CHAPTER 4
PENETRANT TESTING

I. INTRODUCTION

Penetrant testing (PT) is one of the most widely used nondestructive testing methods for the detection of surface discontinuities in nonporous solid materials. It is almost certainly the most commonly used surface NDT method today because it can be applied to virtually any magnetic or nonmagnetic material. PT provides industry with a wide range of sensitivities and techniques that make it especially adaptable to a broad range of sizes and shapes. It is extremely useful for examinations that are conducted in remote field locations, since it is extremely portable. The method is also very appropriate in a production-type environment where many smaller parts can be processed in a relatively short period of time. This method has numerous advantages and limitations that can be found in Section X of this chapter.

II. HISTORY AND DEVELOPMENT

Although the exact date of the first "penetrant" test is unknown, it is generally believed that the earliest tests were performed in the late 19th century and were primarily limited to the examination of various railroad parts, such as axles and shafts. Even though it was a very rudimentary method, it was capable of revealing fairly large cracks in metallic parts by using what is referred to as the "oil and whiting" method. It is interesting to note that the oil and whiting method employed the same processing steps that are in use today with current penetrant testing procedures. In this early penetrant method, the part to be examined was cleaned and then submerged in dirty engine oil. The oil that was used in those days came from large locomotive engines and was very heavy. It was generally diluted with kerosene or alcohol so that it would be thin enough to penetrate surface discontinuities. It seemed that the dirty oil worked the best in the presence of a discontinuity, since it provided a dark, oily stain on the test surface. After saturation with oil, the part was allowed to drain. During the draining time, known today as the "dwell" time, the thinned oil would penetrate surface cracks. After the excess oil was removed from the surface with a solvent, the part was coated with "whiting," which consisted of a chalk-like powder suspended in alcohol. The oil that was entrapped in the void would then "bleed" out into the whiting and a dark, oily stain indicated the presence and location of a discontinuity.

Sometimes the whiting used was a whitewash material similar to that used to wash and paint fences, hence the expression "oil and whiting" method. It is also believed that talcum powder was used in those early days as a developer to help bring the oil back out to the surface so it could be observed.

As can be expected, there were many problems with this early technique. There was a general lack of consistency, since there were no established procedures or standards and the dwell and development times were pretty much left up to the judgment of the user. The materials varied in content and use and only the grossest type of discontinuities could be detected.

The oil and whiting method had a place in the early examinations of railroad parts, but its use began to diminish with the introduction of magnetic particle testing (MT) in the 1930s. Its decline was most notable in the years from 1925 into the mid-1930s. At this time, many parts that were considered to be critical were made of ferromagnetic materials and the advent of MT techniques provided a much more reliable and repeatable method for the detection of surface discontinuities. By the mid-1930s, the use of aluminum and other materials that could not be magnetized was increasing and it was quite apparent that there had to be another nondestructive test method for detecting discontinuities in these nonferromagnetic materials. Certainly, at that time, internal discontinuities could be detected using x-ray techniques, but many of the x-ray techniques in use were not capable of revealing smaller, tight discontinuities at the surface. It follows that there was an obvious need for a method that would be sensitive enough to detect these small surface discontinuities.

The early pioneers Carl Betz, F. B. Doane, and Taber deForest, who worked for the Magnaflux Corporation at the time, were experimenting with many different types of liquids and solvents that might fulfill this need for surface discontinuity detection. These early techniques that were tried used brittle lacquer, electrolysis, anodizing, etching, and various color-contrast penetrants. Some of these early approaches were discarded, with the exception of the anodizing process. During this period, the anodizing process was used for detecting cracks in critical aluminum parts, generally associated with aircraft. This resulted in the publication of a military specification, MIL-I-8474, on September 18th, 1946. The title of this specification was "Anodizing Process for Inspection of Aluminum Alloys and Parts."

Years before the publication of this military standard, Robert Switzer had been working with fluorescent materials, primarily for producing fluorescent advertisements for movie theaters. He and his younger brother, Joseph, were pioneers in the early use and development of various fluorescent materials. As early as 1937, Robert Switzer became aware of a problem that a local casting company was having with parts for the Ford Motor Company. There was a large batch of aluminum castings that were found to contain a number of discontinuities that were not observed until after the surfaces of the castings had been machined. Switzer recalled how the different fluorescent materials he was familiar with were capable of clinging to surfaces and fluorescing when observed using ultraviolet (black) light. He thought that this material would be appropriate for detecting the surface cracks that had been uncovered by machining. He was able to obtain a number of samples and began experimenting with the various fluorescent pigments that he was developing. He found that although these pigments were unique in clinging to a person's hands and other porous-type materials, they were not very effective for the detection of very fine surface cracks. Switzer continued to try different combinations and, eventually introduced them into various liquids that would be used to carry the fluorescent pigment into the discontinuities. His work was ultimately successful and he applied for a patent in August of 1938. It is interesting to note that he asked his brother, Joseph, to share the patent-filing fee, which amounted to $15.00, and Joe declined. Robert then proceeded to file the patent on his own and, ultimately, found information about the Magnaflux Corporation, which at that time was still developing and pioneering the magnetic particle inspection method. He decided to investigate the company and contacted one of their sales representatives in New York City to discuss the possibility of expanding their surface discontinuity efforts to include a fluorescent penetrant.

Some of the early attempts to demonstrate the fluorescent penetrant method to Carl Betz and others from the Magnaflux Corporation were not successful. Lack of success in these early demonstrations was probably due to the fact that the castings being examined were supposed to have discontinuities but those discontinuities probably did not exist. One of the observers, A. V. deForest, who was a pioneer in MT, happened to have a specimen containing known discontinuities that he had used to demonstrate MT, and a fluorescent penetrant test was performed on this specimen. The indications were quite apparent. Naturally, all of the observers were very impressed that the known discontinuities appeared, In addition, other discontinuities that A. V. deForest was not aware of were also observed.

Subsequent to this demonstration, it was found that the castings that were first examined had been peened, thus closing the discontinuities that were at the surface. This demonstration proved unique. The year 1941 became memorable, not only for the patent that was awarded to Switzer that summer, but because it also marked the beginning of the Second World War. This new test would be widely used in supporting the different products that would be used by the military.

Early Penetrant Techniques

Some of the early penetrant processes were quite similar to those in use today. The part would be cleaned with a strong solvent and then, after drying, it was immersed in the penetrant for about 10 minutes. After this penetration, or dwell time, the penetrant was removed, usually with a strong solvent, and the part was wiped until dry and clean. The removal step was usually performed under a black light. According to early accounts, the parts would then be struck with a hammer, which would cause the entrapped penetrant materials to "bleed out" to the surface, at which time the part would be examined under a black light. These early techniques were still quite archaic and the test results were not very consistent. During the following years, in order to achieve the level of consistency that is essential for quality assurance, many different types of materials were tried and a variety of techniques were attempted. These led to a most unique development: the water-washable or water-removable (perhaps a more appropriate term) penetrant.

Water-rinsable penetrant materials and related equipment were first offered around June of 1942. There was much interest in them and a number of companies started to use the water-rinsable technique. As a matter of record, the first purchaser of the water-removable penetrant equipment was Aluminum Industries of Cincinnati, Ohio, which would use the equipment for the examination of aluminum castings. Many other applications and uses followed, including the testing of propeller blades, pistons, valves, and other critical aircraft parts. It should be noted that a major step forward in the application of PT occurred when it was included in the maintenance and overhaul programs for aircraft engines. As a result of this application, the PT method of nondestructive testing was on its way to gaining wide acceptance. A patent on the "water-washable" technique was applied for in June 1942 and was issued in July 1945. The early developer compounds were yellowish materials consisting mainly of talc. The wet developer technique began to be used in late 1944 and early 1945.

One of the problems associated with the water-removable technique was the potential for removal of entrapped penetrant from discontinuities as a result of a vigorous water rinse step; this led to concerns about "overwashing." This overwashing was the result of an emulsifier that had been mixed in with the penetrant. In fact, some early penetrants were marketed as promoting "super washability," which resulted in extremely clean surfaces but also produced a greater danger of the penetrant being removed from surface discontinuity openings. The solution to this overwashing concern was to remove the emulsifier from the penetrant and to apply it later. This finally occurred in 1952 when this process was referred to as the postemulsification, or PE, technique.

The first postemulsification penetrants were introduced in 1953. With this technique, the emulsifier was applied after the penetrant dwell time and carefully controlled, so that the penetrant in the discontinuities was not emulsified. It would remain in the discontinuity even after the emulsified surface penetrant was removed with a water rinse. Although this added an additional step and an additional liquid to the process, it did provide a higher level of control over the detection of small, shallow discontinuities that may not have detected with the use of a typical water-removable technique containing emulsifiers.

Visible Penetrants

The penetrant techniques described to this point were of the fluorescent type. The fluorescent penetrant technique required tanks, a water supply, electricity for the black lights, and a darkened area for the evaluation of indications. In order to permit penetrant tests to be performed in the field and to provide portability, a simpler, visible dye had to be developed. In the 1940s, a Northrop metallurgist named Rebecca Smith developed a visible dye penetrant approach. Rebecca Smith, who would be later known as Becky Starling, collaborated with Northrop chemists Lloyd Stockman and Elliot Brady, who also assisted in the development of a visible dye penetrant. This was considered necessary for examining critical jet engine parts outdoors, where creating a darkened area necessary for the use of fluorescent penetrants was inconvenient. The development of the visible dye penetrant technique would take several years; Stockman applied for a patent in March 1949. By this time, there were several choices of penetrants: fluorescent water removable, fluorescent emulsifiable, and a visible dye.

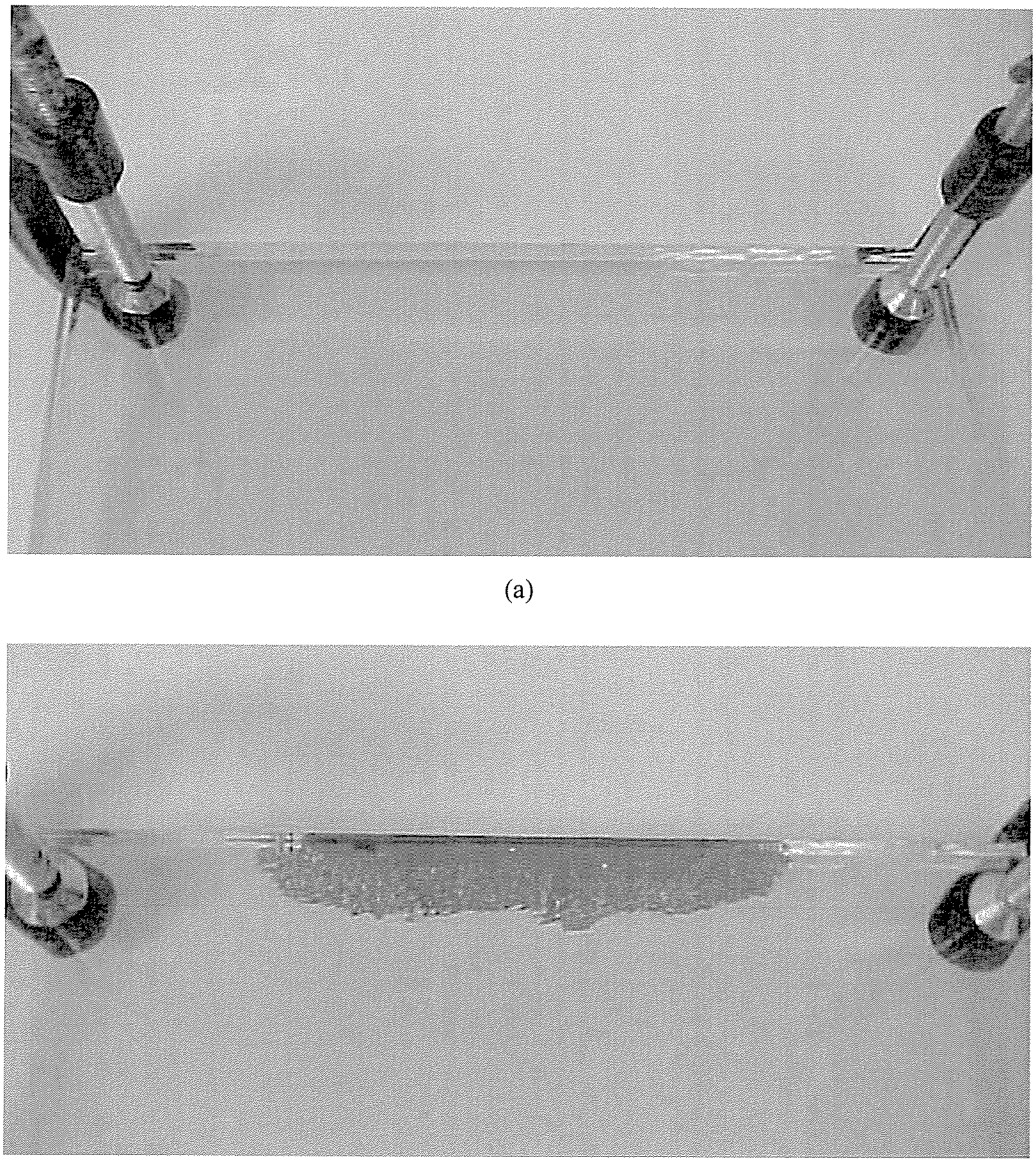
Other Developments

In the late 1950s and early 1960s, much work was done to quantify and analyze the various penetrants that were available. By the early 1960s, a variety of techniques were being used with a range of sensitivities that would satisfy the demanding requirements of many industries. Many of the variables associated with the penetrant tests were evaluated and the entire process was improved, so that consistency and sensitivity would be an intrinsic part of the process. One of the most widely used military standards, MIL-I-6866, was issued in 1950 and is still in use in a number of industries today, with very few changes from the original document. Currently, there has been a shift away from military standards and, eventually, all military standards will be replaced with standards developed by the American Society for Testing and Materials (ASTM). The remainder of this chapter will focus on the materials and techniques that are in use at the present time and will describe the many applications for which this unique NDT method can be effectively applied.

