Inspecting Welds with Liquid Penetrants

A simple NDE method requires proper procedures

BY ROBERT SIEGEL

There are several different requirements and codes pertaining to welds and welding depending on the industry, customer, and region of the world. What is not different is the need to ensure the product quality, initially and during its service life. Nondestructive examination (NDE) is the only way to accomplish this.

There are several established NDE techniques to choose from, and new ones are being developed. Each of these techniques has its time and place.

Liquid penetrant inspection is one of the oldest, simplest, least expensive, and most reliable nondestructive examination methods. For welds to perform as intended they should be free of flaws, or, if any flaws exist, they should be evaluated for their significance. Liquid penetrant inspection is used to detect any surface-connected discontinuities such as cracks from fatigue, quenching, and grinding, as well as fractures, porosity, incomplete fusion, and flaws in joints.

Liquid penetrant inspection is especially suited to weld inspection because

- ◆ It can easily be used on small and large surfaces.
- ◆ It can be used indoors or outdoors.
- ◆ It can be used in most configurations, i.e., on welded surfaces that are upright, sideways, or upside down.
- ◆ It can be used in remote locations.
- ◆ It can be used on ferrous and nonferrous materials, including plastics and ceramics.
- ◆ It will detect a wide variety of discontinuities, ranging in size from those readily visible down to microscopic level.

Liquid Penetrant Materials

Liquid penetrant inspection is simple and easy. However, there are several types of penetrant materials, and it is important to match the materials with the application. Liquid penetrant inspections involve using a specific dye penetrant material and two or three related materials. Each one has been formulated to fulfill a specific function in the inspection process.

The liquid penetrant inspection process consists of six steps, each involving a specific penetrant product.

1. Precleaning
2. Penetrant application
3. Penetrant removal
4. Developer application
5. Examination
6. Postcleaning

Penetrant removal and developer application are the most critical steps in the process.

Penetrant materials are qualified, approved, and verified according to *AMS 2644, Liquid Penetrants*[1] and are divided into two types.

Type 1 penetrants are fluorescent, and inspections are done under ultraviolet light. Type 2 penetrants contain visible dyes, normally red, and inspections are conducted under white light.

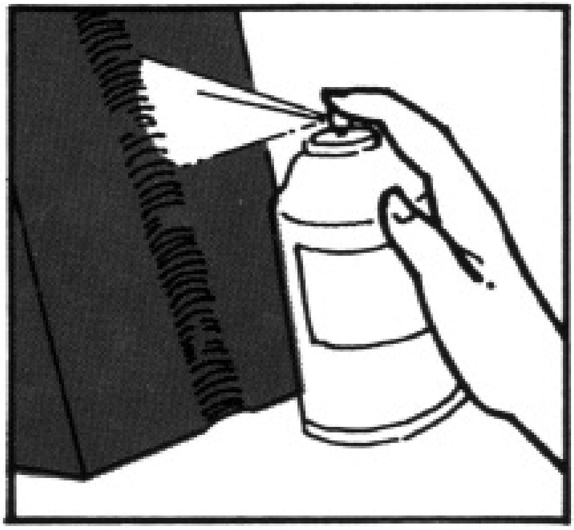

Fig. 1 — When cleaning, saturate the surface with cleaner/remover.

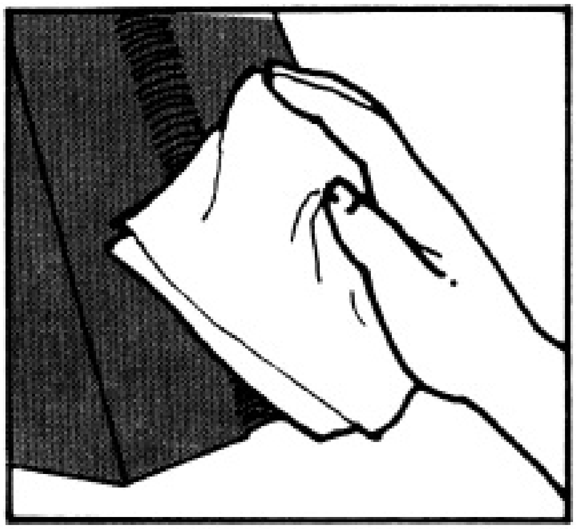

Fig. 2 — Next, wipe the surface dry with cloth or towel.

1. AMS (Aerospace Material Specifications) 2644, published by the Society of Automotive Engineers. The qualifying agency for penetrants is the Air Force Research Laboratory, AFRL/MSA, at Wright-Patterson Air Force Base.

