|
| Solvent-based (Non-aqueous wet) | Spray | Most Sensitive |
| Water soluble | Spray | Most Sensitive |
| Water suspendable | Spray | Most Sensitive |
| Water suspendable | Immersion | Most Sensitive |
| Water Soluble | Immersion | Most Sensitive |
| Dry Powder | Electrostatic spray | Decreasing sensitivity |
| Dry Powder | Fluidized bed | Decreasing sensitivity |
| Dry Powder | Air agitated dust cloud | Decreasing sensitivity |
| Dry Powder | Dip and pour | Least sensitive |

Developer Forms and Application Methods in a Decreasing Sensitivity Order



Materials and Process Control

General

This section provides basic, operating and advanced level information on the procedures necessary to assure a high quality performance from the penetrant inspection system. The first part of the section discusses the reasons for process and materials control. The second part describes procedures to verify materials quality. The third part outlines review functions on the process.

Penetrant inspection is not a fail-safe process. The presence of indications confirms the existence of discontinuities in the part. However, the absence of indications does not guarantee the absence of discontinuities. Flaws can be present and not be indicated for a number of reasons. The two main reasons for discrepancies in inspection results are:

- Substandard materials either as received or through service degradation,
- Process deviations either in equipment, procedures or conditions.

New Materials

Penetrant materials are subjected to extensive testing during their formulation to assure their proper composition. However, materials that do not perform satisfactorily can still be received.

Unsatisfactory materials can result from a number of causes:

- The penetrant supplier may inadvertently omit an ingredient or a process.
- An ingredient with similar characteristics may be substituted due to non-availability of the original material.
- The substitution of ingredients may occur at the penetrant formulator's supplier.

Experience has shown that all newly received penetrant materials should be tested to verify performance characteristics.

In-use Materials

Some inspection processes use the penetrant materials one time with no attempt to recover the excess (total loss systems). The materials are usually applied by spraying and only enough material to properly function is applied. The materials are stored in closed containers, until they are used. These processes minimize the possibility of material contamination or degradation during use and reduce required process checks.

However, more often the materials are used in open tanks or open containers. When the immersion method is used, the surplus materials are allowed to drain from the part back into the tank. When the materials are applied by brushing, the brush is alternately stroking the part surface and being immersed in the container. Both methods provide numerous opportunities for contamination and deterioration and such materials must be checked periodically to be sure they are functioning acceptably.



Causes of Materials Degradation

Materials Contamination:

Materials contamination is a primary source of degrading a penetrant system's performance. There are a number of contaminating materials and their effect on performance depends upon the type of material. Some of the common contaminants frequently encountered are:

- Water is the most common type of contaminant. It can occur because of careless or improper rinsing, be carried in on parts from a previous operation; or, may result from leaking or dripping pipes.
- Organic materials such as paint, lubricants, oils, greases, and sealants are another source of contamination. These materials, if not removed from parts during pre cleaning, can dissolve in the penetrant and react with or dilute it so that it loses some or all of its ability to function.
- Organic solvents such as degreasing fluid, cleaning solvent, gasoline, and antifreeze solution are common types of contaminants.
- Dirt, soil and other insoluble solids are carried into the penetrant, emulsifier and developer as a result of improper pre cleaning and falling debris from overhead structure.
- Acid and alkaline materials are serious contaminants to penetrant solutions, especially water washable penetrants. They react with the penetrant to destroy fluorescence and washability, even when present in fairly small quantities.
- Penetrant is a normal contaminant of emulsifier in the post emulsified process. It is carried in on penetrated parts. As the penetrant builds up in volume, it will gradually slow the emulsifying action, and if the level becomes high enough, completely stop the emulsification process.

Evaporation Losses:

Penetrant materials used in open tanks are continuously undergoing evaporation.

- The rate of evaporation is increased with warmer temperatures and large tank surfaces. Evaporation losses of penetrant result in an increase in viscosity, thus slowing penetration and emulsification.
- Evaporation of water washable penetrant may slow or speed washability, depending on the penetrant formula.
- Evaporation losses in developer solutions increase the concentration which produces a heavier coating that may mask smaller indications.
- Evaporation losses take place very gradually so performance change may become significant before it is noticed.

