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CLASSROOM TRAINING HANDBOOK - LIQUID PENETRANT TESTING

Prepared under Contract NAS 8-20185 by

Convair Division
General Dynamics Corporation
San Diego, Calif.

for George C. Marshall Space Flight Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

Classroom Training Handbook - Liquid Penetrant Testing (5330.15) is one of a series of training handbooks designed for use in the classroom and practical exercise portions of Nondestructive Testing. It is intended that this handbook be used in the instruction of those persons who have successfully completed Programmed Instruction Handbook - Liquid Penetrant Testing (5330.10).

Although formal classroom training is not scheduled at the present time, this handbook contains material that is beneficial to personnel engaged in Nondestructive Testing.

NASA's programs involve tightly scheduled procurement of only small quantities of space vehicles and ground support equipment, requiring the extreme in reliability for the first as well as later models. The failure of one article could result in mission failure. This requirement for complete reliability necessitates a thoroughly disciplined approach to Nondestructive Testing.

A major share of the responsibility for assuring such high levels of reliability lies with NASA, other Government agencies, and contractor Nondestructive Testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error -- no chance for reexamination. The decision must be right -- unquestionably -- the first time.

General technical questions concerning this publication should be referred to the George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory, Huntsville, Alabama 35812.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for correction of errors in this initial compilation to George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

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Aerojet General Corp.; Automation Industries, Inc., Sperry Products Division; AVCO Corporation; The Boeing Company; Douglas Aircraft Co., Inc.; Grumman Aircraft; Lockheed Aircraft Corp.; Magnaflux Corp.; The Martin Co. (Denver); McDonnell Aircraft Corp.; Met-L-Check Co.; North American Aviation, Inc.; Rohr Corporation; Shannon Luminous Materials Co., Tracer-Tech Division; St. Louis Testing Laboratories, Inc.; Turco Products, Inc.; Uresco, Inc.; X-Ray Products Corp.

CLASSROOM TRAINING HANDBOOK
LIQUID PENETRANT TESTING

CHAPTER 1: INTRODUCTION
TABLE OF CONTENTS

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CHAPTER 1: INTRODUCTION

100 GENERAL

The complexity and expense of space programs dictate fabrication and testing procedures that insure reliability of space vehicles and associated ground support equipment. Nondestructive testing (testing without destroying) provides many of these procedures. Of the number of nondestructive test procedures available, liquid penetrant testing, with which this handbook is concerned, is the oldest and most widely used.

101 PURPOSE

The purpose of this handbook is to provide the fundamental knowledge of liquid penetrant testing required by quality assurance and test personnel to enable them to: ascertain that the proper test technique, or combination of techniques, is used to assure the quality of the finished product; interpret, evaluate, and make a sound decision as to the results of the test; and recognize those areas of doubtful test results that require either retest or assistance in interpretation and evaluation.

102 DESCRIPTION OF CONTENTS

1. ARRANGEMENT

The material contained in this handbook is presented in a logical sequence and consists of:

a. Chapter 1: Introduction and testing philosophy

b. Chapter 2: Liquid penetrant testing principles with description of procedures, applications and capabilities

c. Chapter 3: Equipment and material (types and grouping)

d. Chapter 4: Testing techniques including selection of penetrant materials and processes

e. Chapter 5: Interpretation of test results with description of indications and their characteristics

f. Chapter 6: Quality control of penetrant materials

g. Chapter 7: Comparison and selection of NDT processes as related to the five nondestructive testing methods.

h. Chapter 8: Safety precautions for fire and toxic hazards.

2. LOCATORS

The first page of each chapter consists of a table of contents for the chapter. Major paragraphs, figures, and tables are listed in each table of contents.

103 INDUSTRIAL APPLICATIONS OF LIQUID PENETRANT TESTING

Because of the basic characteristics of liquid penetrant testing, it is used to test a variety of both metallic and nonmetallic products such as welds, forgings, castings, plastics and ceramics, etc. Since liquid penetrant testing is capable of economically revealing surface discontinuities (variations in material composition) in a variety of dissimilar materials, it is one of the most effective tools available to quality assurance personnel.

104 TESTING PHILOSOPHY

The basic reason for use of nondestructive testing is to assure maximum reliability of space and associated ground support hardware, fabricated of many materials. To accomplish such reliability, standards have been set by NASA, and test results must meet these standards.

105 PERSONNEL

It is imperative that personnel responsible for liquid penetrant testing be trained and highly qualified with a technical understanding of the test equipment and materials, the item under test (specimen), and the test procedures. Quality assurance personnel must be equally qualified. To make optimum use of liquid penetrant testing, personnel conducting tests must continually keep abreast of new developments. There is no substitute for knowledge.

106 TESTING CRITERIA

When required by appropriate documentation, every vehicle and support article must be tested using applicable Nondestructive Testing techniques. The criteria is part of a building block test philosophy which dectates that each item must be tested individually before it is required to perform in sub-assemblies which are in turn tested individually before they are required to perform in assemblies. Using this approach, unsatisfactory and faulty articles are discovered at the earliest possible time, resulting in higher system reliability and reduced cost.

107 TEST PROCEDURES

Approved procedures for liquid penetrant testing are formulated from analysis of the test specimen, review of past history, experience on like or similar specimens, and information available concerning similar specimen discontinuities. It is the responsibility of personnel conducting or checking tests to insure that test procedures are adequately performed, and that the test objective is accomplished. Procedures found to be incorrect or inadequate must be brought to the attention of responsible supervision for correction and incorporation into revised procedure.

108 TEST OBJECTIVE

1. The objective of liquid penetrant testing is to insure product reliability by providing a means of:

   a. Obtaining a visual image related to a discontinuity on the surface of the specimen under test.

   b. Disclosing the nature of the discontinuity without impairing the material.

   c. Separating acceptable and unacceptable material in accordance with predetermined standards.

2. No test is successfully completed until an evaluation of the test results is made. Evaluation of test procedures and results requires understanding of the test objective.

CHAPTER 2: PRINCIPLES
TABLE OF CONTENTS

CHAPTER 2: PRINCIPLES

200 GENERAL

Liquid penetrant testing, a nondestructive means of locating and determining the severity of surface discontinuities in materials, is based upon capillarity. Capillarity, or capillary attraction, is the action by which the surface of a liquid, where it is in contact with a solid, is elevated or depressed. The materials, processes, and procedures used in liquid penetrant testing are all designed to facilitate capillarity and to make the results of such action visible and capable of interpretation.

201 PHYSICS

1. GENERAL

The phenomenon of capillary action is one of the most important forces in nature. The rate and extent of the action associated with capillarity are dependent upon such factors as forces of cohesion and adhesion, surface tension and viscosity. Capillarity can be observed when a plastic straw is inserted into a glass of water. When the straw is inserted, the water molecules enter the straw and begin to attract other nearby molecules, pulling them up the straw by cohesion. This process continues as the water rises higher and higher. The water continues to rise until the pull of the surface tension is equalized. Cohesive forces prevent the water from falling back down the straw. Capillary action as applied in nondestructive testing is somewhat more complex, since various surface conditions hindering or assisting the action are encountered. Liquid penetrants in nondestructive testing have low tension and high capillarity. Capillary action is illustrated in Figure 2-1.

2. APPLICATION OF PENETRANT

In the liquid penetrant method, the liquid is applied to the surface of the specimen, and

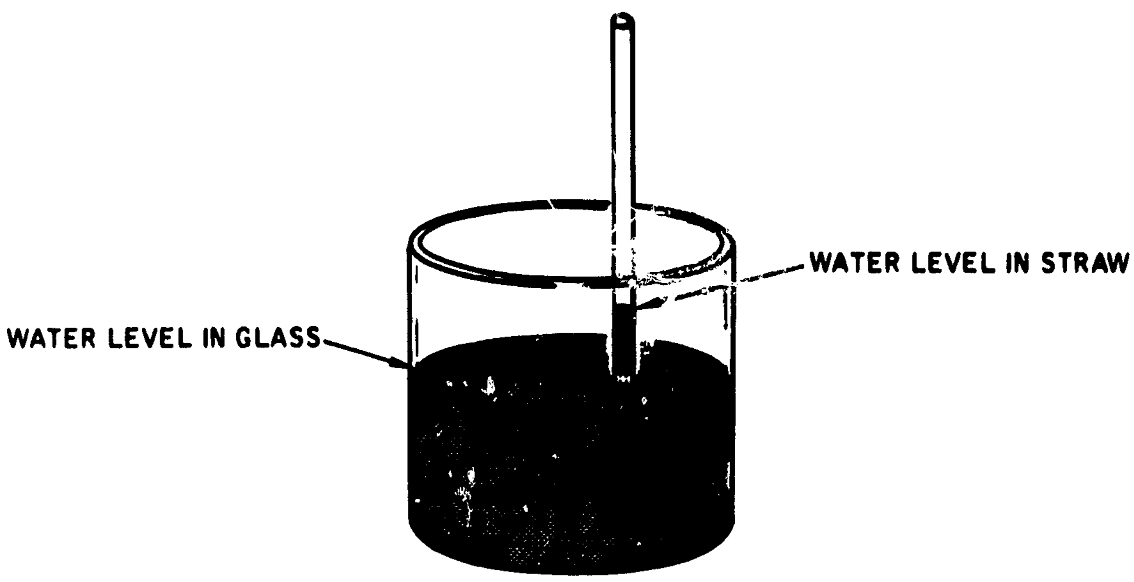

Figure 2-1. Capillary Action

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sufficient time is allowed for penetration of surface discontinuities. (See Figure 2-2.) If the discontinuity is small or narrow, as in a crack or pinhole, capillarity assists the penetration. When the opening is gross in nature, such as a tear or core blow, the liquid may be trapped when poured over the specimen.

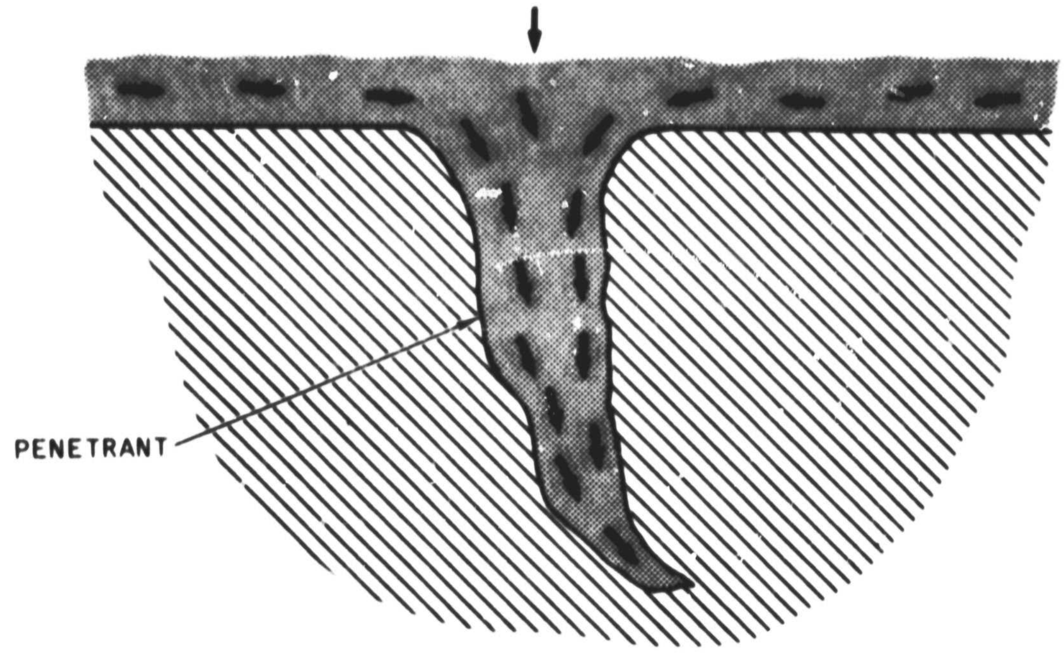

Figure 2-2. Penetration of Surface Discontinuities

3. DISCONTINUITY INDICATIONS

After sufficient time has passed for the penetrant to enter the surface discontinuities, it is removed. The removal process clears the surface of the specimen but permits the penetrant in the discontinuities to remain. Capillary action is again employed in the process. A developer, which acts as a blotter, is then applied to the test surface. (See Figure 2-3). The blotting action of the developer draws the penetrant from the discontinuity and the penetrant appears on the surface of the specimen as an indication.

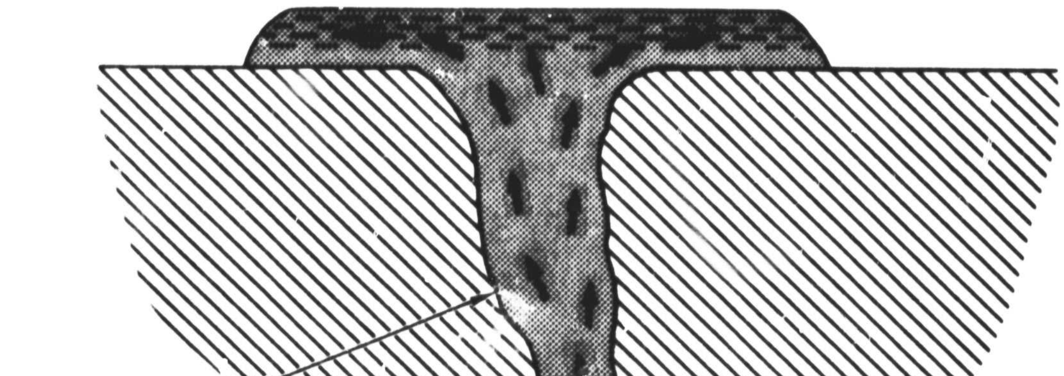

Figure 2-3. Reversed Capilary Action

The indication, because of the diffusion of the penetrant in the developer, is always greater than the discontinuity.

202 VISIBILITY OF INDICATIONS

The ultimate success of liquid penetrant testing depends upon the visibility of indications. To insure utmost visibility, the liquid penetrant contains either a colored dye easily seen in white light, or a fluorescent dye visible under black (ultraviolet) light. The colored dye penetrant is obtainable in a variety of colors.

203 TEST PROCEDURE

The sequence of the test procedure, although basically the same for all penetrant tests, can be broken into six main steps. These steps are illustrated in Figure 2-4, where it is shown that (a) the penetrant is applied to the surface of the specimen; (b) time is allowed for the penetrant to seep into the opening; (c) the penetrant remaining on the surface is removed without removing penetrant from the opening; (d) the developer is applied to aid in drawing the penetrant up or out to the surface; (e) the surface of the specimen is visually examined to locate penetrant indications which have formed in the developer coating, and finally; (f) the developer coating, together with minute amounts of penetrant remaining in it, is completely removed. The main steps and additional sub-steps required by the type of penetrant and process used are detailed in later chapters.

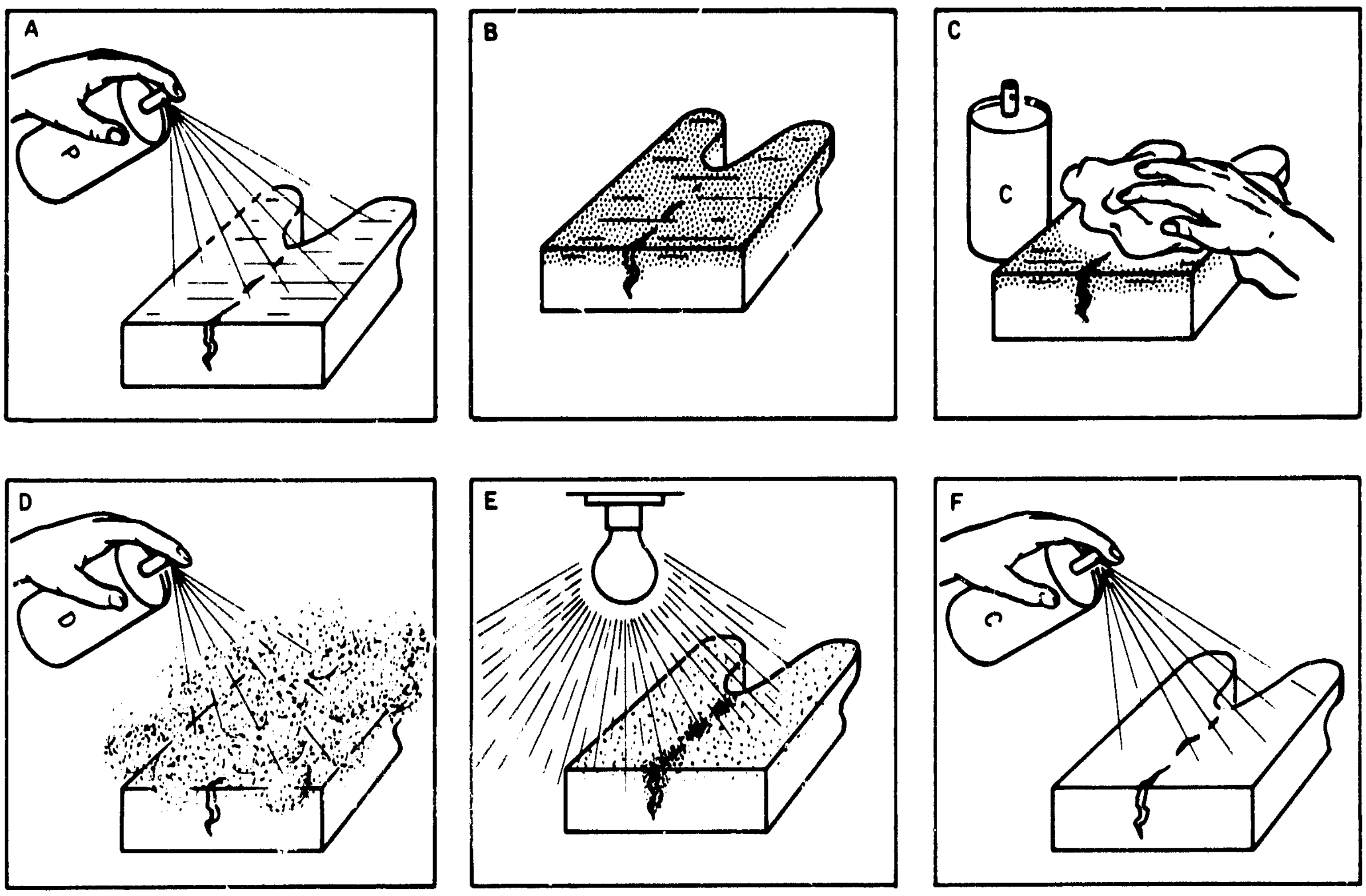

Figure 2-4. Sequence of Liquid Penetrant Tests

204 TEST PROCESSES

The liquid penetrants used in nondestructive testing can be categorized by the type dye that they contain and the process required to remove them from a specimen. In this handbook those penetrants containing a fluorescent dye are referred to as Type I, and those containing a visible colored dye, (usually red) as Type II. Any process using penetrants removable by water (water-washable) is referred to as Process A; any process using penetrants that require emulsification prior to removal (post-emulsification) is referred to as Process B; and any process using a penetrant that requires removal by a solvent is referred to as Process C. Thus Type I, Process A, denotes a process using a water-washable penetrant containing fluorescent dye; Type II, Process C, denotes a process using a solvent removable penetrant containing visible dye, etc. Figure 2-5 illustrates the three processes with Type I penetrants and Figure 2-6 illustrates them with Type II penetrants.

205 PROCESS SELECTION

Selection of the suitable type and process for a particular liquid penetrant test depends upon the sensitivity required; the number of articles to be tested; surface condition of the material under test; configuration of the test specimen; and availability of water, electricity, compressed air, suitable testing area, etc.

206 CAPABILITIES OF TEST

Liquid penetrant testing is capable of locating discontinuities open to the surface, in articles made of any non-porous material. With the penetrant tests, detectable discontinuities such as surface cracks, porosity, and "through" leaks can be found. These may be caused by fatigue cracks, shrinkage porosity, cold shuts, grinding and heat-treat cracks, seams, forging laps and bursts, as well as lack of bond between joined metals. Penetrant testing is successfully used on metals such as aluminum, magnesium, brass, copper, cast iron, stainless steel, titanium and most non-metallic alloys. It also can be used to test other materials, including ceramics, plastics, molded rubber, powdered metal products, or glass. Since some plastics and rubber compositions are affected by oil, sample tests are accomplished prior to actual testing of these materials to assure that the penetrant will not damage the material.

207 LIMITATIONS

The chief limitation of penetrant testing is that it can detect only those discontinuities open to the surface. It is also limited by its inability to test materials with porous surfaces.

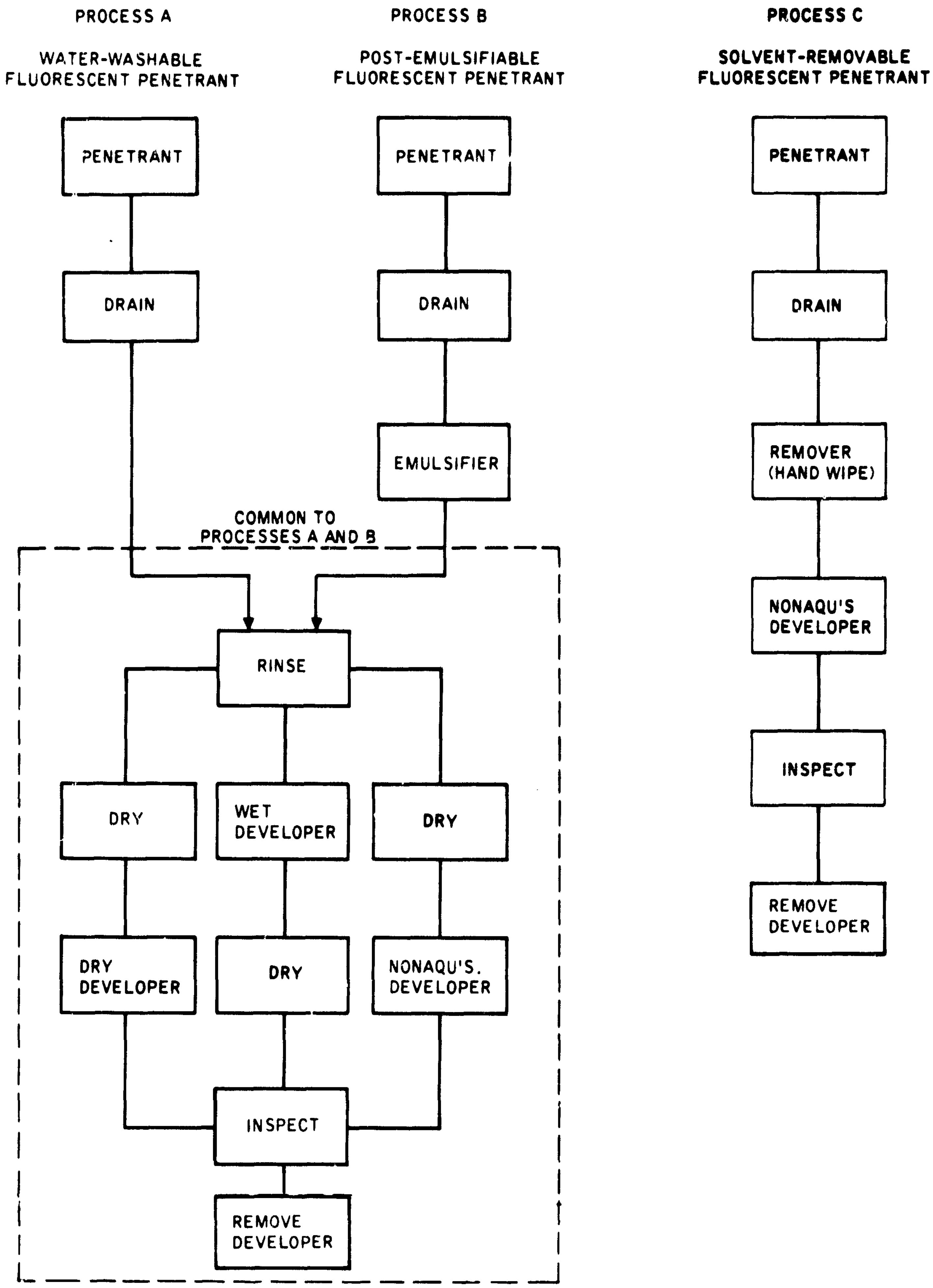

Figure 2-5. Fluorescent Penetrant Processes (Type I)

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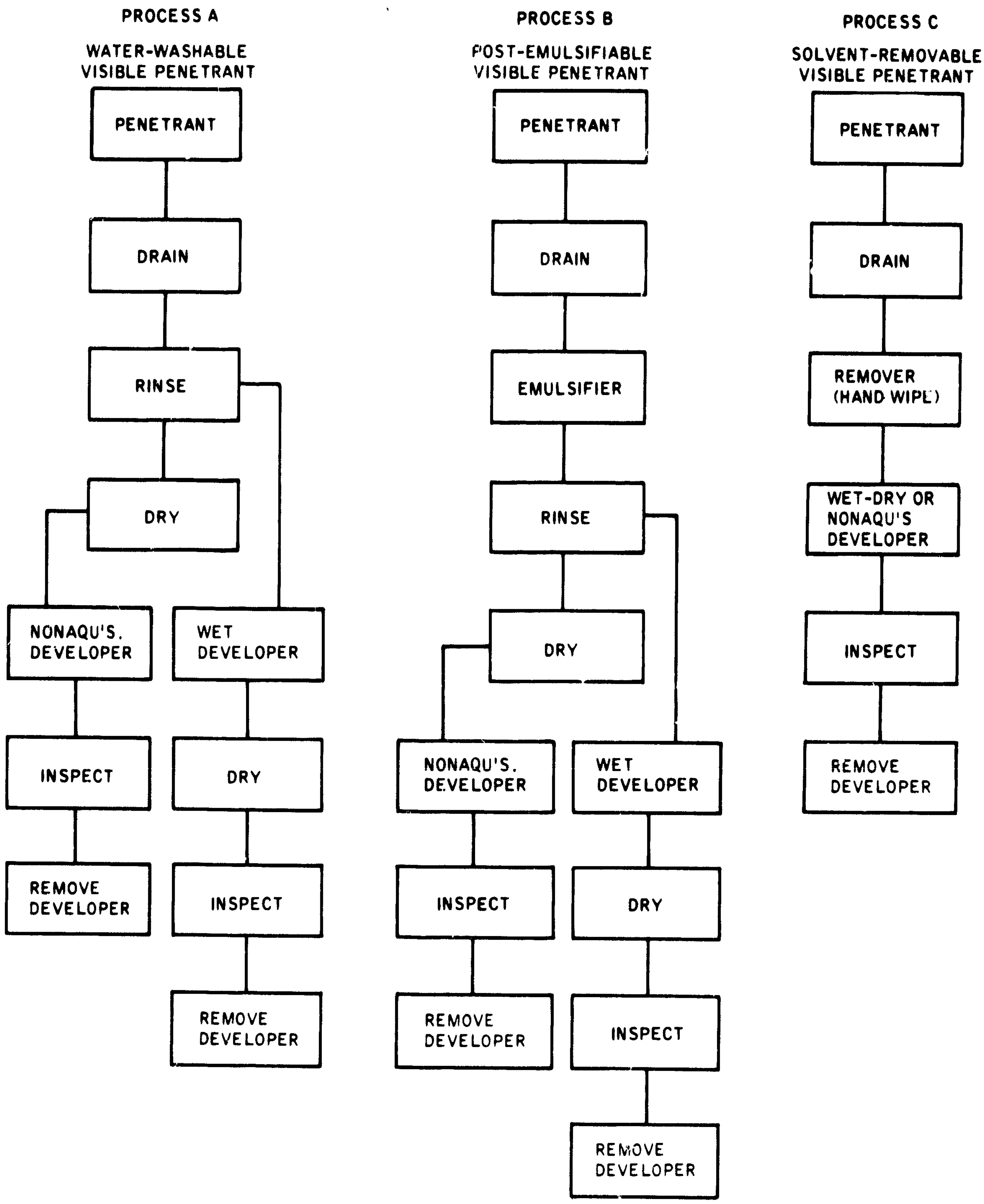

Figure 2-6. Visible Penetrant Processes (Type II)

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CHAPTER 3: EQUIPMENT AND MATERIALS
TABLE OF CONTENTS

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TABLE OF CONTENTS (CONT)

CHAPTER 3: EQUIPMENT AND MATERIALS

300 GENERAL

The specific equipment and material used in any liquid penetrant test are determined by the inherent requirements of the test procedure; the composition of the specimen under test; the size of the specimen; the frequency of like tests; and the size and type of suspected discontinuities. This chapter discusses the equipment and material required to perform the various penetrant tests and the required pre- and post-test cleaning.