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Fig. 3 — Cover the surface to be inspected with red dye penetrants.

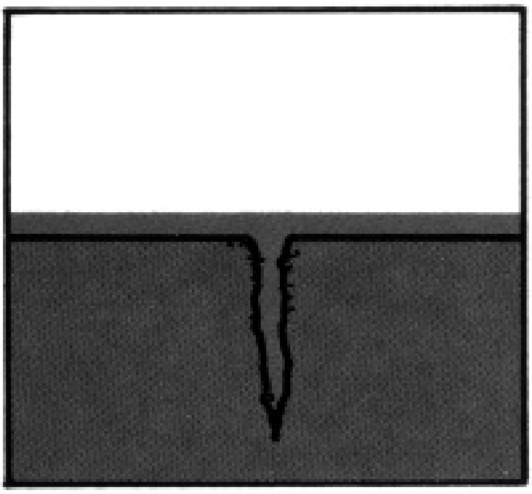

Fig. 4 — Dye penetrant is pulled into the crack by capillary force.

Fig. 5 — Surface penetrant is removed by wiping both with dry and with cleaner/remover moistened towels.

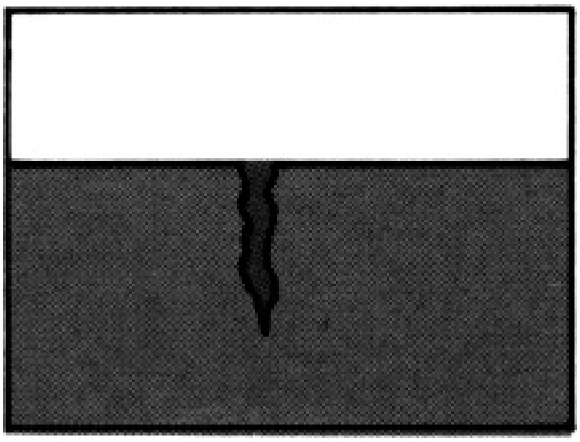

Fig. 6 — The surface is wiped clean but dye penetrant remains in crack.

Type I, fluorescent penetrants, are available in five sensitivities ranging from ultralow, level ½, to ultrahigh, level 4. Type II, visible penetrants, have no sensitivity classifications.

Both fluorescent and visible penetrants are approved for use in four different penetrant inspection methods. These methods relate to how excess penetrant — material that has not entered the flaws — is removed prior to actual inspection.

Method A is water washable, where water is sprayed or wiped on the part.

Method B is postemulsifiable lipophilic, where a part is dipped in a lipophilic emulsifier and then rinsed with water.

Method C is solvent removable, where a solvent is wiped on the part. This is the process most used in inspecting welds.

Method D is postemulsifiable hydrophilic, where a part is dipped or sprayed with a hydophilic emulsifier solution and then rinsed with water.

There are six forms of developers, of which the nonaqueous are normally used for inspecting welds. Nonaqueous developers are white powders mixed with a volatile solvent. The following are the six developer forms:

- Dry developer
- Water soluble
- Water suspendable
- Nonaqueous Type 1 Fluorescent (solvent based)
- Nonaqueous Type 2 Visible (solvent based)
- Special application.

General Considerations

For an inspection service company, the inspection process begins even before the customer calls. The service company's inspectors must be certified to perform the inspections.[2] Inspectors with a Level II certification are qualified to perform inspections without any supervision. Level I certified persons can only do inspections under the guidance of a Level II inspector. The other major precustomer activity is to prepare in-house inspection procedures. These procedures must comply with applicable industry procedures, e.g., the ASME *Boiler and Pressure Vessel Code*.

A weld that looks good on the surface is often considered to

2. There are several such programs including ASTM Recommended Practices SNT-TC-1A.

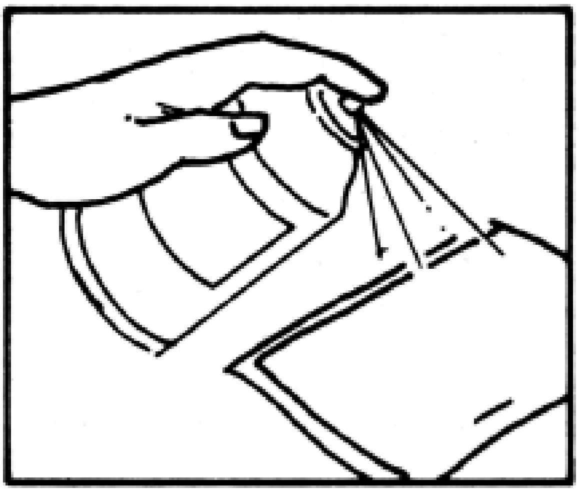

Fig. 7 — Moisten a towel with a spray of cleaner/remover for removing traces of red.

