PROGRAMMED INSTRUCTION HANDBOOK

NONDESTRUCTIVE TESTING

Liquid Penetrant

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INSTRUCTIONS

The pages in this book should **not** be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page:

- Turn to the next page.
- Turn ahead to page 3-15.
- Turn back to page 3-8.

On many of the pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is most correct and turn to the indicated page. If you happen to select an incorrect answer, continue to read, as the page will provide supplemental information to help you understand the concept.

We know that sometimes the information in this self-study format may seem oversimplified or repetitious. Bear with us; the reinforcement of basic Level I concepts is essential if you expect to retain the knowledge and apply it to Level II training or on-the-job NDT applications.

Do not rush through the volumes. Take whatever time you need to make sure you have a clear understanding of the material. Depending on your background knowledge, reading speed, etc., the time needed to complete this book may vary from **10 to 15 hours** or more. As you will soon see, this self-study handbook is easy to use—just follow instructions.

TURN TO THE NEXT PAGE.

CHAPTER 1

INTRODUCTION TO LIQUID PENETRANT TESTING

Liquid penetrant testing is one of several methods used in nondestructive testing to locate discontinuities. Discontinuities, you will recall from our *Introduction to Nondestructive Testing*, are simply breaks in the continuity of a material or structure. Laminations, cracks, seams, inclusions, and porosity are typical discontinuities. In short, liquid penetrant testing is a method used to find discontinuities in materials that are open or connected to the examination surface.

When referring to "materials," we mean most any material, including metallic and nonmetallic objects. Metallic materials include aluminum, magnesium, titanium, iron, copper, brass, and bronze, as well as most alloys. Ceramics, plastic, composites, and glass are examples of nonmetallic materials. However, extremely porous materials present special considerations which we'll briefly review later in the program.

Penetrant inspection ranks as one of the most widely used nondestructive testing methods. Perhaps this is due to the method's relative ease of use, its widespread application and the fact that extensive training is not required for routine applications. However, let's *not* assume that interpretation and evaluation of penetrant indications is straightforward.

Turn to the next page.

From page 1-1

A penetrant examination consists of the following basic steps, regardless of the material tested. A dye-carrying liquid (penetrant) is applied to the surface of the article to be tested. The liquid is left on the surface for a period of time so the liquid can be drawn into any discontinuities that are present. The excess liquid remaining on the surface is then removed and a powder (developer) is applied. This powder acts like a blotter and draws the penetrant in the discontinuities back to the surface, producing an indication. Indication evaluations are made and the article is cleaned.

Oversimplified? Surely, but that's essentially all there is to liquid penetrant testing. But since we're going to be required to use the method, we'll have to tackle the subject in more detail. So, let's begin.

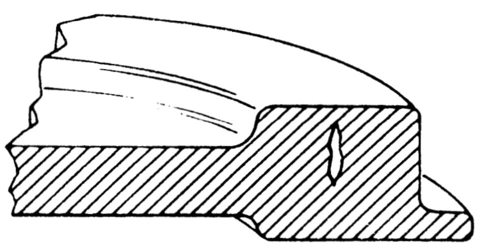
Liquid penetrant inspection is a physical-chemical process. Application and reaction of the penetrant (chemical) is dependent upon the nature of the test article and the discontinuity it contains (physical). Liquid penetrant is not dependent on outside sources of power (battery, line voltage, etc.) and is therefore extremely portable and available at a moment's notice.

Turn to the next page.

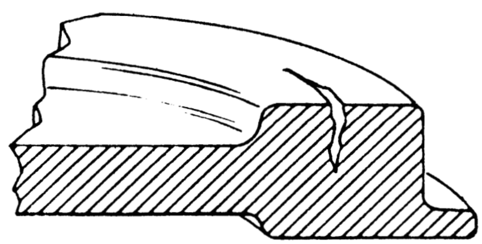
Typical liquid penetrant applications include the detection of cracks, porosity and, on occasion, "through-wall" leaks—leaks that pass from one surface to another. In locating discontinuities, however, *a liquid penetrant test will find only those discontinuities that are open to the surface*! Think about it for a moment and you will see that this simple point is mighty important. If penetrant cannot enter the discontinuity, no penetrant indication will be produced.