Heat Degradation:

Penetrants, especially fluorescent penetrants, are sensitive to elevated temperatures. Temperatures of over 60°C can reduce the fluorescence and temperatures over 121°C may destroy it completely. High temperatures also speed evaporation of the volatile components of penetrants, causing undesired performance changes. High temperatures in penetrants can occur from the following:

- Immersion of heated or hot parts.
- Inspection of surfaces exposed to the sun, such as flight line aircraft.
- Improper storage before being placed in use, such as storage in direct sunlight.



Process Degradation:

In addition to materials degradation during use, the equipment and process can deteriorate. Black light bulbs age and become dirty, reducing their output. Drying oven thermostats can be improperly set or may malfunction, resulting in excessive temperatures and critical procedures may be performed incorrectly.

Frequency of Materials Verification and Process Control Checks

One of the factors influencing the degradation of a penetrant system, (materials, equipment and procedures) is the volume of parts being processed. Each activity should therefore set inspection intervals based on their workloads.

Note: The materials in penetrant systems can deteriorate, whether or not they are used. Materials verification must be accomplished at least once a month on all penetrant systems.

Equipment and process control inspection intervals vary depending upon the specific item to be checked. Many items will degrade on a time rather than a use basis. Equipment and process must be inspected at weekly, monthly, 90 or 180 day intervals as specified.

Materials Control

Newly Received Materials:

Penetrant system materials (penetrants, emulsifiers and removers, and wet and dry developers) are compounded or formulated in batches or lots. It is possible for one batch or lot among several to have characteristics that do not meet the specification requirements. Therefore, each batch or lot of penetrant, emulsifier and remover, and wet and dry developers might be tested on receipt, prior to in service use. The batch or lot of material can be identified batch or lot number on each container.

Process Control Reference Sample Size:

A portion of the system materials are set aside to be used as reference or master standards in comparing the performance of the in use material. The sample size will depend upon the workload which determines the frequency of process control testing. The reference sample must be large enough to permit the required process control checks during the life of the material and still have a quantity of reference sample to run a comparison check against the new materials when the old solution is finally discarded.

Sample Handling and Storage:

Care must be exercised in obtaining, handling and storage of the reference samples to pre-vent contamination or degradation. The containers should be metal or glass as many plastics are attacked by the penetrant oils and solvents. The sample containers should be clean, dry and have tight fitting lids or covers. The samples must be stored in a cool area and not exposed to sunlight, black lights or high intensity lights.



Process Control Testing

EN ISO 3452-1 Annex B determines the process control tests to be carried out and their frequency.

Control tests include:

- System performance
- A general review of the system
- Penetrants
- Emulsifiers
- Developers
- Equipment calibration

It is the responsibility of the authorised Level 3 to decide which tests to EN ISO 3452-1 Annex B are applicable to the particular process line.

Penetrant System Monitor (PSM)

The Penetrant System Monitor (PSM) (Block n° 2) panel is intended to be used as a daily or weekly process performance monitor. It is not a substitute for the cracked chrome plate panels which are used to compare materials performance.

The PSM panel is specified in EN ISO 3452-3.

The PSM panel is especially suitable for high volume, semi-automated, automated, and fully automated depot systems. It is a stainless-steel panel having a chrome plated strip running lengthwise while the other side is a medium roughness, grit blasted surface. The chrome plated strip contains five, evenly spaced, crack centres.

No two panels are completely identical crack patterns and sizes vary from panel to panel. The panels are supplied in sets of two, with the supplier matching the panels as closely as possible. One panel is reserved for use as a "reference" or "transfer" standard while the other is the "working" panel.

The PSM panel does not indicate sensitivity as is the case with cracked chrome panels. It is intended to signal changes in the performance of the penetrant system. One advantage is the ability to process the panel directly in the working tanks along with production parts. Another advantage is the oxide blasted strip which indicates the effectiveness of the removal process step. A disadvantage is that small or gradual changes are not readily noticed. As with cracked chrome plate panels, the PSM deteriorates with handling and clogging. Also, the PSM panel can retain large amounts of residual penetrant, thus careful and thorough cleaning is mandatory.

Penetrant System Monitor (PSM) Procedures

The working panel must be clean, dry and free of any solvent before use. It should be processed through the penetrant system in the near upright position by placing it in the center of a basket of parts, hanging it on a production rack, or by hand processing individually. It should be processed with the same technique, position and posture every time.