301 PRE- AND POST-TEST CLEANING EQUIPMENT

1. GENERAL

Proper cleaning is essential to liquid penetrant testing for two reasons: if the specimen is not clean and dry, penetrant testing is ineffective; if all traces of penetrant test materials are not removed after test, they may have a harmful effect when the specimen is placed in service. The cleaning processes commonly used with penetrant testing are discussed in the following paragraphs. The equipment and material routinely used with these processes are all that are necessary for the cleaning required by penetrant testing.

2. DETERGENT CLEANING

Immersion tanks and detergent solutions are the most common means of accomplishing the cleaning required by liquid penetrant tests. The detergents wet, penetrate, emulsify and saponify (change to soap) various soils. The only special equipment requirement imposed by penetrant test cleaning is the need for suitable rinse facilities. When thoroughly rinsed, detergent cleaning leaves a specimen surface that is both physically and chemically clean.

3. VAPOR DEGREASING

Cleaning by vapor degreasing is particularly effective in the removal of oil, grease, and similar organic contamination. However, there are restrictions as to its use before and after liquid penetrant testing. Certain alloys have an affinity for specific elements and if exposed to them will become structurally damaged. Degreasing must be limited to those alloys which have been approved for this method of cleaning.

4. STEAM CLEANING

Steam cleaning equipment is particlarly adaptable to the cleaning of large unwieldy articles not easily cleanable by immersion. No special equipment is required for steam cleaning of specimens destined for liquid penetrant testing.

5. SOLVENT CLEANING

Solvent cleaning may use tanks for immersion, or the solvent material maybe used in a wipe-on and wipe-off technique. Usually this cleaning process is used only when vapor degreasing, detergent cleaning, and steam cleaning equipment are not available.

6. RUST AND SURFACE SCALE REMOVAL

Any good commercially available acid or alkaline rust remover may be used for pre-test cleaning. Required equipment and procedures are as specified in the manufacturer's directions.

7. PAINT REMOVAL

Dissolving-type hot-tank paint strippers, bond release, or solvent paint strippers may be used to remove paint in pre-test cleaning. Required equipment and procedures are as specified in the manufacturer's directions.

8. ETCHING

Articles that have been ground or machined often require etching to prepare them for liquid penetrant test. This process uses an acid or an alkaline solution to open up grinding burrs and remove metal from surface discontinuities. If an acid is used for etching, an alkaline solution is used as a neutralizing agent; if an alkali is used for etching, an acid is used as a neutralizing agent. The etching and neutralizing processes use either tanks and immersion, or wipe-on and wipe-off equipment and materials.

9. REMOVAL PROCESSES TO BE AVOIDED

Blast (shot, sand, grit, or pressure), liquid honing, emery cloth, wire brushes and metal scrapers are all used in processes that should not be employed in conjunction with liquid penetrant testing. These processes tend to close discontinuities by peening or cold working the surface of the specimen. On occasion a wire brush may be helpful in removing rust, surface scale or paint but it is used only when no other means of removal will suffice.

302 PENETRANT TEST EQUIPMENT (STATIONARY)

1. GENERAL

The stationary equipment used in liquid penetrant testing varies in size, layout, and arrangement with the requirements of specific tests. The size of the equipment used is largely dependent upon the size of the test specimen. The layout of the equipment, i.e., whether U, L, or straight line, is determined by the facilities available, the production rate, and the required ease of handling. The arrangement of the equipment is dependent on the process used, but is readily changed for use with other processes by the addition or deletion of components.

2. STATIONS

Depending on the Type and Process used (see Figure 2-5 and 2-6) the liquid penetrant test facility requires certain stations as shown in Figures 3-1 through 3-5. The required equipment components (stations) are combined to suit any particular test process. In a typical testing facility for a post-emulsification process, the following stations are required.

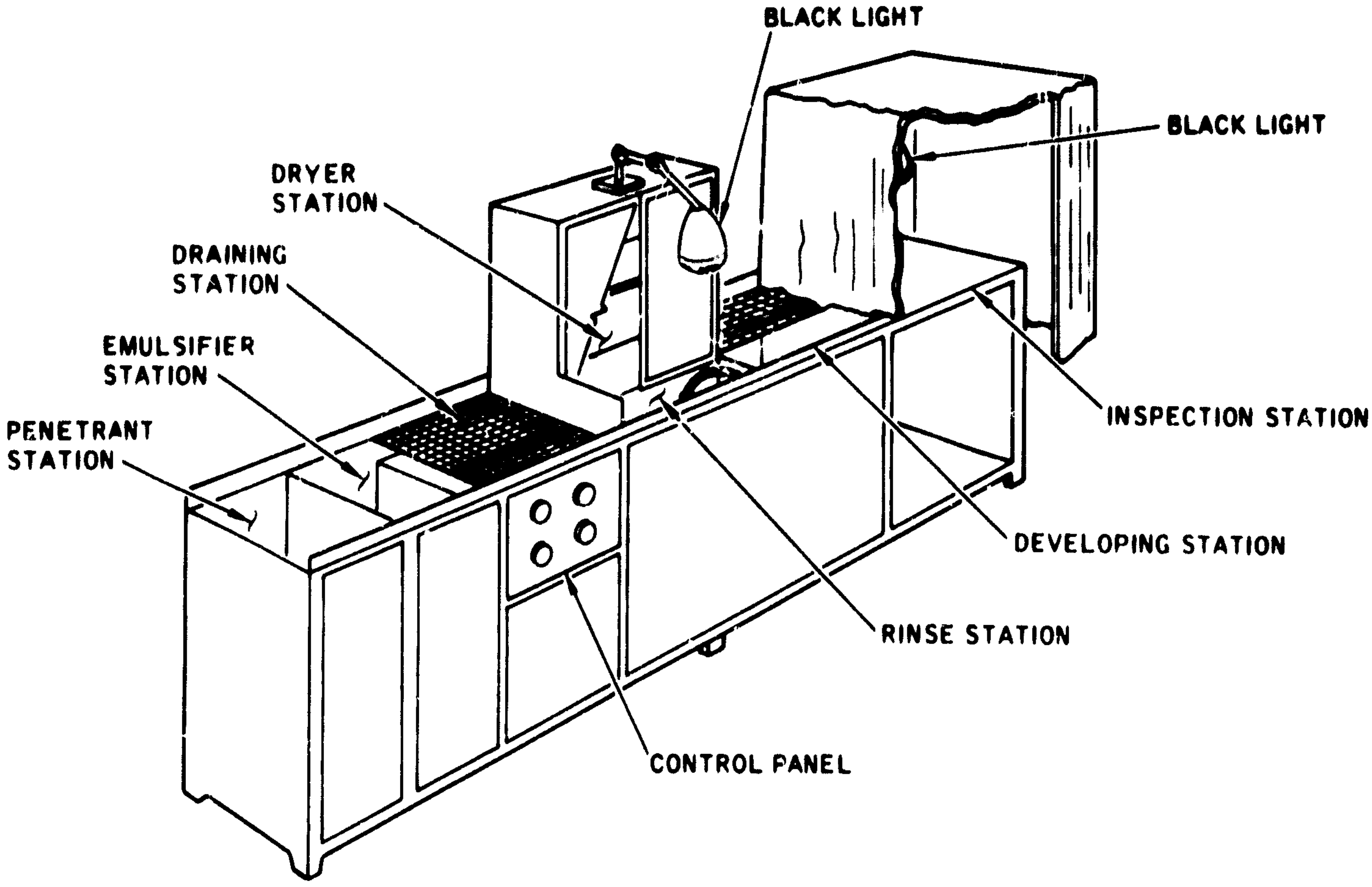

Figure 3-1. Equipment Used for Processes A and B

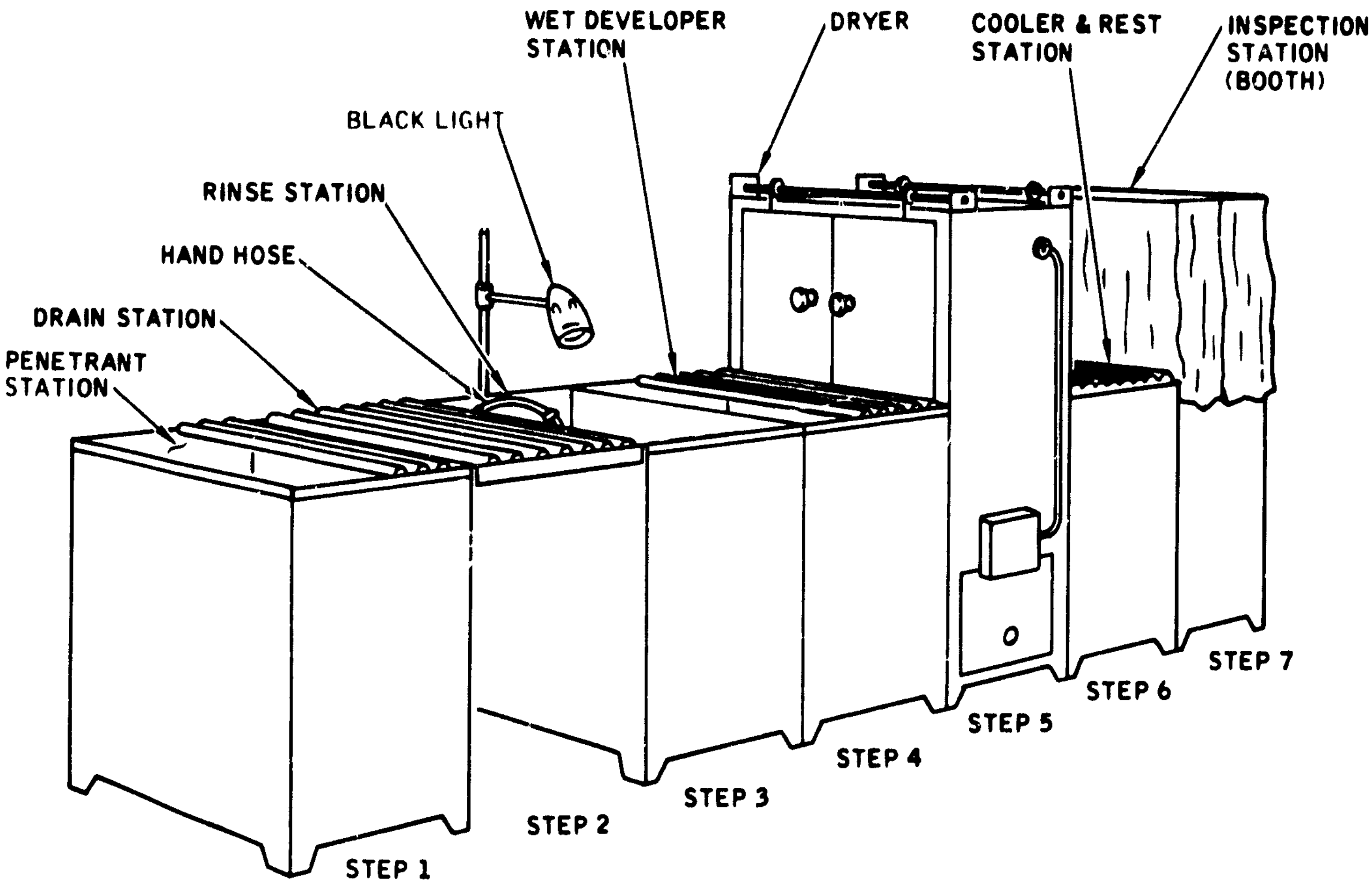

Figure 3-2. Medium-Sized Test Equipment

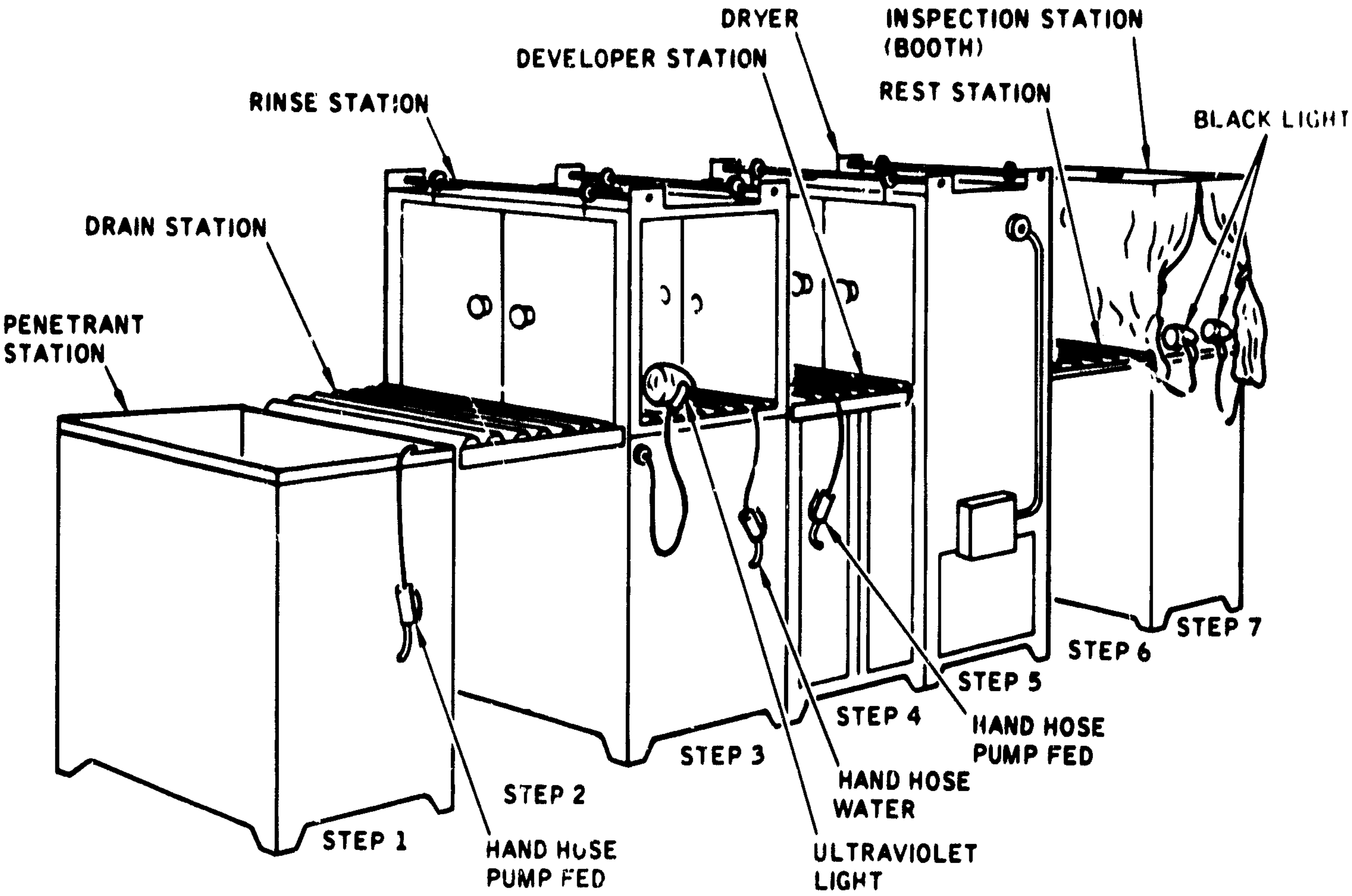

Figure 3-3. Large-Sized Test Equipment

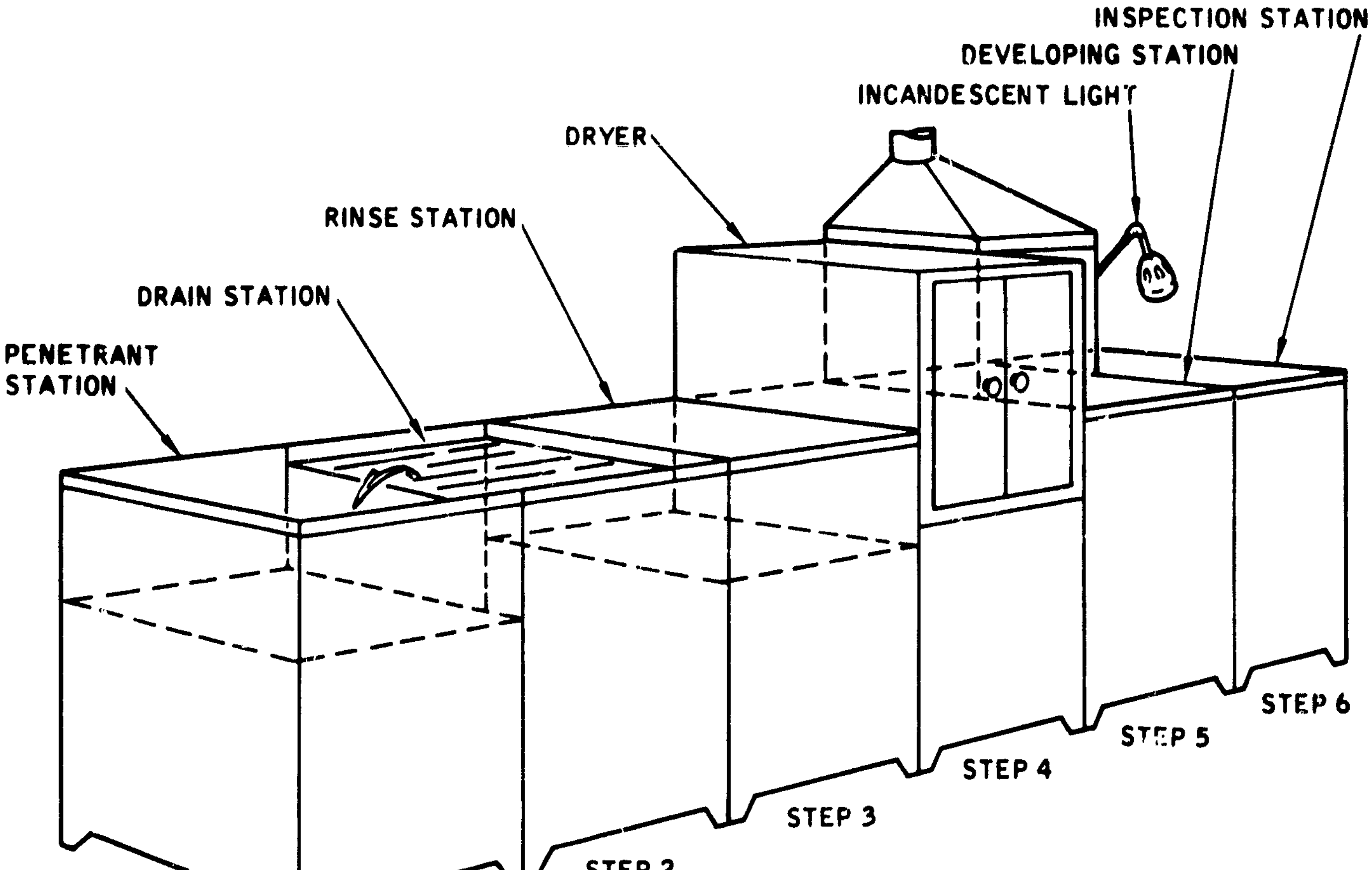

Figure 3-4. Type II, Process A, Test Equipment

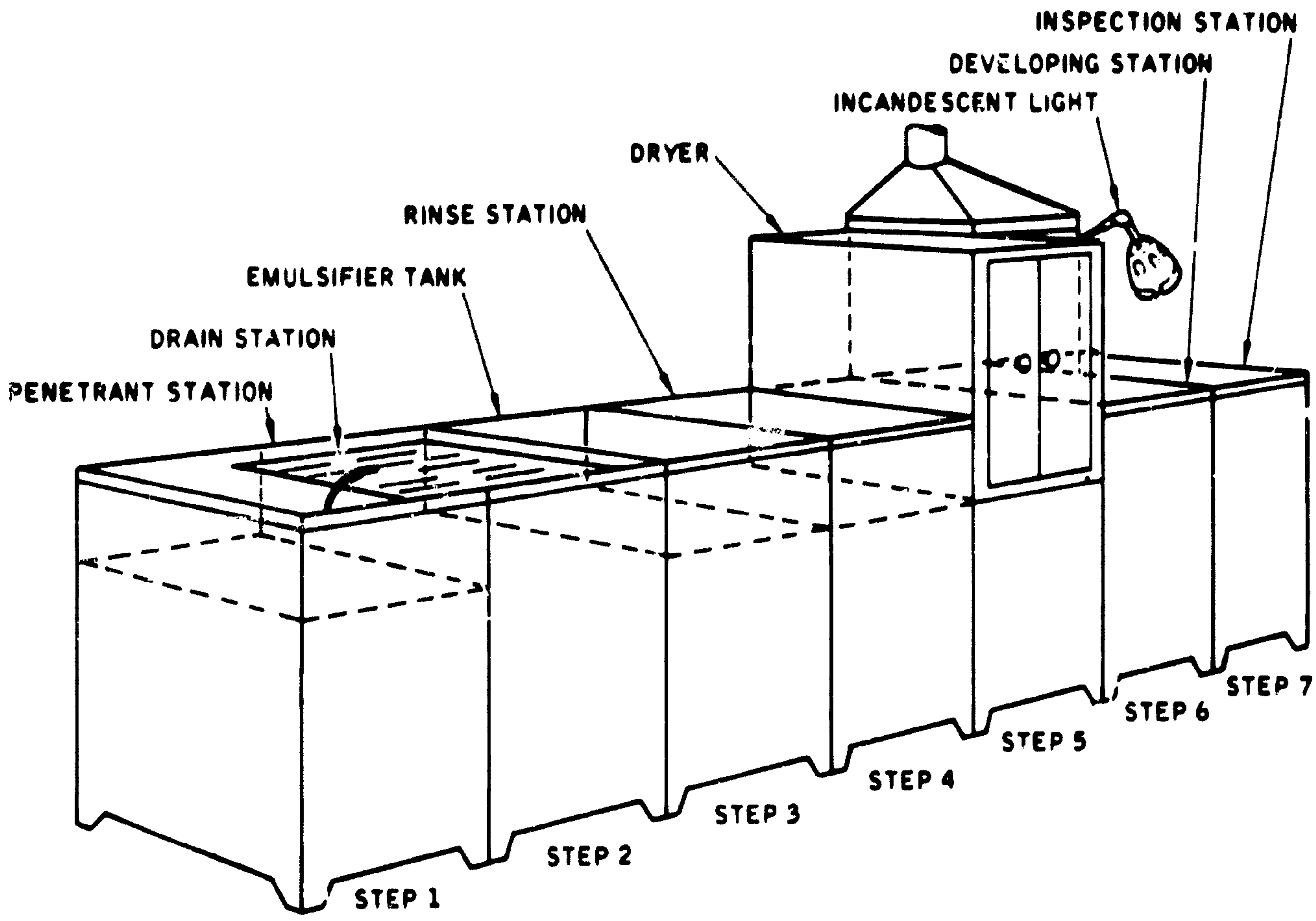

Figure 3-5. Type II, Process B, Test Equipment

a. Pre-cleaning Station (usually remote from penetrant test station)

b. Penetrant Station (tank)

c. Drain Station (used with penetrant tank)

d. Emulsification Station (tank)

e. Rinse Station (tank)

f. Developing Station (tank)

g. Drying Station (usually an oven type)

h. Inspection Station (enclosed booth or table with lighting facilities)

i. Post-cleaning Station (usually remote from penetrant test facility)

3. AUXILIARY EQUIPMENT

For the purpose of this handbook, auxiliary equipment is defined as the equipment located at penetrant test stations (other than cleaning stations) required to perform penetrant testing. The auxiliary equipment discussed may in some instances be built-in at one of the test stations.

a. Pumps. Various pumps installed at the penetrant, emulsifier, rinse, and developer stations are used to agitate the solutions, to pump drain-off material into the proper tank for reuse, and to power hand hoses.

b. Hoses and Applicators. Pump-driven hoses and applicators are used at the penetrant, emulsifier, rinse and developer stations. They decrease total test time by permitting rapid even application of the penetrant materials and the water rinse.

c. Lights. Sufficient white and fluorescent (black light) lights are installed to ensure adequate and correct lighting at all stations. When fluorescent materials are used, black light is installed at the rinse, inspection, and pre- and post-cleaning stations.

d. Timer. One or more 60-minute timers with alarm are used to control penetrant, emulsifier, developing, and drying cycles.

e. Thermostats and Thermometers. These items are required and used to control the temperature of the drying oven and the penetrant materials.

f. Exhaust Fan. Exhaust fans are used when testing is performed in closed areas. The fans facilitate removal of fumes and dust from the dry developers.

g. Spray Guns. Spray guns are used in applying dry developers. They are also used when penetrant materials in bulk form are used in areas remote from the stationary test installation.

h. Hydrometer. Hydrometers used in liquid penetrant testing are floating type instruments. They are used to measure the specific gravity of wet developers (see Figure 3-6).

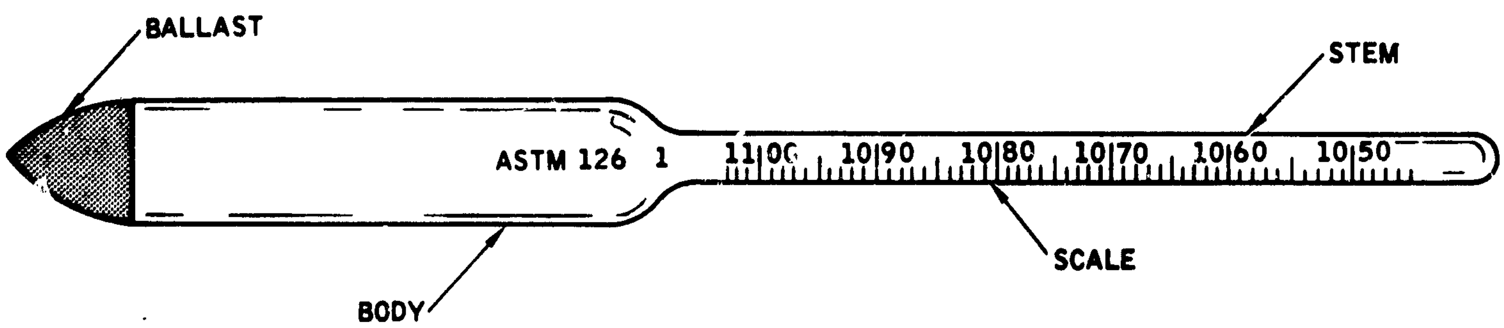

Figure 3-6. Hydrometer

303 PENETRANT TEST EQUIPMENT (PORTABLE)

1. GENERAL

It is possible to perform penetrant tests on a limited basis without stationary equipment. When testing is required at a location remote from stationary equipment, or only a small portion of a large article requires test, liquid penetrant kits are used. Both fluorescent and visible dye penetrants are available in kits.

2. VISIBLE DYE PENETRANT KITS

A visible dye penetrant test kit is light in weight and usually contains all items necessary for test. It consists of a metal box with at least the following items:

a. Four pressurized spray cans of cleaning or removal fluid.

b. Two pressurized spray cans of penetrant.

c. Two pressurized spray cans of non-acqueous developer.

d. Wiping cloths and brushes.