III. THEORY AND PRINCIPLES

The basic principle upon which penetrant testing is based is that of capillary "attraction" or "action." Capillary action is a surface tension phenomenon that permits liquids to be drawn into tight openings as a result of the energies that are present at the surfaces of the openings. In most high school physics classes, the principle of capillary action is demonstrated by placing a glass straw into a beaker filled with colored water. The surface tension associated with the opening of the glass straw, or capillary, causes the liquid level to move to a higher level inside that capillary than the level of the liquid in the beaker. A simple demonstration of capillary action using two glass panels clamped together is illustrated in Figure 4-1a and b.

One can consider that discontinuities open to the surface behave in much the same fashion as shown by the glass panels in Figure 4-1b. The liquid used in this example is a



(a)

(b)

FIGURE 4-1 Demonstration of capillary action. (All illustrations in this chapter courtesy C. J. Hellier.) (a) Glass panels clamped together. (b) Visible color contrast penetrant applied to edge of panels.

typical visible contrast penetrant. The capillary action forces are very strong and, in fact, if a penetrant test were being performed on a specimen in an overhead position, the penetrant would be drawn into the opening, against the force of gravity. The capillary force is much stronger than gravity and the discontinuities will be detected even though they may be in an overhead specimen.

IV. PENETRANT EQUIPMENT AND MATERIALS

Penetrant Equipment

Penetrant systems range from simple portable kits to large, complex in-line test systems. The kits contain pressurized cans of the penetrant, cleaner/remover, solvent, and developer and, in some cases, brushes, swabs, and cloths. A larger fluorescent penetrant kit will include a black light. These kits are used when examinations are to be conducted in remote areas, in the field, or for a small area of a test surface. In contrast to these portable penetrant kits, there are a number of diverse stationary-type systems. These range from a manually operated penetrant line with a number of tanks, to very expensive automated lines, in which most steps in the process are performed automatically. The penetrant lines can be very simple, as illustrated in Figure 4-2.

In this particular system, there is a tank for the penetrant, a tank for the water rinse, a drying oven, and a developer station. The final station is the examination area, which includes a black light. This manually operated system is a typical small water-removable penetrant line. The steps in the testing process would be: cleaning of the parts, application of the penetrant, removal of the penetrant with a water spray, drying, application of the developer, and finally, inspection. This entire process is covered in much greater detail in Section V, Techniques.

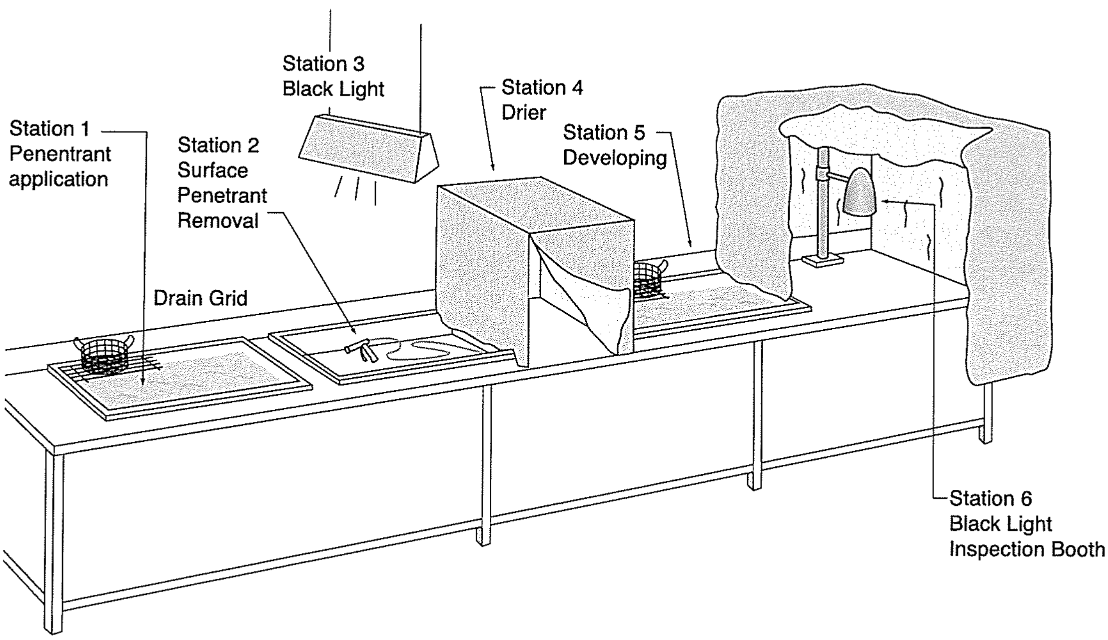


FIGURE 4-2 Typical fluorescent penetrant line arrangement.

If a postemulsifiable penetrant is to be used, the manually operated line will require an additional tank. This tank will contain an emulsifier that will render the surface penetrant removable after a specified emulsification time. Again, this technique will be covered in much greater detail later in this chapter. The automatic penetrant lines in use today vary from small, rather simple systems to very large complex lines that are computer controlled. Figure 4-3 illustrates a large automatic penetrant line.

Although the steps in an automated penetrant system have been somewhat mechanized, it is interesting to note that the examinations still must be conducted by inspectors who have been trained and are qualified in the process. The arrangement of these large automated penetrant lines vary with different layouts to permit the most flexibility from the standpoint of processing the parts. Normally, the systems will be arranged in a straight line; however a U shape or other configuration may be used to provide more effective use of floor space.

Other Equipment

The *black light* (see Figure 4-4) is an essential accessory for fluorescent penetrant inspection. Black lights used in penetrant testing typically produce wavelengths in the range of

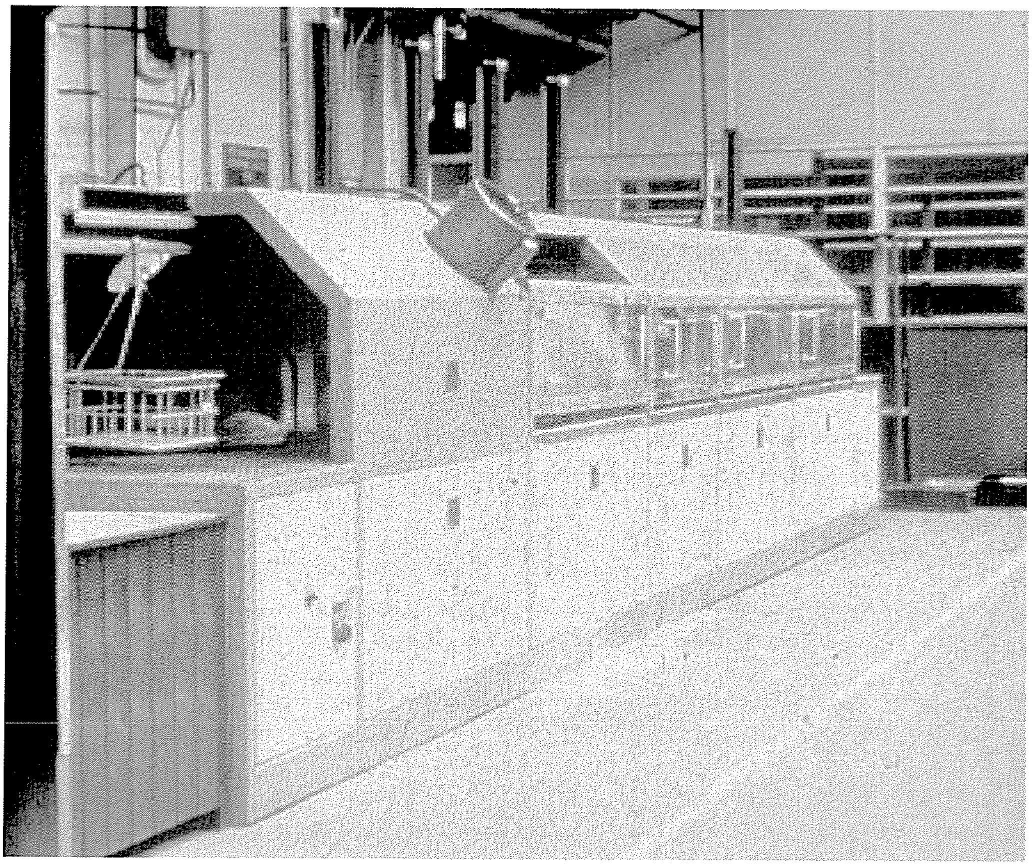


FIGURE 4-3 Automated fluorescent penetrant line.

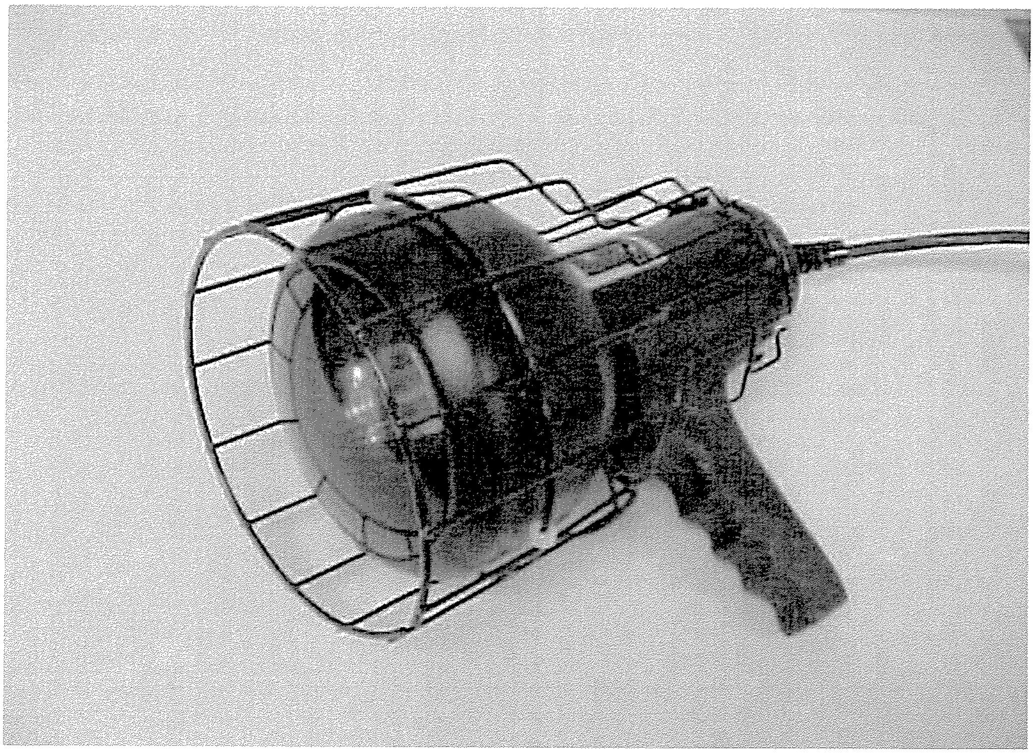


FIGURE 4-4 Black light.