When the panel is hand processed through a system used with different processing techniques, the following should be used:

- Use minimum penetrant dwell time.



- Use maximum emulsifier contact and wash times.
- Use maximum oven temperature and exposure time.
- Use minimum developer dwell time.

Examine the panel under black light, holding it at a slight angle so that the black light is not reflected back into the eyes. Observe not only the number of crack centers visible, but also the brightness and sharpness of the indications. A change in indications or in residual background indicates a malfunction and requires further investigation.

Usually, the first step is to clean the panel and reprocess it along with the transfer panel. This will determine whether the change is due to degradation of the working panel or to a problem with the penetrant process. Experience is required in reading the panels and the inspector must be aware of the previous appearance of the panel. A Polaroid photograph of the Crack center indications when processed under optimum conditions and with the new materials is an excellent reference tool.

Following inspection, the panels should be cleaned as soon as possible. Wash them with detergent in water while hand wiping to remove developer as soon as possible. Dry with a mild air blow (5 psg) and vapour degrease or ultrasonically clean to remove any entrapped penetrant.

Note: Adequacy of the cleaning procedure can be verified by applying non-aqueous developer after cleaning. If penetrant indications are produced, then the panel must be cleaned again.

Solvent entrapped in cracks will interfere with the test. Do not use solvent that will leave a residue and briefly oven dry the panel to evaporate entrapped solvent. Cool the panel to room temperature before using.

System Performance Testing

System performance testing involves the inspection of a test panel containing known defects using samples of the penetrant, emulsifier or remover, and developer from the work tanks, while another panel is processed with the reference material and the resultant indications are compared.

It is the responsibility of the authorised Level 3 to decide which tests to EN ISO 34521 Annex B are applicable to the particular process line.

Storage of Panels

The panels must be stored in a clean, dry air environment to retard degradation. One practice is to store the panels in mineral spirits or alcohol and to degrease them prior to use. The panels do not have indefinite life as penetrant and developer residues plus oxides retained in the cracks, will gradually clog or fill the cracks, thus reducing the apparent size of the indication.

In-Process Penetrant Testing

The preferred method of testing the penetrant is the System Performance Test. Perform the System Performance Test using the cracked chrome panels to determine sensitivity and brightness.



If the System Performance Test indicates a loss of sensitivity or indication of brightness, the following test should be accomplished:

- A clean, dry cracked chrome panel should be used.
- Penetrant from the working tank should be applied to one of the panels using reference standards of emulsifier or remover and developer.
- Examine the panel.
- Clearly visible differences in sensitivity, brightness or colour are due to degraded penetrant which must be discarded as an oil waste. If there is little or no difference to account for the change in penetrant system test, the panel should be cleaned.
- The test must be repeated using reference standard penetrant on both panels, working bath emulsifier on one panel and reference standard emulsifier on the other, followed by reference standard developer. If the working bath emulsifier is not causing the problem, repeat the test comparing the work bath developer.

Special Purpose Materials

General

There are a number of penetrant materials that are different than the materials described in the previous sections. These materials are formulated for special applications and purposes. This section describes these special purpose materials and discusses the reasons for their use. Application procedures are not covered. The procedures vary widely between materials and manufacturers. Each of the manufacturers provides detailed application procedures for the particular material when it is procured.

The materials described in this section are not covered by many specifications on penetrant materials. Many of the penetrant materials in this chapter are not approved for aerospace applications and may only be used when the specification stipulates the requirement.

Oxygen Compatible Penetrants

Oxygen has a high degree of chemical reactivity. It will explosively react or combine with a large number of materials. This includes traces or residues from normal penetrant inspection materials. There are special cleaning procedures to be used on parts and components that will be contacting gaseous or liquid oxygen. There is not too much of an inspection problem on simple, assembled parts that can be sent to the cleaning shop for complete removal of residual inspection materials. Difficulties are encountered with assemblies and complex shaped parts containing crevices, recessed areas, or faying surfaces where inspection materials become trapped and are not removed by cleaning. Such items should be inspected by another non-destructive test method. There are liquid oxygen (LOX) compatible materials available by special order. These materials are mainly intended for use on space vehicles and can be used on aircraft when required.