3. FLUORESCENT DYE PENETRANT KITS

Fluorescent penetrant kits combine portability of test material with the high sensitivity and visibility associated with fluorescent materials. The kits hold all the essential material required for test, including a black light. A fluorescent test kit consists of a metal box with at least the following items:

a. One portable black light and transformer.

b. Four pressurized spray cans of cleaning or removal fluid.

c. Two pressurized spray cans of fluorescent penetrant.

d. Two pressurized spray cans of non-aqueous developer.

e. One can of dry developer.

f. Wiping cloths and brushes.

304 BLACK LIGHT

Black light equipment is required in fluorescent penetrant testing, since it supplies light of the correct wavelengths to cause the penetrant to fluoresce. The equipment usually consists of a current regulating transformer, a mercury arc bulb, and a filter. The transformer is housed separately and the bulb and filter are contained in a reflector lamp unit. For correct test results the lamp should produce an intensity of 125 foot-candles in a three-inch circle, fifteen inches distant from the front surface of the filter. The deep red-purple filter is designed to pass only those wavelengths of light that will activate the fluorescent material. Since dust, dirt, and oil greatly reduce the intensity of the emitted light, the filter is to be frequently cleaned. In use the full intensity of the lamp is not attained until the mercury arc is sufficiently heated. At least five min-

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utes heat-up time is required to reach the required arc temperature. Once turned on, the lamp is usually left on during the entire test or working period, because switching on and off shortens the life of the bulb.

305 MATERIALS

1. GENERAL

The materials used in liquid penetrant testing include penetrants, emulsifiers, removers or cleaners, and developers. They are available in either liquid or powder form; the powders, except for those used in the dry state, are mixed with a suitable liquid prior to use. Most of the materials are available in spray cans and in bulk quantities. Though the materials obtained from various manufacturers are similar in nature they are sufficiently different that it is always necessary to use the companion products of a single manufacturer in any one test. It is equally necessary to comply with the manufacturer's instructions in the preparation and use of the materials.

2. PRE- AND POST-TEST CLEANING MATERIALS

Except for the solvents required for post-test cleaning of specimens tested by process C methods (see para. 204) no special cleaning materials are used with liquid penetrant testing.

3. MATERIAL GROUPING

In use, penetrant testing materials are restricted to specific groups and are additionally restricted by the requirement that all the items in a group must be furnished complete by one manufacturer. These restrictions insure that the materials used in the sequential steps of an liquid penetrant test are compatible with each other and capable of performing the required task. Table 3-1 tabulates penetrant materials by process, by type, and by NASA approved grouping which are defined as follows:

a. Group I. A solvent-removable visible dye penetrant; a penetrant remover (solvent); and a dry, wet, or non-aqueous wet developer.

b. Group II. A post-emulsifiable visible dye penetrant; an emulsifier; and a dry, wet, or non-aqueous wet developer.

c. Group III. A water-washable visible dye penetrant and a dry, wet, or non-aqueous wet developer.

d. Group IV. A water-washable fluorescent penetrant and a dry, wet, or non-aqueous wet developer.

e. Group V. A post-emulsifiable fluorescent penetrant; an emulsifier; and a dry, wet, or non-aqueous wet developer.

f. Group VI. A high-sensitivity post-emulsifiable fluorescent penetrant; an emulsifier; and a dry, wet, or non-aqueous wet developer.

Table 3-1. Materials Grouping

MATERIAL DESCRIPTION	GROUP	TYPE	PROCESS
FLUORESCENT DYE PENETRANT WATER-WASHABLE	IV	I	A
FLUORESCENT DYE PENETRANT WATER-WASHABLE OXYGEN COMPATIBLE	IV**	I	A
FLUORESCENT DYE PENETRANT POST-EMULSIFIABLE	V	I	B
FLUORESCENT DYE PENETRANT POST-EMULSIFIABLE NICKEL BASE ALLOY COMPATIBLE	V**	I	B
FLUORESCENT DYE PENETRANT POST-EMULSIFIABLE (HIGH SENSITIVITY)	VI	I	B
FLUORESCENT DYE PENETRANT POST-EMULSIFIABLE (HIGH SENSITIVITY) NICKEL BASE ALLOY COMPATIBLE	VI**	I	B
FLUORESCENT DYE PENETRANT SOLVENT REMOVABLE	VII	I	C
VISIBLE DYE PENETRANT WATER-WASHABLE	III	II	A
VISIBLE DYE PENETRANT WATER-WASHABLE OXYGEN COMPATIBLE	III**	II	A
VISIBLE DYE PENETRANT POST-EMULSIFIABLE	II	II	B
VISIBLE DYE PENETRANT SOLVENT-REMOVABLE	I	II	C
EMULSIFIER (FLUORESCENT)	V, VI	I	B
EMULSIFIER (FLUORESCENT) NICKEL BASE ALLOY COMPATIBLE	V**, VI**	I	B
EMULSIFIER (VISIBLE DYE)	II	II	B
PENETRANT REMOVER (SOLVENT-FLUORESCENT)	VII	I	C
PENETRANT REMOVER (SOLVENT-VISIBLE DYE)	I	II	C
NON-AQUEOUS DEVELOPER	I, II, III, IV, V, VI, VII	I, II	A, B, C
NON-AQUEOUS DEVELOPER OXYGEN COMPATIBLE	III**, IV**	I, II	A
NON-AQUEOUS DEVELOPER NICKEL BASE ALLOY COMPATIBLE	V**, VI**	I	B
WET DEVELOPER	I, II, III, IV, V, VI	I, II	A, B, C*
WET DEVELOPER OXYGEN COMPATIBLE	III**, IV**	I, II	A
WET DEVELOPER NICKEL BASE ALLOY COMPATIBLE	V**, VI**	I	B
DRY DEVELOPER	I, II, III, IV, V, VI	I, II	A, B, C*
DRY DEVELOPER OXYGEN COMPATIBLE	III**, IV**	I	A
DRY DEVELOPER NICKEL BASE ALLOY COMPATIBLE	V**, VI**	I	B

* PROCESS C, TYPE II ONLY. ** REQUIRES ADDED TEST IN ACCORDANCE WITH NASA REQUIREMENTS.

g. Group VII. A solvent-removable fluorescent penetrant; a remover; and a non-aqueous wet developer.

4. WATER-WASHABLE PENETRANTS

Water-washable penetrants contain an emulsifying agent which makes them easily removable by a water rinse or wash. The only difference between Type I and Type II water-washable penetrants is the basic difference between the two types. Type I contains a fluorescent material which glows yellow-green when exposed to black light. Type II contains a visible dye, usually red, which is easily seen under ordinary white light.

5. POST-EMULSIFIABLE PENETRANTS

Post-emulsifiable penetrants are highly penetrating oily penetrants which do not contain an emulsifying agent and consequently are not soluble in water. These penetrants must be treated with an emulsifier before they can be removed by a water rinse or wash.

6. SOLVENT-REMOVABLE PENETRANTS

Solvent-removable penetrants are oily penetrants that do not contain an emulsifying agent and differ from post-emulsifiable penetrants in that they do not accept emulsification. They are removable only by solvents specifically designed for that purpose.

7. EMULSIFIERS

Emulsifiers when applied to a penetrant coated specimen combine with the penetrant so as to make the resultant mixture removable by water rinse or wash. The emulsifiers themselves have low penetrant characteristics and do not penetrate into or remove indications from the specimen surface discontinuities.

8. REMOVERS (SOLVENT)

Solvent removers are designed to be used in conjunction with specific penetrants. They are available in either bulk quantities or in pressurized spray containers. Methylene chloride, and isopropyl alchohol are typical of the removers used in liquid penetrant testing.

9. DRY DEVELOPER

Dry developer is a fluffy absorbent white powder which functions to absorb and concentrate penetrant indications thus making them visible. It is used equally well in both fluorescent and visible dye penetrant tests.

10. WET DEVELOPER

Wet developer functions similarly to dry developer. It is a mixture of a developing powder and water. It is used in both fluorescent and visible dye penetrant tests.

11. NON-AQUEOUS WET DEVELOPER

Non-aqueous wet developer is defined by its name. It differs from wet developer in that the developer powder is mixed with a rapid-drying liquid solvent.

12. LIQUID AND GASEOUS OXYGEN COMPATIBLE MATERIALS

Penetrant materials used on articles which when in use are subject to contact with either liquid or gaseous oxygen are specifically designed to be oxygen compatible. These materials are inert when combined with, or in the presence of, either liquid or gaseous oxygen. As shown in Table 3-1 oxygen-compatible penetrant materials may be either fluorescent or visible dye materials.

CHAPTER 4: TECHNIQUES
TABLE OF CONTENTS

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TABLE OF CONTENTS (CONT)

CHAPTER 4: TECHNIQUES

400 GENERAL

The techniques discussed in this chapter are based on liquid penetrant testing techniques applicable to NASA articles. A portion of this chapter is devoted to the techniques required in testing articles that are to be used in a liquid oxygen (LOX) or gaseous oxygen (GOX) environment.

401 CLEANING

1. GENERAL

The effectiveness of liquid penetrant testing is based upon the ability of the penetrant to enter surface discontinuities. The article to be tested must be clean and free from foreign matter that may cover or fill its discontinuities. All paint, carbon, oil, varnish, oxide, plating, water, dirt and similar coatings are removed from the article prior to application of the penetrant. The cleaning technique used is in each case determined by the composition of the article under test and the type of soil that must be removed. Any cleaning process that leaves the surface of the specimen clean and dry; that does not harm the specimen; and that does not use materials that are incompatible with the penetrant materials is acceptable. Post-cleaning (cleaning after the test is completed) removes the residue of penetrant materials from the specimen. Post-cleaning is always required but is of particular importance when the test specimens are destined for use in an oxygen environment. Though many specimens will receive further processing such as etching or special cleaning prior to use, the cleanliness of any specimen after completion of a penetrant test is the responsibility of the test personnel.

2. DETERGENT CLEANING

Detergent cleaning may be used on almost any specimen. Since the cleaners may be either acid or alkaline in nature, precautions are taken to insure that the selected detergent is noncorrosive to the specimen. Detergent cleaning is most effective when it is a hot process accomplished in a washing machine though it may also be used with scrub, rinse and wipe techniques. After detergent cleaning, the specimen is carefully rinsed and dried. The drying process is of sufficient time duration that all moisture is driven from the discontinuities.

3. VAPOR DEGREASING

Vapor degreasing is the most effective means of pre-test cleaning. The process not only thoroughly cleans, it also heats the specimen so that after cleaning no moisture remains in discontinuities. Vapor degreasing is the preferred cleaning method and should be used whenever practicable. The only precaution required in the use of the process is that caused by the need of using only those degreasing materials that are not harmful to the specimen.

4. STEAM CLEANING

Steam cleaning is an excellent method of cleaning usually employed to clean large specimens, or portions of large specimens, that cannot conveniently be vapor degreased or washed with detergents. Routine steam cleaning procedures usually suffice for penetrant precleaning. As with any cleaning process involving water the specimen must be thoroughly dried after the cleaning process is completed.

5. RUST AND SURFACE SCALE REMOVAL

Rust removers (descaling solutions, either alkaline or acid), pickling solutions (acid), or wire brushing are used to remove rust and surface scale. Wire brushing is accomplished with a minimum of pressure to avoid closing surface discontinuities or filling them with smeared metal. Descaling solutions are chosen so that they are noncorrosive to the specimen. Regardless of the method selected for rust and scale removal, after the process is completed the specimen must be completely clean, dry, and so treated that surface discontinuities are not clogged, filled or contaminated.

6. PAINT REMOVAL

Any method of paint removal that does not harm the specimen is satisfactory. Chemical means such as solvent stripping and dissolving type hot-tank stripping are preferred since any mechanical removal process adversely affects the surface of the specimen.

7. ETCHING

Etching is required with metallic articles that have been mechanically processed by machining, grinding or similar procedure. The etching is accomplished with either an acid or an alkaline solution which is then neutralized. After neutralization the article must be water washed and dried or otherwise cleaned to remove all traces of the etching and neutralizing agents.

402 APPLICATION OF PENETRANTS

1. GENERAL

Penetrants are applied by spraying, swabbing, brushing, and dipping (immersion). The area under test is covered with penetrant that remains on the specimen for a predetermined amount of time known as dwell time. After dwell time is complete the specimen is ready for the next step in the testing cycle. The means of application and the length of dwell time are determined by the specimen, the penetrant used, the temperature of the specimen, and the temperature of the testing area. Terminology used in penetrant application is listed in Table 4-1.

Table 4-1. Liquid Penetrant Application Terminology

TECHNIQUES	SOAK-TIME	DWELL-TIME	PENETRATION TIME
IMMERSION	PERIOD ARTICLE IS IN BATH	DRAINING	SOAK-TIME PLUS DWELL-TIME
ALL OTHERS		TIME PENETRANT REMAINS ON ARTICLE	DWELL-TIME

2. SPRAYING

Spraying of penetrant when accomplished at the penetrant tank of stationary equipment refers to the use of a hose and nozzle through which penetrant is circulated by a low pressure pump, usually the pump which acts as agitator for the penetrant solution in the tank. The penetrant is flowed on the specimen so that all of the test area is covered. No particular precautions except those of cleanliness and neatness need be observed in this flow-on process. Spraying also is used to define the application of penetrant from pressurized spray cans. Again the penetrant is applied so that all of the test area of the specimen is covered, but personnel must make allowances for the pressure remaining in the can and the distance the can is held from the specimen. Usually pressurized spray cans are used in areas where fans or blowers remove fumes, or in open areas where spot testing (testing a small area on a large specimen) is taking place.

3. SWABBING OR BRUSHING

Penetrants may be applied by swabbing with rags or cotton waste, or by brushing. Either method is acceptable when spray or dip equipment is not available. Usually swabbing or brushing is used when test of a small, specific area of the specimen is required.

4. IMMERSION

The best procedure for applying penetrant is immersion (dipping) of the specimen or specimens into a tank of penetrant. Small specimens are placed in an open wire basket for dipping, large specimens are handled by hand or if required, by cranes and suitable clamping devices. This method is impractical when dealing with large specimens or assemblies and wasteful when only small areas of a large specimen are to be tested. It is however, the most thorough and certain means of applying penetrant and is used whenever possible.

5. PENETRATION (DWELL) TIME

The period of time during which the penetrant is permitted to remain on the specimen is a vital part of the test. This time, known as dwell time, is directly related to the size and shape of the discontinuities anticipated, since the dimensions of the discontinuities determine the rapidity with which penetration occurs. Tight cracklike discontinuities may require in excess of thirty minutes for penetration to an extent that an adequate indication can be expected. Gross discontinuities may be suitably penetrated in three to five minutes. Dwell time in each instance of test is determined by the anticipated discontinuities and the manufacturers' recommendations. Typical minimum penetration times are shown in Table 4-2.

a. Because the basic properties of penetrants are affected by temperature, the time of penetration is also affected. The temperature of the specimen and the temperature of the penetrant can therefore affect the required dwell time. Dependent upon the type of penetrant employed, warming the specimen to 70° F or higher accelerates penetration and shortens dwell time. Warming the specimen not only permits the penetrant to penetrate more readily, it also tends to eliminate moisture from the specimen, thereby reducing the possibility of contaminating the penetrant or clogging discontinuities. Care is taken not to overheat the specimen since too much heat may cause evaporation of the penetrant from discontinuities.

b. The temperature and humidity of the work area also affect penetrant action, since they determine the temperature of the penetrant and the length of time it takes the penetrant to dry. Generally, the higher the ambient temperature the shorter the required dwell time. If the humidity is too low the penetrant dries rapidly and testing becomes difficult if not impossible. If the air is very dry the penetrant dries before it has had time to enter discontinuities.

403 APPLICATION OF EMULSIFIER

When post-emulsifiable penetrants are used an emulsifier must be applied to the penetrant to make it removable by water rinse. Emulsifier is applied by any of the means used to apply penetrant except spraying but dipping or immersion is preferred. The amount of time that the emulsifier is permitted to remain (dwell) prior to the removal process is usually in the range of one to four minutes. Exact emulsifier dwell time is in accordance with the manufacturers' recommendation for the particular emulsifier.

Table 4-2. Liquid Penetrant Penetration Time (Typical)

MATERIAL	FORM	TYPE OF DISCONTINUITY	TYPES I & II PROCESS (A) WATER-WASHABLE PENETRATION TIME *	TYPES I & II PROCESS (B) POST-EMULSIFIED PENETRATION TIME *	TYPES I & II PROCESS (C) SOLVENT-REMOVABLE PENETRATION TIME *
ALUMINUM	CASTINGS	POROSITY	5 TO 10 MIN.	**5 MIN.	3
		COLD SHUTS	5 TO 15	**5	3
	EXTRUSIONS & FORGINGS	LAPS	NR***	10	7
	WELDS	LACK OF FUSION	30	5	3
		POROSITY	30	5	3
	ALL	CRACKS	30	10	5
	ALL	FATIGUE CRACKS	NR	30	5
MAGNESIUM	CASTINGS	POROSITY	15	5	3
		COLD SHUTS	15	5	3
	EXTRUSIONS & FORGINGS	LAPS	NR***	10	7
	WELDS	LACK OF FUSION	30	10	5
		POROSITY	30	10	5
	ALL	CRACKS	30	10	5
	ALL	FATIGUE CRACKS	NR	30	7
STEEL	CASTINGS	POROSITY	30	**10	5
		COLD SHUTS	30	**10	7
	EXTRUSIONS & FORGINGS	LAPS	NR***	10	7
	WELDS	LACK OF FUSION	60	20	7
		POROSITY	60	20	7
	ALL	CRACKS	30	20	7
	ALL	FATIGUE CRACKS	NR***	30	10
BRASS & BRONZE	CASTINGS	POROSITY	10	*5	3
		COLD SHUTS	10	*5	3
	EXTRUSIONS & FORGINGS	LAPS	NR***	10	7
	BRAZED PARTS	LACK OF FUSION	15	10	3
		POROSITY	15	10	3
	ALL	CRACKS	30	10	3
PLASTICS	ALL	CRACKS	5 TO 30	5	5
GLASS	ALL	CRACKS	5 TO 30	5	5
CARBIDE-TIPPED TOOLS		LACK OF FUSION	30	5	3
		POROSITY	30	5	3
		CRACKS	30	20	5
TITANIUM & HIGH TEMP. ALLOYS	ALL		NR***	20 TO 30	15
ALL METALS	ALL	STRESS OR INTER-GRANULAR CORROSION	NR***	240	240

* FOR PARTS HAVING A TEMPERATURE OF 60°F OR HIGHER
** PRECISION CASTINGS ONLY
*** NR - NOT RECOMMENDED

[redacted]

404 REMOVAL OF PENETRANTS

1. GENERAL

Following application of the penetrant and elapse of sufficient time for penetration, the penetrant is removed from the surface of the specimen. This operation is meant to remove the penetrant from the surface without disturbing any penetrant which has entered a discontinuity. Complete removal of the surface penetrant is effected to ensure against formation of irrelevant indications.

2. WATER-WASHABLE PENETRANTS

Since water-washable penetrants have a built-in emulsifier the removal of this type penetrant from the surface of the specimen is easily accomplished by a water rinse. Care is taken in applying the rinse to insure that the spray volume and force does not wash the penetrant out of discontinuities. Thirty to forty pounds per square inch is a maximum safe pressure for the water rinse. The rinse is applied through the use of an adjustable spray nozzle held so that the spray reaches the surface plane of the specimen at an angle of 45 degrees.

3. POST-EMULSIFYING PENETRANTS

The removal of post-emulsifier penetrants is a two-step process. The emulsifier is applied as described in paragraph 403 and, after suitable dwell time, the resultant penetrant-emulsifier mixture is removed by water rinse as described in paragraph 404.2.

4. SOLVENT REMOVABLE PENETRANTS

A solvent removable penetrant is properly removed only by the solvent designated for that particular penetrant by the penetrant manufacturer. Prior to the use of the solvent, excess penetrant is wiped from the specimen with absorbent towels. After the excess penetrant is wiped off, the specimen surface is cleaned with clean towels dampened with solvent. Solvent is never applied directly to the specimen since it might wash out or dilute the penetrant in a discontinuity.

5. VISUAL INSPECTION

When fluorescent penetrants are used, it is helpful to examine the specimen under black light following the removal operation, thereby insuring complete removal of the penetrant. For visible dye penetrants the absence of penetrant (red) traces on the wiping materials insures complete penetrant removal. Corrosion may result from entrapped penetrants residue found under splices, fasteners, rivets, etc., which due to their chemical nature have an affinity for moisture.

405 APPLICATION OF DEVELOPER

1. GENERAL

Because penetrant commences to bleed out of discontinuities immediately following removal of surface penetrant, developer is applied to the specimen as soon as the penetrant removal process is completed. Developer assists in the detection of penetrants retained in discontinuities by aiding in the capillary bleed-out process (the developer acts as a blotting agent), and by accentuating the presence of penetrant in a discontinuity. Developer accentuates the presence of a discontinuity because it causes the penetrant from the discontinuity to spread out over a greater area. It also serves as a color contrast background for the visible dye used in the visible dye processes and for the fluorescent material used in the fluorescent processes. Developer is available in both dry and liquid forms and the selection of developer is in accordance with the manufacturers' recommendation for the type penetrant used. When a dry or non-aqueous developer is used the specimen must be completely dry before the developer is applied. When a wet developer is used it is applied immediately after the penetrant removal is accomplished, and the specimen is then dried.

2. DRY DEVELOPER

Dry developer being a loose, fluffy talcose powder with high absorbent properties is applied to a specimen by dusting, blowing, or dipping the specimen. The application is usually accomplished in a booth with a blower or fan arrangement that removes loose powder from the atmosphere. No preparation of the powder is necessary and the only requirement is that it be evenly distributed over the test surface which must be completely dry. Developing time with dry powder is approximately one-half of the dwell time of its companion penetrant. Dry developer is used only with fluorescent dye penetrants.

3. NON-AQUEOUS DEVELOPER

Non-aqueous developer is a suspension of absorptive white powder in a solvent vehicle. It is usually applied by spraying from a pressurized spray can or other spraying device such as a paint spray gun. When used in bulk form, care must be exercised to keep the powder thoroughly mixed in the solvent. The developer is applied so as to form a moist, thin, white coating on the specimen which must be completely dry. When properly mixed and applied, non-aqueous developer assures a high degree of penetrant visibility.

4. WET DEVELOPER

Wet developer is a suspension of absorptive white powder in water. The mixture is prepared in accordance with manufacturers' directions and is mildly agitated prior to and during use so that the powder remains evenly distributed throughout the water

[redacted]

vehicle. After excess penetrant is removed from the specimen, and while it is still wet, wet developer is applied by either dip (immersion) or flow-on technique. These fast and effective methods of application combined with the time saved by applying developer to the wet specimen make wet developer well suited for use in rapid, production line testing. Wet developer is applied so as to form a smooth even coating, and particular care is taken to avoid concentrations of developer in dished or hollowed areas of the specimen. Such concentrations of developer mask penetrant indications and are to be avoided. After wet developer has beer applied the specimen is thoroughly dried, it is then ready for visual inspection.

406 DRYING

When dry or non-aqueous developer is used, the specimen is dried after removal of excess penetrant and prior to application of the developer. When wet developer is used, the specimen is dried after the developer has been applied. Any means of drying that does not interfere with the test process by overheating, or by contamination of materials, is acceptable but, controlled drying at even regulated temperatures is preferred. A thermostat controlled drier with a range up to 225° F is usually employed in stationary test installations. Required drying time is determined by the size and shape of the specimen, and by the nature of its suspected discontinuities. It is particularly necessary that the drying process used prior to application of dry or non-aqueous developer be closely controlled. It is to be of sufficient duration to dry the surface of the specimen without affecting the penetrant in the discontinuities.

407 PENETRANT TESTING PROCESSES

1. GENERAL

In Chapter 2 the possible penetrant testing processes are described as six in number. The six processes are listed in two groups of three each. One group of three, Type I consists of those processes employing fluorescent penetrants; the other, Type II consists of those processes employing visible dye penetrants. Within each type listing, the three processes are Process A, which employs water washable penetrants; Process B, which employs post-emulsifiable penetrants; and Process C, which employs solvent-removable penetrants. Step-by-step procedures for these processes, which are illustrated in Figures 4-1 and 4-2. are contained in the following paragraphs. Table 4-3 lists preferred processes for various penetrant test problems.

2. WATER-WASHABLE FLUORESCENT PENETRANT TEST (TYPE I, PROCESS A)

The characteristic advantages and disadvantages of water-washable fluorescent penetrants are listed in Table 4-4.

a. Penetrant Application. Either immersion, flow-on, or brushing technique is used to apply the penetrant to the precleaned, dry specimen. The penetrant is applied evenly over the entire test area.