315 to 400 nm (3150–4000 Angstrom units) and utilize mercury vapor bulbs of the sealed-reflector type. These lights are provided with a "Woods" filter, which eliminates the undesirable longer wavelengths. Black light intensity requirements will range from 800–1500 microwatts per square centimeter ($\mu W/cm^2$) at the test surface. Specific requirements will vary, depending upon the code or specification(s) being used. Recent developments in black light technology provide lights that can produce intensities up to 4800 $\mu W/cm^2$ at 15″ (38.1 cm).

Light intensity meters are used to measure both white light intensities when visible PT is used and black light intensities for fluorescent penetrant techniques. This measurement is necessary to verify code compliance and to assure that there is no serious degradation of the lights. Some meters are designed to measure both white light and black light intensities.

Test panels, including comparator blocks, controlled cracked panels, tapered plated panels, and others for specific industries such as the TAM panel (typically used in aerospace), are employed to control the various attributes of the PT system. They also provide a means for monitoring the materials and the process. This is discussed in Section X, Quality Control Considerations.

In summary, the equipment used will be greatly influenced by the size, shape, and quantity of products that are to be examined. If there are large quantities involved on a continuing basis, the use of an automated system may be appropriate, whereas with small quantities of parts, the use of penetrant kits may be more suitable. The size and configuration of the part will also influence the type of penetrants that will be most appropriate.

Penetrant Materials

The various materials that will be used in the different penetrant processes must exhibit certain characteristics. Above all, these materials must be compatible with each other and collectively provide the highest sensitivity for the application. The term "penetrant family" is sometimes used to indicate a group of materials all from the same manufacturer. The intent is to provide a degree of assurance that the different materials will be compatible with each other. There are usually some provisions for using materials outside the "family" if the combination of the different materials can be proven compatible through qualification tests.

The materials used in the penetrant process are classified into four groups. The characteristics for each will be presented in detail. The first group of materials that are essential for a penetrant test are precleaners. The second group of materials, which has the greatest influence on sensitivity, are penetrants. The third group comprises the emulsifiers and solvent removers, and the fourth group the developers.

Precleaners

Precleaning is an essential first step in the penetrant process. The surface must be thoroughly cleaned to assure that all contaminants and other materials that may prohibit or restrict the entry of the penetrant into surface openings are removed. Thorough cleaning is essential if the examination results are to be reliable. Not only does the surface have to be thoroughly cleaned, but openings must be free from contaminants such as oil and water, oxides of any kind, paint or other foreign material which can greatly reduce the penetrant sensitivity.

Typical cleaners include the following.

Solvents are probably the most widely used liquids for precleaning parts in penetrant testing. There are a variety of solvents that can be effective in dissolving oil, films, grease, and other contaminants. These solvents should be free of any residues that would remain on the surface. Solvents cannot be used for the removal of spatter, rust, or similar materials on the surface. These must be removed by some type of a mechanical cleaning process (see Section V, Prerequisites).

Ultrasonic Cleaning. Of all the precleaner materials and processes, ultrasonic cleaning is probably the most effective. Not only will the contaminants be removed from the surface, but also if there are entrapped contaminants in discontinuities and other surface openings, the power that is generated in the ultrasonic cleaning process will usually be effective in breaking up and removing them. A typical small ultrasonic cleaner is illustrated in Figure 4-5.

Alkaline cleaning. Alkaline cleaners used for precleaning are nonflammable water solutions that, typically, contain specially selected detergents that are capable of removing various types of contamination.

Steam Cleaning. In some rare instances, steam may be used to remove contaminants from the surface. Although very effective in removing oil-based contaminants, this is not a widely used technique.

Water and detergent cleaning. There are various devices that utilize hot water and detergents to clean part surfaces. This technique depends largely upon the type of contamination that is present on the test surfaces. Usually, if parts are covered with oil or grease, the contaminants will not be satisfactorily removed from the surface with this cleaning technique.

Chemical cleaning. Chemical cleaning techniques usually involve etchants, acids, or alkaline baths. This precleaning approach is primarily confined to softer materials, such as aluminum and titanium, where prior mechanical surface treatments, such as machining

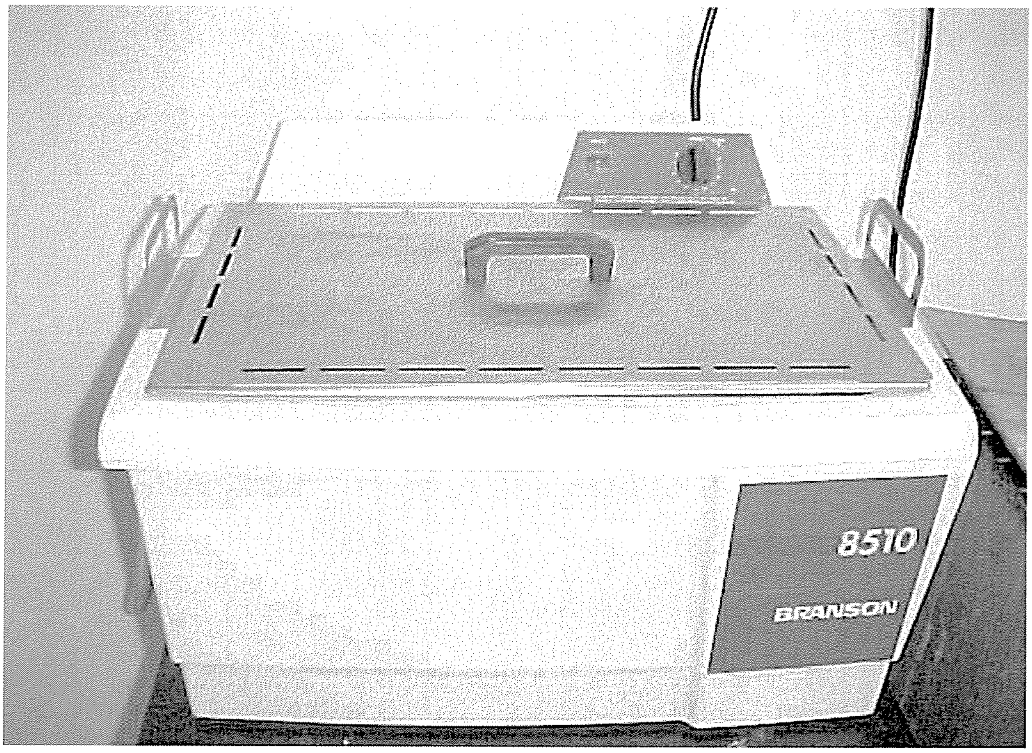


FIGURE 4-5 Ultrasonic cleaner.

or grinding, could possibly have smeared metal over discontinuity openings. Both acid or alkaline liquids are usually effective in the removal of rust and surface scale; however, a slight amount of the surface material is also removed, so this process must be very carefully controlled. Steps must be taken to assure the complete removal of these liquids from all surface openings.

Penetrants

The most important characteristic that affects the ability of a penetrant to penetrate an opening is that of "wetability." Wetability is a characteristic of a liquid and its response to a surface. If a drop of water is placed on a very smooth, flat surface, a droplet with a very pronounced contour will result, as shown in Figure 4-6(c). Although water is a liquid and is "wet," its wetting characteristics are not good enough to make it an effective penetrant.

The "contact angle," θ, is measured from a line drawn in an arc from its junction point with the surface to the opposite surface (see Figure 4-6). If that same droplet of liquid is emulsified, such as would be the case with the addition of a small amount of liquid soap, the droplet will tend to flatten out and the contact angle will be somewhat decreased (see Figure 4-6(b). In the case of a liquid penetrant, its wetting properties are so great that it will, essentially, lie almost flat on a smooth surface and the contact angle will be very low, as in Figure 4-6(a). Therefore, the penetrants with the lowest contact angles will have the best wetability and provide good penetrability for a given material. Two other important characteristics of the penetrant are the dye concentrate and the viscosity. Dye concentrate has a major and direct influence on the "seeability" or sensitivity of the pene-

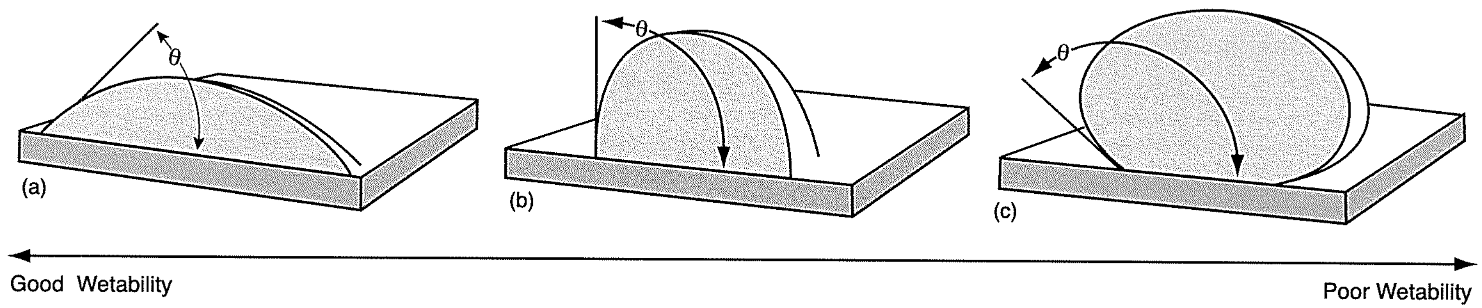


FIGURE 4-6 Wetability characteristics.

trant material, assuming that the wetting properties and the penetrability are of a very high level. The dye concentrate makes the penetrant more visable to the human eye. In some early penetrants, different colored dyes were tried, including blue, yellow, and green, but it seemed that the red dye resulted in the best response to visible observation. In fact, the term "contrast ratio" is generally used to express the seeability of a penetrant. If a white penetrant were used on a white developed background, the contrast ratio would be one-to-one. In other words, there would be no contrast between the penetrant and the background. In the case of a red penetrant, the contrast ratio is said to be six-to-one, making that contrast very noticeable on a white background surface. The dye concentrate is also important in a fluorescent penetrant. The contrast ratio of a fluorescent penetrant is said by many references to be forty-to-one, compared to the six-to-one of a visible red dye. In reality, the contrast ratio of the fluorescent penetrant being viewed under a black light in a virtually dark room would essentially be the same as would exist if there were a single candle in a perfectly pitch-black room. The contrast ratio in this case would be exceptional and, for this reason, the fluorescent penetrant produces a much higher degree of seeability or sensitivity as compared to the visible dye penetrants.

Viscosity is defined as the state or quality of being viscous. Liquids with higher viscosity values are thicker than those with lower ones. Although viscosity is an important characteristic of a penetrant, it is not as influential as the wetting characteristics and dye concentrate. If the penetrant has good wetting characteristics and exceptional dye concentration, it will still provide a meaningful examination, even if the viscosity is high. The difference in viscosity will influence the actual dwell time, or the amount of time that it will take for the liquid to effectively penetrate a given surface opening.

There are other characteristics that an effective penetrant should possess. In addition to being able to penetrate small surface openings, they must also:

- Be relatively easy to remove from the surface during the removal step
- Be able to remain in the discontinuities until they are withdrawn during the development step
- Be able to bleed from the discontinuities when the developer interacts with it and have the ability to spread out in the developer layer
- Have excellent color and the ability to be displayed as a contrasting indication in order to provide the sensitivity that is necessary
- Exhibit no chemical reaction between the penetrant materials and the test specimen
- Not evaporate or dry rapidly

In addition, they should be nonflammable, odorless, and nontoxic; possess stability under conditions of storage; and be cohesive, adhesive, and relatively low in cost.

In summary, the most important characteristics of a penetrant when performing a penetrant test are (1) capillary action, (2) wetting characteristics, (3) dye concentrate, and (4) viscosity.