Below is an illustration of two typical specimens. Each view is a cross-section of the test article. Both include an exaggerated and enlarged discontinuity, but only one of the discontinuities is detectable with liquid penetrant testing before the cross section was cut.

Which view has the discontinuity that could be found with a liquid penetrant test?



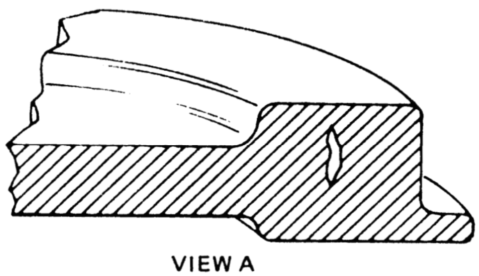
VIEW A

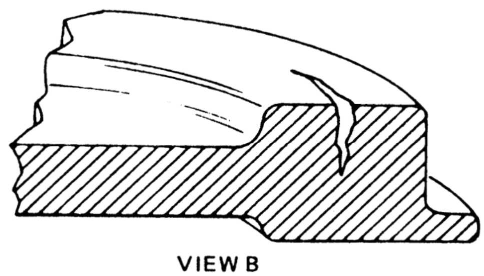


VIEW B

View A . . . . Page 1-4
View B . . . . Page 1-7

Another look at the two pictures is in order.





Although View A has a discontinuity, this discontinuity is not open to the surface and therefore cannot be reached by a liquid penetrant applied to the test article's surfaces prior to cutting.

The very first point to remember in this program is that in a liquid penetrant test you can expect to learn the location of only those discontinuities that are *open to the surface*. View A couldn't be the answer since a liquid cannot reach the discontinuity, but look again at View B. That discontinuity could be reached with liquid penetrant, couldn't it? View B is the correct choice.

Turn ahead to page 1-7.

Sorry, but your selection is incorrect. For discontinuities to be detected by liquid penetrant testing, they must ***be open to the surface***. The penetrant must be able to enter the discontinuity. If the penetrant cannot enter the discontinuity, no indication will be produced. The discontinuity will remain undetected.

With this in mind, turn to page 1-8 and continue.

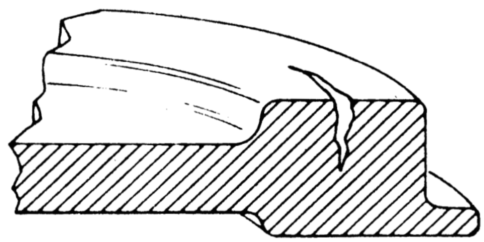
And when welding, these are some of the discontinuities you could encounter:

- Crater cracks
- Shrink cracks
- Porosity
- Nonmetallic inclusions

The question is, which of these may be open to the surface and can be detected with liquid penetrant testing?

Turn ahead to page 1-9.

Good—you've spotted the illustration of the surface discontinuity (View B). This program will show you how a surface discontinuity such as this can be found with a liquid penetrant test.



VIEW B

As we take a close look at liquid penetrant testing, you will learn the answers to such questions as:

- What can be learned from a liquid penetrant test?
- How does liquid penetrant testing work?
- What materials are required for a liquid penetrant test?
- What are the limitations of liquid penetrant testing?

In fact, we've already begun to provide answers to these questions!

Which of the following statements is true? Using liquid penetrant testing, one can:

detect all discontinuities . . . . Page 1-5
locate discontinuities open to the surface . . . . Page 1-8

Right! With the liquid penetrant test, you can find only those discontinuities that are open to the surface. To detect *subsurface* discontinuities, another method of testing, such as radiographic or ultrasonic testing, even perhaps magnetic particle testing, must be used.

In many cases, the use of **intentionally flawed specimens** can demonstrate the effectiveness of a given test technique or procedure. Flaws of known sizes and types can be implanted in mockups to replicate the conditions that are expected during the actual liquid penetrant test. Typical flawed specimens and mockups are readily available from several commercial sources, including the publisher of this text.