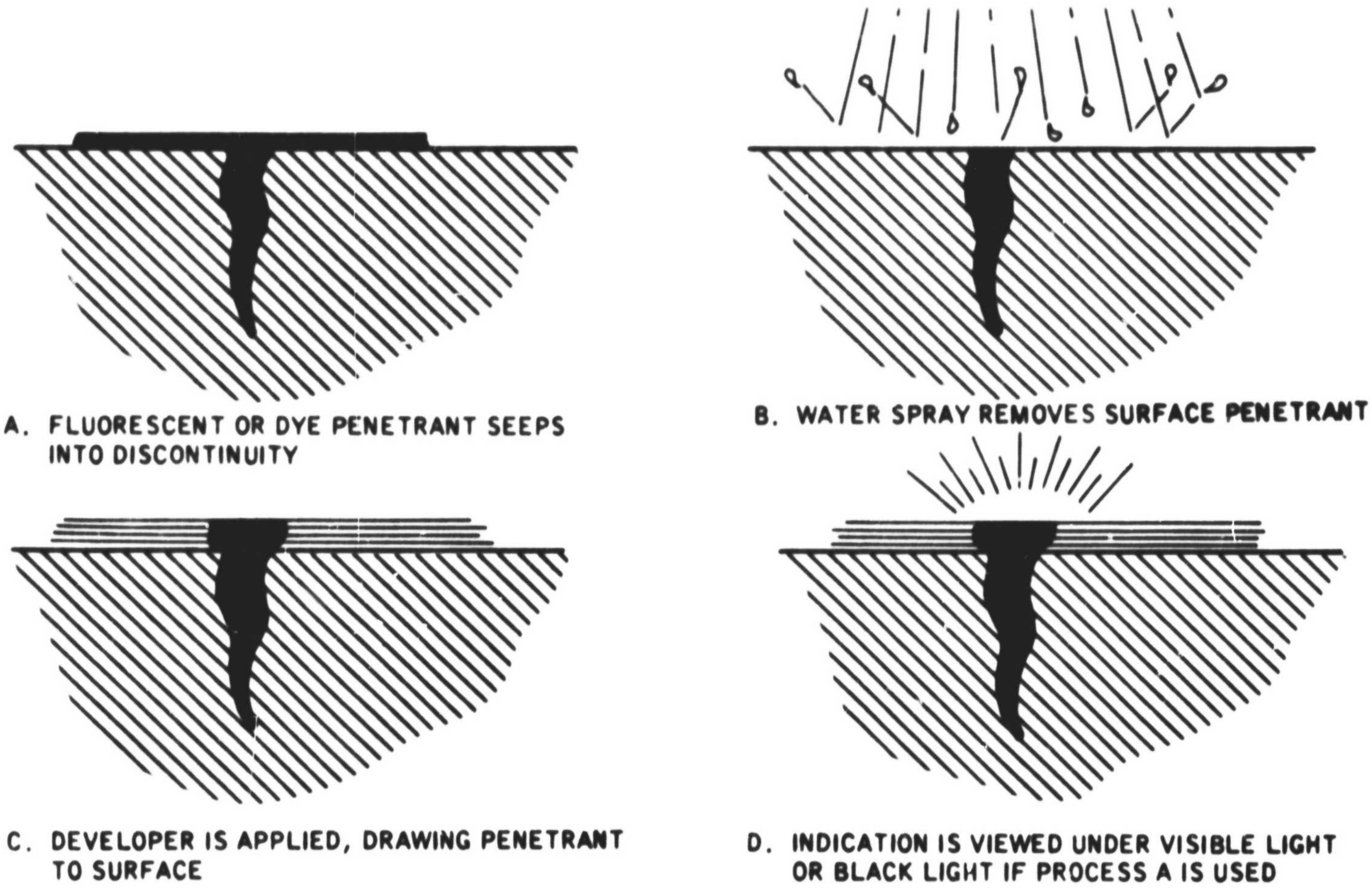

Figure 4-1. Processes A and C

b. Dwell Time. The penetrant is left on the specimen for the required length of dwell time. A broad guide to correct dwell time is contained in Table 4-2 but the specimen size, composition, and discontinuities, and the temperature of the specimen and the test area all affect required dwell time.

c. Penetrant Removal. Excess penetrant (all penetrant except that in discontinuities) is washed from the specimen after dwell time has elapsed. Warm water at a pressure not exceeding 40 psi is applied from a spray nozzle. The nozzle is held so that the water strikes the surface of the specimen at an angle of approximately 45 degrees. Care is taken to avoid over-washing which causes washout of penetrant from discontinuities. The wash process is accomplished under black light so that the operator can observe when the excess penetrant is completely removed.

d. Drying. Upon completion of the wash process the specimen is dried prior to the application of either dry or non-aqueous developer. If wet developer is used it is applied to the still damp specimen immediately after the penetrant removal wash cycle. Drying is best accomplished in a thermostat-controlled oven at a temperature not in excess of 225° F. Drying time is determined by the size and composition of the specimen, and visual observation usually fixes the length of the drying cycle. Excessive heat or too long a drying

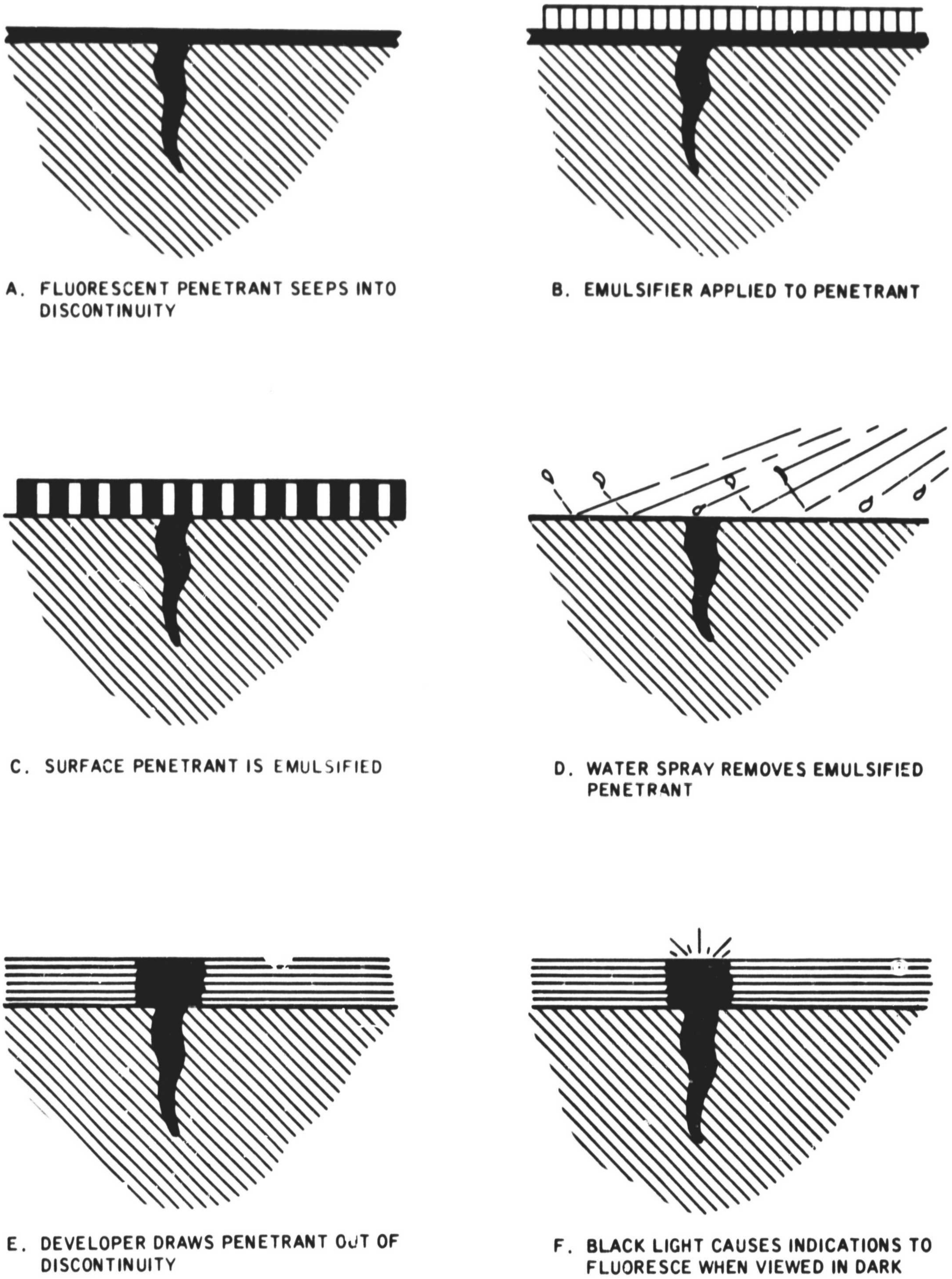

Figure 4-2. Process B

Table 4-3. Process Selection Guide

TESTING PROBLEM	TYPES I & II PREFERRED PROCESS	REMARKS
HIGH PRODUCTION OF MANY SMALL ARTICLES REQUIRED	A	SMALL PARTICLES HANDLED IN BASKETS
HIGH PRODUCTION OF LARGE INDIVIDUAL ARTICLES	B	LARGE FORGINGS, EXTRUSIONS, ETC.
HIGHEST SENSITIVITY TO FINE DISCONTINUITIES	B	BRIGHTEST INDICATION MOST SENSITIVE
SHALLOW DISCONTINUITIES SCRATCHES, ETC., MUST BE DETECTED	B	DEPTH OF EMULSIFICATION CAN BE CONTROLLED
ARTICLES HAVING A ROUGH SURFACE	A	
ARTICLES HAVING THREADS AND KEYWAYS	A	PROCESS B PENETRANT MIGHT LODGE IN CORNERS
ARTICLES HAVING MEDIUM ROUGH SURFACES	A-B	CHOICE DEPENDS UPON PRODUCTION AND SENSITIVITY REQUIREMENTS
SPOT TESTING OF LOCAL AREAS DESIRED	C	
PORTABLE EQUIPMENT NECESSARY	C	
WATER AND ELECTRICITY NOT AVAILABLE	C	
ANODIZED ARTICLES, CRACKED AFTER ANODIZING, TO BE TESTED	C-B-A	ORDER OF PREFERENCE INDICATED
REPEATED APPLICATION OF PROCESS IS DESIRED	C	FIVE OR SIX REPEATS SHOULD BE THE LIMIT
LEAK DETECTION	A-B	

[redacted]

Table 4-4. Characteristics of Water-Washable Fluorescent Penetrants

ADVANTAGES	DISADVANTAGES
FLUORESCENCE INSURES VISIBILITY	REQUIRES DARK AREA BLACK LIGHT INSPECTION
EASILY WASHED WITH WATER	NOT RELIABLE FOR DETECTING SCRATCHES AND SIMILAR SHALLOW SURFACE DISCONTINUITIES
GOOD FOR QUANTITIES OF SMALL SPECIMENS	NOT RELIABLE ON RERUNS OF SPECIMENS
GOOD ON ROUGH SURFACES	NOT RELIABLE ON ANODIZED SURFACES
GOOD ON KEYWAYS AND THREADS	ACIDS AND CHROMATES AFFECT SENSITIVITY
GOOD ON WIDE RANGE OF DISCONTINUITIES	EASILY OVER-WASHED
FAST, SINGLE STEP PROCESS	PENETRANT SUBJECT TO WATER CONTAMINATION
RELATIVELY INEXPENSIVE	
AVAILABLE IN OXYGEN COMPATIBLE FORM	

cycle tends to bake the penetrant out of discontinuities.

e. Developer Application. When the drying process is complete the specimen is ready for the application of either dry or non-aqueous developer. When wet developer is used, it is applied to the wet specimen immediately after excess penetrant is removed.

(1) Dry developer is applied to the specimen by brushing with a soft brush, by use of a powder gun, or by dipping the specimen in a tank of the developer and removing excess powder with a low pressure air flow.

(2) Non-aqueous developer is applied by spraying. It is applied sparingly so that a thin coating covers all of the specimen test area. When using non-aqueous developer the specimen is to be cool enough to prevent too rapid evaporation of the developer vehicle.

(3) Wet developer is applied to the specimen as it comes from the wash cycle, either by immersion or flow-on. The developer is applied so as to form a smooth even coating over the entire test area. After the developer is applied the specimen is dried as described in paragraph 410.1.d.

f. Inspection. After sufficient time has passed for developer action to bring the penetrant from discontinuities as indications, the specimen is ready for inspection under black light. The interpretation of various indications discovered during inspection is discussed in Chapter 5 of this handbook. The efficiency of the inspection operation is controlled by the variables of the human eye. These variables are further complicated by the average persons lack of understanding of eye fatigue and of the time required for the iris of the eye to dilate to a point of maximum vision in the darkness of the black light inspection booth. For maximum visual efficiency the operator must:

(1) Let his eyes become accustomed to the darkness by entering the darkened area (booth) several minutes prior to examining the specimen under the black light.

(2) Avoid looking directly into the black light source since the eyeball contains a fluid that fluoresces if black light shines directly into the eye.

3. <u>POST-EMULSIFIABLE FLUORESCENT PENETRANT TEST (TYPE I, PROCESS B)</u>

The characteristic advantages and disadvantages of post-emulsifiable fluorescent penetrants are listed in Table 4-5. This process is identical with that of the water-washable fluorescent penetrant test except for the inclusion of an emulsification step after the completion of penetrant dwell time and before penetrant removal.

a. <u>Penetrant Application</u>. See paragraph 410.1.a.

b. <u>Dwell Time</u>. See paragraph 410.1.b.

c. <u>Emulsifier Application</u>. After the elapse of sufficient dwell time, emulsifier is applied to the penetrant coated specimen. Immersion, flow-on, or spray technique is used to apply the emulsifier in an even coating. The particular technique employed is determined by the number and size of the specimens under test.

d. <u>Emulsifier Dwell Time</u>. The length of time the emulsifier is left to dwell before commencing the penetrant removal cycle is determined by the emulsifier used and the type discontinuities suspected. Detection of shallow, wide dents, machine marks, and nicks requires a minimum emulsification time.

Table 4-5. Characteristics of Post-Emulsifiable Fluorescent Penetrants

ADVANTAGES	DISADVANTAGES
FLUORESCENCE INSURES VISIBILITY	REQUIRES DARK AREA BLACK LIGHT INSPECTION
HIGH SENSITIVITY FOR VERY FINE DISCONTINUITIES	TWO STEP PROCESS
GOOD ON WIDE SHALLOW DISCONTINUITIES	EQUIPMENT REQUIRED FOR EMULSIFIER APPLICATION
EASILY WASHED WITH WATER AFTER EMULSIFICATION	DIFFICULT TO REMOVE PENETRANT FROM THREADS, KEYWAYS, BLIND HOLES AND ROUGH SURFACES
SHORT PENETRATION TIME	
CANNOT BE EASILY OVER-WASHED	

[redacted]

Detection of fine, light cracks requires emulsification time of sufficient duration that superficial discontinuities are washed clean during the penetrant removal cycle, but the time is not to be so long that the penetrant in the cracks is affected. One to three minutes emulsification dwell time is usually required, though rough surfaced articles may require five minutes or more. Manufacturers recommendations concerning length of emulsifier dwell time are accurate and dependable.

e. Penetrant Removal. See paragraph 410.1.c.

f. Drying. See paragraph 410.1.d.

g. Developer Application. See paragraph 410.1.e.

h. Inspection. See paragraph 410.1.f.

4. SOLVENT REMOVABLE FLUORESCENT PENETRANT TEST (TYPE I, PROCESS C)

The characteristic advantages and disadvantages of solvent removable fluorescent penetrants are listed in Table 4-6.

a. Penetrant Application. Solvent removable penetrant may be applied by brush-on technique but is more often applied by use of a spray gun or pressurized spray can. With any application process, correct application covers the test surface with an even coat of penetrant. When a spray gun or pressurized can is used, the gun or can is held approximately 12 inches from the specimen and moved slowly from side to side until the specimen is evenly coated.

b. Dwell Time. See paragraph 410.1.b.

Table 4-6. Characteristics of Solvent Removable Fluorescent Penetrants

ADVANTAGES	DISADVANTAGES
FLUORESCENCE INSURES VISIBILITY	REQUIRES DARK AREA BLACK LIGHT INSPECTION
PORTABILITY	FLAMMABLE MATERIALS
NO WATER REQUIRED	REMOVAL OF EXCESS SURFACE PENETRANT IS TIME CONSUMING
GOOD ON ANODIZED SPECIMENS	MATERIALS CANNOT BE USED IN OPEN TANKS
GOOD FOR SPOT CHECKING	DIFFICULT TO USE ON ROUGH SURFACES SUCH AS CAST MAGNESIUM
SPECIMENS CAN BE RERUN	

c. Penetrant Removal. Excess penetrant is removed from the specimen, after suitable dwell time has elapsed, by wiping with absorbent towels. After the bulk of the excess penetrant is wiped off, towels are moistened with the companion solvent of the penetrant (solvent specified by the penetrant manufacturer). The specimen is wiped clean with the moistened towels. Solvent is never applied directly to the specimen. The removal process is accomplished under black light so the operator can observe that all excess penetrant is removed.

d. Developer Application. Only non-aqueous developer is used with solvent removable penetrants. A thin coating of developer is sprayed on the test area of the specimen.

e. Inspection. See paragraph 410.1.f.

5. VISIBLE DYE PENETRANT TESTS

The characteristic advantages and disadvantages of visible dye penetrants are the same as those listed in Tables 4-4, 4-5 and 4-6 for their fluorescent counterparts, except that visible dye penetrants are slightly less sensitive, not as brilliantly visible, and do not require the use of black light.

a. Water-Washable Visible Dye Penetrant Test (Type II, Process A). Procedures for use of water-washable visible dye penetrants are identical with those listed in paragraphs 410.1.a thru f, except that dry developer is never used with visible dye penetrants and there is no black light requirement.

b. Post-Emulsifiable Visible Dye Penetrant Test (Type II, Process B). Procedures for use of post-emulsifiable visible dye penetrants are identical with those listed in paragraphs 410.2.a thru h, except that dry developer is never used with visible dye penetrants and there is no black light requirement.

c. Solvent Removable Visible Dye Penetrant Test (Type II, Process C). Procedures for use of solvent removable visible dye penetrants are identical with those listed in paragraphs 410.3.a thru e, except that there is no black light requirement.

408 OXYGEN COMPATIBLE PENETRANTS

There is no basic difference in the techniques used with liquid and gaseous oxygen compatible penetrant materials and those used with other penetrant materials, except for the special precautions required to avoid contamination of the test materials.

[redacted]

409 TYPICAL OXYGEN COMPATIBLE PENETRANT TEST PROCEDURE

1. GENERAL

The procedures detailed in the following paragraphs are for the inspection of welds on articles which will be used in a liquid oxygen environment. It is typical of the procedures used with oxygen compatible penetrant materials.

2. MATERIAL PREPARATION

When pressurized containers are used, the instructions on the containers must be complied with in detail. When bulk material is used, certain preliminary procedures, detailed in the following paragraphs, must be followed. Since contamination of the oxygen compatible materials must be avoided, only a small batch is prepared in advance.

a. Cleaning of Containers. Two 64-ounce glass bottles, two 8-ounce polyethylene bottles, one 32-ounce graduate, one 3-gallon graduated molded bucket, two inorganic brushes, and the stirring blade of an electric stirrer are thoroughly washed. These items are then rinsed with demineralized water.

b. Penetrant Preparation. Sixteen ounces, by volume, of penetrant stock solution and 48 ounces, by volume, of demineralized water are poured into one of the 64-ounce glass bottles. The mixture is shaken vigorously with the bottle tightly capped. One of the 8-ounce polyethylene bottles is filled with the penetrant solution and the bottle is tightly capped. Each bottle is marked "LOX Penetrant (and designated number)."

c. Wet Developer Preparation. Sixty-four ounces (1/2-gallon), by volume, of demineralized water is poured into the 3-gallon molded bucket, and 2-1/2 ounces, by weight, of developer powder is slowly added to the water while stirring continuously with the electric stirrer. The graduations inside the bucket are used to measure the specific volume of the water. The stirring operation, though constant, is controlled to avoid foaming of the solution. The second 64-ounce bottle is filled with the developer solution, tightly capped, allowed to stand for at least one hour, and then restirred. The second 8-ounce bottle is filled with developer solution and tightly capped. Each of the bottles containing developer solution is labelled "LOX Developer (and designated number)."

d. Washing Bottle. The 16-ounce polyethylene bottle is filled with demineralized water and labelled "Demineralized Water."

3. WORKING PROCEDURES

a. Penetrant Application. Penetrant from the 8-ounce bottle is applied to the weld surface by brushing with the inorganic brush.

b. Dwell Time. The penetrant is allowed to remain on the weld surface for a period of at least 10 minutes, but not longer than 20 minutes.

c. Penetrant Removal. Immediately following the dwell period, disposable wipers are moistened with demineralized water from the washing bottle and used to wipe the excess penetrant from the weld surface. The wipers are only lightly moistened and water is never applied directly onto the weld surface. When fluorescent penetrants are used, penetrant removal is accomplished under black light.

d. Developer Application. Following the removal of excess penetrant and while the surface is still wet, a thin uniform coating of developer solution from the polyethylene bottle is applied to the weld surface with the other camel hair brush. The developer solution is applied carefully so as to avoid foaming or bubbling.

NOTE: The developer solution is stirred prior to use. The bottle of developer solution is never shaken since this produces unwanted foam and bubbles.

e. Developer Dwell Time. Developer dwell time is approximately the same as penetrant dwell time, i.e., at least 10 minutes but not longer than 20 minutes.

f. Inspection. After the developing period, the weld and adjacent parent metal are inspected for penetrant indications of discontinuities and the findings are recorded. When fluorescent penetrants are used, inspection is accomplished under black light.

g. Post-Test Cleaning. After all discontinuity indications have been evaluated and recorded, developer residue is cleaned from the test area with demineralized water from the washing bottle and disposable wipers. When fluorescent penetrants are used, post-test cleaning is accomplished under black light.

410 LEAK-THROUGH TECHNIQUE

Frequently, articles are so designed that the penetrant solution may be poured into them and the outer surface examined for evidence of leak-through. Use of liquid penetrant in this manner detects leaks only, and little or no knowledge concerning other quality characteristics of the specimen are obtained. The leak-through technique is well suited for finding leaks in such articles as tanks, piping, tubing, and hollow castings. Figure 4-3 illustrates the liquid penetrant leak-through test as used on a large plate section.

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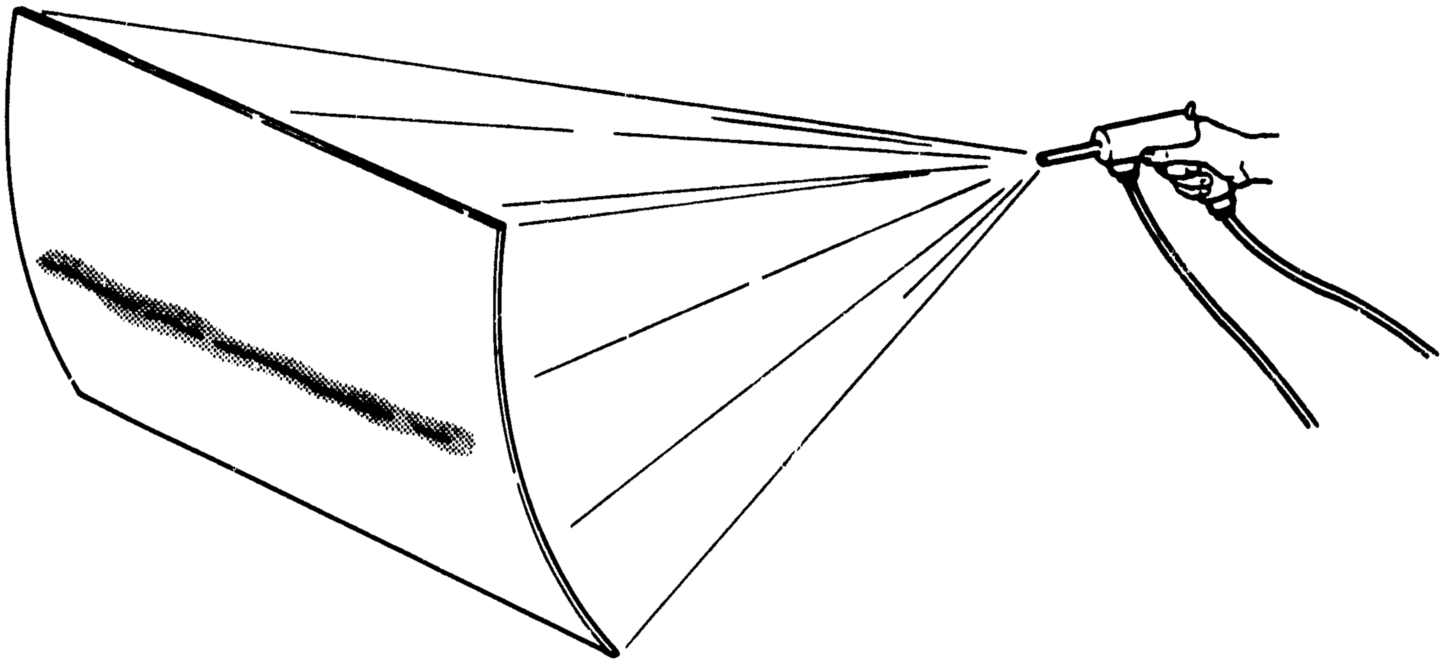

Figure 4-3. Leak-Through Test

CHAPTER 5: INTERPRETATION OF TEST RESULTS
TABLE OF CONTENTS

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CHAPTER 5: INTERPRETATION OF TEST RESULTS

500 GENERAL

The terms "interpretation" and "evaluation" are often confused by testing personnel. Actually, the terms refer to two entirely different steps in the testing process. To interpret an indication means to decide what condition caused it. It may be a crack, porosity, lack of bond, or merely some surface discontinuity. Evaluation follows interpretation. If a discontinuity exists, its effect on the usefulness of the article requires evaluation, i. e., the article is either accepted as is, reworked, or scrapped. The success and reliability of the interpretation and evaluation of liquid penetrant test indications depend upon the thoroughness of the process. The liquid penetrant test is not a method by which a specimen is processed through a machine which separates the good article from the bad. Testing personnel are required to carefully process each specimen, interpret indications, evaluate the seriousness of discontinuities, and determine disposition of the specimen. Failure of a single article may cause injury to personnel and be the difference between success or failure of an important mission.

501 INDICATIONS

1. GENERAL

Since penetrant cannot indicate any but surface discontinuities, an indication is caused by a discontinuity in the surface, or by penetrant remaining on the surface from some non-relevant cause.

2. FALSE INDICATIONS

The most common source of false indications is poor washing of water-washable and post-emulsifiable penetrants. The use of black light during the washing process, when using fluorescent penetrant, is very important. The operator can easily tell whether a good rinse is obtained or whether patches of fluorescence remain on the specimen. With penetrants requiring solvent removal, the removal process is much more likely to be thorough. To guard against confusion resulting from fluorescent or color spots other than true indications, care is taken so that no outside contamination occurs. Typical sources of contamination are:

a. Penetrant on hands of operator

b. Contamination of wet or dry developer

c. Penetrant rubbing off of an indication on one specimen to a clean portion of the surface of another specimen

d. Penetrant spots on the inspection table

(1) To avoid contamination, its causes are eliminated or guarded against. Process tanks and inspection areas are kept clean; only lint-free wiping cloths or rags are used; and specimens are kept free of fingerprints and tool marks.

(2) Figure 5-1 illustrates some of the more common types of false indications, caused by certain handling or cleaning processes.

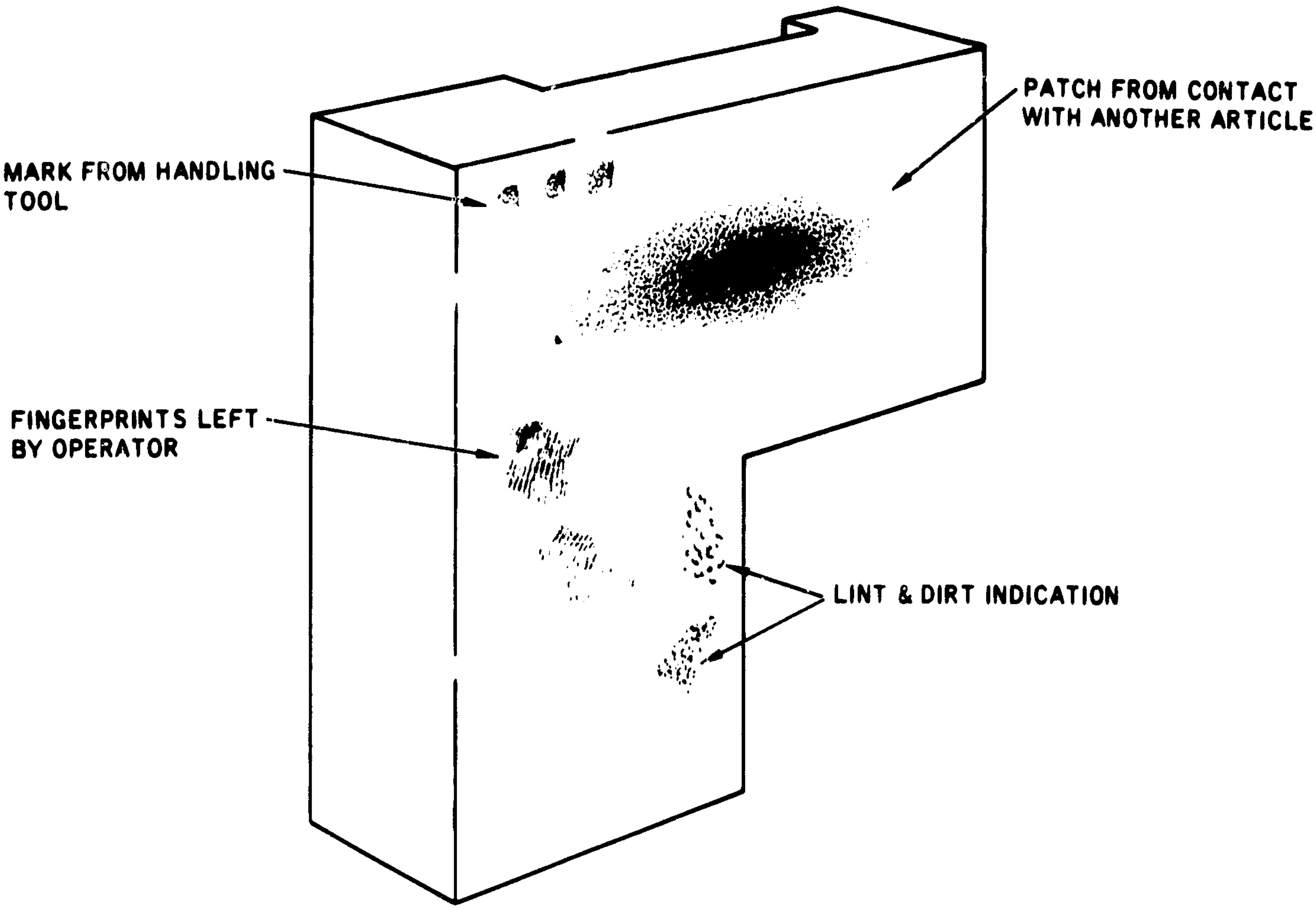


Figure 5-1. Typical False Indications

3. NON-RELEVANT INDICATIONS

Outside the realm of truly false indications there is a category of non-relevant indications, which testing personnel can recognize. These are true indications in the sense that they are caused by surface discontinuities, but the discontinuities are there by design and are in no way a true discontinuity. Most of such non-relevant indications are easy to recognize since they are related directly to some feature of the assembly that accounts for their presence. Non-relevant indications include those that appear on articles that are press-fitted, keyed, splined, riveted, or spot welded together and those appearing on castings as a result of loosely adherent scale or a rough surface due to burned-in sand. Such non-relevant indications must be carefully noted since they may interfere with correct interpretation. Commonly detectable non-relevant indications are shown in Figure 5-2.