Emulsifiers/Removers

The purpose of the emulsifiers used in penetrant testing is to emulsify or break down the excess surface penetrant material. In order for these emulsifiers to be effective, they should also possess certain characteristics, including:

- The reaction of the emulsifier with any entrapped penetrant in a discontinuity should be minimal in order to assure that maximum sensitivity is achieved.
- The emulsifier must be compatible with the penetrant.

- The emulsifier must readily mix with and emulsify this excess surface penetrant.
- The emulsifier mixed with the surface penetrant should be readily removable from the surface with a water spray.

Solvent Removers

Solvent removers are used with the solvent removable technique and must be capable of effectively removing the excess surface penetrant. There are a number of commercially available solvents that make excellent removers. These solvents should readily mix with the penetrant residues and be capable of removing the final remnants from the surface. They should also evaporate quickly and not leave any residue themselves. It is essential that the removers not be applied directly to the surface, since they are also good penetrants. Spraying or flushing the part with the solvent during the removal step is prohibited by many specifications. Even so, there are still users who insist on performing this unacceptable practice in order to "thoroughly" remove the surface penetrant. When using the visible color contrast penetrants, a slight trace of pink on the cloth or paper towel will indicate that the removal is adequate. For fluorescent penetrants, slight traces of the fluorescent penetrant as observed under the black light will also indicate the proper level of removal.

Developers

There are four basic types of developers:

1. Dry developer
2. Solvent-based developers, also referred to as "spirit" or nonaqueous
3. Wet developers suspended in water
4. Wet developers that are soluble in water

Developers have been described as "chalk" particles, primarily because of their white, chalk-like appearance.

In order for the developers to be effective in pulling or extracting the penetrant from entrapped discontinuities, thus presenting the penetrant bleed-out as an indication that can be evaluated, they should possess certain key characteristics. They should:

- Be able to uniformly cover the surface with a thin, smooth coating
- Have good absorption characteristics to promote the maximum blotting of the penetrant that is entrapped in discontinuities
- Be nonfluorescent if used with fluorescent penetrants
- Provide a good contrast background that will result in an acceptable contrast ratio
- Be easily applied to the test specimen
- Be inert with respect to the test materials
- Be nontoxic and compatible with the penetrant materials
- Be easy to remove from the test specimen after the examination is complete

There are other types of developers that are used on rare occasions. These are referred to as strippable, plastic film, or lacquer developers. They are typically nonaqueous suspensions containing a resin dissolved in the solvent carrier. This developer sets up after application and is then stripped off the surface, with the indications in place. It can then be stored and maintained as part of the inspection report.

V. PENETRANT PROCEDURES

Selecting the correct technique for penetrant testing is very important. Prior to performing the examination, a procedure should be developed and qualified. When preparing the procedure, the following should be considered:

- The requirements of the code, specification, or contract
- The type and size of discontinuity that is anticipated
- The surface condition of the test specimen
- The configuration of the part
- The quantity of parts to be examined
- Systems and equipment that are available

Prerequisites

Prior to any penetrant test, there are certain prerequisites that have to be addressed.

Temperature
Penetrant materials are influenced by temperature variations. Most codes and specifications require that the test part and the penetrant materials be within a specified temperature range, typically between 40 °F (4.4 °C) up to as high as 125 °F (51.6 °C). The part and the penetrant materials must fall within the specified temperature range. If the test part or the penetrant is extremely cold, the penetrant becomes very thick and viscous, which will affect the time it will take to penetrate the discontinuities. If the test surface or penetrants are high in temperature, some of the more volatile constituents may evaporate from the penetrant, leaving a thick residue that will not effectively penetrate the discontinuities.

Environmental Considerations
Since some of the solvent cleaners and removers used with penetrant testing can be somewhat flammable, it is essential that the penetrant test be performed in an area where there are no open flames or sparks that may tend to cause the penetrant materials to ignite. Typically, penetrant materials have relatively high flash points, but some of the cleaner/remover solvents could ignite when exposed to sparks or open flames. Also, some of the solvents may give off fumes. Therefore, penetrant testing should be performed in an area where there is adequate ventilation.

Lighting
There must be adequate lighting in the examination area, especially during the time when the evaluation is performed.

Surface Condition Considerations
Surfaces to be examined having coatings such as paint or plating, or extremely rough conditions, must be addressed. If the surface contains scale and rust, some type of strong mechanical cleaning process is required. Many codes and specifications do not permit the use of some mechanical cleaning techniques, such as shot-blasting, shot-peening, or sandblasting, since these processes tend to peen over the test surface, potentially closing a crack or other surface discontinuity. If wire brushing is used to remove scale or rust, it should be

done with extreme care for the same reason. If extreme pressure is applied to a grinding wheel or power wire brush, it is possible to cause a smearing of the metal on the surface.

The Penetrant Procedure

Precleaning

After addressing the prerequisites, it is necessary to remove all contaminants from the surface and, after the surface has been cleaned, all evidence of any residues that may remain. (See Figure 4-7) After precleaning, it is essential that the precleaners evaporate and that the test surface be totally dry prior to application of the penetrant. This will prevent contamination or dilution of the penetrant in the event that it interacts and becomes mixed with the precleaner.

Penetrant Application

The penetrant can be applied to the surface of the test part in virtually any effective manner, including brushing (Figure 4-8), dipping the part into the penetrant, immersion, spraying, or just pouring it on the surface. Figure 4-9 shows a water-removable fluorescent penetrant being applied with an electrostatic sprayer. The key is to assure that the area of interest is effectively wetted and that the penetrant liquid does not dry during the penetration or *dwell time,* which is the period of time from when the penetrant is applied to the surface until it is removed. The codes and specifications give detailed dwell times that must be followed. It is quite common to have a dwell time of 10 to 15 minutes for many applications.

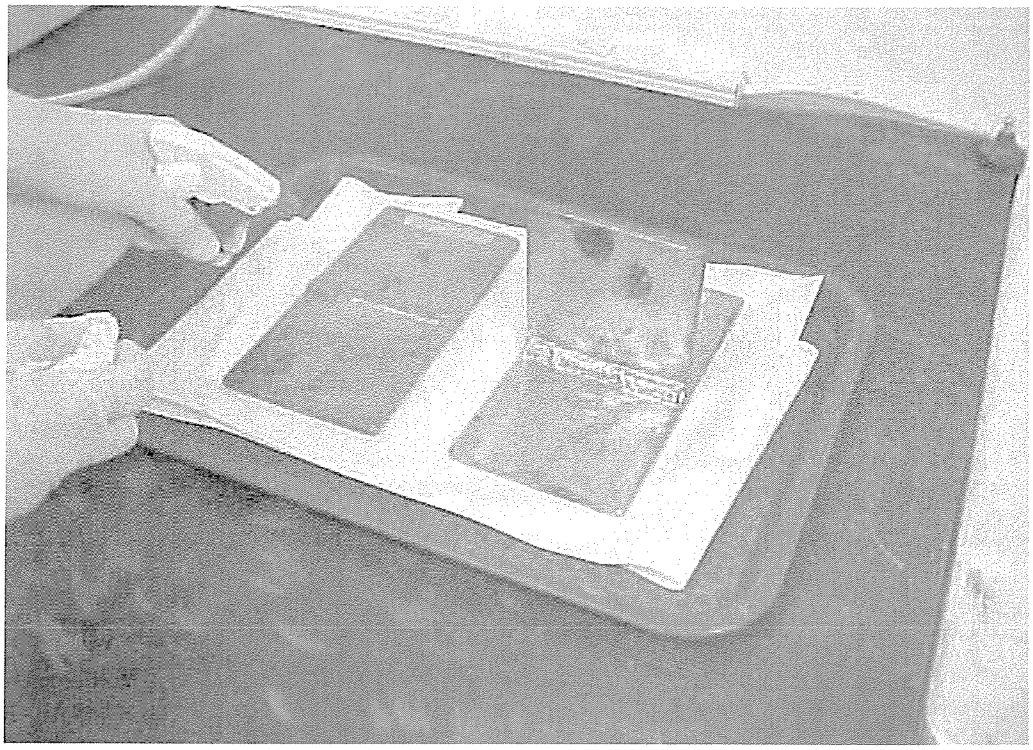


FIGURE 4-7 Precleaning of a weld surface.

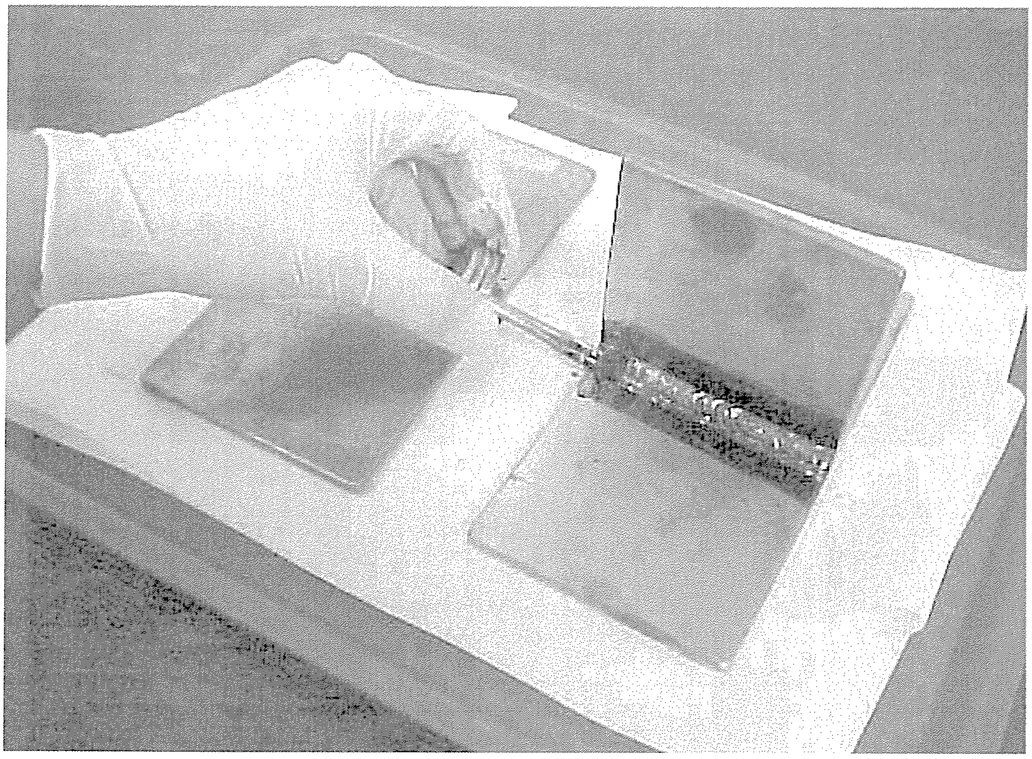


FIGURE 4-8 Application of a visible penetrant.

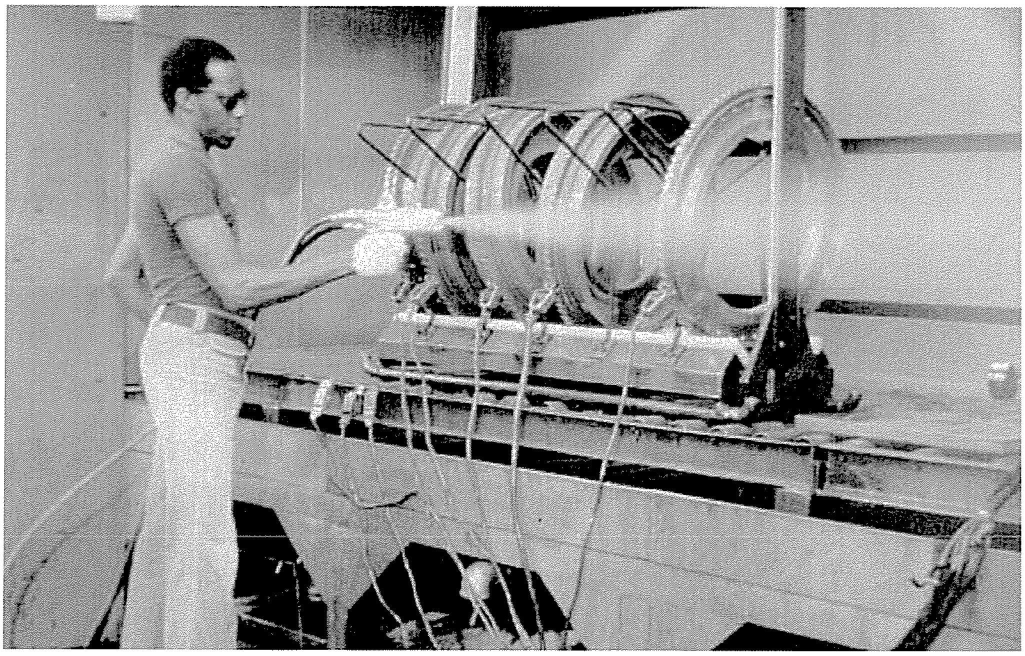


FIGURE 4-9 Water-removable fluorescent penetrant being applied with electrostatic spray.