By now you are also well aware that there are many, many types of discontinuities. Any of them are, or can be, made open to the surface. Here are just some of the discontinuities that one could encounter:

- Nonmetallic inclusions
- Porosity
- Stringers
- Seams
- Forging laps
- Heat treat cracks
- Forging bursts, or cracks
- Cold shuts
- Shrink cracks
- Blow holes
- Grinding cracks
- Fatigue cracks

Turn to page 1-6.

Some discontinuities formed during rolling, forging, or casting are always open to the surface. They are detectable with penetrants from the time they are formed. Forging laps, grinding cracks, and crater cracks are examples of this type of discontinuity.

However, some of the others are not *always* open to the surface. Examples of this type of discontinuity are nonmetallic inclusions, stringers, and porosity. Nonmetallic inclusions, for example, are formed when the ingot is poured. They could very well be subsurface in the ingot and even if the entire surface of the ingot were subjected to liquid penetrant tests, no indications of the inclusions would be found. The ingot is then cropped. The top of the ingot is removed, and a billet is formed. Would the inclusions now be detectable? If the cropping cut through them, those exposed by the cut or "brought to the surface" by the cut, could be located with penetrants; those still within the billet would not be detectable.

During rolling, forging, or casting (the next operation), the same possibility exists. If the operation brought discontinuities to the surface, a subsequent penetrant test would reveal their presence. And, to carry the example one step further, subsurface discontinuities might yet be exposed during finishing operations such as grinding or machining. A liquid penetrant test conducted after grinding or machining could then reveal the presence of a discontinuity that had been hidden during earlier tests.

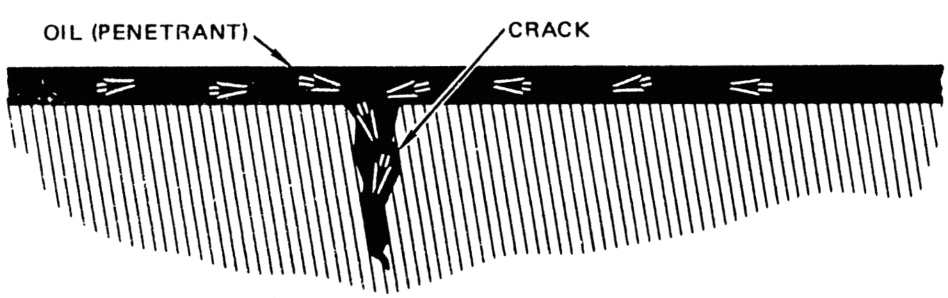
I understand why discontinuities that are subsurface at one state in production could be open to the surface at another . . . . Page 1-10

I would like to know more about the development of discontinuities during the processing of metals . . . . Page 1-11

Fine—discontinuities that are subsurface at one stage in production could very well be open to the surface at another. When they are, they're detectable with liquid penetrants. This means a penetrant test could be performed successfully following any operation that might cause or expose surface discontinuities. In fact, many of the controlling specifications and standards make in-process inspections mandatory.