Fig. 8 — Avoid over-removal! Do not spray cleaner/remover directly on the surface to remove dye penetrant.

Fig. 9 — Developer is sprayed in 2 or 3 light applications, slightly damp on contact, from a distance of 8 to 12 inches.

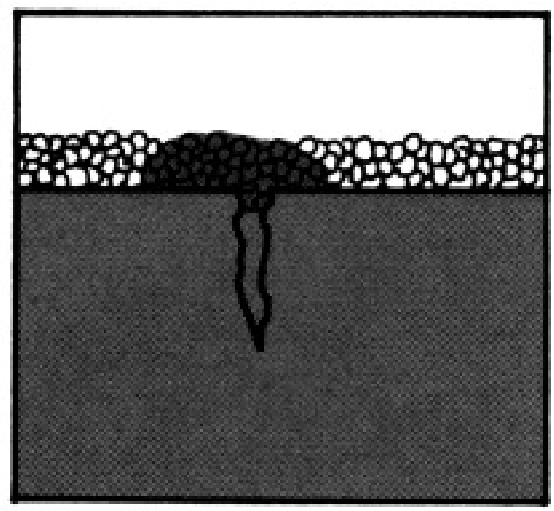

Fig. 10 — An even, light developer covering of white particles pulls the red dye penetrant from the crack to the surface by adsorption.

be of high quality. However, surface appearance does not guarantee good quality or performance. Nondestructive examinations verify that welds meet standards initially and at intervals during service. When an inspection service for welds and other jobs is employed, the customer specifies several items:

◆ The customer will determine which methodology and acceptance criteria will be used, normally citing a national standard such as ASME/ANSI B31.1, *Power Piping*, and B31.3, *Process Piping*.

◆ The customer will specify which areas are to be inspected, the extent of the heat zones around the weld, and/or if leak testing is to be conducted.

◆ They will specify the penetrant process to be used (visible or fluorescent), the removal process, and the form of developer.

Normally, fluorescent penetrants are used for inspections inside vessels, such as tanks, deaerators, and heat exchangers. These areas are already darkened and, thus, lend themselves to examination under ultraviolet light. Conversely, visible penetrants are normally used for the welds that are on piping, equipment, and on the outside of vessels, where white light dominates.

The penetrant removal process when inspecting welds is normally the solvent removal method. Solvent removal is chosen because it is easy, creates less waste, and is reliable. Plus, the solvents dry quickly under ambient conditions.

Nonaqueous solvent developers are normally used because their drying is fast and the solvent improves and hastens the developing process. In addition, they are available in aerosol cans, which are easy to use, and the developer thickness is easily controlled.

The Process

Before the inspection process begins, issues involving ambient and equipment temperatures must be addressed. The normal specified temperature range for liquid penetrant inspection is 40 to 125°F. If the ambient or equipment temperatures are outside of this range, the inspection is either postponed or a "qualified" procedure may be substituted in conformance with applicable codes and with the acceptance of the customer.[3]

The first step in liquid penetrant inspection is surface preparation. A clean, relatively smooth surface is needed for successful penetrant inspection. In addition, the surface to be examined and adjacent areas should be free of contaminants such as flux, weld spatter, scale, rust, paint, oil, and grease. Contaminants can prevent or delay the penetrant from entering the flaws, thereby undermining the inspection process.

Organic soils such as oil and grease can usually be removed with the same solvent used for penetrant removal. Hence, these materials are often called cleaner/removers. Other types of contaminants, such as scale, rust, etc., can trap penetrant, creating false indications, or can prevent penetrant from entering real discontinuities. These contaminants may require using wire brushes or other methods in order to remove them. Precleaning is usually done by the customer and should conform to applicable specifications and codes.

The inspector usually does a final cleaning with the cleaner/remover prior to penetrant application. This is done by spraying the solvent directly on the part, saturating it, and allowing the solvent to stand on the surface for about 30 seconds — Fig. 1. A clean, lint-free cloth or towel is used to wipe off the cleaner/remover before it evaporates completely — Fig. 2. The surface is then allowed to dry.