Penetrant Removal

In this step the excess surface penetrant is removed from the test specimen surface; the method of removal depends on the type of penetrant that is being used. There are three techniques for excess surface penetrant removal: water, emulsifiers, and solvents. Figure 4-10 illustrates excess surface visible contrast penetrant being removed with a solvent-dampened cloth. Removal of fluorescent penetrants is usually accomplished under a black light. This provides a means of assuring complete removal of the excess surface penetrant while minimizing the possibility of overremoval.

Application of Developer

The type of developer to be used will be specified in the penetrant procedure. As mentioned above, the four types of developers are dry, nonaqueous, aqueous suspendable, and aqueous soluble. The entire test surface or area of interest must be properly developed, although there are rare applications where developers are not used. A nonaqueous developer is applied by spraying (See Figure 4-11). It must be applied in a thin, uniform coating. Thick layers of developer, whether nonaqueous, dry, or aqueous, can tend to mask a discontinuity bleed-out, especially if that discontinuity is small and tight.

Development Time

The developer must be given ample time to draw the entrapped penetrant from the discontinuity out to the test surface. Many codes and specifications will require a development time from 7 to 30 minutes and, in some cases, as long as 60 minutes. Development is de-

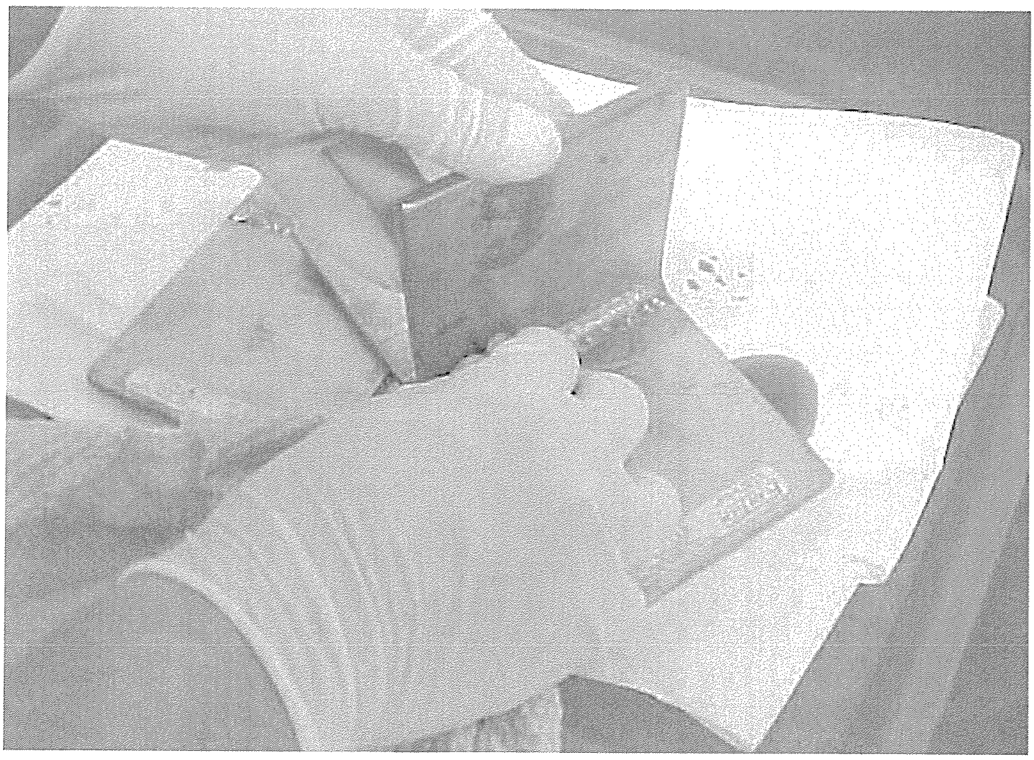


FIGURE 4-10 Removal of excess surface penetrant.

FIGURE 4-11 Application of a nonaqueous developer.

fined as the time it takes from the application of the developer until the actual evaluation commences. It is recommended that the surface be observed immediately after the application of the developer to assist in the characterizing and to determine the extent of the indication(s).

Interpretation

Upon completion of the development time, the indications from discontinuities or other sources that have formed must be interpreted. A visible contrast penetrant bleedout is illustrated in Figure 4-12 and fluorescent penetrant indications are shown in Figure 4-13. Bleedouts are interpreted based primarily on their size, shape, and intensity (see Section VII).

Postcleaning

After the part has been evaluated and the report completed, all traces of any remaining penetrant and developer must be thoroughly removed from the test surface prior to it being placed into service or returned for further processing.

VI. TECHNIQUES AND VARIABLES

It should be apparent by now that there are a number of PT techniques that can be used with the different materials described. A summary of these techniques is listed in Table 4-1. A detailed description of each technique follows. (*Note:* The technique and process designations in this section are for simplification and do not directly relate to code or specification classifications.)

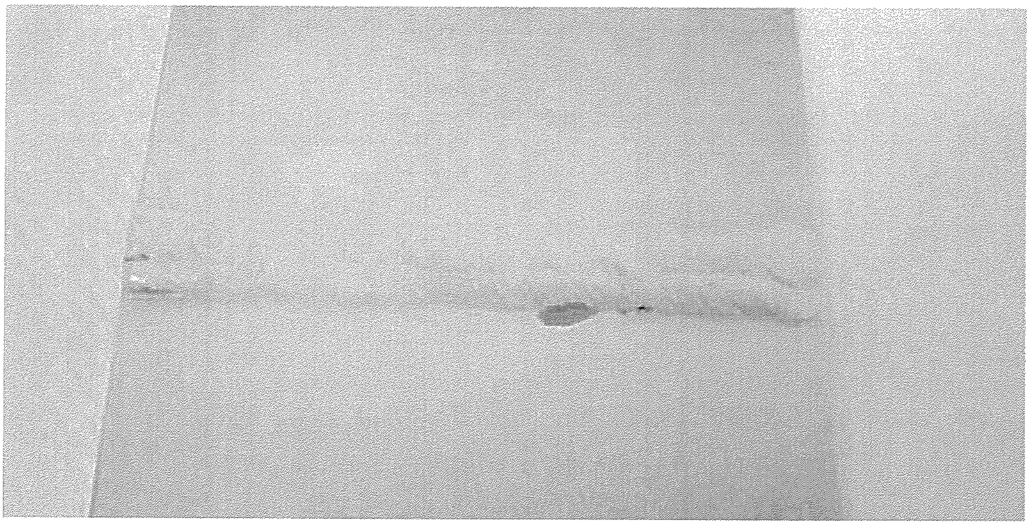


FIGURE 4-12 Indication of a bleedout.

Technique I, Process A (I-A)

Technique I Process A uses a fluorescent water-removable penetrant that can be used with either dry, aqueous, or nonaqueous developers (see Figure 4-14). This technique is generally used for the following applications:

1. When a large number of parts or large surface areas are to be examined
2. When discontinuities that are not broad or shallow are anticipated
3. When parts to be examined have complex configurations such as threads, keyways, or other geometric variation

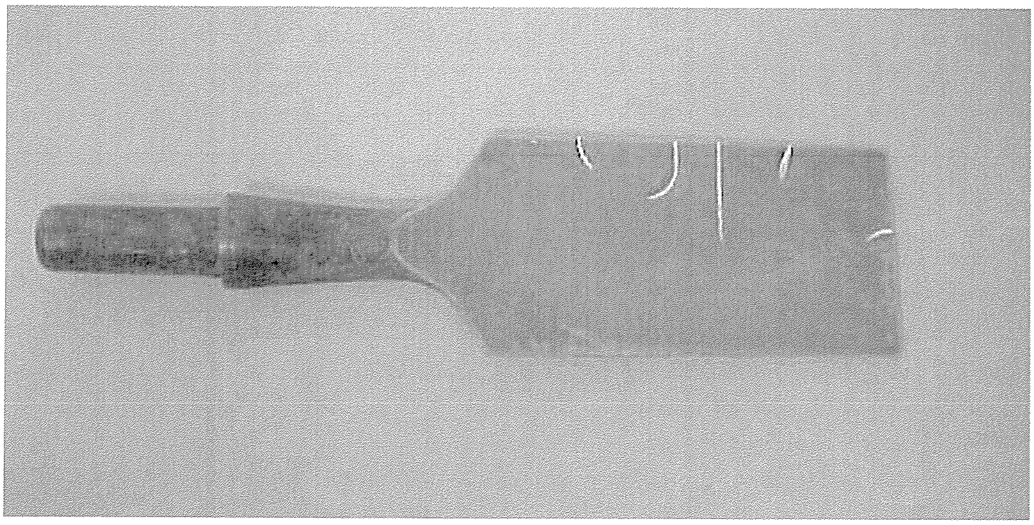


FIGURE 4-13 Fluorescent penetrant bleedouts.

TABLE 4-1 Penetrant Technique Classification Summary

Technique	Process	Materials
I (Fluorescent)	A (Figure 4-14)	Water-removable penetrant; dry, aqueous, or nonaqueous developer
	B (Figure 4-15)	Postemulsifiable penentrant; lipophilic emulsifier; dry, aqueous, or nonaqueous developer
	C (Figure 4-16)	Solvent-removable penetrant; solvent cleaner/remover; dry or nonaqueous developer
	D (Figure 4-17)	Same as I B except the emulsifier is hydrophilic
II (Visible, color contrast)	A (Figure 4-14)	Water-removable penetrant; aqueous or nonaqueous developer
	B (Figure 4-15)	Postemulsifiable penetrant, emulsifier, and aqueous or nonaqueous developer
	C (Figure 4-16)	Solvent-removable penetrant; solvent cleaner/remover, aqueous or nonaqueous developer

4. When the parts to be examined have surfaces that are rough, such as with sand castings or as-welded conditions

Advantages:

1. Higher sensitivity
2. Excess penetrant is easily removed with a coarse spray
3. Easily adaptable for large surfaces and large quantities of small parts
4. The cost is relatively low

Limitations:

1. A darkened area is required for evaluation
2. Under- or overremoval of penetrant material is possible
3. Water contamination can degrade the effectiveness of the penetrant
4. Not effective for broad or shallow discontinuities
5. Dryers are required (usually) when using developers
6. This technique is usually not portable

Technique I Process B (Lipophilic) and Process D (Hydrophilic)

Technique I, Processes B and D use a fluorescent postemulsifiable penetrant, a lipophilic (L) or hydrophilic (H) emulsifier, and dry, aqueous, or nonaqueous developers. (Figures 4-15 and 4-17 illustrate overviews of Processes B and D, respectively.) The materials used are very similar to those described for Technique I Process A, except that these penetrants are not water-removable without emulsification. A lipophilic or hydrophilic emul-