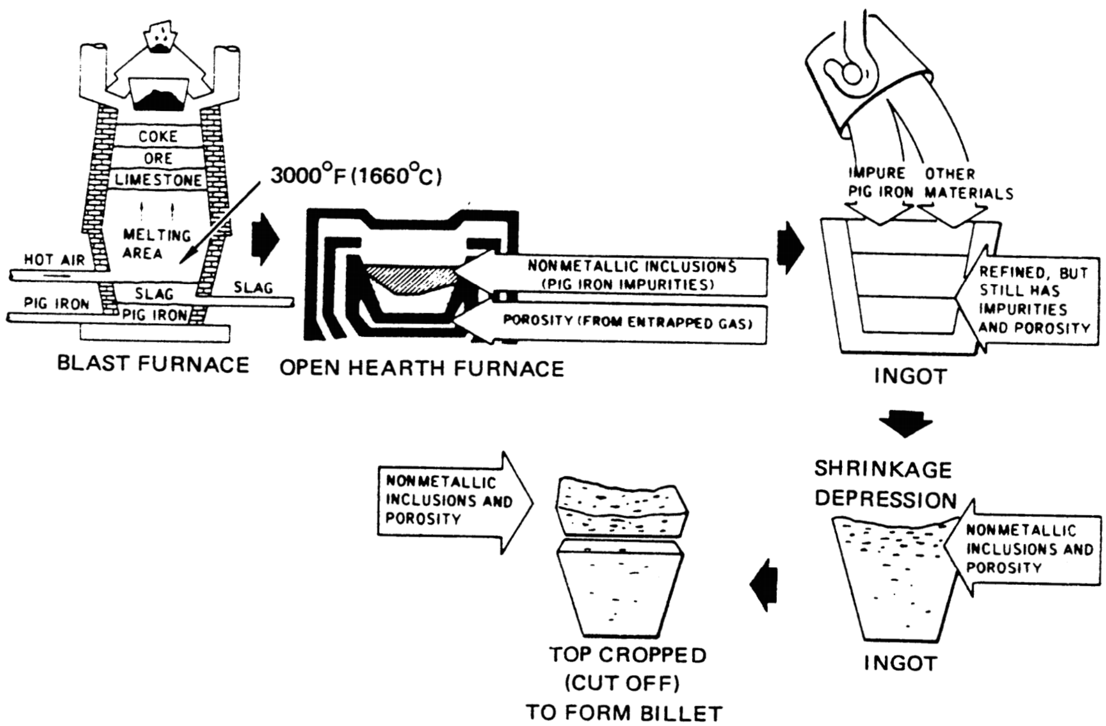
We now have the answer to the question, What can be learned from liquid penetrant testing? We can learn the location of discontinuities that are open to the surface at the time penetrants are applied.

How does a liquid penetrant test work? The answer to that can best be seen in a brief look at the "oil and whiting" method—the forerunner of modern liquid penetrant testing. The oil and whiting (chalk) method was used in the early 1900's by the railroads in testing locomotive parts, etc., such as axles, crank pins and couplers. First, the parts were prepared for test by removing as much dirt, grease, rust and scale, etc., as possible. This often involved boiling the parts in a caustic soda solution and then drying. Following drying, the parts were dipped in a heavy, dirty or dark-colored lubricating oil that was thinned with kerosene or some other thin oil. This served as the "penetrant." A time interval of up to several hours was then allowed for the diluted oil to soak into possible cracks. What occurred can be seen in this picture.



Turn ahead to page 1-16.

Good for you. Let's consider again the steel-making process as presented in the *Introduction to Nondestructive Testing* text in this series. Here are the first few steps taken in the process as illustrated in a flow chart from that text.