Next, apply penetrant (the steps for penetrant appliction are shown in Figs. 3–10). For weld inspection, application by brushing is generally preferred over spraying because it is less messy and the area covered is minimized. The latter is important to the inspector because what is applied must be removed, and the less applied, the less to remove. Once applied, the penetrant is allowed to dwell or remain on the inspection area for five minutes or more. During this time the penetrant flows into any flaws or discontinuities.

In practical terms, under normal ambient conditions, it is hard to let the penetrant dwell on the part too long. The dwell time is generally specified in the codes and procedures and may depend on the temperature. At temperatures below 50°F, the dwell times are increased up to 20–30 minutes. At high temperatures, e.g., those above 300°F, the dwell times are shortened to as low as 30 seconds. The inspector must also follow any temperature and dwell instructions provided by the penetrant manufacturer.

Penetrant removal is a critical process step and is closely controlled. Care must be taken not to use too much solvent, water, or emulsifier that might dilute or disturb the penetrant in the flaw. Conversely, too little penetrant removal may cause excessive background that can obscure, or mask, any indications. Leaving a light background is normal.

For the solvent removal process, first use a dry, lint-free cloth or towel to wipe the surface to remove the majority of the surface penetrant. Smooth surfaces may not even require the use of any solvent. Remove the remaining surface penetrant by spraying a towel with the solvent and wiping the surface, repeating as necessary. Solvent should never be sprayed directly on the surface to be inspected. The area should be allowed to dry, which normally takes a few moments.[4]

Spraying is the only recommended method of applying nonaqueous developers. The objective is to spray a light, even coat of developer that is slightly damp when it hits the surface. It should be damp to enable the solvent, which is volatile (evaporates quickly), to couple with the penetrant in the flaw and speed the return of the penetrant to the surface. It should not be so damp as to dilute or overspread the penetrant. Two or three light sprays of developer are better than one heavy application. For leak detection, if developer is used, it is sprayed on the opposite side of the surface where the penetrant was applied. Dwell time for developers is normally about ten minutes but, again, this depends on the temperature. Higher temperatures require lower dwell times and vice versa. Small, tight cracks may also require longer dwell times.

Proper developer application is essential for sharp flaw definition. The developer, when dry, is a white powder. Too much powder may obscure small or tight flaws, and too little may not provide a good contrast or sufficient particle density for good developing. If nonaqueous developers are used, they must be thoroughly mixed immediately before use because the powder will settle out of solution. In aerosol cans, a marble is included in the can to aid in mixing.

Weak, blurred indications result from applying too much developer. A light, even coating of the developer will provide a good capillary track for the penetrant to the surface and a good contrast for the red dye or fluorescent penetrant.

Developer removal from welds can be done by wiping off the powder with a brush or towel. Water or the solvent cleaner can also be used for a more thorough cleaning of the developer and penetrant. Additional cleaning may be needed, depending on the area inspected, and is conducted by the customer.

Inspection Criteria

The inspector reports all indications. It is the customer who determines if the indications are a problem or if the part is acceptable. The codes and standards include procedures for evaluating indications. Flaws may be indicated in various ways. Lines indicate cracks, seams, or incomplete fusion. Dots in a line or a curve may indicate a tight crack. Porosity appears as a series of dots. The customer or inspector may reexamine the weld if there are any questionable or doubtful indications.

Conclusion

Liquid penetrant inspection has many advantages for inspecting welds. Nondestructive examination assessments of welds should be conducted to ensure their initial and continuing performance. Liquid penetrants are versatile enough in types and process to inspect the wide and diversified range of applications, positions, types, and conditions of welds. In addition, penetrant inspection is a simple, straightforward process and does not require sophisticated or costly equipment. Penetrant inspection can also be used on equipment in service and requires no special setup. If used in conjunction with other NDE methods, penetrants complement other inspection processes.❖

Acknowledgments

For this article, the author interviewed several employees of GE Inspection Services on how they use liquid penetrant inspection to inspect welds. The author would like to give special thanks to Gail Flagor and Leslie Smith for their help and input.

3. Qualifying a procedure entails inspecting a certified test piece under the test temperatures and showing that the flaws can be found. In addition, special penetrant materials are available to use at nonstandard temperatures. Penetrants that can be used at up to 350°F are on the market.

4. For leak detection, penetrant removal is not necessary because the inspection is done on the other side of the surface and one is looking for any penetrant that makes its way through.