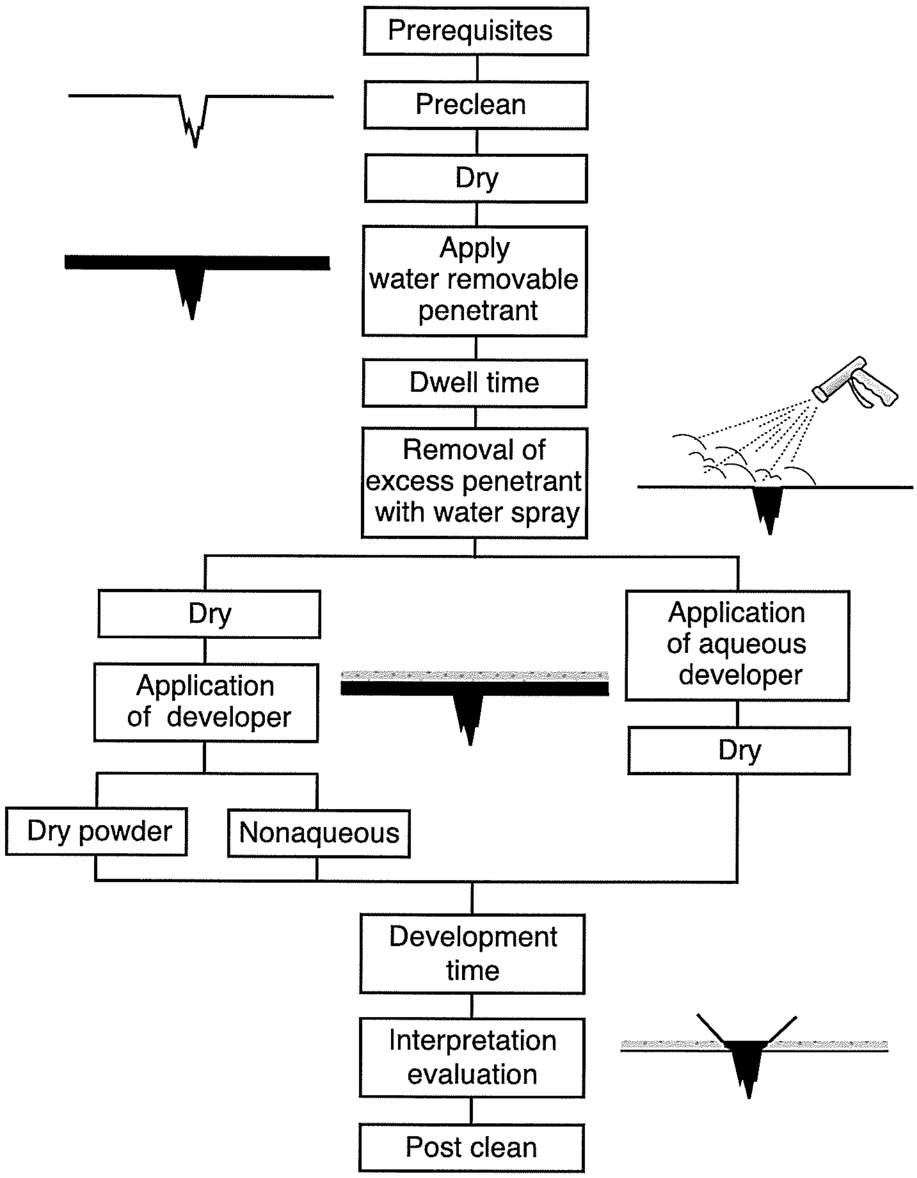


FIGURE 4-14 Water-removable technique (Process I-A or II-A).

sifier must be used after the dwell time has expired. This technique is generally used in the following situations:

1. When a large quantity of parts must be examined
2. When discontinuities that are broad and shallow are anticipated
3. For the detection of stress cracks or intergranular corrosion
4. For the detection of small discontinuities such as grinding cracks
5. Applications requiring higher-sensitivity techniques

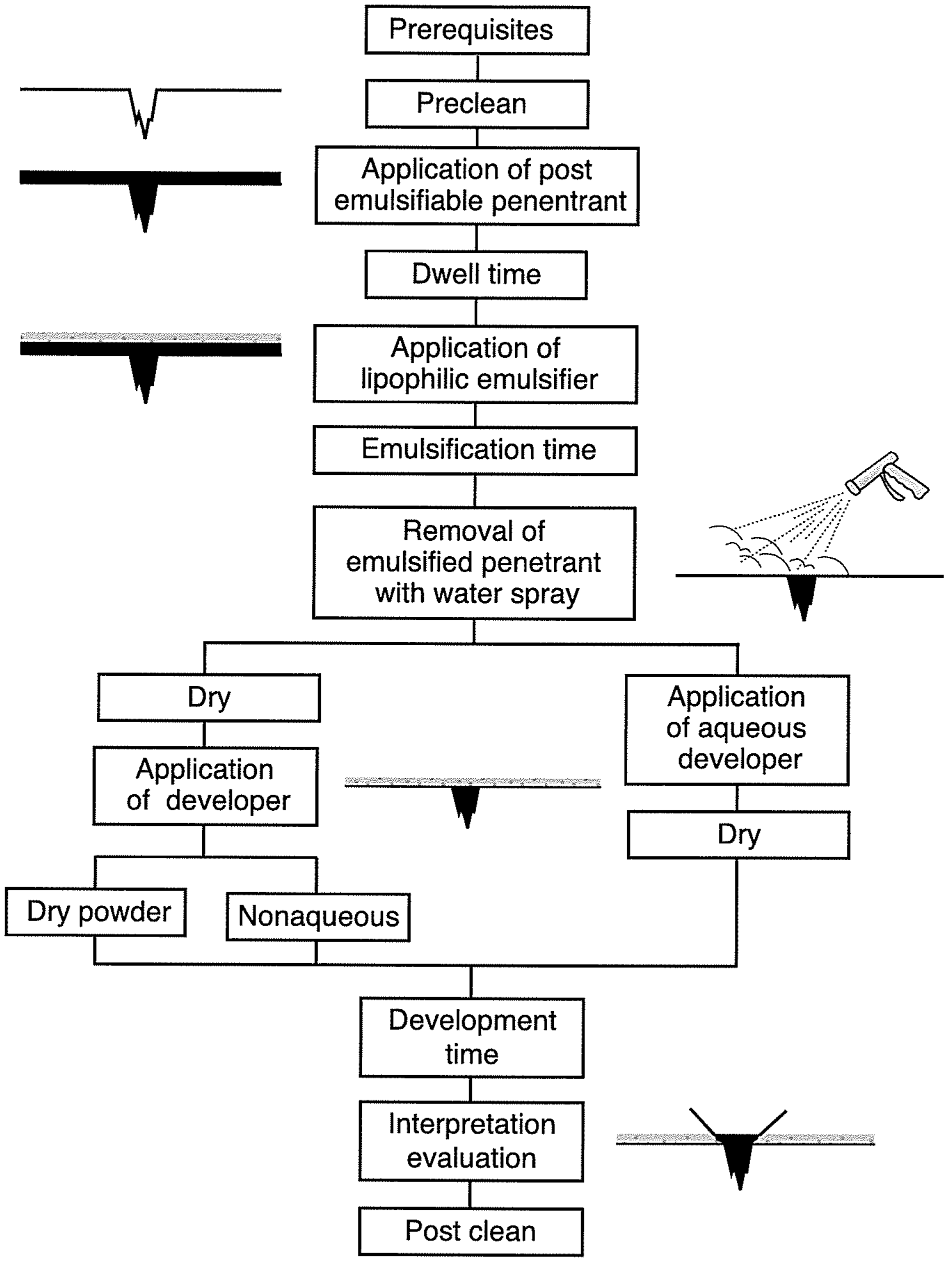


FIGURE 4-15 Postemulsifiable technique (lipophilic) (Process I-B or II-B).

Advantages:

1. High sensitivity for the detection of smaller discontinuities
2. For broad or shallow discontinuities (when they are expected)
3. Adaptable for high-quantity testing
4. Not easily affected by acids
5. Less susceptible to overremoval than Technique I-A

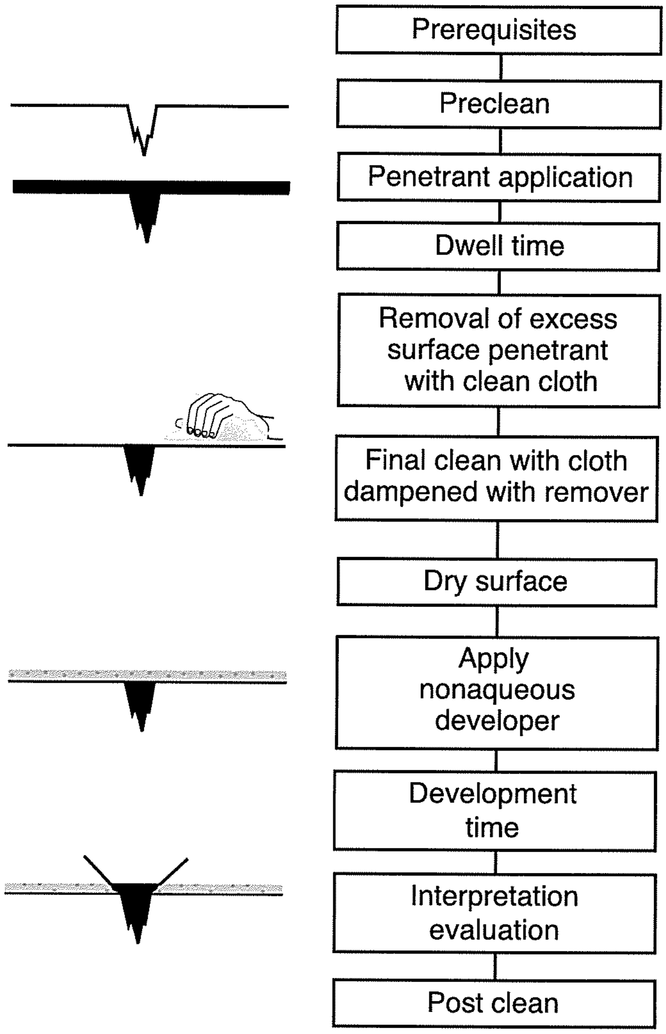


FIGURE 4-16 Solvent-removable technique (Process I-C or II-C).

Limitations:

1. This technique has an additional step, which requires an emulsifier. Therefore, more time and material is necessary.
2. It is not as effective for parts with complex shapes (e.g., threads) or rough surfaces, as is Technique I-A.
3. The emulsification time must be closely controlled.
4. As with Technique I-A, it requires drying prior to the application of dry or nonaqueous developers.
5. It is usually not portable.

Technique I, Process C (I-C)

Technique I Process C uses a fluorescent penetrant, which is solvent-removable, a solvent cleaner/remover, and a nonaqueous developer. The excess surface penetrant is first re-

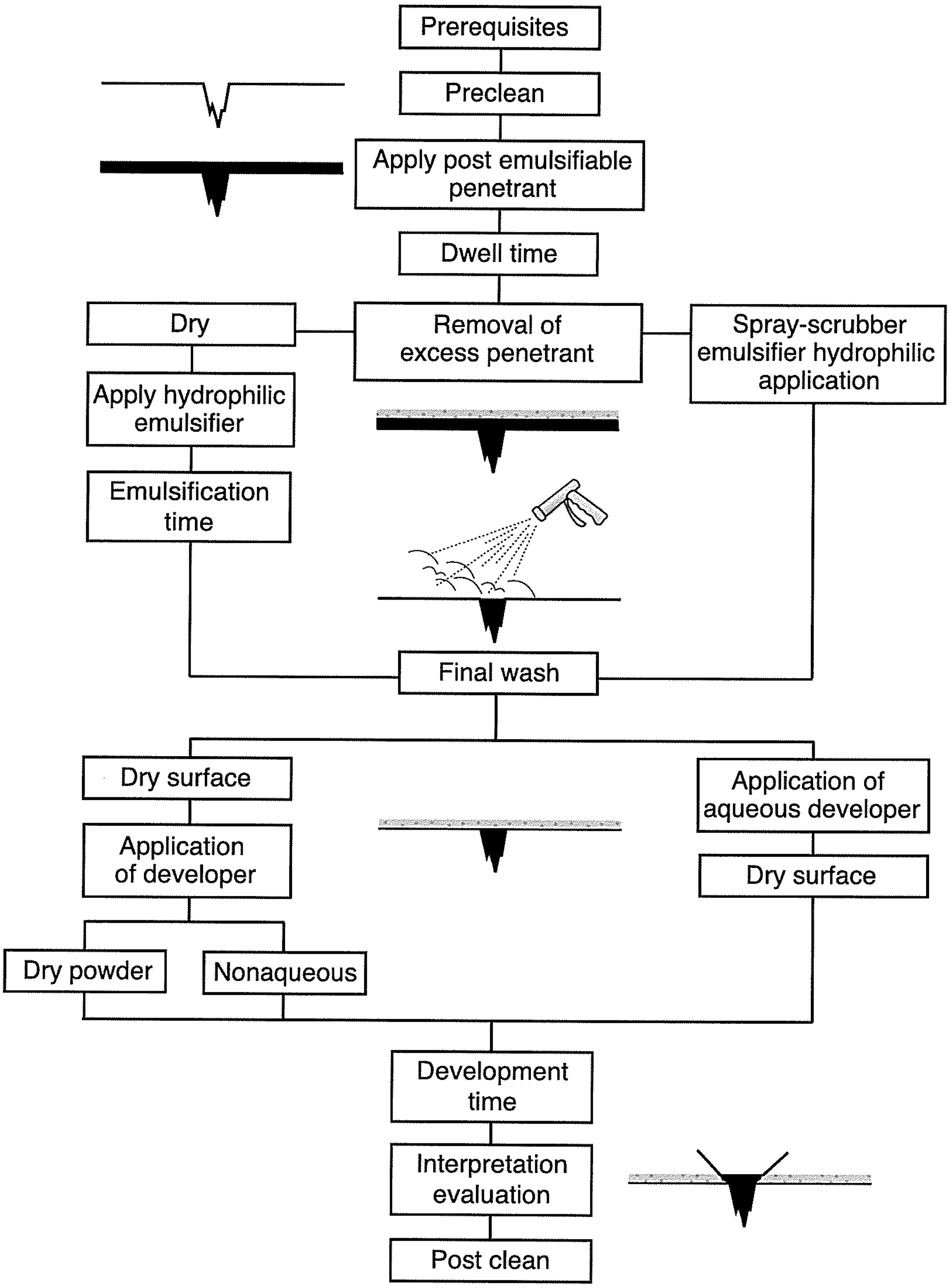


FIGURE 4-17 Postemulsifiable technique (hydrophilic) (Process I-D).