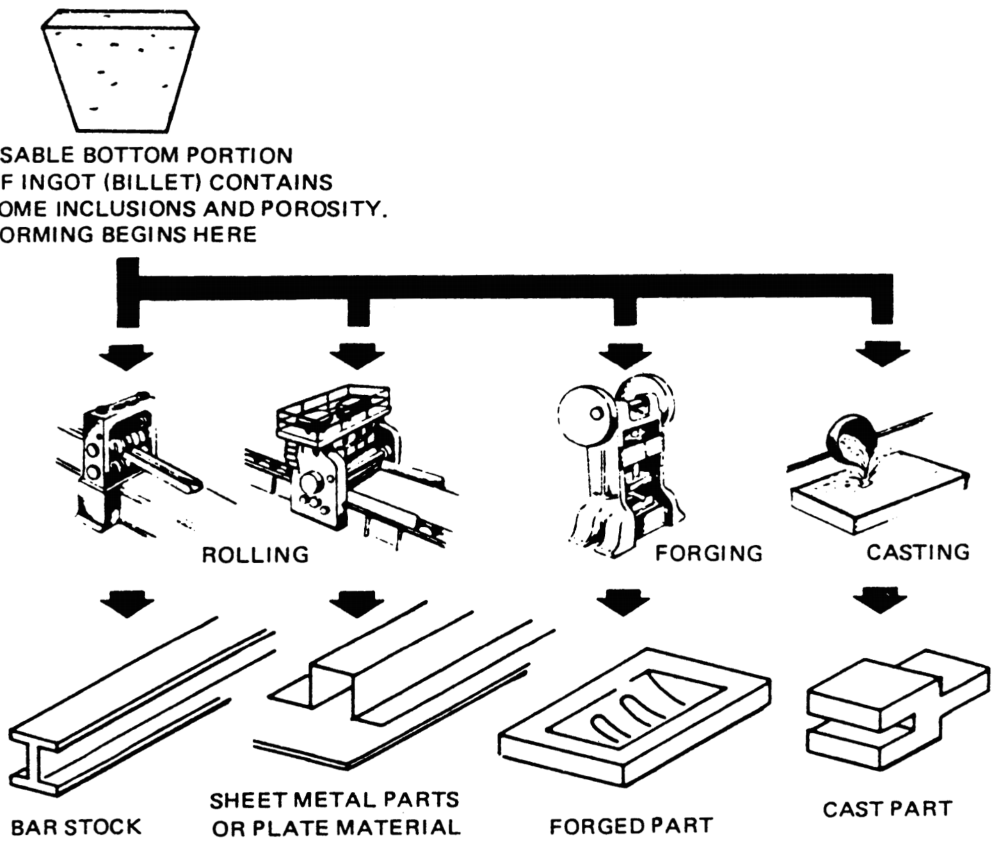


Although thus far in the steel-making process only a few of the many possible discontinuities could have been created, those that the process has brought to the surface would be examined with liquid penetrants. Thus, if ingot cropping cuts through an area of porosity or nonmetallic inclusions, examination of the cropped ingot with a liquid penetrant test would reveal the location of those discontinuities.

Turn to the next page.

From page 1-11

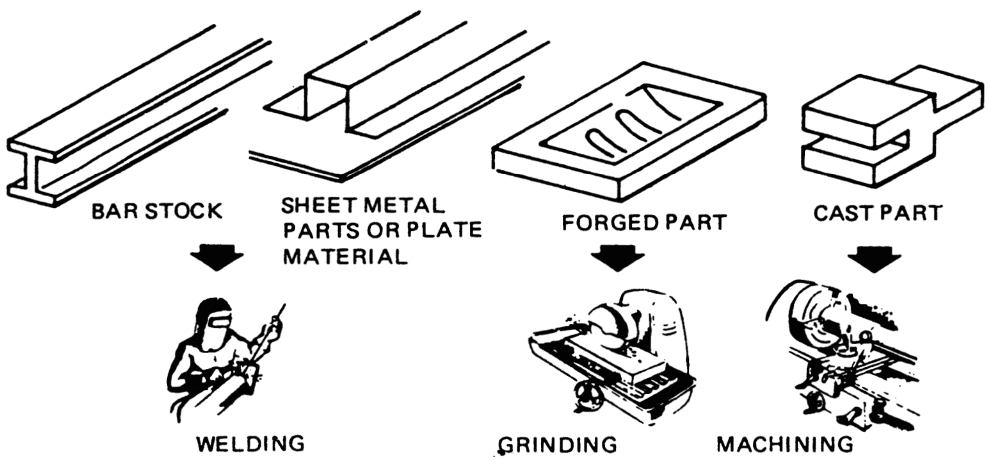
As the steel-making process becomes a production process, the flow chart shows that additional types of discontinuities (such as stringers, seams, forging laps, and cold shuts) can be created by rolling, forging, or casting.



Many discontinuities associated with these processes are open to the surface. They, and any other discontinuities that have been opened to the surface during the production process, are detectable with liquid penetrants.

Turn to the next page.

Now let's carry the flow chart one step further to show a later state in development that can reveal discontinuities which may be found with liquid penetrant testing. That state is the "finishing" stage where the materials developed from rolling, forging, and casting are further worked to form finished products. The finishing stage may include welding, grinding, and machining.

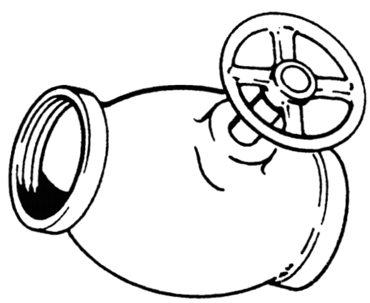


Two examples of new discontinuities that may develop during finishing operations are grinding cracks and crater cracks. The finishing stage may also expose subsurface discontinuities, such as nonmetallic inclusions, which can now be located by liquid penetrant testing.