4. TRUE INDICATIONS

True indications are those caused by a discontinuity. The interpretation of an indication as true is a matter of observing the indication, eliminating the possibility of it being a false indication, and then further determining that it is not a non-relevant indi-

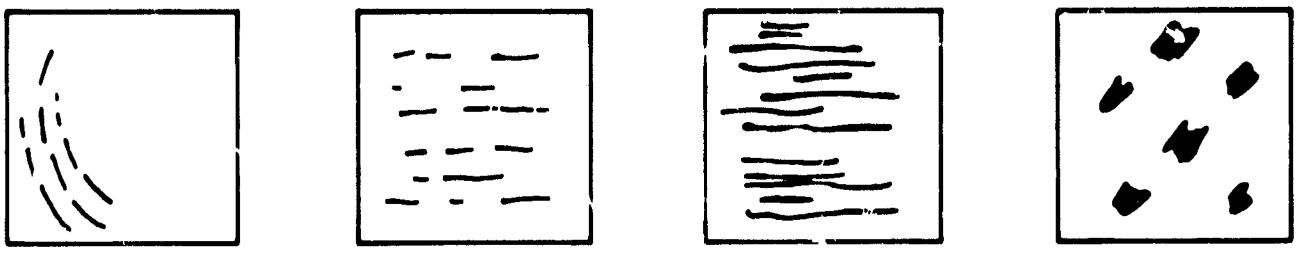


Figure 5-2. Typical Non-Relevant Indications

cation. Any true indication immediately becomes subject to evaluation as to its cause (type of discontinuity) and the effect of the indicated discontinuity on the service life of the specimen. There are no hard and fast rules that lay down sure methods of determining whether an indication is true. Such definite appraisals require knowledge of the fabrication processes used in creating the specimen or, in the case of a used article, knowledge of its operational use and the stresses to which it has been subjected.

502 CATEGORIES OF TRUE INDICATIONS

1. GENERAL

Discontinuity indications vary widely in appearance but for each indication two interpretive questions must be answered. What type of discontinuity caused the indication? What is the extent of the discontinuity as evidenced by the extent of the indication? Each indication also requires an answer to the evaluation question. What effect will the indicated discontinuity have on the service life of the specimen? The answers to the interpretive questions are obtained by observing the indication and identifying the discontinuity from the characteristics appearance of the indication. The answer to the evaluation question is based on a certain knowledge of the seriousness of the discontinuity and complete understanding of the ultimate use of the specimen. True indications logically fall into five categories; continuous line, intermittent line; rounded; small dots; and diffused or weak.

2. CONTINUOUS LINE

Continuous line indications are caused by cracks, cold shuts, forging laps, scratches, or die marks. Cracks usually appear as jagged lines; cold shuts as smooth, narrow, straight lines; and forging laps as smooth, wavy lines. Scratches and die marks appear in a variety of linear patterns but are readily recognizable when all penetrant traces are removed, since the bottom of the discontinuity is usually visible.

3. INTERMITTENT LINE

The same discontinuities that cause continuous line indications may, under different circumstances, cause intermittent line indications. When an article is worked by grinding, peening, forgings, machining, etc., portions of the discontinuities in the surface of the article may be closed by the metal working process. When this occurs, the discontinuities will appear as intermittent lines. (See Figure 5-3.)

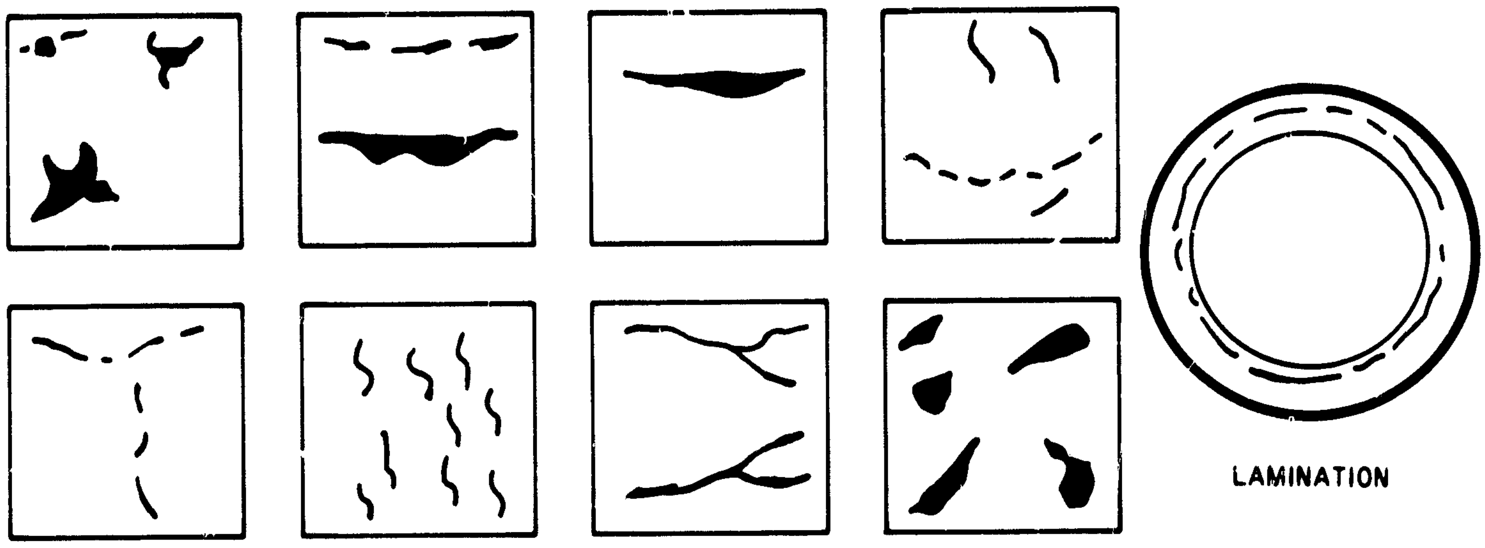


Figure 5-3. Typical True Indications

4. ROUND

Round indications usually are caused by porosity. The porosity may be the result of gas holes, pin holes, or the generally porous makeup of the specimen. Deep cracks may also appear as round indications since they trap a large amount of penetrant that spreads when the developer is applied. Any round indication that appears singly in an isolated position usually indicates a discrepancy of depth that may or may not be round. Figure 5-4 illustrates typical round indications.

5. SMALL DOTS

Small dot indications result from discrepancies caused by pin holes, by the porous nature of the specimen, or by excessively coarse grains being used in producing a casting. They may also be the result of cast alloy microshrinkage.

6. DIFFUSED OR WEAK

Diffused or weak indications are particularly difficult to interpret. Weak indications appearing over a large area are always suspect and when they appear the specimen is to be thoroughly cleaned and retested. Other weak or diffused indications may be caused by surface porosity but more often are the result of insufficient cleaning, incomplete penetrant removal, or excessive developer.

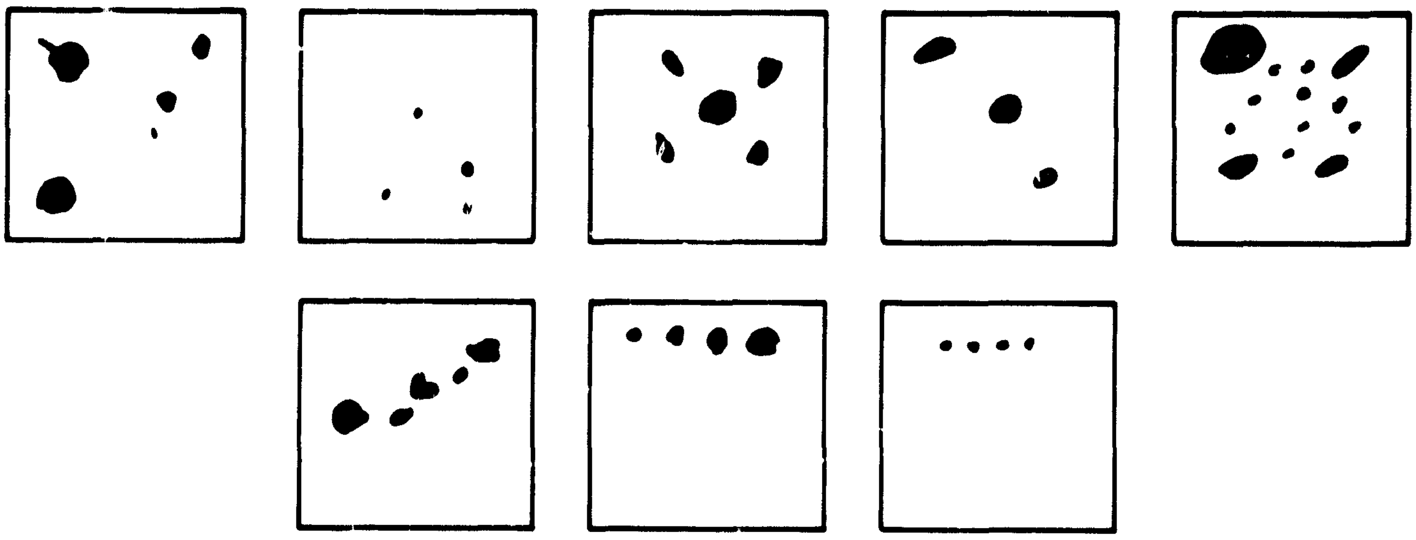


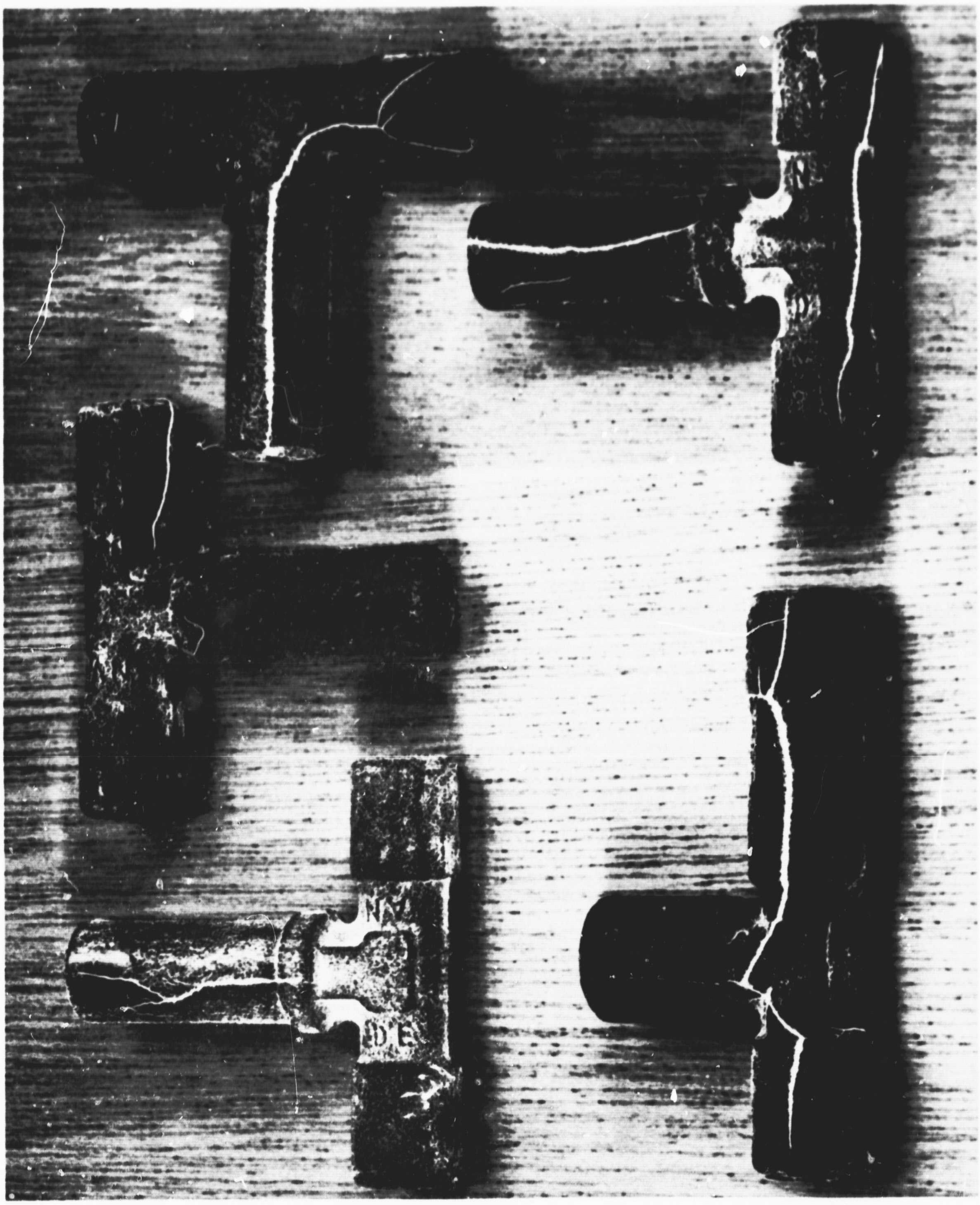
Figure 5-4. Typical Rounded Indications

503 DISCONTINUITY DEPTH DETERMINATION

The vividness of a visible dye indication or the brilliance of a fluorescent indication are measures of the depth of a discontinuity. The greater the depth of a discontinuity the more penetrant it holds and the larger and brighter the indication. Shallow discontinuities entrap only small amounts of penetrant and appear as fine line indications of relatively low brilliance. When evaluation requires more accurate knowledge of the depth of a discontinuity it is often obtained by removing the surface indication and reapplying developer. The subsequent amount and rate of penetrant bleed-out is proportionate to the depth of the discontinuity.

504 TYPICAL INDICATIONS

Figures 5-5 through 5-9 illustrate typical liquid penetrant indications of various types of discrepancies in various materials.

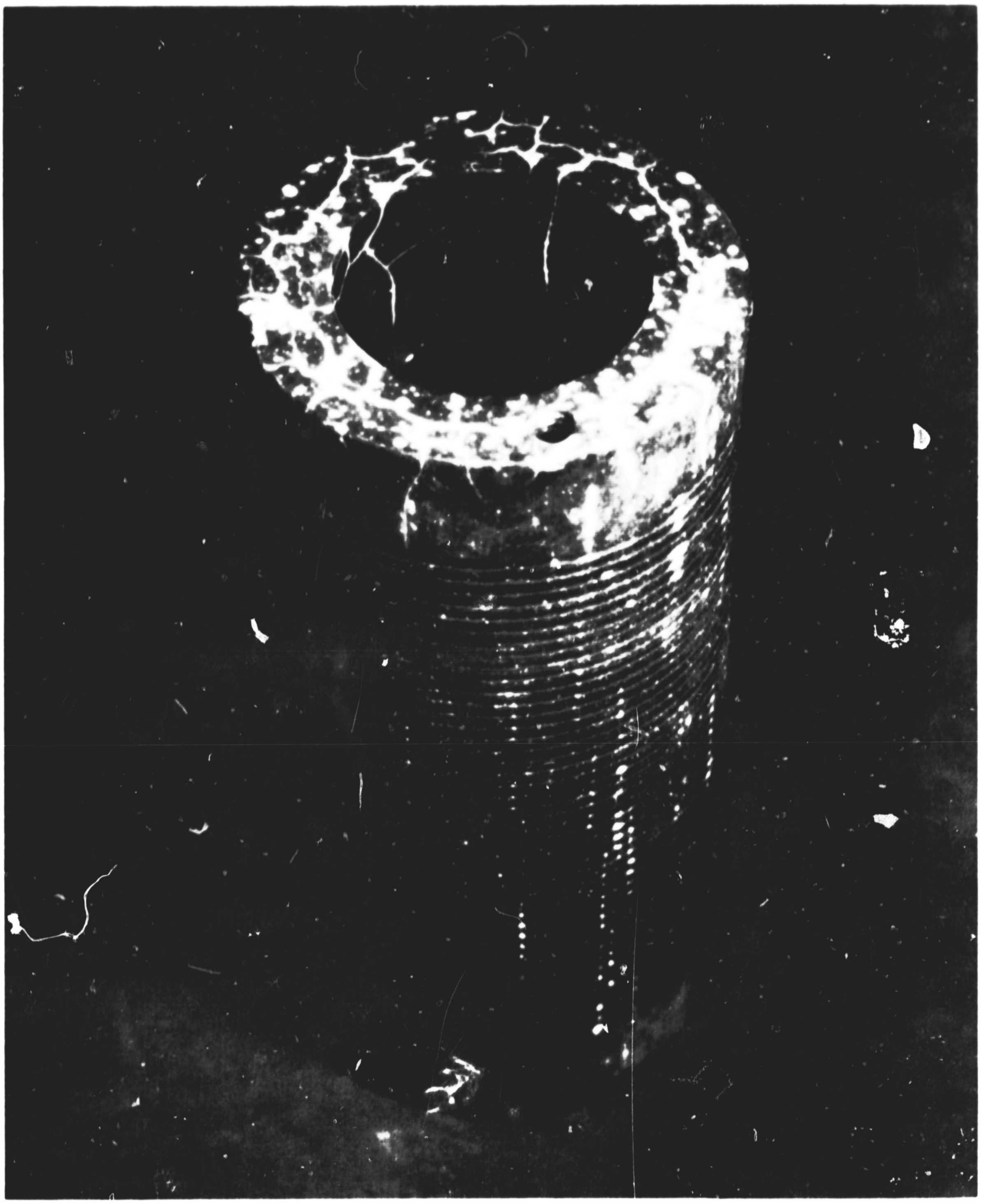


COURTESY MAGNAFLUX CORPORATION

Figure 5-5. Shrinkage Cracks in Unfinished Coupling Castings

COURTESY MAGNAFLUX CORPORATION

Figure 5-6. Surface Porosity on Magnesium Sand Casting



COURTESY MAGNAFLUX CORPORATION

Figure 5-7. Indication of Thermal Shock Cracks, Porosity and Seams on Unglazed Ceramic Coil-Form

COURTESY MAGNAFLUX CORPORATION

Figure 5-8. Indication of Crater Cracks and Pores in Stainless Steel Weld

COURTESY MAGNAFLUX CORPORATION

Figure 5-9. Cracks Produced by Thermal Shock in Hard-Fired Unglazed Ceramic Rod

CHAPTER 6: QUALITY CONTROL OF PENETRANT TEST MATERIALS
TABLE OF CONTENTS

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CHAPTER 6: QUALITY CONTROL OF PENETRANT TEST MATERIALS

600 GENERAL

The efficiency of any penetrant test is determined in large part by the condition (utility) of the materials used. The best of procedures are worthless if any of the test materials are faulty. To insure the satisfactory condition of penetrant test materials, various quality control tests are used. This chapter discusses the most important of these tests. Manufacturers of penetrant test materials establish acceptability limits of contamination and dilution of their products, and detailed instructions for their use. Each of the quality control tests mentioned herein are based on the assumption that the purity, care, handling, and use of materials are strictly in accordance with the manufacturers recommendations. There are many additional quality control procedures that are of greater interest to the laboratory technician than to the man performing or monitoring penetrant tests. These procedures are readily available from manufacturers or from various societies such as the American Society for Testing and Materials (ASTM).

601 TEST BLOCKS

1. GENERAL

Both aluminum and steel blocks are used in quality control tests of penetrant testing materials. The test blocks are prepared to rigid specifications as detailed in the following paragraphs.

2. ALUMINUM TEST BLOCKS

Aluminum test blocks measure 3 by 4 inches and are cut from 5/16-inch thick bare 2024-T3 aluminum alloy plate. The 4-inch dimension is in the direction of rolling of the plate. The blocks are heated nonuniformly and water quenched so as to produce thermal cracks. This is accomplished by supporting the block in a frame and heating it with the flame of a gas burner or torch in the center on the lower side of the block. The flame remains centered and does not move in any direction during the heating process. A 950° to 980° F Tempilstik, Tempilac, or equivalent, is applied to an area the size of a penny on the top side and directly in the center of the block. The heat of the torch or burner is adjusted so that the block is heated approximately 4 minutes before the Tempilstik or Tempilac melts, after which the block is immediately quenched in cold water (Figure 6-1). The same operation is then repeated on the other side of the block. A groove approximately 1/16-inch wide by 1/16-inch deep is cut in the 3-inch direction across the center of the heat-affected zone on both sides of the block, forming the block into two similar specimens.

a. Preparation For Use. Prior to use, aluminum test blocks are scrubbed with a bristle brush and liquid solvent, followed by vapor degreasing.

b. Preparation For Re-Use. After a test block has been used it is cleaned prior to re-use. The block is heated slowly with a gas burner to 800° F, as determined by an 800° F Tempilstik, or equivalent, after which the block is

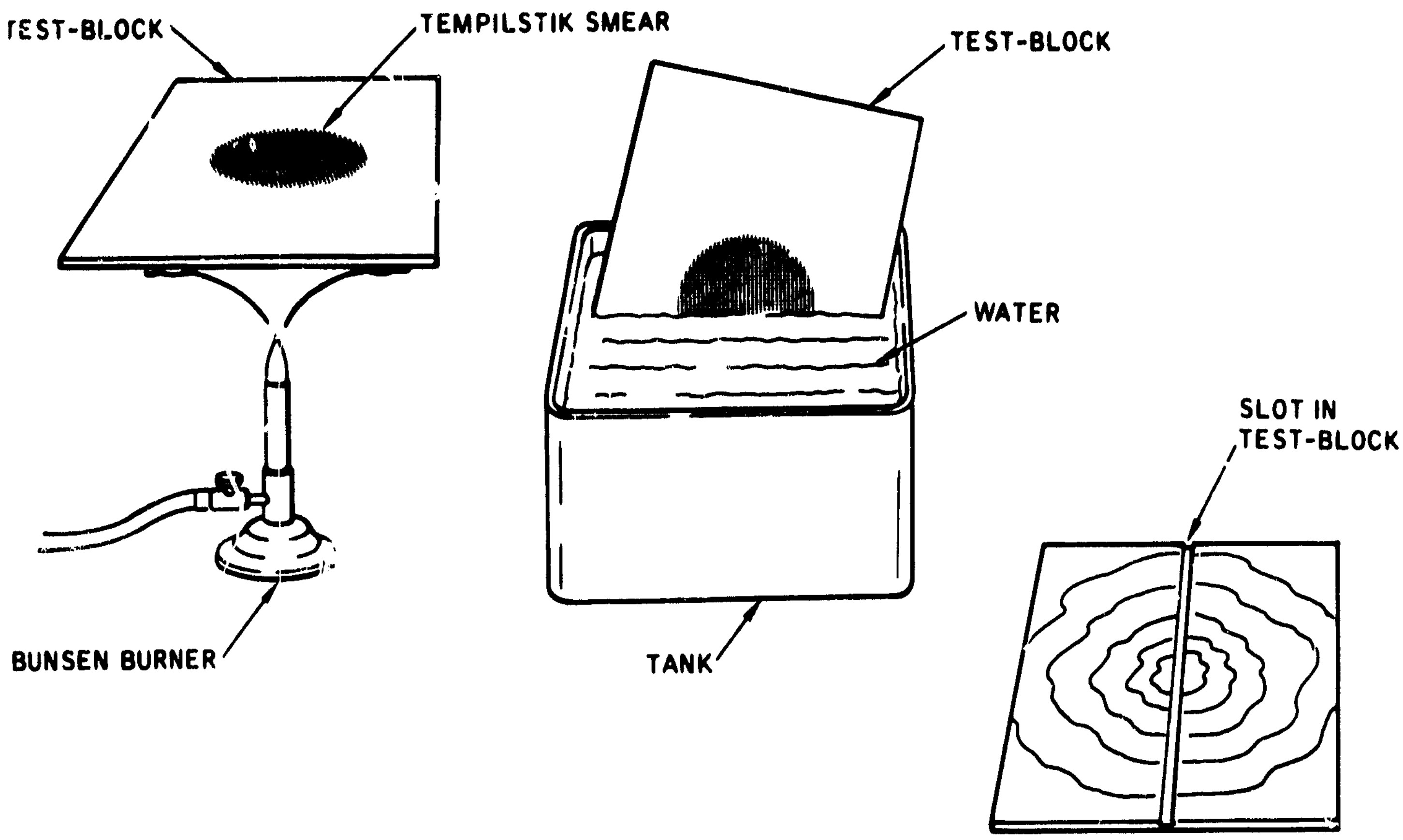


Figure 6-1. Heating and Quenching of Test Block

quenched in cold water. It is then heated at approximately 225° F for 15 minutes to drive off any moisture in the cracks, and is allowed to cool to room temperature. After cooling and before using, the block is cleaned by a good scrubbing with a bristle brush and liquid solvent, followed by vapor degreasing.

3. STEEL TEST BLOCKS

Steel test blocks may be any convenient size, 2 by 3 inches or larger, and are prepared from annealed type 301 or 302 stainless steel. The block is sandblasted on one side only with 100 mesh, average size grit. The gun is held approximately 18 inches from the block; 60 pounds air pressure is used. When a velvety finish is achieved on the block, it is ready for use.

602 PENETRANT TESTS

1. GENERAL

The quality of the penetrants (visible dye and fluorescent) used in liquid penetrant testing is usually determined by a check of the penetrant sensitivity, its water content, and its viscosity. Additionally, the tendency toward fade of fluorescent penetrants under black light is usually checked by a simple comparison test. The tests described in the

[redacted]

following paragraphs are those made on used or suspected faulty penetrants. As a general rule the test referenced in paragraphs 602.3, 602.4, and 602.5 would be performed by laboratory technicians in a laboratory and not by the individual liquid penetrant specialist,

2. SENSITIVITY TEST

When performing the sensitivity test, the penetrant to be tested is applied to one half of the surface of the aluminum test block (Para. 601.2), in accordance to the manufacturers instructions, and new penetrant is applied to the remaining half of the surface. Penetrant dwell time, emulsification or removal, and developing are consistent with operational procedures as recommended by the manufacturer. If the sensitivity of the tested penetrant is less than that of the new penetrant (as determined by visual observation) the penetrant being tested is considered contaminated and is discarded.

3. WATER CONTENT TEST

Water content of a penetrant is best determined by the test described in ASTM Standard D-95. One hundred milli-liters (ml) of the penetrant is placed in a boiling flask with a similar quantity of moisture-free xylene. The flask is connected to a reflux condenser so that the condensate drops into a 25-ml graduated tube where the water settles out. When no more water is being gathered in the graduated tube (usually after a period of an hour) the boiling process is terminated. After cooling, the volume of water in the graduated tube is read. The volume in ml is the percent of water by volume present in the penetrant. If the percent of water exceeds manufacturers recommendations, the penetrant is discarded.

4. VISCOSITY TEST

The viscosity of penetrants is measured with a viscometer tube at a constant temperature of 100° F. If the centistoke (the unit of kinematic viscocity) measurement obtained is outside the range recommended by the manufacturer, the penetrant is discarded.