moved with a dry cloth, followed by cleaning with a cloth dampened with a solvent remover. (Figure 4-16 illustrates an overview of Technique I-C.) This process is generally used when removal with water is not desirable due to part size, weight, surface condition, water availability, or when a heat source is not readily available for drying.

Advantages:

1. Can be used for spot examinations on large parts
2. Effective when water removal is not feasible

Limitations:

1. The use of solvent for removal limits this technique to smaller areas
2. A black light and darkened area are required
3. The sensitivity can be reduced if excessive remover is applied
4. A "background" may occur with this technique, which could affect the contrast ratio, especially with rougher surfaces

Technique II Process A (II-A)

Technique II Process A uses a visible color-contrast, water-removable penetrant and an aqueous or nonaqueous developer. Dry developer is not usually used with Technique II penetrants. Some specifications, in fact, do not permit the use of dry developers with Technique II penetrants. Figure 4-14 illustrates Technique II-A.

The penetrant contains an emulsifier, making it water-removable. This technique is generally used for the following applications:

1. Examinations of a large quantity of parts or large surface areas
2. For discontinuities that are generally tight
3. For the examination of parts with threads, keyways, and other complex geometries
4. For parts with generally rough surfaces

Advantages:

1. No blacklight or darkened area is required for evaluation.
2. It is relatively quick and inexpensive.
3. The excess penetrant is easily removed with a coarse water spray.
4. It is effective for the examinations of a large quantity of parts.
5. It can be used for rough surfaces, keyways, threads, and other complex geometries.

Limitations:

1. Its sensitivity is inferior to Technique I-A.
2. Penetrant can be overremoved.
3. Water contamination can degrade the effectiveness of the penetrant.
4. It is not usually effective for the detection of broad or shallow discontinuities.

Technique II Process B (II-B)

Technique II Process B uses a visible color-contrast, postemulsifiable penetrant, an emulsifier, and an aqueous or nonaqueous developer. The materials used (except for the penetrant) are very similar to those described for Technique I Process B (as illustrated in Figure 4-15). An emulsifier (usually lipophilic) is applied to the surface penetrant after the dwell time to make it water-removable. Technique II Process B is generally used for the following applications:

1. When a large quantity of parts must be examined
2. Whenever lower sensitivity than that achieved with Technique I is acceptable
3. When broad and shallow discontinuities are anticipated

Advantages:

1. No black light or darkened area for evaluation is required.
2. Broad or shallow discontinuities may be detected.
3. Useful when there are large quantities of parts to be examined.
4. This technique is not as susceptible to overremoval, as are the Process A penetrants.

Limitations:

1. The additional step of an emulsifier requires more time and additional material.
2. It is not as effective for parts with a complex geometry (e.g., threads), as is Process A.
3. The emulsification time is very critical and must be closely controlled.
4. Drying is required if nonaqueous developers are used.

Technique II, Process C (II-C)

Technique II Process C uses a visible, color-contrast, solvent-removable penetrant, a solvent cleaner/remover, and an aqueous or nonaqueous developer. Figure 4-16 illustrates this technique.

The excess penetrant is not water-removable and must be removed with a solvent remover. This technique is widely used for field applications when water removal is not feasible, or when examinations are to be conducted in a remote location.

Advantages:

1. This technique is very portable and can be used virtually anywhere.
2. It can be used when water removal is not possible.
3. Black lights or darkened evaluation areas are not required. Evaluation is done in visible light.
4. It is very adaptable for a wide range of applications.

Limitations:

1. The use of solvent to remove excess surface penetrant limits the examinations to smaller areas and parts without a complex geometry.
2. Sensitivity is reduced when an excessive amount of remover is used during the removal step.
3. Excess penetrant removal is difficult on rough surfaces, such as sand casting and as-welded surfaces, and usually results in a "background."

4. This technique has a lower level of sensitivity compared to Technique I penetrants.
5. It is more "operator-dependent" due to the variables involved in the removal step.

Summary

Of all the techniques described in Section VI, the most widely used fluorescent penetrant technique is I-A (water-removable). Technique II-C is the most widely used visible color-contrast penetrant.

VII. EVALUATION AND DISPOSITION

After the penetrant process has been completed and the indications are observed and recorded, the final step will be to establish whether or not these conditions are acceptable or rejectable. The size of the indication can usually be related to the amount of penetrant entrapped in the discontinuity. The larger the discontinuity volume, the greater the amount of penetrant that will be entrapped and, therefore, the larger the bleed-out after development. The shape of the indication is important because it relates to the type or nature of the discontinuity; e.g., a crack or lack of fusion will show up as a linear bleed-out rather than a rounded one. A linear indication, by most codes and specifications, is defined as a bleed-out whose length is three times or greater than its width. The intensity of the bleed-out gives some evidence as to how tight the discontinuity is. A broad shallow-type discontinuity will tend to be diluted, to an extent, by the remover liquid, and not be as brilliant as a bleed-out from a very tight discontinuity. It is essential that corrective action be taken to remove or repair the discontinuity if it is deemed to be rejectable. In most cases, a crack or other serious discontinuity will be cause for the rejection or scrapping of the part. Repairs to discontinuities will often be accomplished by grinding. A recommended technique to assure complete removal of an indication after grinding is to merely reapply the developer. This usually verifies whether the discontinuity has been removed, since the bleedout will reappear if it has not (see Figure 4-18).

This process should be repeated, i.e., grinding, reapplication of developer, and then grinding again until no further bleedout occurs. At that point, the area that has been ground out must be reexamined, following the penetrant procedure from the beginning, to assure that in fact, the discontinuity has been totally removed. It is further recommended that the grinding be performed in the same direction as the longest dimension of the discontinuity. This is to minimize the possibility of smearing the material over the discontinuity. After the repair is completed, the repaired surface must be reexamined. During the evaluation process, it is necessary that a suitable light source be used. For visible penetrants, a light source of 100 foot-candles is common, although codes and specifications may require different light intensities. A black light is used for evaluation of fluorescent penetrants, as seen Figure 4-19. An intensity of between 800 to 1200 μW per square centimeter is typically required.

Penetrant indications must be recorded. For recording purposes, a number of satisfactory techniques can be used, including photographs, hand sketches, and the transparent tape lift-off technique. Photographic techniques employed for recording visible penetrant indications are quite standard. When photographing indications under black light conditions, specialized exposures and filters may be necessary when using photographic film. Digital cameras are usually quite exceptional for recording both visible and fluorescent

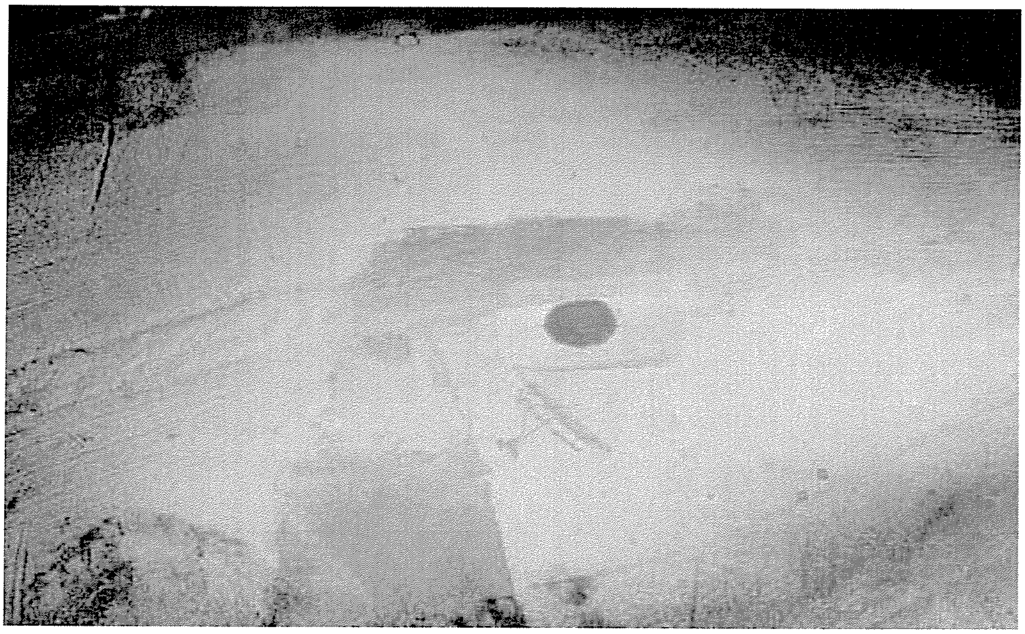


FIGURE 4-18 Initial grindout of an indication.

penetrant indications. In addition, the digital image can be observed immediately after exposure. Hand drawings, when used with test reports, should be prepared with as much accuracy and detail as possible. The transparent tape lift-off technique is usually very effective for visible dye penetrants, since the tape can be placed directly on the developed indication, lifted off, then placed on the test report. This will provide a means of displaying the actual bleed-out indication with its true size and intensity. This technique is not

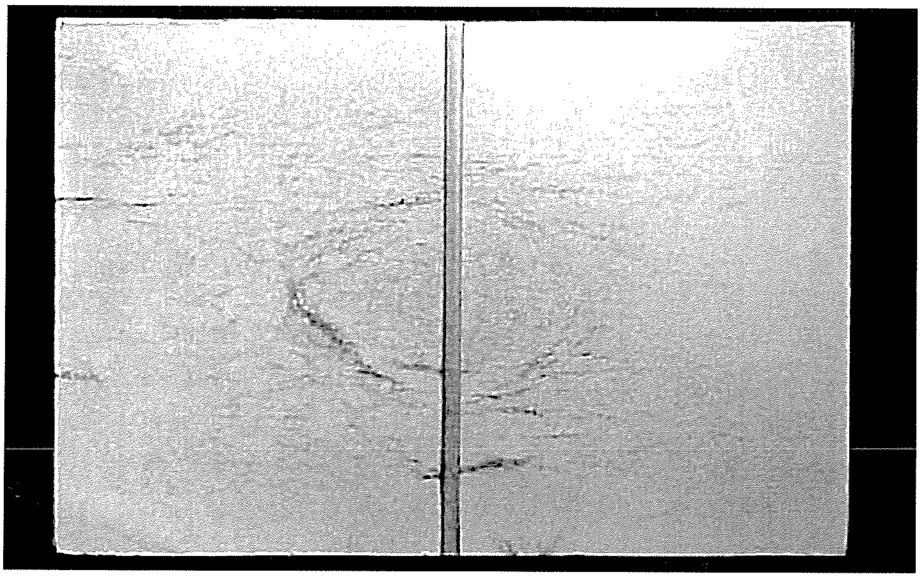


FIGURE 4-19 Comparator block.

usually effective with fluorescent penetrants, unless the test report is to be evaluated under a black light.