Turn to the next page.

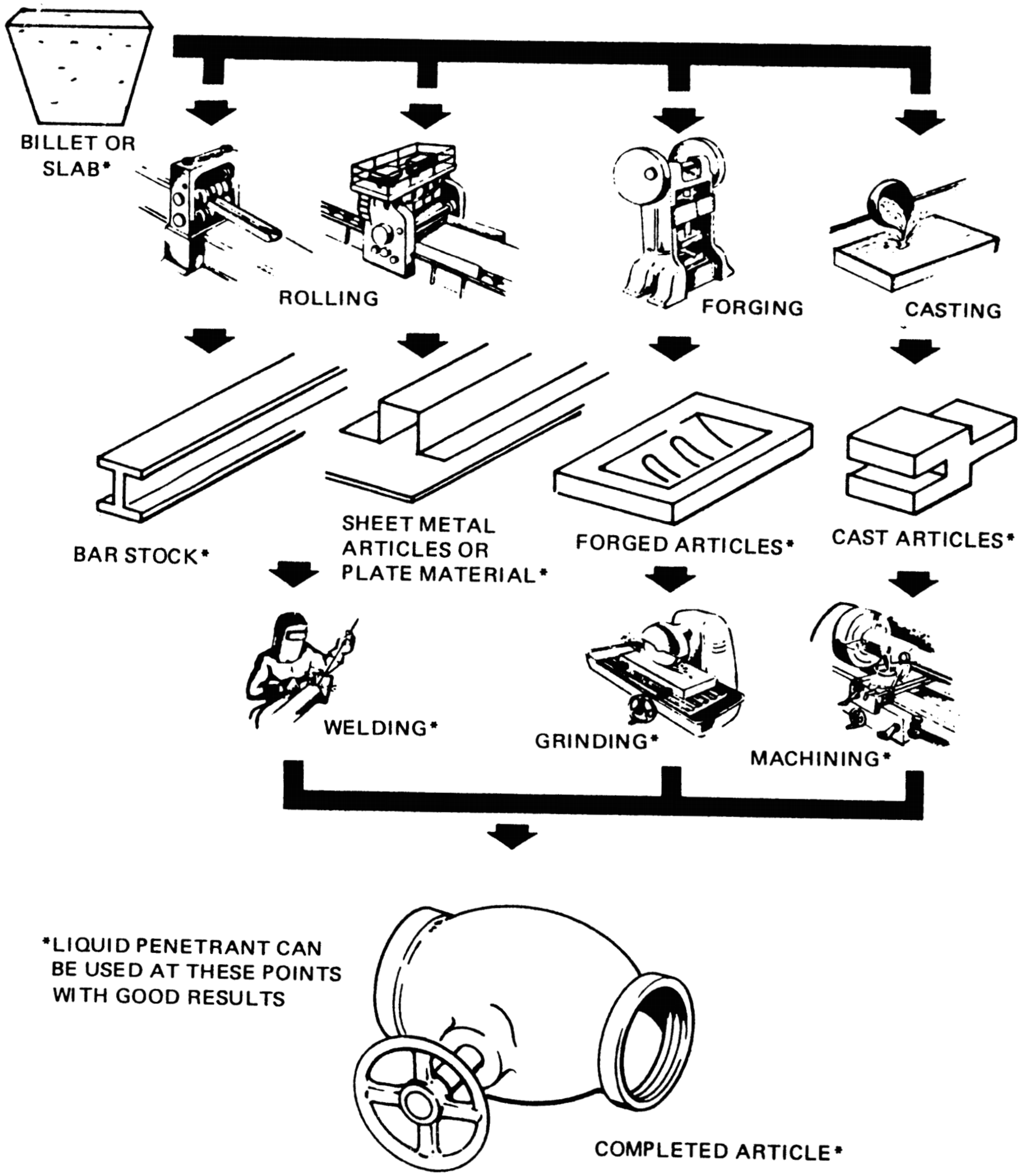
It is possible to expand the flow chart one step further and include the one other time that liquid penetrants can be used to locate discontinuities that would not have been detectable in the various stages we've discussed so far. This final stage occurs long after steel making, forming, and finishing. It occurs during operational use of the article. Fatigue cracks are a good example of this type of "inservice" discontinuity. Inservice discontinuities may occur as the article is weakened through repeated use or as a result of overloading.