5. FLUORESCENT PENETRANT FADE TEST

The comparison test for checking the fade tendency of fluorescent penetrants under black light employs an aluminum test block, the penetrant to be tested, and a sheet of paper at least as large as one half the surface area of the block. The penetrant is applied to the surface of the block in accordance with the manufacturers instructions. Penetrant dwell time, emulsification or removal, and developing are consistent with operational procedures as recommended by the manufacturer. The block is then placed directly in the light of a standard 100-watt spotlight-type black light at a distance of 15 inches. One half of the block is covered with the paper. After an hour exposure to the light, the paper is removed and the fluorescent brilliance of the two sides of the block is observed. If the side that has been exposed to black light is noticeably less brilliant, the penetrant is discarded.

[redacted]

603 EMULSIFIER TESTS

1. GENERAL

Emulsifiers are usually tested for their washability, water content, and viscosity. As a general rule the test referenced in paragraph 603.2, 603.3 and 603.4 would be performed by laboratory technicians and not by the individual liquid penetrant specialist.

2. WATER WASHABILITY TEST

The water washability test described in this paragraph is simple, yet indicative of the efficiency of the emulsifier. The test used a steel test block (Para. 601.3), the emulsifier to be tested, and a supply of new emulsifier and new penetrant. Two blends of emulsifier and penetrant are prepared. The first blend consists of 50% new emulsifier and 50% new penetrant, the second of 75% emulsifier being tested and 25% new penetrant. The steel block is placed at an angle of 75° to any level supporting surface with its velvety (sandblasted) surface uppermost. Ten cc of each blend is applied to the velvety surface in such manner that they flow down the block forming two ribbons of blend, each approximately 1-1/2 inches wide. After a five minute waiting period the block is washed in accordance with the manufacturers recommendations for removing emulsified penetrant. If the two smears wash equally well the emulsifier being tested is satisfactory. If the second blend washes more slowly or leaves traces of penetrant on the block (when observed under black or white light as appropriate) the emulsifier is discarded.

3. WATER CONTENT TEST

The water content test of emulsifiers is identical to that used with penetrants as described in paragraph 602.3.

4. VISCOSITY TEST

The viscosity test of emulsifiers is identical to that used with penetrants as described in paragraph 602.4

604 DEVELOPER TESTS

1. DRY DEVELOPER

Dry developers are usually tested only by observation. Since they are not hydroscopic, they do not absorb moisture from the air, and are relatively trouble free if they do not come in contact with water. Any dry developer that is lumpy or caked instead of fluffy and light, or that shows any other sign of having been wet, is discarded.

2. WET DEVELOPER

Wet developers are usually tested only for density. The density reading is obtained by use of a hydrometer. (See Figure 3-6.) If the indicated density differs from that recommended by the manufacturer either powder or vehicle is added to the developer in sufficient quantities to bring the specific gravity reading within acceptable limits. As a general rule the test referenced in this paragraph would be performed by laboratory technicians and not by the individual liquid penetrant specialist.

605 OXYGEN COMPATIBLE MATERIALS

The quality control tests for Groups IIIa and IVa materials described in paragraph 305.3 include some of those listed in the foregoing tests. Additional tests required for oxygen compatible materials are detailed in applicable NASA specifications. These tests are to be accomplished when required by, and in strict accordance with, the procedures detailed in the specifications.

CHAPTER 7: COMPARISON AND SELECTION OF NDT PROCESSES
TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

CHAPTER 7: COMPARISON AND SELECTION OF NDT PROCESSES

700 GENERAL

The purpose of this chapter is to summarize the characteristics of various types of discontinuities, and to list the NDT methods which may be employed to detect each type of discontinuity.

The relationship between the various NDT methods and their capabilities and limitations when applied to the detection of a specific discontinuity will be shown. Such variables as type of discontinuity (inherent, process, or service), manufacturing processes (heat treating, machining, or plating), and limitations (metallurgical, structural, or processing) all will help determine the sequence of testing and the ultimate selection of one test method over another.

701 METHOD IDENTIFICATION

Figures 7-1 through 7-5 illustrate five NDT methods. Each illustration shows the three elements involved in all five tests, the different methods in each test category, and tasks that may be accomplished with a specific method.

702 NDT DISCONTINUITY SELECTION

The discontinuities that will be reviewed in paragraphs 706 through 732 are only a part of the many hundreds that are associated with the various products of the aerospace industry. During the selection of discontinuities for inclusion in this section, only a few of those discontinuities which would not be radically changed under different conditions of design, configuration, standards, and environment were chosen.

703 DISCONTINUITY CATEGORIES

Each of the specific discontinuities are divided into three general categories: inherent, processing, and service. Each of these categories is further classified as to whether the discontinuity is associated with ferrous or nonferrous materials, the specific material configuration, and the manufacturing processes if applicable.

1. INHERENT DISCONTINUITIES

Inherent discontinuities are those discontinuities that are related to the solidification of the molten metal. There are two types.

a. Wrought. Inherent wrought discontinuities cover those discontinuities which are related to the melting and original solidification of the metal or ingot.

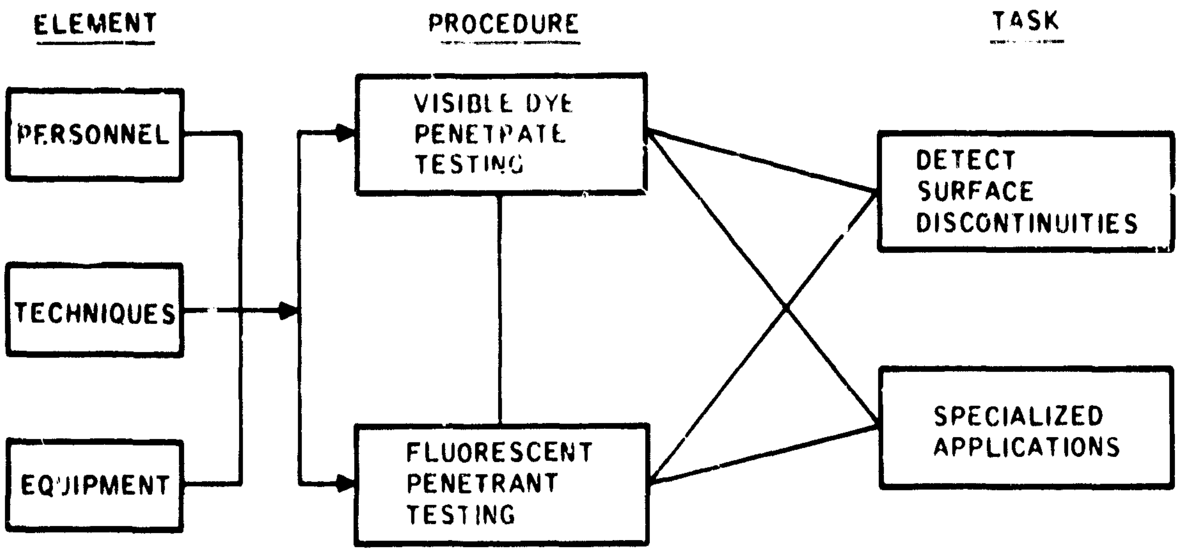


Figure 7-1. Liquid Penetrant Test

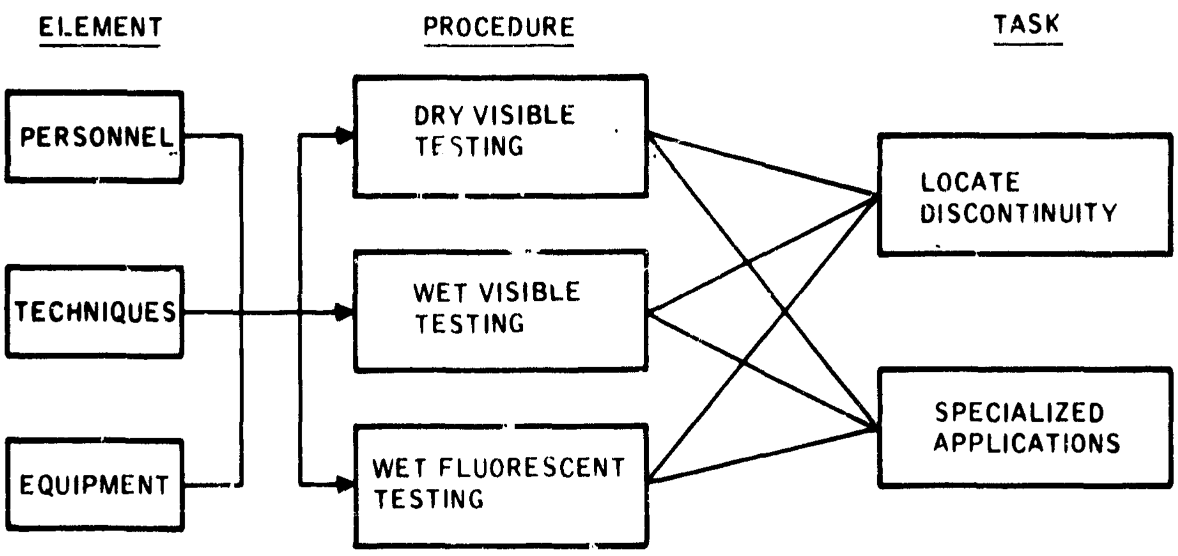


Figure 7-2. Magnetic Particle Test

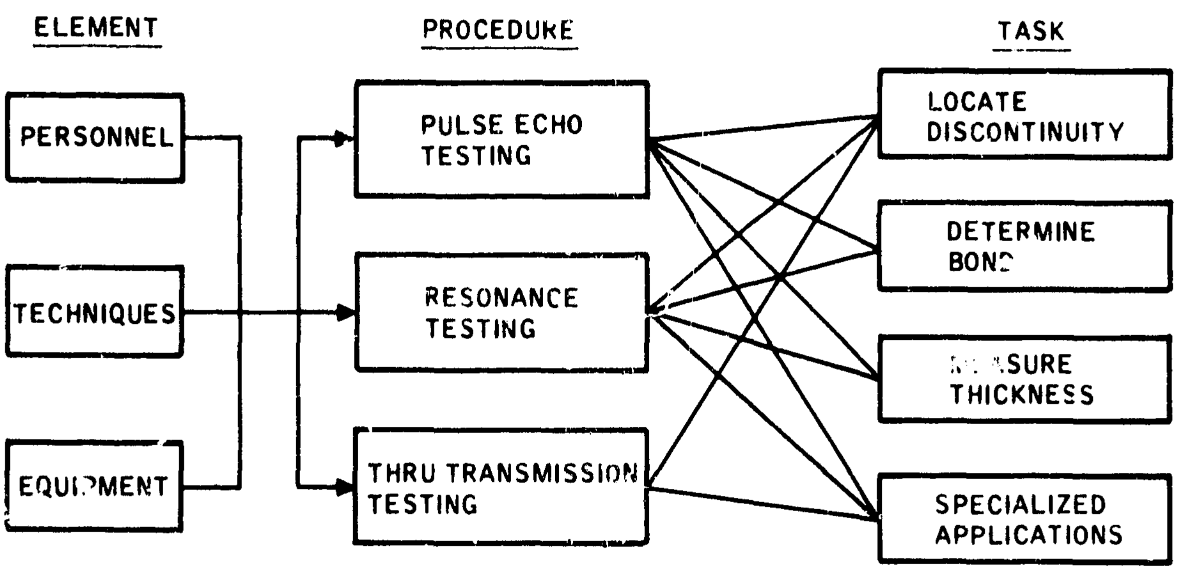


Figure 7-3. Ultrasonic Test

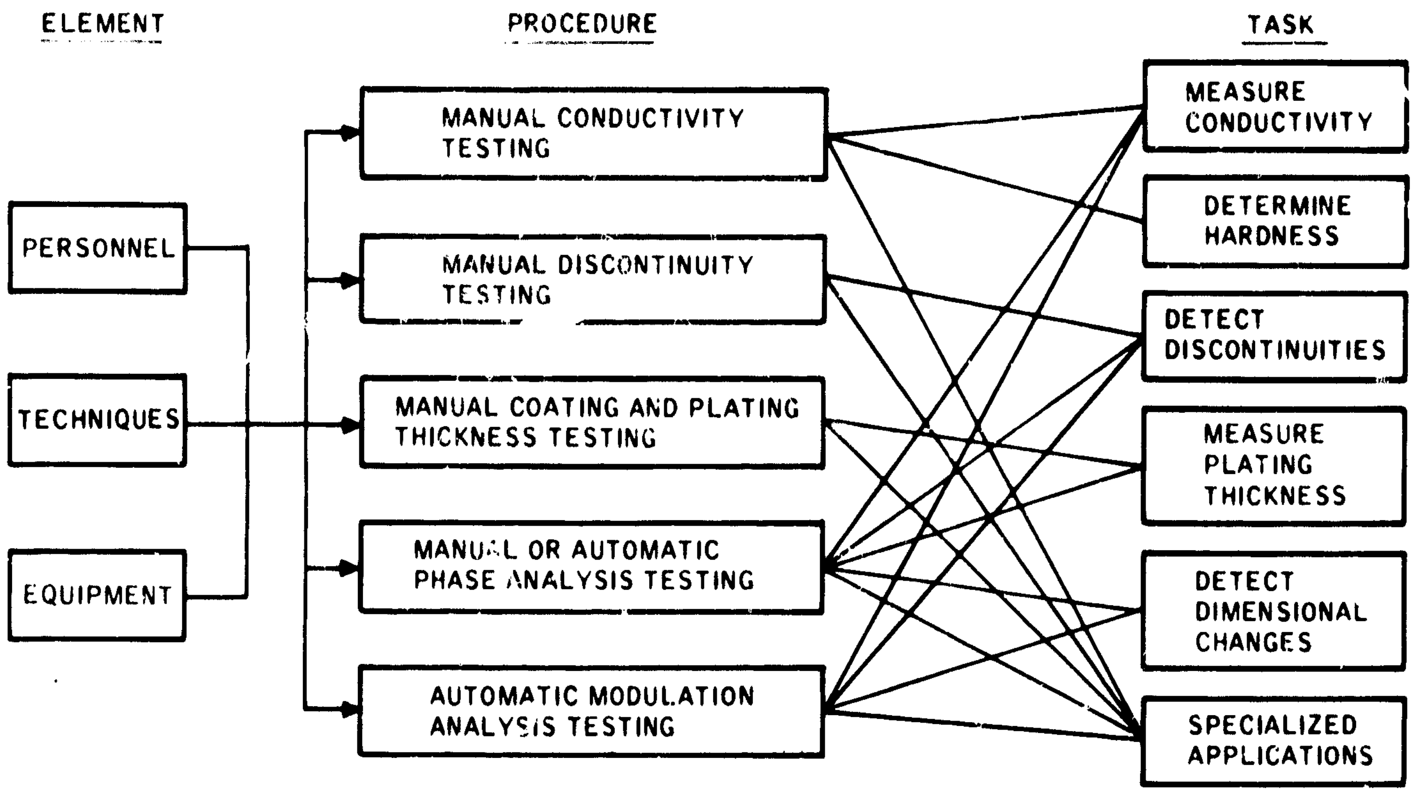


Figure 7-4. Eddy Current Test

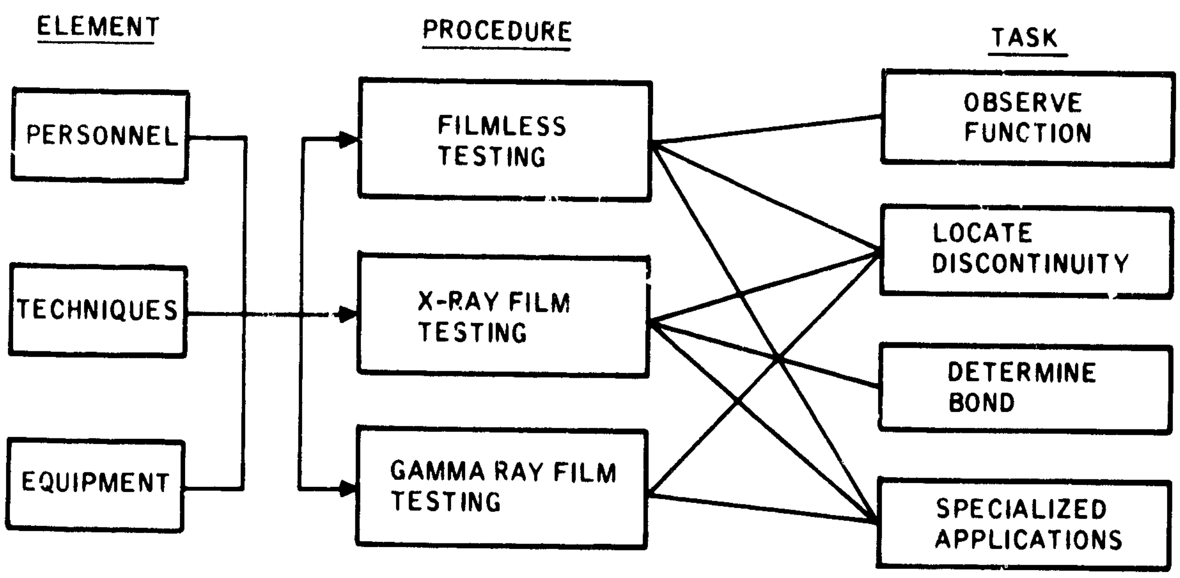


Figure 7-5. Radiographic Test

b. **Cast.** Inherent cast discontinuities are those discontinuities which are related to the melting, casting, and solidification of the cast article. It includes those discontinuities that would be inherent to manufacturing variables such as inadequate feeding, gating, excessively high pouring temperature, entrapped gases, handling, and stacking.

2. PROCESSING DISCONTINUITIES

Processing discontinuities are those discontinuities that are related to the various manufacturing processes such as machining, forming, extruding, rolling, welding, heat treating, and plating.

3. SERVICE DISCONTINUITIES

Service discontinuities cover those discontinuities that are related to the various service conditions such as stress corrosion, fatigue, and errosion.

704 DISCONTINUITY CHARACTERISTICS AND METALLURGICAL ANALYSIS

Discontinuity characteristics encompasses an analysis of the specific discontinuity and reference actual photos that illustrate examples of the discontinuity. The discussion will cover:

a. Origin and location of discontinuity (surface, near surface, or internal).

b. Orientation (parallel or normal to the grain).

c. Shape (flat, irregularly shaped, or spiral).

d. Photo (micrograph and/or typical overall view of the discontinuity).

e. Metallurgical analysis (how the discontinuity is produced and at what stage of manufacture).

705 NDT METHODS APPLICATION AND LIMITATIONS

1. GENERAL

The technological accomplishments in the field of nondestructive testing have brought the level of test reliability and reproducibility to a point where the design engineer may now selectively zone the specific article. This zoning is based upon the structural application of the end product and takes into consideration the environment as well as the loading characteristics of the article. Such an evaluation in no way reduces the end reliability of the product, but it does reduce needless rejection of material that otherwise would have been acceptable.

Just as the structural application within the article varies, the allowable discontinuity size will vary depending on the method of manufacture and configuration. For example, a die forging that has large masses of material and extremely thin web sections would not require the same level of acceptance for the whole forging. The forging can be zoned for rigid control where the structural applications are higher, and zoned for less rigid control where the structural requirements permit larger discontinuities.

The nondestructive testing specialist must also select the method which will satisfy the design objective of the specific article and not assume that all NDT methods can produce the same reliability for the same type of discontinuity.

2. SELECTION OF THE NDT METHOD

In selecting the NDT method for the evaluation of a specific discontinuity it should be kept in mind that NDT methods may supplement each other and that several NDT methods may be capable of performing the same task. The selection of one method over another is based upon variables such as:

a. Type and origin of discontinuity

b. Material manufacturing processes

c. Accessibility of article

d. Level of acceptability desired

e. Equipment available

f. Cost

To satisfactorily develop knowledge of the above variables, a planned analysis of the task must be made for each article requiring NDT testing.

The NDT methods listed for each discontinuity in paragraphs 706 through 732 are in order of preference for that particular discontinuity. However, when reviewing that portion of the chapter it should be kept in mind that the rapidly developing NDT field and new techniques may alter the order of test preference.

3. LIMITATIONS

The limitations applicable to the various NDT methods will vary with the applicable standard, the material, and the service environment. Limitations not only affect the NDT test, but in many cases the structural reliability of the test article is affected. For these reasons, limitations that are listed for one discontinuity may also be applicable to other discontinuities under slightly different conditions of material or environment. In addition, the many combinations of environment, location, material, and test capability do not permit mentioning all limitations that may be associated with a specific discontinuity. The intent of this chapter is fulfilled if you are made aware of the many factors that influence the selection of a valid NDT test.

706 BURST

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface or internal. Straight or irregular cavities varying in size with large interfaces or very tight. Usually parallel with the grain. Found in wrought material which required forging, rolling, or extruding. (See Figure 7-6.)

4. METALLURGICAL ANALYSIS

a. Forging bursts are surface or internal ruptures which are attributed to processing at an incorrect temperature, or excessive working or metal movement during the forging, rolling, or extruding operation.

b. A burst does not have a spongy appearance and, therefore, is distinguishable from a pipe, even if it should occur at the center.

c. Bursts are often large and very seldom healed during subsequent working.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Normally used for the detection of internal bursts.

(2) Bursts are definite breaks in the material and they resemble a crack, producing a very sharp reflection on the scope.

(3) Ultrasonic testing is capable of detecting varying degrees of burst which could not be detected by other NDT methods.

(4) Nicks, gouges, raised areas, tool tears, foreign material, gas bubbles on the article may produce adverse ultrasonic test results.

b. EDDY CURRENT TESTING METHOD. Not normally used. Testing is restricted to wire, rod, and other articles under 0.250 inch diameter.

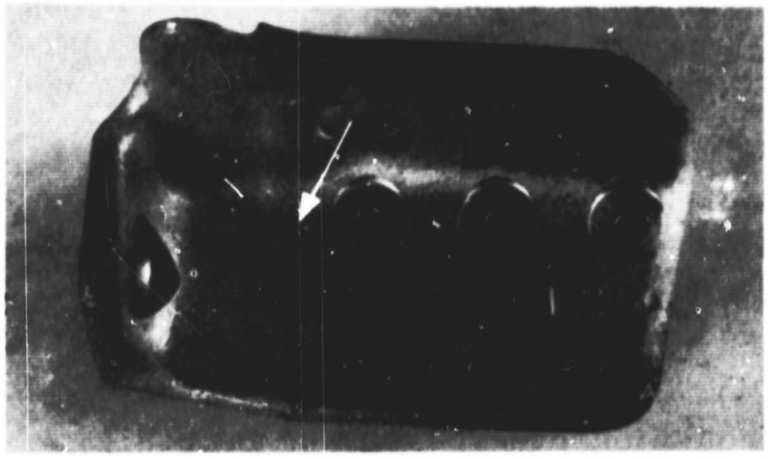
c. MAGNETIC PARTICLE TESTING METHOD

(1) Usually used on wrought ferrous material that has surface or exposed internal burst.

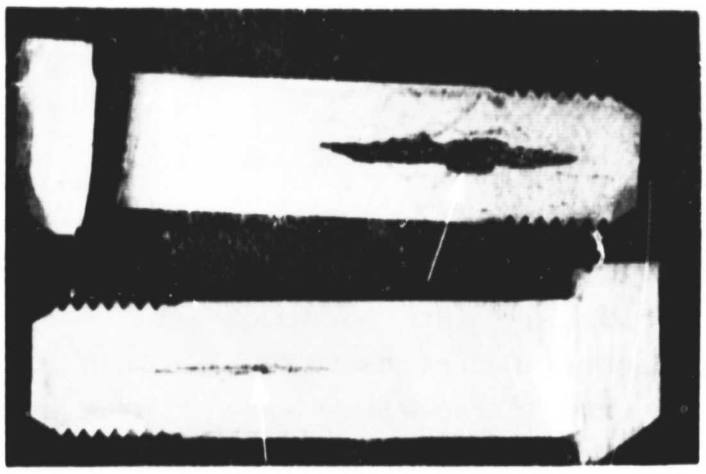
(2) Results are limited to surface and near surface evaluation.

d. LIQUID PENETRANT TESTING METHOD. Not normally used. When fluorescent penetrant is to be applied to an article previously dye penetrant tested, all traces of dye penetrant should first be removed by prolonged cleaning in applicable solvent.

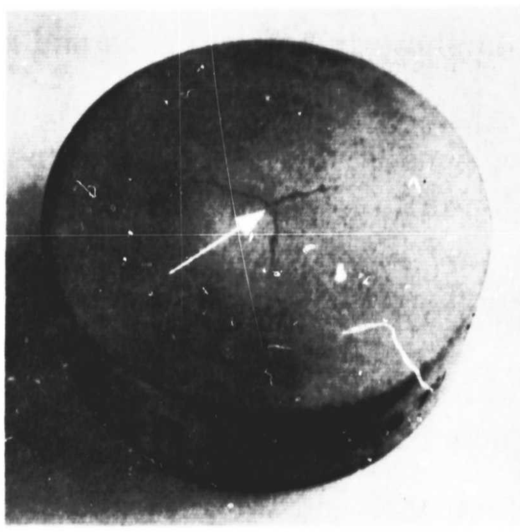
e. **RADIOGRAPHIC TESTING METHOD. Not normally used. Such variables as the direction of the burst, close interfaces, wrought material, discontinuity size, and material thickness restrict the capability of radiography.**



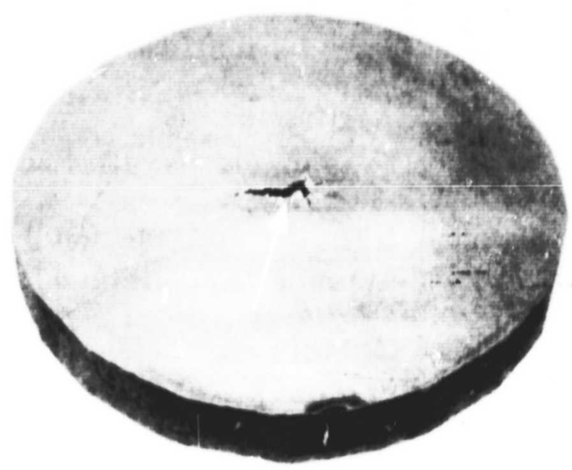
A FORGING EXTERNAL BURST



B BOLT INTERNAL BURST



C ROLLED BAR INTERNAL BURST



D FORGED BAR INTERNAL BURST

Figure 7-6. Burst Discontinuities

707 COLD SHUTS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous and Nonferrous Cast Material

3. DISCONTINUITY CHARACTERISTICS

Surface and subsurface. Generally smooth indentations on the cast surface resembling a forging lap. (See Figure 7-7.)

4. METALLURGICAL ANALYSIS

Cold shuts are produced during casting molten metal. They may result from splashing, surging, interrupted pouring, or meeting of two streams of metal coming from different directions. Also, solidification of one surface before the other metal flows over it, the presence of interposing surface films on cold, sluggish metal, or any factor that will prevent a fusion where two surfaces meet will produce cold shuts. They are more prevalent in castings which are formed in a mold with several sprues or gates.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. LIQUID PENETRANT TESTING METHOD.

      (1) Normally used to evaluate surface cold shuts in both ferrous and non-ferrous materials.

      (2) Will appear as a smooth, regular, continuous, or intermittent indication, reasonably parallel to the cross section of the area in which it occurs.

      (3) Liquid penetrant used for the testing of nickel base alloys (such as Inconel "X," Rene 41) should not exceed 0.5 percent sulfur.

      (4) Certain castings may have surfaces which may be blind and from which removal of the excessive penetrants may be difficult.

      (5) Geometric configuration (recesses, orifices, and flanges) may permit buildup of wet developer thereby masking any detection of a discontinuity.

   b. MAGNETIC PARTICLE TESTING METHOD

      (1) Normally used for the screening of ferrous materials.