Requirements for a LOX Compatible Material:

There are two ways of avoiding a LOX reaction from penetrant materials:

- Completely remove all inspection material residues.



- Use only process materials that are inert in an oxygen environment.

This is not simple since the penetrant system must still be capable of detecting very small flaws. Normal penetrants are designed to resist removal from cracks and crevices and the organic dye stuffs are oxygen reactive.

LOX Compatible Penetrant Types:

There are three approaches used in formulating LOX compatible penetrant systems:

- Use of materials that are soluble in water and lend themselves to complete removal during post cleaning.
- Use of materials that are completely volatile and evaporate from the parts without leaving a residue.
- Use of non-reactive liquids that maintain the dye stuffs in solution and completely wetted by the liquid at all times.

Water Based LOX Compatible Penetrants:

There are dye stuffs and developer materials that are soluble in water. Water base penetrants, if their water content is high, are LOX insensitive. However, when the water evaporates, the residues can become LOX sensitive. Water base penetrant systems have been approved for some LOX related applications since their residues are water soluble, surface agents similar to detergents. Approval for LOX applications is based on their ease of removal from surfaces and flaw entrapments using plain water.

Low Sulphur, Low Chlorine Penetrant

Influence of Sulphur and Halogens in Penetrant Materials:

There is considerable concern over the effects of small quantities of sulphur and halogens present in penetrant materials. This concern is due to the increased use of high temperature alloys such as nickel and cobalt base alloys, austenitic stainless steel, and titanium in aircraft and engines. These materials are susceptible to hydrogen embrittlement, inter-granular corrosion, and stress corrosion. Small amounts of sulphur and halogens, principally chloride, remaining on the alloys during service, will increase their susceptibility to attack. Sulphur and halogens are not essential compounds in penetrant materials nor are they deliberately added.

High Temperature Penetrant Materials

Standard penetrant materials are limited to temperatures of 50°C. There are special penetrant systems formulated for use above 50°C. These special high temperature penetrants contain visible and fluorescent dye stuffs that resist heat degradation. The vehicles and solvents are carefully chosen to remain liquid and resist evaporation at the operating temperature.

Dye Precipitation Penetrant Systems

Dye precipitation penetrant systems are commonly referred to as high resolution penetrants. The penetrant contains a high concentration of either visible or fluorescent dye stuffs dissolved in a highly penetrating, volatile solvent. The



penetrant is usually applied by brushing on the surface to be inspected. The penetrant will enter any discontinuities and, during the dwell period, the solvent evaporates, precipitating the dye stuff as a solid which fills the discontinuity.

After removal of the excess surface penetrant and when using the two-step development process, a very thin layer of solvent developer is sprayed on the surface. The developer re-dissolves the solid penetrant dye stuff entrapped in the flaw, expands its volume and extracts it from the flaw. Dye precipitation penetrant systems are extremely sensitive.

Reversed Fluorescence Method

The reversed fluorescence method is a sort of photographic negative of the standard fluorescent penetrant inspection. A standard visible dye penetrant is applied to the surface to be inspected and after the dwell, the excess is removed in the normal manner. A special developer, containing a low intensity fluorescing dye and a relatively small amount of developer powder, is applied by spraying under a black light; the entire surface will fluoresce, except for the flaw which appears as a dark line where the penetrant has quenched the fluorescent dye.

Thixotropic Penetrant

A thixotropic material is one which changes form or structure as a function of time or shear stress. Thixotropic penetrants are applied as a solid or gel and then change to a liquid after application. They are used when it is difficult to apply the penetrant as a liquid.

Plastic Film Developers

Plastic film developers form a dry, flexible layer that can be peeled or stripped to provide a record of indications on test surfaces. The most frequently used plastic film developers are two part systems. The first part provides developer action while forming a white, reflecting background. The second part forms a clear layer that freezes the indication and provides film strength and some flexibility. The layers combine and can be removed from the part as a thin film.

Filtered Particle Penetrants

Larger dye stuff components allow inspection of porous materials. While the liquid suspension enters cracks and porous areas, particles are too large and are held on the surface in the vicinity of larger capillary drains. The presence of the accumulation of fluorescent dye stuff particles shows clearly the presence of cracks or excess porosity.