Inspections are performed at predetermined time intervals throughout the service life of the article or when there is reason to suspect the article has been damaged or has deteriorated. Liquid penetrant testing of large valve bodies on a periodic basis would be an example of the former, while testing of the same valve after operation at pressures that exceed its design would illustrate the latter.



During these inspections, often previously subsurface discontinuities as well as service-created discontinuities might now be open to the surface and could be located with penetrants. (Fatigue cracks are sometimes traceable to subsurface discontinuities that have weakened the article during its use.) Adding the valve example used here to the flow chart, we now get the overall picture that shows us when we can expect liquid penetrant evidence of various discontinuities. This has been done on the facing page.

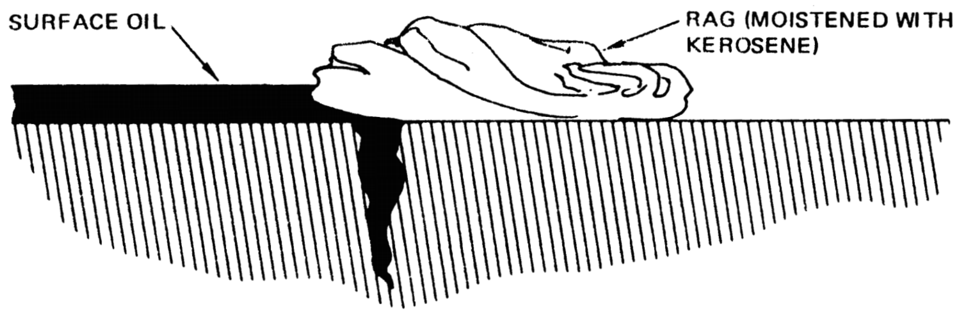
Turn to the next page.



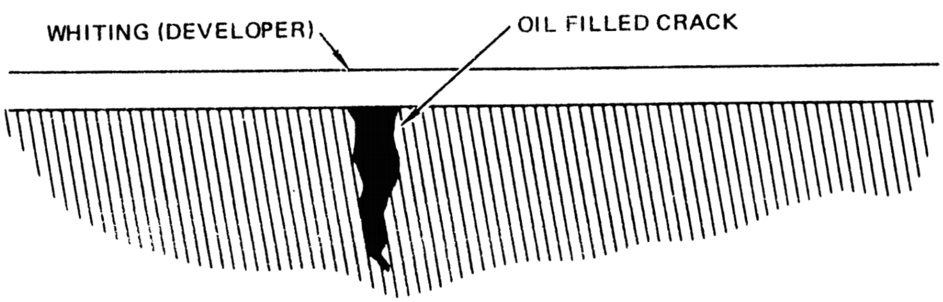
In summary, a discontinuity that is not detectable with liquid penetrants in early production stages could be detected with liquid penetrants at later stages.

Turn back to page 1-10 and continue.

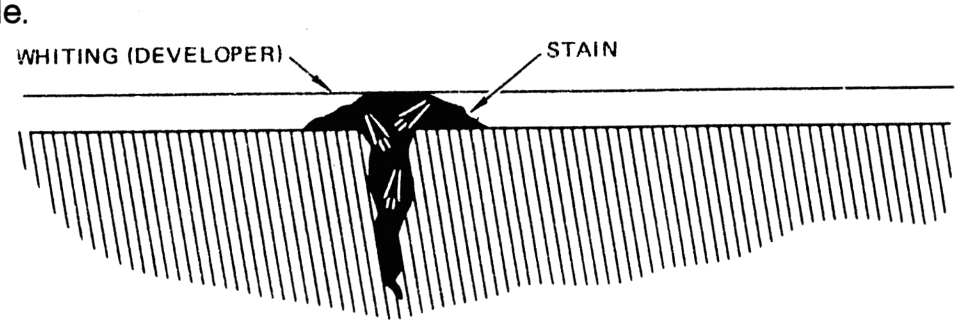
The oil remaining on the surface was then wiped off with rags or swabs usually moistened with kerosene. The kerosene was the "excess penetrant remover."