      (2) The metallurgical nature of 431 corrosion-resistant steel is such that in some cases magnetic particle testing indications are obtained which do not result from a crack or other harmful discontinuities. These indications arise from a duplex structure within the material, wherein one portion exhibits strong magnetic retentivity and the other does not.

c. RADIOGRAPHIC TESTING METHOD

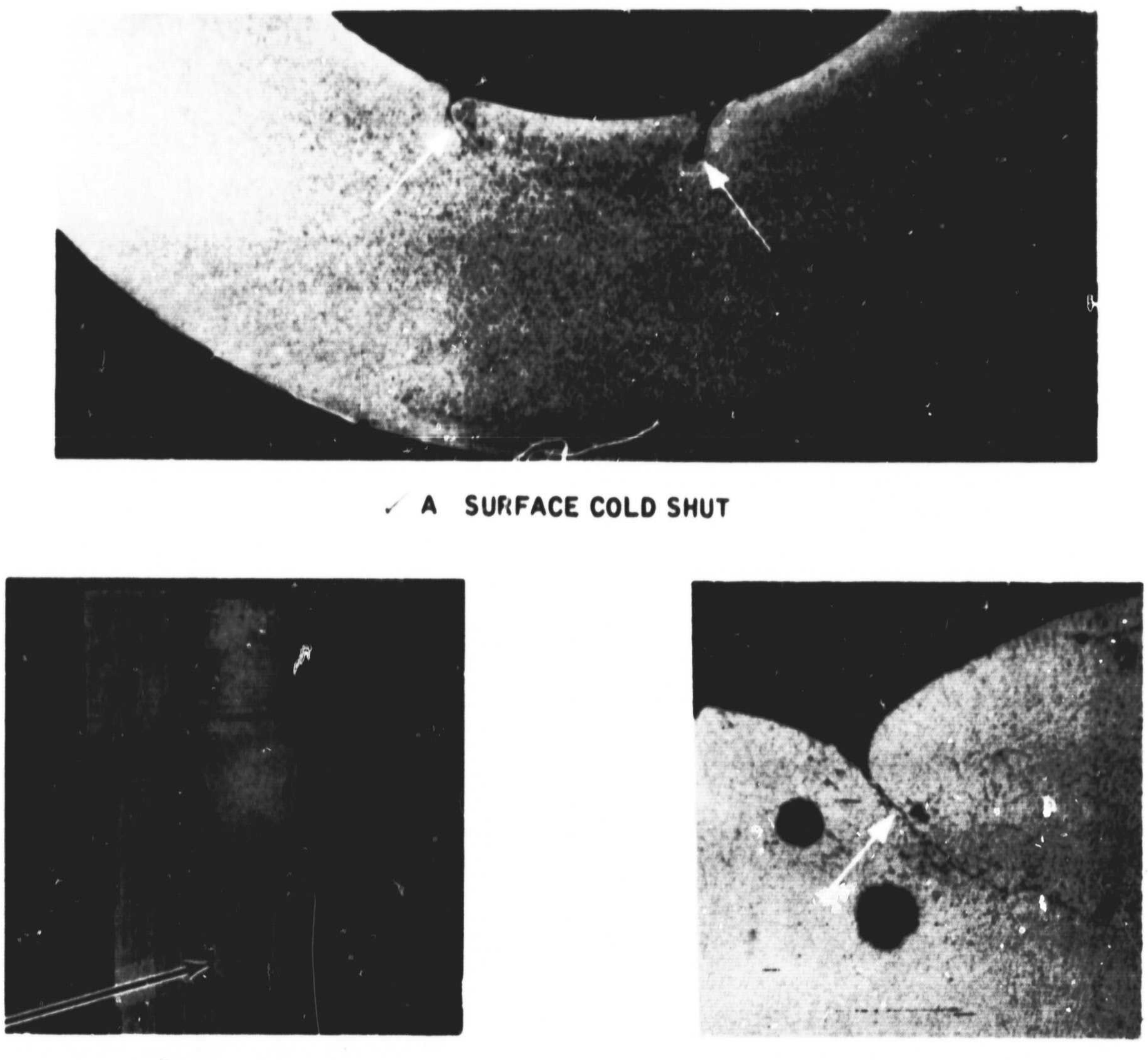
(1) Normally detectable by radiography while testing for other casting discontinuities.

(2) Appear as a distinct dark line or band of variable length and width, and definite smooth outline.

(3) Casting configuration may have inaccessible areas which can only be detected by radiography.

d. ULTRASONIC TESTING METHOD. Not recommended. Cast structure and article configuration do not as a general rule lend themselves to ultrasonic testing.

e. EDDY CURRENT TESTING METHOD. Not recommended. Article configuration and inherent material variables restrict the use of this method.



A SURFACE COLD SHUT

B INTERNAL COLD SHUT

C SURFACE COLD SHUT MICROGRAPH

Figure 7-7. Cold Shuts Discontinuity

708 FILLET CRACKS (BOLTS)

1. CATEGORY. Service

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface. Located at the junction of the fillet with the shank of the bolt and progressing inward. (See Figure 7-8.)

4. METALLURGICAL ANALYSIS

Fillet cracks occur where a marked change in diameter occurs, such as between the head-to-shank junction where stress risers are created. During the application of this bolt in service repeated loading takes place, whereby the tensile load fluctuates in magnitude due to the operation of the mechanism. These tensile loads can cause fatigue failure, starting at the point where the stress risers are built in. Fatigue failure, which is surface phenomenon, starts at the surface and propagates inward.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Used extensively for service associated discontinuities of this type.

(2) A wide selection of transducers and equipment enable on the spot evaluation for fillet crack.

(3) Being a definite break in the material, the scope pattern will be a very sharp reflection. (Actual propagation can be monitored by using ultrasonics.)

(4) Ultrasonic equipment has extreme sensitivity, and established standards should be used to give reproducible and reliable results.

b. LIQUID PENETRANT TESTING METHOD

(1) Normally used during in-service overhaul or troubleshooting.

(2) May be used for both ferrous and nonferrous bolts, although usually confined to the nonferrous.

(3) Will appear as a sharp clear indication.

(4) Structural damage may result from exposure of high strength steels to paint strippers, alkaline coating removers, deoxidizer solutions, etc.

(5) Entrapment under fasteners, in holes, under splices, and in similar areas may cause corrosion due to the penetrant's affinity for moisture.

c. **MAGNETIC PARTICLE TESTING METHOD**

(1) Normally used on ferrous bolts.

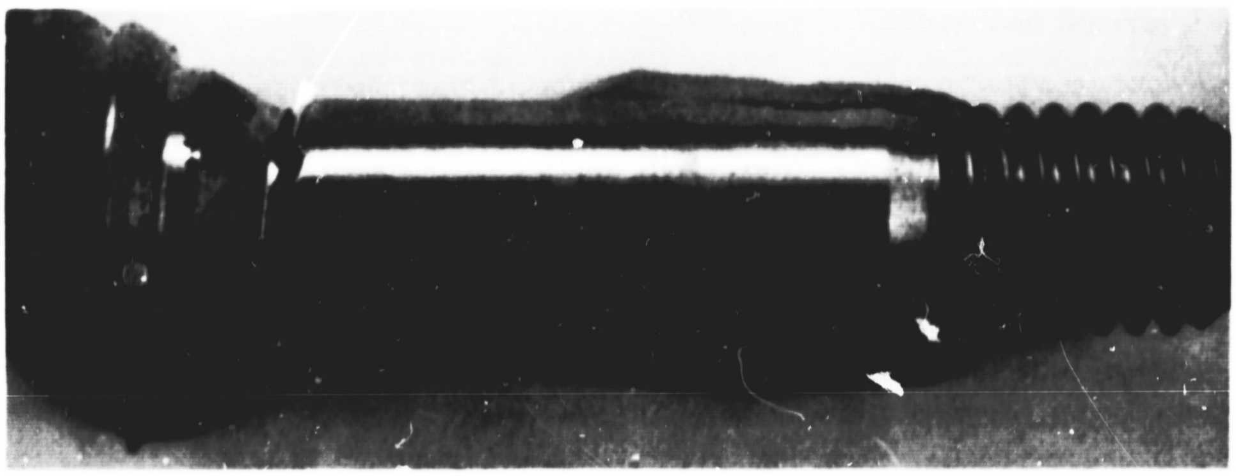
(2) Will appear as clear sharp indication with a heavy buildup.

(3) Sharp fillet areas may produce non-relevant magnetic indications.

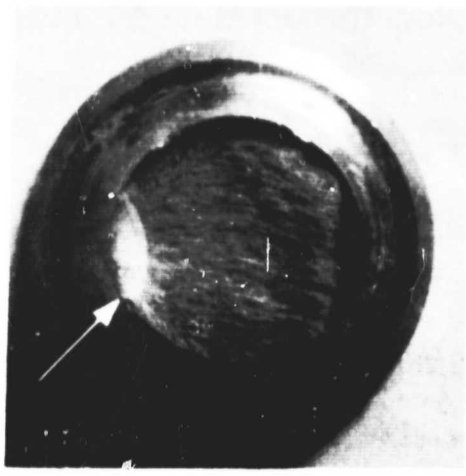
(4) 17.7 pH is only slightly magnetic in the annealed condition, but becomes strongly magnetic after heat treatment, when it may be magnetic particle tested.

d. **EDDY CURRENT TESTING METHOD.** Not normally used for detection of fillet cracks. Other NDT methods are more compatible to the detection of this type of discontinuity.

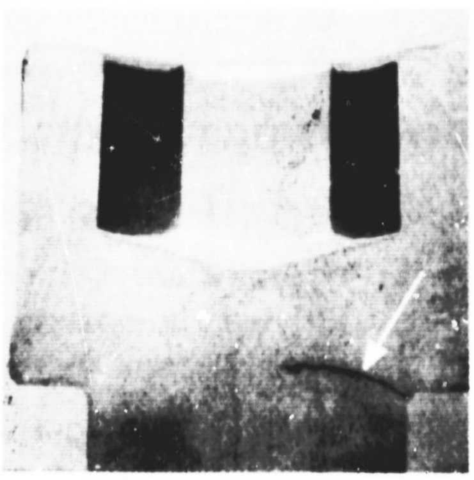
e. **RADIOGRAPHIC TESTING METHOD.** Not normally used for detection of fillet cracks. Surface discontinuities of this type would be difficult to evaluate due to size of crack in relation to the thickness of material.



A FILLET FATIGUE FAILURE



B FRACTURE AREA OF (A) SHOWING TANGENCY POINT OF FAILURE



C CROSS-SECTIONAL AREA OF FATIGUE CRACK IN FILLET SHOWING TANGENCY POINT IN RADIUS

Figure 7-8. Fillet Crack Discontinuity

709 GRINDING CRACKS

1. **CATEGORY.** Processing

2. **MATERIAL.** Ferrous and Nonferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Very shallow and sharp at the root. Similar to heat treat cracks and usually, but not always, occur in groups. Grinding cracks are generally at right angles to the direction of grinding. They are found in highly heat treated articles, chrome plated, case hardened and ceramic materials that are subjected to grinding operations. (See Figure 7-9.)

4. **METALLURGICAL ANALYSIS**

Grinding of hardened surfaces frequently introduces cracks. These thermal cracks are caused by local overheating of the surface being ground. The overheating is usually caused by lack of or poor coolant, a dull or improperly ground wheel, too rapid feed, or too heavy cut.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

a. LIQUID PENETRANT TESTING METHOD

(1) Normally used on both ferrous and nonferrous materials for the detection of grinding cracks.

(2) Liquid penetrant indication will appear as irregular, checked, or shattered pattern of fine lines.

(3) Cracks are the most difficult discontinuity to indicate and require the longest penetration time.

(4) Articles that have been degreased may still have solvent entrapped in the discontinuity and should be allowed sufficient time for evaporation prior to the application of the penetrant.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Restricted to ferrous materials.

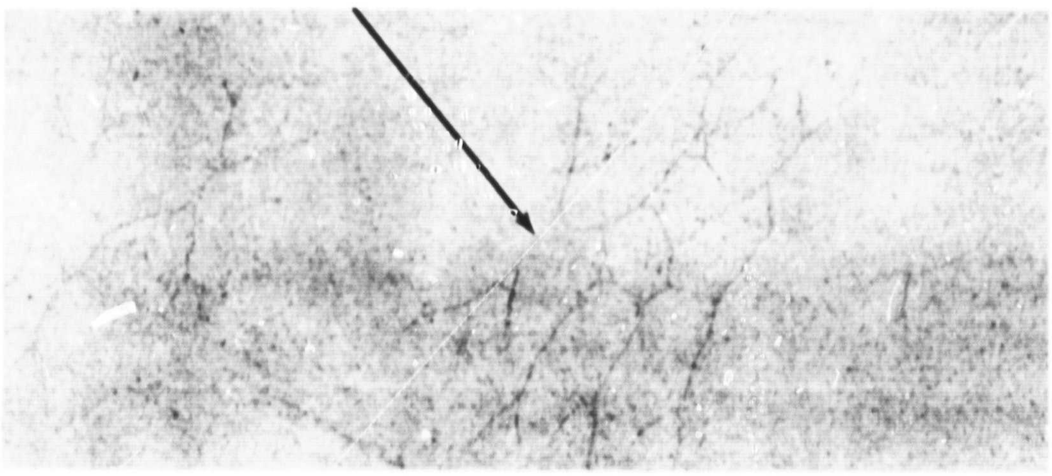
(2) Grinding cracks are generally at right angles to grinding direction, although in extreme cases a complete network of cracks may appear, in which case they may be parallel to the magnetic field.

(3) Magnetic sensitivity decreases as the size of grinding crack decreases and as its depth below the surface increases.

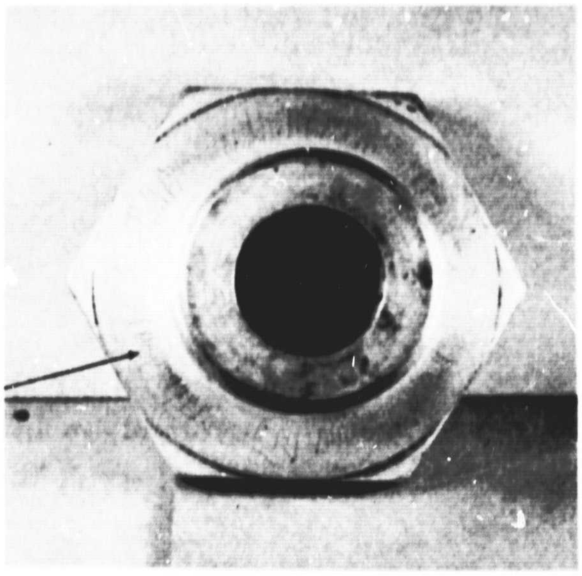
c. **EDDY CURRENT TESTING METHOD.** Not normally used for detection of grinding cracks. Eddy current equipment has the capability and can be developed for a specific nonferrous application.

d. **ULTRASONIC TESTING METHOD.** Not normally used for detection of grinding cracks. Other forms or NDT are more economical, faster, and better adapted to this type of discontinuity than ultrasonics.

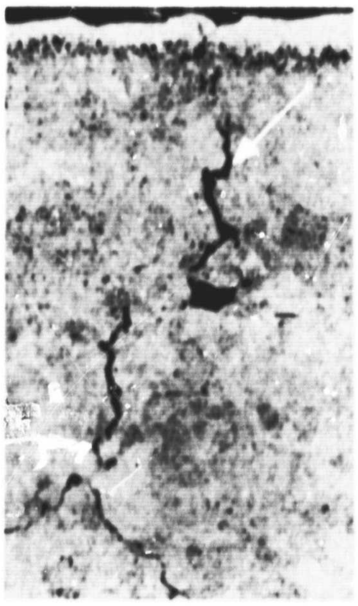
e. **RADIOGRAPHIC TESTING METHOD.** Not recommended for detection of grinding cracks. Grinding cracks are too tight and small. Other NDT methods are more suitable for detection of grinding cracks.



A TYPICAL CHECKED GRINDING CRACK PATTERN



B GRINDING CRACK PATTERN NORMAL TO GRINDING



C MICROGRAPH OF GRINDING CRACK

Figure 7-9. Grinding Crack Discontinuity

710 CONVOLUTION CRACKS

1. CATEGORY. Processing

2. MATERIAL. Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Range in size from micro fractures to open fissures. Situated on the periphery of the convolutions and extend longitudinally in direction of rolling. (See Figure 7-10.)

4. METALLURGICAL ANALYSIS

The rough 'orange peel' effect of convolution cracks is the result of either a forming operation which stretches the material or from chemical attack such as pickling treatment. The roughened surface contains small pits which form stress risers. Subsequent service application (vibration and flexing) may introduce stresses that act on these pits and form fatigue cracks as shown in the accompanying photograph.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Used extensively for this type of failure.

(2) Configuration of article and location of discontinuity limits detection almost exclusively to radiography.

(3) Orientation of convolutions to X-ray source is very critical since those discontinuities which are not normal to X-ray may not register on the film due to the lack of difference in density.

(4) Liquid penetrant and magnetic particle testing may supplement but not replace radiographic and ultrasonic testing.

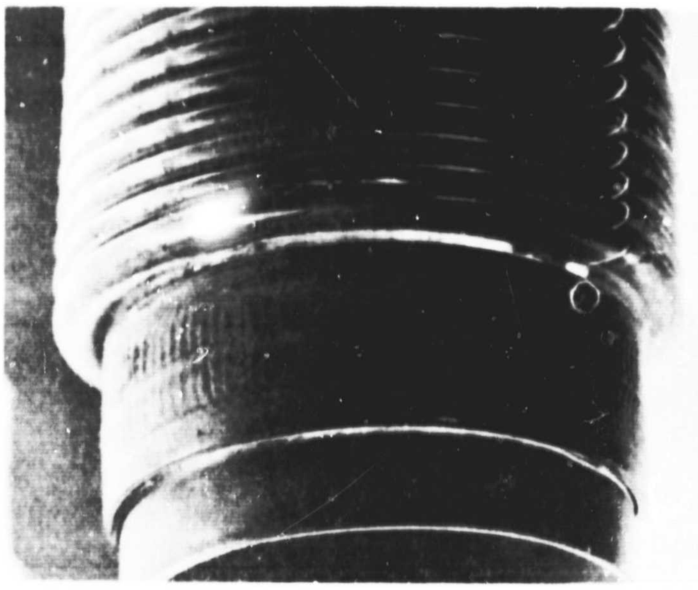
(5) The type of marking material (e.g., grease pencil on titanium) used to identify the area of discontinuities may affect the structure of the article.

b. ULTRASONIC TESTING METHOD. Not normally used for the detection of convolution cracks. Configuration of the article (double-walled convolutions) and internal micro fractures are all factors which restrict the use of ultrasonics.

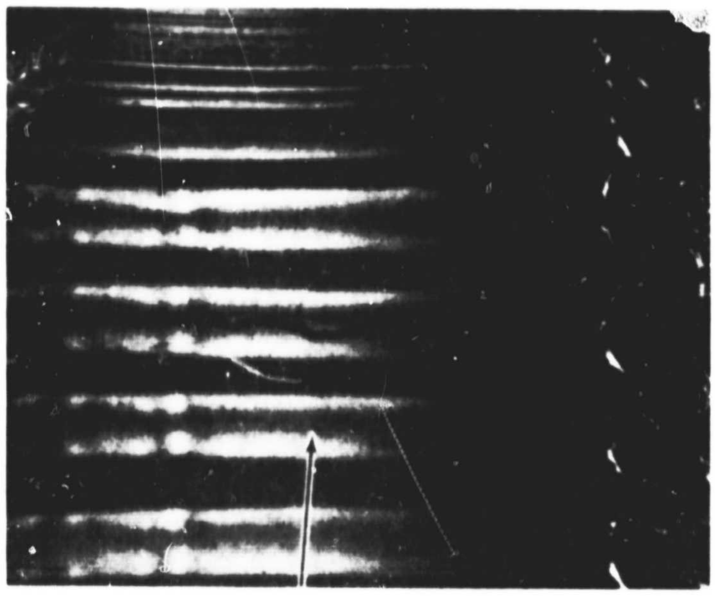
c. EDDY CURRENT TESTING METHOD. Not normally used for the detection of convolution cracks. As in the case of ultrasonic testing, the configuration does not lend itself to this method of testing.

d. **LIQUID PENETRANT TESTING METHOD.** Not recommended for the detection of convolution cracks. Although the discontinuities are surface, they are internal and are superimposed over an exterior shell which creates a serious problem of entrapment.

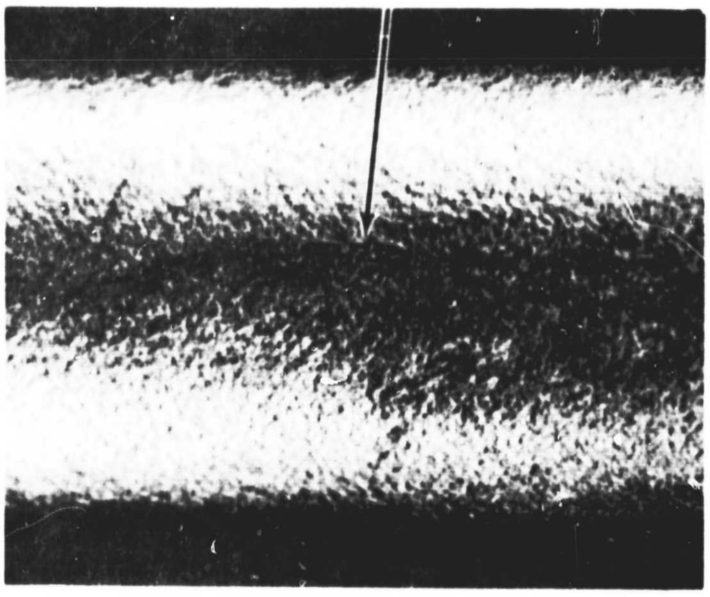
e. **MAGNETIC TESTING METHOD.** Not applicable. Material is nonferrous.



A TYPICAL CONVOLUTION DUCTING



B CROSS-SECTION OF CRACKED CONVOLUTION



C HIGHER MAGNIFICATION OF CRACK SHOWING ORANGE PEEL

D MICROGRAPH OF CONVOLUTION WITH PARTIAL CRACKING ON SIDES

Figure 7-10. Convolution Cracks Discontinuity

711 HEAT-AFFECTED ZONE CRACKING

1. CATEGORY. Processing (Weldments)

2. MATERIAL. Ferrous and Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Often quite deep and very tight. Usually parallel with the weld in the heat-affect zone of the weldment. (See Figure 7-11.)

4. METALLURGICAL ANALYSIS

Hot cracking of heat-affected zones of weldments increases in severity with increasing carbon content. Steels that contain more than 0.30% carbon are prone to this type of failure and require preheating prior to welding.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used for ferrous weldments.

(2) Prod burns are very detrimental, especially on highly heat treated articles. May contribute to structural failure of article.

(3) Demagnetization of highly heat treated articles can be very difficult due to metallurgical structure.

b. LIQUID PENETRANT TESTING METHOD

(1) Normally used for nonferrous weldments.

(2) Material that has had its surface obliterated, blurred, or blended due to manufacturing processes should not be penetrant tested until the smeared surface has been removed.

(3) Liquid penetrant testing after the application of certain types of chemical film coatings may be invalid due to the covering or filling of the discontinuities.

c. RADIOGRAPHIC TESTING METHOD. Not normally used for the detection of heat-affected zone cracking. Discontinuity orientation and surface origin make other NDT methods more suitable.

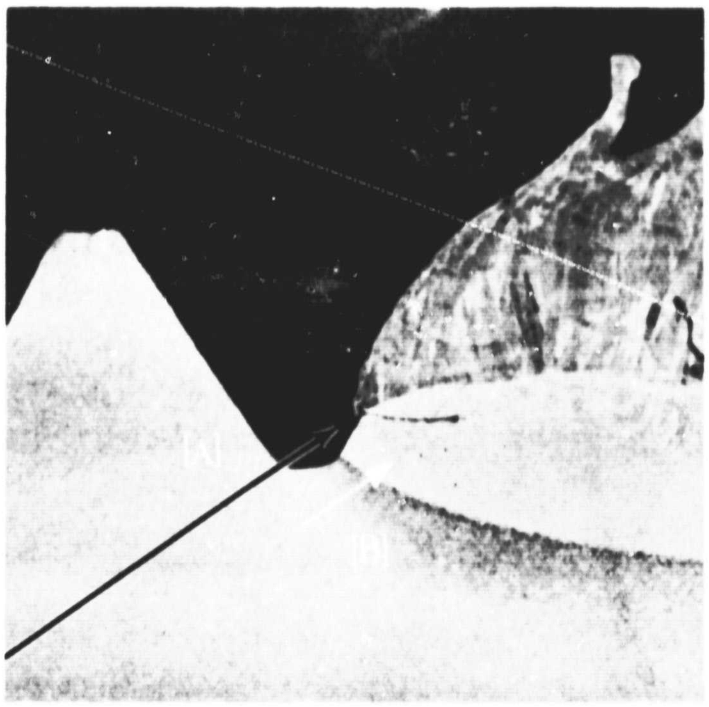
d. ULTRASONIC TESTING METHOD

(1) Used where specialized applications have been developed.

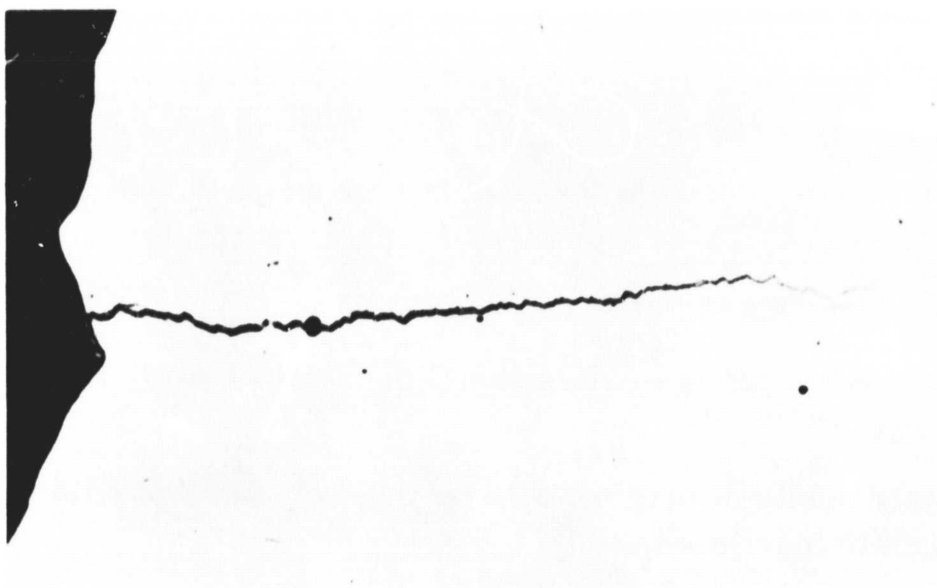
(2) Rigid standards and procedures are required to develop valid tests.

(3) The configuration of the surface roughness (i.e., sharp versus rounded root radii and the slope condition) are major factors in deflecting the sound beam.

e. **EDDY CURRENT TESTING METHOD.** Not normally used for the detection of heat-affected zone cracking. Eddy current equipment has capability of detecting nonferrous surface discontinuities; however, it is not as universally used as magnetic particle or liquid penetrant.



A MICROGRAPH OF WELD AND HEAT-AFFECTED ZONE SHOWING CRACK NOTE COLD LAP WHICH MASKS THE ENTRANCE TO THE CRACK



B MICROGRAPH OF CRACK SHOWN IN (A)

Figure 7-11. Heat-Affected Zone Cracking Discontinuity

712 HEAT TREAT CRACKS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought and Cast Material

3. DISCONTINUITY CHARACTERISTICS

Surface. Usually deep and forked. Seldom follow a definite pattern and can be in any direction on the part. Originate in areas with rapid change of material thickness, sharp machining marks, fillets, nicks, and discontinuities which have been exposed to the surface of the material. (See Figure 7-12.)

4. METALLURGICAL ANALYSIS

During the heating and cooling process localized stresses may be set up by unequal heating or cooling, restricted movement of the article, or unequal cross-sectional thickness. These stresses may exceed the tensile strength of the material causing it to rupture. Where built-in stress risers occur (keyways or grooves) additional cracks may develop.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. MAGNETIC PARTICLE TESTING METHOD

(1) For ferrous materials, heat treat cracks are normally detected by magnetic particles testing.