VIII. PENETRANT TESTING APPLICATIONS

Penetrant testing is extremely versatile and has many applications. It is used in virtually every major industry and for a wide variety of product forms. Industries that widely use penetrant testing techniques include:

Power generation, both fossil- and nuclear-fueled

Petrochemical

Marine/Shipbuilding

Metalworking, including foundries and forging shops

Aerospace

Virtually all of the various welding processes and metals-joining industries

Another unique application of penetrant testing is for the detection of through-wall leaks. With this application, penetrant is applied to one surface, for example, of a tank, and developer applied to the opposite surface. If there is an unimpeded through leak, the penetrant will follow that path and be exposed on the opposite developed surface as an indication. Some leak tests, such as those for complex components and piping systems that must be evaluated to determine the source and location of a leak path, are conducted using fluorescent tracers.

IX. QUALITY CONTROL CONSIDERATIONS

In order to control the many variables associated with penetrant testing, there are a number of quality control (QC) checks that should be made periodically. The applicable requirements will specify which ones must be made and how often. There are three major areas that include the various QC issues, and once these are identified as essential or required, they should be added to the procedure. The three major categories are:

1. Material checks
   - New
   - In-use
2. System checks
3. Equipment checks

Material Checks—New

All incoming or new penetrant materials should be verified to assure compliance with specifications. Some codes and specifications contain unique requirements regarding the presence of contaminants in the PT materials such as chlorine, sulfur, and halogens. Some codes and standards include analytical tests to determine the amount of these contaminants but most of the penetrant manufacturers will provide material certifications that specify the amount in that particular batch of materials. Each can or container of the penetrant will have the batch number clearly marked to make it easy to correlate with the certifications. These certifications should be maintained in the QA files for future reference and for ready access in the event of an audit.

Material Checks—In-Use

It is good practice, and in some cases a requirement, that penetrant materials be checked periodically to assure that they have not degraded and are still performing satisfactorily. These checks may include but are not limited to the following:

1. Contamination of the penetrant
2. Water content in the penetrant (for water-removable penetrants)
3. Water content in lipophilic emulsifier
4. The condition of the dry developer (fluorescent penetrant carry-over, etc.)
5. Wet developer contamination
6. Aqueous developer concentration (using a hydrometer)
7. Hydrophilic emulsifier concentration

The results of these checks should be entered in a logbook to permit periodic reviews of the condition and the trends of the materials as they are being used.

System checks

Probably the most effective overall checks of the performance of penetrant systems involve the periodic use of panels or samples containing known discontinuities (see Figure 4-20). As mentioned earlier, there are a number of cracked panels available for this purpose, including plated, single thickness; plated, tapered to provide for a range of crack depths; and industry-specific panels. Prior to use, these panels should be thoroughly cleaned, preferably in an ultrasonic cleaner to ensure that there are no residual penetrants remaining that could affect their response.

There are other systems checks that may be waived if the system performance check with the panels is satisfactory. They include tests for:

1. Penetrant brightness
2. Penetrant removability
3. Penetrant sensitivity
4. Emulsifier removability

Equipment Checks

There are routine checks that should be made on the equipment that is used in the PT process. They include, but are not limited to, the following:

1. Black lights—for intensity, filter condition, bulb, and reflector.
2. Light meters, black and white—for functionality and calibration status. Some codes require that these meters be periodically calibrated; this is usually done by the meter manufacturer.

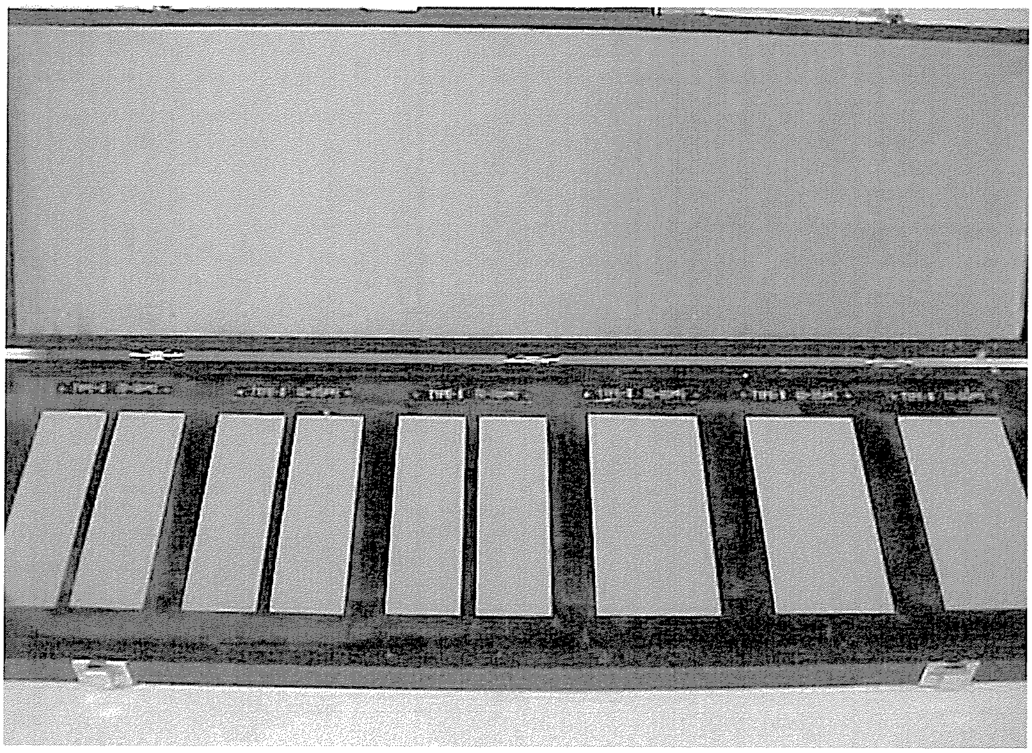


FIGURE 4-20 Cracked plated panels.

TABLE 4-2 Recommended Tests and Frequency of Performance

Test	Frequency
System performance	Daily
Penetrant contamination	Daily
Developer contamination (aqueous: soluble and suspension)	Daily
Developer condition (dry)	Daily
Water spray pressure	Each Shift
Water spray temperature	Each Shift
Black light intensity	Daily
Black light reflectors, filters, and bulbs	Daily
Inspection area cleanliness	Daily
Emulsifier concentration (hydrophilic)	Weekly
Penetrant sensitivity	Weekly
Fluorescent brightness	Quarterly
Penetrant removability	Monthly
Emulsifier removability	Monthly
Emulsifier water content (lipophilic)	Monthly
Drying oven temperature	Quarterly
Light meter calibration	Semiannually

3. The temperature of the drying oven—to assure that it is within the specified range.
4. The water used for removal—temperature and pressure.
5. Pressure gauges, when compressed air is used for application of the penetrant, emulsifiers, and developers.

X. ADVANTAGES AND LIMITATIONS

The major advantages of penetrant testing include:

Portability
Cost (inexpensive)
Sensitivity
Versatile—virtually any solid nonporous material can be inspected
Effective for production inspection
Nondestructive

The limitations include:

Only discontinuities open to the surface of the test specimen can be detected
There are many processing variables that must be controlled
Temperature variation effects
Surface condition and configuration
Surface preparation is necessary
The process is usually messy

XI. GLOSSARY OF PENETRANT TESTING TERMS

Adhesion—The tendency of the penetrant to adhere to the surface

Angstrom unit (Å)—A unit of length that may be used to express the wavelength of electromagnetic radiation (i.e., light). One angstrom unit is equal to 0.1 nanometers (1 nm = 10^{-9}m).

Background—The surface of the test part against which the indication is viewed. It may be the natural surface of the test part or the developer coating on the surface.

Black light—Electromagnetic radiation in the near-ultraviolet range of wavelength (315–400 nm, 3150–4000 Å).

Black light filter—A filter that transmits near-ultraviolet radiation while absorbing other wavelengths.

Bleedout—The surfacing of penetrant entrapped in discontinuities to form indications.

Blotting—Developer soaking up penetrant from a discontinuity to accelerate bleedout.

Carrier—A liquid, either aqueous or nonaqueous, in which penetrant examination materials are dissolved or suspended.

Clean—Free of contaminants.

Cohesion—The intermolecular action by which the elements of a penetrant are held together.

Contaminant—Any foreign substance present on the test surface or in the examination materials that adversely affects the performance of penetrant materials.

Contrast—The difference in visibility (brightness or coloration) between an indication and the background.

Contrast ratio—The ratio of the amount of light reflected or emitted between a penetrant and a background (usually the test surface). The contrast ratio for visible color contrast penetrants is 6:1; it is 40:1 for fluorescent penetrants.

Developer—A material that is applied to the test surface to accelerate bleedout and to enhance the contrast of indications.

Developer, aqueous—A suspension of developer particles in water.

Developer, dry powder—A fine, free-flowing powder used as supplied.

Developer, liquid film—A suspension of developer particles in a vehicle that leaves a resin/polymer film on the test surface after drying.

Developer, nonaqueous—Developer particles suspended in a nonaqueous vehicle prior to application.

Developer, soluble—A developer completely soluble in its carrier (not a suspension of powder in a liquid) that dries to an absorptive coating.

Development time—The elapsed time between the application of the developer and the examination of the part.

Drain time—That portion of the dwell time during which the excess penetrant or emulsifier drains from the part.

Drying oven—An oven used for increasing the evaporation rate of rinse water or an aqueous developer vehicle from test parts.

Drying time—The time required for a cleaned, rinsed, or wet developed part to dry.

Dwell time—The total time that the penetrant is in contact with the test surface, including the time required for application and the drain time.

Emulsification time—The time that an emulsifier is permitted to remain on the part to combine with the surface penetrant prior to removal.

Emulsifier—A liquid that interacts with an oily substance to make it water-removable.

Emulsifier, hydrophilic—A water-based liquid used in penetrant examination that interacts with the penetrant oil, rendering it water-removable.

Emulsifier, lipophilic—An oil-based liquid used in penetrant testing that interacts with the penetrant oil, rendering it water-removable.

Etching—The removal of surface material by chemical or electrochemical methods.

Evaluation—A review to determine whether indications meet specified acceptance criteria.

False indication—A response not attributed to a discontinuity or test object condition (usually caused by faulty or improper NDT processing).

Family—A complete series of penetrant materials required for the performance of a penetrant examination; usually from the same manufacturer.

Foot-candle (fc)—The illumination on a surface 1 ft^2 in area, on which is uniformly distributed a flux of 1 lm (lumen). It equals 10.8 lm/m^2.

Immersion rinse—A means of removing surface penetrant, in which the test part is immersed in a tank of either water or remover.

Nonrelevant indication—An indication caused by a condition related to the test object shape or design that entraps penetrant but is not rejectable.

Overemulsification—Excessive emulsification time that may result in the removal of penetrant from discontinuities.

Overremoval—Too long and/or too vigorous use of the remover liquid that may result in the removal of penetrant from discontinuities.

Penetrant—A solution or suspension of dye (visible or fluorescent) that is used for the detection and evaluation of surface-breaking discontinuities.

Penetrant comparator block—An intentionally flawed specimen having separate but adjacent areas for the application of different penetrant materials so that a direct comparison of their relative effectiveness can be obtained.

Penetrant, postemulsifiable—A penetrant that requires the application of a separate emulsifier to render the excess surface penetrant water-washable.

Penetrant, solvent removable—A penetrant so formulated that most of the excess surface penetrant can be removed by wiping, with the remaining surface penetrant traces removable by further wiping with a cloth or similar material lightly moistened with a solvent remover.

Penetrant, visible—A penetrant that is characterized by an intense color, usually red.

Penetrant, water-removable—A penetrant with a built-in emulsifier.

Postemulsification—The application of a separate emulsifier after the penetrant dwell time.

Postcleaning—The removal of residual penetrant test materials from the test part after the penetrant test has been completed.

Precleaning—The removal of surface contaminants from the test part so that they will not interfere with the examination process.

Solvent remover—A volatile liquid used to remove excess penetrant from the surface being examined.

TAM Panel—(Tool Aerospace Manufacturing) A controlled test panel for checking system performance

Viscosity—The property of a fluid that presents a resistance to shearing flow (measured in centistokes).

Wetability—The ability of a liquid to spread over and adhere to solid surfaces.