When the surfaces dried, a coating of powdered chalk or whiting was applied. The whiting served as the "developer."



If there were discontinuities, the oil in them would begin "seeping" back to the surface and appear as a dirty brown stain in the whiting, making them visible.



The parallel between the oil and whiting method and modern-day liquid penetrant testing becomes most obvious when compared to the "visible dye" penetrants used today, as you'll see later on in this program. But first, turn to the next page for a quick review of this chapter.

CHAPTER REVIEW

_____ 1. Liquid penetrant testing is one of several nondestructive testing methods used to locate:

A. seams.
B. structures.
C. discontinuities.
D. cracks.

_____ 2. In the oil and whiting technique, the dirty oil is allowed to penetrate the discontinuities and the excess is removed with rags, usually moistened with kerosene. The kerosene is the excess penetrant:

A. blotter.
B. remover.
C. scaler.
D. agent.

_____ 3. Crater cracks, because they are open to the ______, (can/can't) ______ be located by liquid penetrant inspection.

A. surface, can't
B. surface, can
C. top, can't
D. bottom, can't

_____ 4. Other types of discontinuities, such as porosity and nonmetallic inclusions, may not always be detected by liquid penetrant testing. When they *cannot* be detected, they will be ______ discontinuities.

A. surface
B. subsurface

_____ 5. If they are open to the surface, discontinuities such as ______ can be located with liquid penetrant testing.

A. porosity
B. forging bursts
C. shrinkage cracks
D. nonmetallic inclusions
E. All of the above.

_____ 6. In many cases, a discontinuity that is subsurface in an early stage of production will be exposed in a later production stage. It may then be detected by ______ testing.

A. hot bath
B. roll forging
C. crater blotting
D. liquid penetrant

____ 7. The oil and whiting method, though it was quite crude, set the stage for modern liquid penetrant testing. We still use:

A. a penetrant, an agent, and a developer.
B. a scaler, a remover, and an agent.
C. a penetrant, an agent, and a scaler.
D. a penetrant, a remover, and a developer.

____ 8. Even after production is completed on an article and the article is in use, ______ may develop.

A. discontinuities
B. stresses
C. limits
D. craters

____ 9. An example of a post-production discontinuity is a fatigue crack. If ______ to the ______ it can be detected with liquid penetrant testing.

A. open, bottom
B. closed, surface
C. open, surface
D. subsurface, bottom

_____ 10. An early test technique used by the railroads to locate fatigue cracks was called the:

A. oil and staff method.
B. wet and dry method.
C. oil and whiting method.
D. trial and error method.

_____ 11. In one technique described in this chapter, the dirty oil was used as the:

A. penetrant.
B. drier.
C. developer.
D. cleaner.

_____ 12. When the test article's surfaces had dried, a coating of chalk was applied. This was the:

A. scaler.
B. agent.
C. remover.
D. developer.

_____ 13. It is important to note that liquid penetrant testing will locate only those discontinuities that are _______ to the surface.

A. open
B. closed

_____ 14. The effectiveness of a given test technique or procedure can often be demonstrated by using:

A. at least three different colors of penetrant.
B. a hot bath followed by a cold bath.
C. nonmetallic inclusions in the penetrant bath.
D. intentionally flawed specimens.

_____ 15. Forging laps are a type of "formed" discontinuity that will always be:

A. open to the surface.
B. closed to the surface.

Turn to page 1-22 for the answers to these questions.

ANSWERS TO REVIEW QUESTIONS FOR CHAPTER 1

Question & Answer		Reference Page(s)
1.	C	1-1
2.	B	1-16
3.	B	1-6, 1-9
4.	B	1-9
5.	E	1-8
6.	D	1-9
7.	D	1-1, 1-16
8.	A	1-14
9.	C	1-14
10.	C	1-10
11.	A	1-10
12.	D	1-16
13.	A	1-3
14.	D	1-8
15.	A	1-9

Turn to the next page and begin Chapter 2.