(2) The magnetic particles indications will normally be straight, forked, or curved indications.

(3) Likely points of origin are areas that would develop stress risers, such as keyways, fillets, or areas with rapid changes in material thickness.

(4) Metallurgical structure of age hardenable and heat treatable stainless steels (17.4, 17.7, and 431) may produce irrelevant indications.

b. LIQUID PENETRANT TESTING METHOD

(1) For nonferrous materials liquid penetrant testing is the recommended method.

(2) Likely points of origin would be the same as those listed above for magnetic particle testing

(3) Materials or articles that will eventually be used in LOX systems must be tested with compatible penetrants.

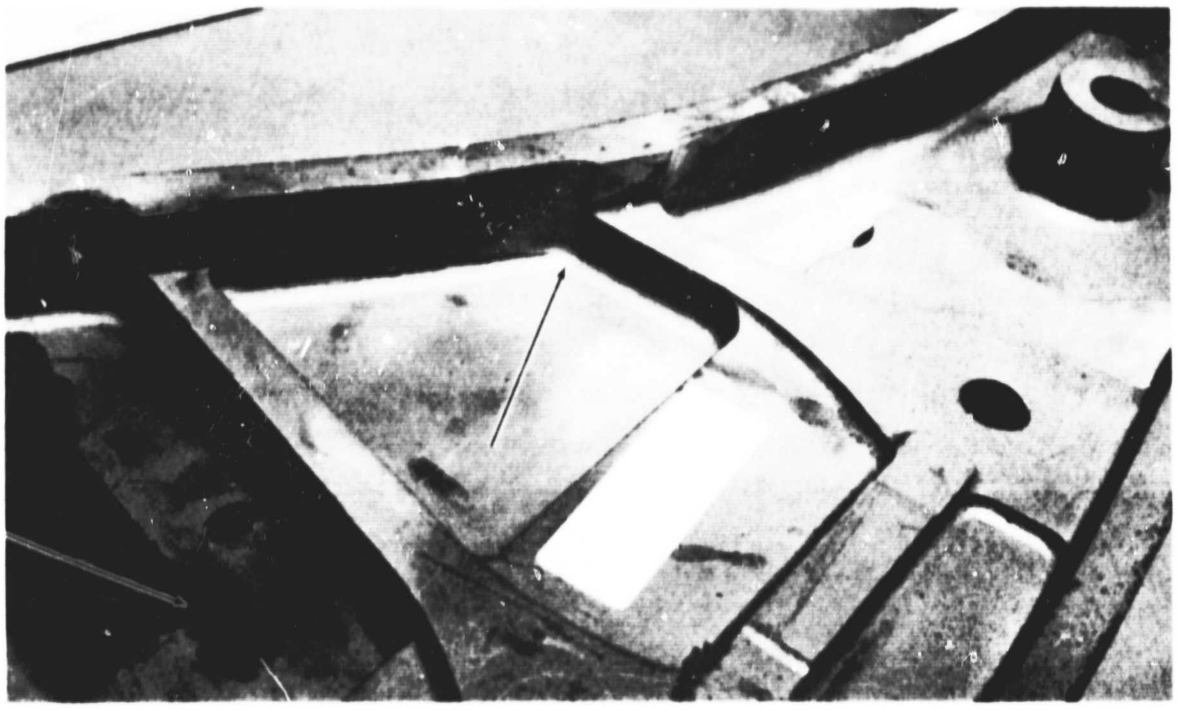
c. EDDY CURRENT TESTING METHOD

(1) Normally not used.

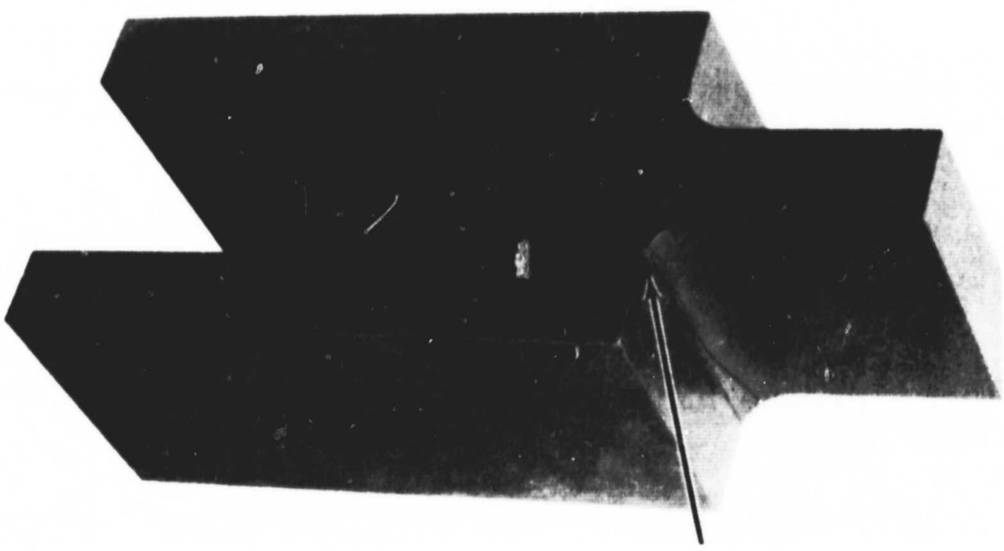
(2) Magnetic particles and liquid penetrant are more direct and economical.

d. **ULTRASONIC TESTING METHOD.** Not normally used for detection of heat treat cracks. If used the scope pattern will show a definite indication of a discontinuity. Recommended wave mode would be surface.

e. **RADIOGRAPHIC TESTING METHOD.** Not normally used for detection of heat treat cracks. Surface discontinuities are more easily detected by other NDT methods designed for surface application.



A FILLET AND MATERIAL THICKNESS CRACKS (TOP CENTER)
RELIEF RADIUS CRACKING (LOWER LEFT)



B HEAT TREAT CRACK DUE TO SHARP MACHINING MARKS

Figure 7-12. Heat Treat Cracks Discontinuity

713 SURFACE SHRINK CRACKS

1. CATEGORY. Processing (Welding)

2. MATERIAL. Ferrous and Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Situated on the face of the weld, fusion zone, and base metal. Range in size from very small, tight, and shallow, to open and deep. Cracks may run parallel or transverse the direction of welding. (See Figure 7-13.)

4. METALLURGICAL ANALYSIS

Surface shrink cracks are generally the result of improper heat application, either in heating or welding of the article. Heating or cooling in a localized area may set up stresses that exceed the tensile strength of the material causing the material to crack. Restriction of the movement (contraction or expansion) of the material during heating, cooling, or welding may also set up excessive stresses.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Surface shrink cracks are normally detected by liquid penetrant.

(2) Liquid penetrant equipment is easily portable and can be used during in-process control for both ferrous and nonferrous weldments.

(3) Assemblies which are joined by bolting, riveting, intermittent welding, or press fittings will retain the penetrant, which will seep out after developing and mask the adjoining surfaces.

(4) When articles are dried in a hot air dryer or by similar means, excessive drying temperature should be avoided to prevent evaporation of the penetrant.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Ferrous weldments are normally tested by magnetic particle method.

(2) Surface discontinuities that are parallel to the magnetic field will not produce indications since they do not interrupt or distort the magnetic field.

(3) Areas of grease fittings, bearing races, or other similar items that might be damaged or clogged by the suspension solution or magnetic solids should be masked before testing.

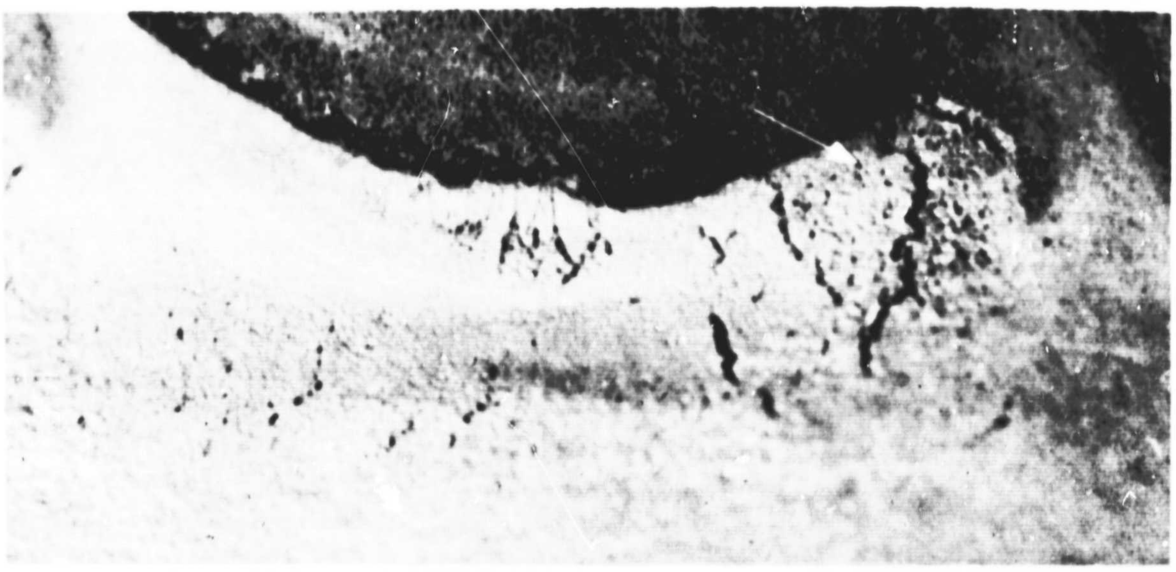
c. EDDY CURRENT TESTING METHOD

(1) Normally confined to nonferrous welded pipe and tubing.

(2) Probe or encircling coil could be used where article configuration permits.

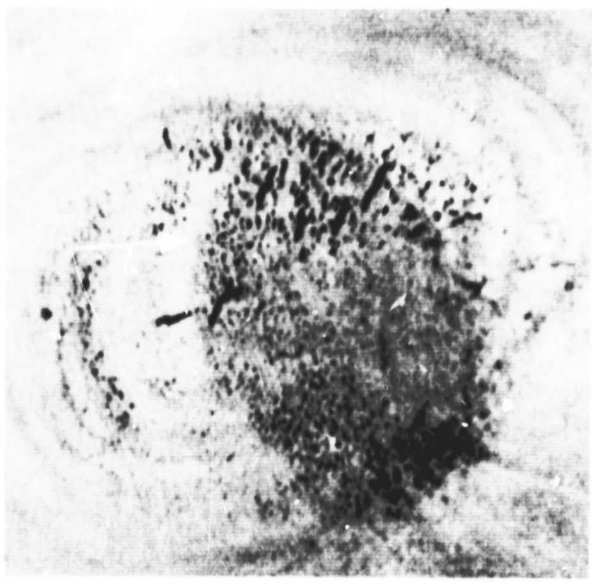
d. RADIOGRAPHIC TESTING METHOD. Not normally used for the detection of surface discontinuities. During the radiographic testing of weldments for other types of discontinuities, surface indications may be detected.

e. ULTRASONIC TESTING METHOD. Not normally used for detection of surface shrink cracks. Other forms of NDT (liquid penetrant and magnetic particle) give better results, are more economical, and are faster.



A TRANSVERSE CRACKS IN HEAT-AFFECTED ZONE

B TYPICAL STAR-SHAPED CRATER CRACK



C SHRINKAGE CRACK AT WELD TERMINAL

Figure 7-13. Surface Shrink Crack Discontinuity

714 THREAD CRACKS

1. CATEGORY. Service

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface. Cracks are transverse to the grain (transgranular) starting at the root of the thread. (See Figure 7-14.)

4. METALLURGICAL ANALYSIS

Fatigue failures of this type are not uncommon. High cyclic stresses resulting from vibration and/or flexing act on the stress risers created by the thread roots and produce cracks. Fatigue cracks may start as fine submicroscopic discontinuities and/or cracks and propagate in the direction of applied stresses.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Fluorescent penetrant is recommended over non-fluorescent.

(2) Low surface tension solvents such as gasoline and kerosene are not recommended cleaners.

(3) When applying liquid penetrant to components within an assembly or structure, the adjacent areas should be effectively masked to prevent overspraying.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used on ferrous materials.

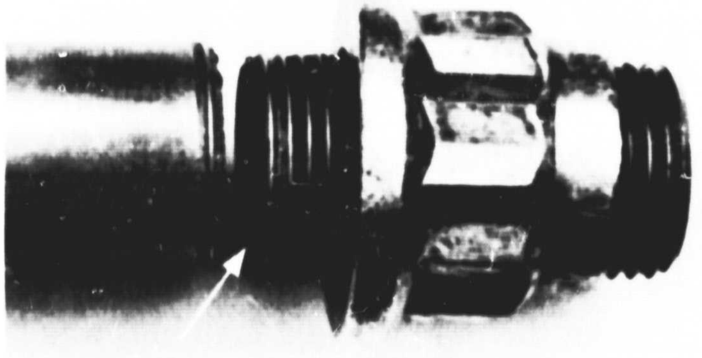
(2) Irrelevent magnetic indications may result from the thread configuration.

(3) Cleaning titanium and 440C stainless in halogeneated hydrocarbons may result in structural damage to the material.

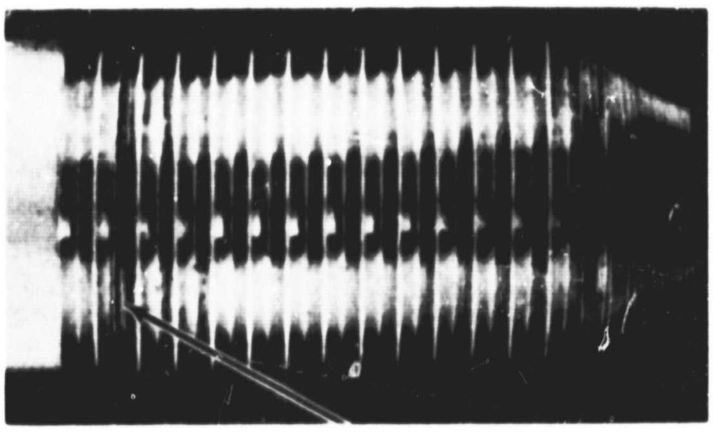
c. EDDY CURRENT TESTING METHOD. Not normally used for detecting thread cracks. The article configuration would require specialized equipment if adaptable.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting thread cracks. Thread configuration does not lend itself to ultrasonic testing.

e. **RADIOGRAPHIC TESTING METHOD.** Not recommended for detecting thread cracks. Surface discontinuities are best screened by NDT method designed for the specific condition. Fatigue cracks of this type are very tight and surface connected, their detection by radiography would be extremely difficult.



A COMPLETE THREAD ROOT FAILURE



B TYPICAL THREAD ROOT FAILURE

C MICROGRAPH OF (A) SHOWING CRACK AT BASE OF ROOT

D MICROGRAPH OF (B) SHOWING TRANSGRANULAR CRACK AT THREAD ROOT

Figure 7-14. Thread Crack Discontinuity

715 TUBING CRACKS (INCONEL "X")

1. CATEGORY. Inherent

2. MATERIAL. Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Tubing cracks formed on the inner surface (I.D.), parallel to direction of grain flow. (See Figure 7-15.)

4. METALLURGICAL ANALYSIS

Tubing I. D. cracks may be attributed to one or a combination of the following:

a. Improper cold reduction of the tube during fabrication.

b. Foreign material may have been embedded on the inner surface of the tubes causing embrittlement and cracking when the cold worked material was heated during the annealing operation.

c. Insufficient heating rate to the annealing temperature with possible cracking occurring in the 1200-1400° F range.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. EDDY CURRENT TESTING METHOD

(1) Normally used for detection of this type of discontinuity.

(2) The diameter (1 inch) and wall thickness (0. 156 inch) are well within equipment capability.

(3) Testing of ferro-magnetic material may be difficult.

b. ULTRASONIC TESTING METHOD

(1) Normally used on heavy gauge tubing.

(2) A wide variety of equipment and transducers are available for screening tubing for internal discontinuities of this type.

(3) Ultrasonic transducers have varying temperature limitations.

(4) Certain ultrasonic contact couplants may have high sulfur content which will have an adverse effect on high nickel alloys.

c. RADIOGRAPHIC TESTING METHOD

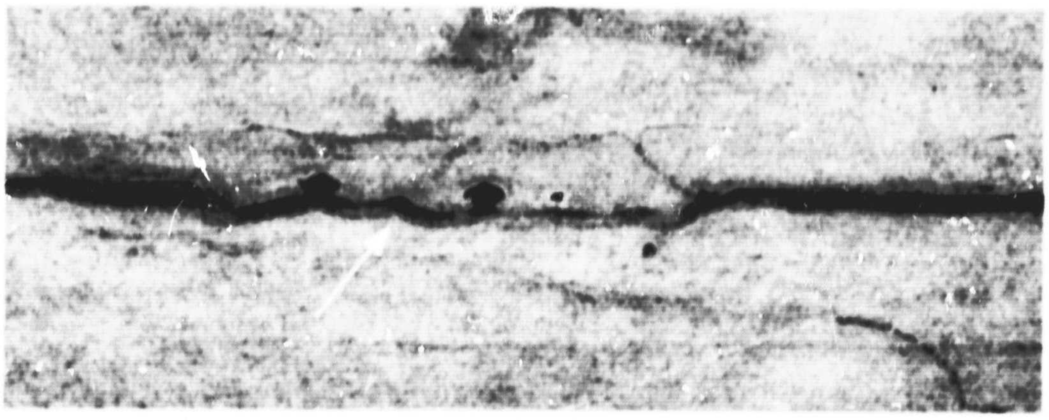
(1) Not normally used for detecting tubing cracks.

(2) Discontinuity orientation and thickness of material govern the radiographic sensitivity.

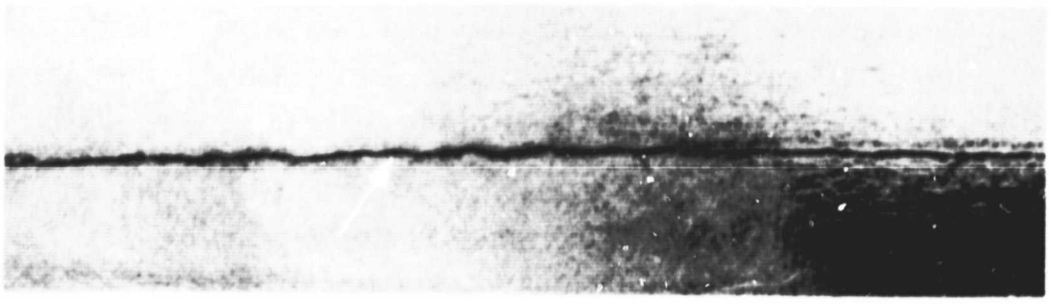
(3) Other forms of NDT (eddy current and ultrasonic) are more economical, faster, and reliable.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting tubing cracks. Internal discontinuity would be difficult to process and interpret.

e. MAGNETIC PARTICLES TESTING METHOD. Not applicable. Material is nonferrous under normal conditions.



A TYPICAL CRACK ON INSIDE OF TUBING SHOWING COLD LAP



B ANOTHER PORTION OF SAME CRACK SHOWING CLEAN FRACTURE

C MICROGRAPH OF (B)

Figure 7-15. Tubing Crack Discontinuity

716 HYDROGEN FLAKE

1. CATEGORY. Processing

2. MATERIAL. Ferrous

3. DISCONTINUITY CHARACTERISTICS

Internal fissures in a fractured surface, flakes appear as bright silvery areas. On an etched surface they appear as short discontinuities. Sometimes known as chrome checks and hairline cracks when revealed by machining, flakes are extremely thin and generally aligned parallel with the grain. They are usually found in heavy steel forgings, billets, and bars. (See Figure 7-16.)

4. METALLURGICAL ANALYSIS

Flakes are internal fissures attributed to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working. Usually found only in heavy alloy steel forgings.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Used extensively for the detection of hydrogen flake.

(2) Material in the wrought condition can be screened successfully using either the immersion or the contact method. The surface condition will determine the method most suited.

(3) On the A-scan presentation, hydrogen flake will appear as hash on the screen or as loss of back reflection.

(4) All foreign materials (loose scale, dirt, oil, grease) should be removed prior to any testing. Surface irregularities such as nicks, gouges, tool marks, and scarfing may cause loss of back reflection.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used on finished machined articles.

(2) Flakes appear as short discontinuities and resemble chrome checks or hairline cracks.

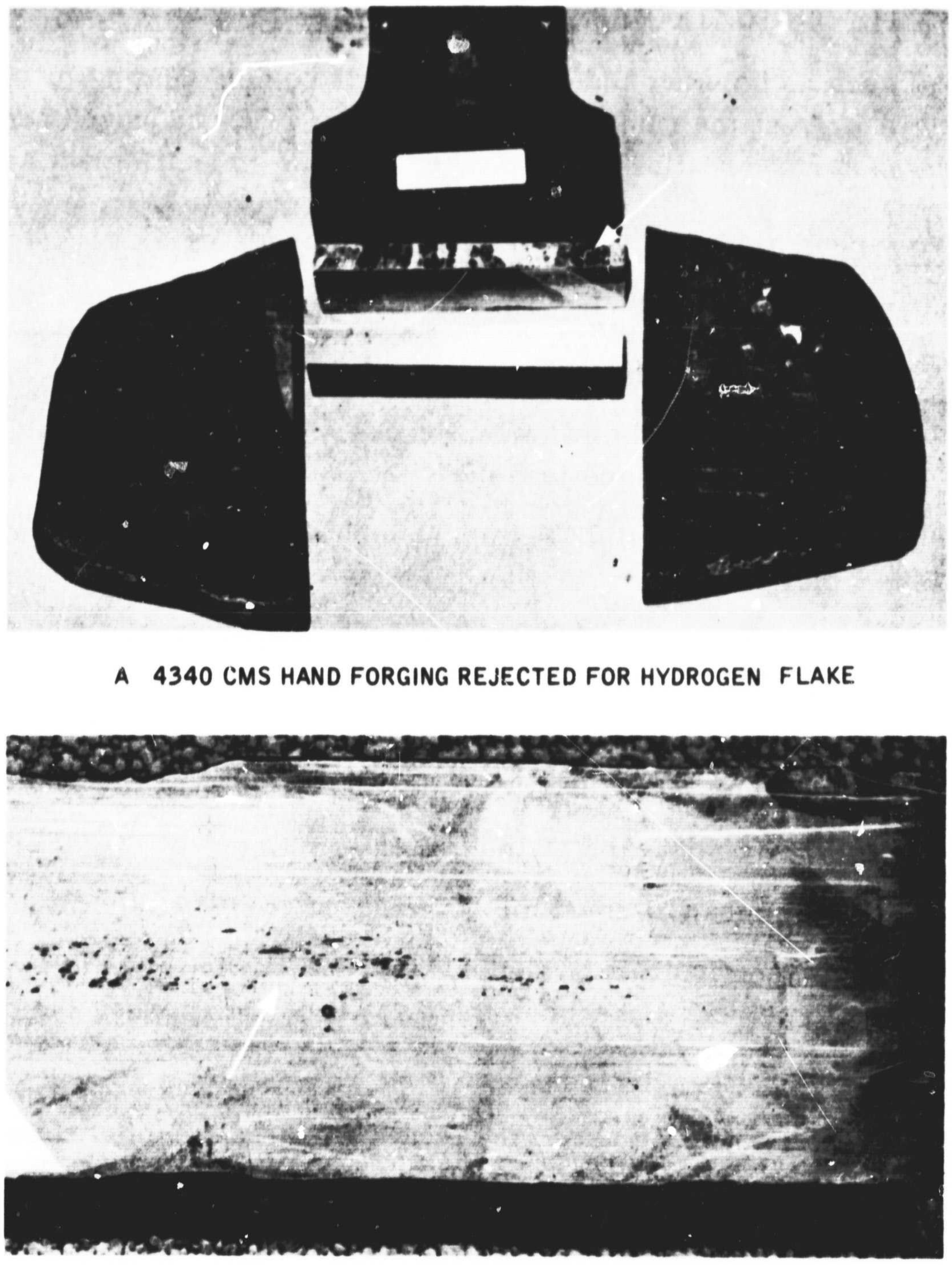
(3) Machined surfaces with deep tool marks may obliterate the detection of the flake.

(4) Where the general direction of a discontinuity is questionable, it may be necessary to magnetize in two or more directions.

c. **LIQUID PENETRANT TESTING METHOD.** Not normally used for detecting flakes. Discontinuities are very small and tight and would be difficult to detect by liquid penetrant.

d. **EDDY CURRENT TESTING METHOD.** Not recommended for detecting flakes. The metallurgical structure of ferrous materials limits their adaptability to the use of eddy current.

e. **RADIOGRAPHIC TESTING METHOD.** Not recommended for detecting flakes. The size of the discontinuity, its location and orientation with respect to the material surface restricts the application of radiography.



A 4340 CMS HAND FORGING REJECTED FOR HYDROGEN FLAKE

B CROSS-SECTION OF (A) SHOWING FLAKE CONDITION IN CENTER OF MATERIAL

Figure 7-16. Hydrogen Flake Discontinuity

717 HYDROGEN EMBRITTLEMENT

1. CATEGORY. Processing and Service

2. MATERIAL. Ferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Small, nondimensional (interface) with no orientation or direction. Found in highly heat treated material that was subjected to pickling and/or plating or in material exposed to free hydrogen. (See Figure 7-17.)

4. METALLURGICAL ANALYSIS

Operations such as pickling and cleaning prior to electroplating or electroplating generate hydrogen at the surface of the material. This hydrogen penetrates the surface of the material creating immediate or delayed embrittlement and cracking.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. MAGNETIC PARTICLES TESTING METHOD

(1) Magnetic indications appear as a fractured pattern.

(2) Hydrogen embrittlement cracks are randomly orientated and may follow the magnetic field.

(3) Magnetic particle testing should be accomplished before and after plating.

(4) Care should be taken to produce no confusing or irrelevant indications or cause damage to the article by overheating.

(5) 301 corrosion resistant steel is non-magnetic in the annealed condition, but becomes magnetic with cold working.

b. LIQUID PENETRANT TESTING METHOD

(1) Not normally used for detecting hydrogen embrittlement.

(2) Discontinuities on the surface are extremely tight, small, and difficult to detect. Subsequent plating deposit may mask the discontinuity.

c. ULTRASONIC TESTING METHOD

(1) Not normally used for detecting hydrogen embrittlement.

(2) Article configurations and size do not, in general, lend themselves to this method of testing.

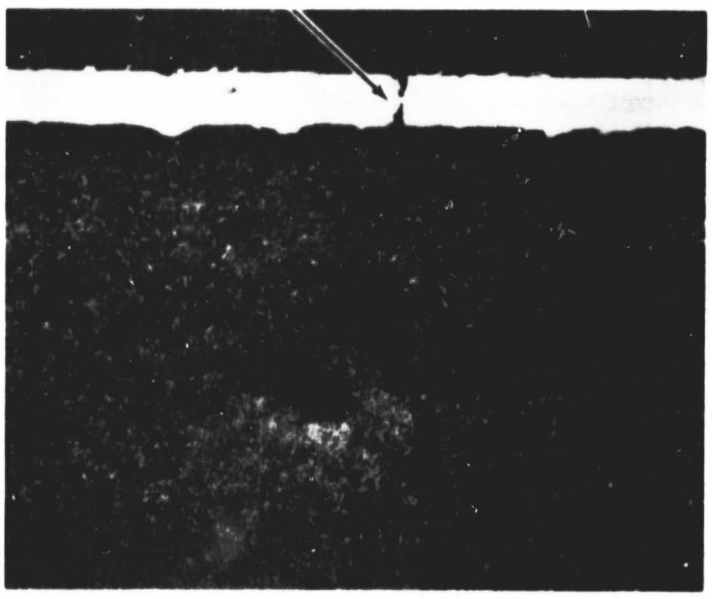
(3) Equipment has capability of detecting hydrogen embrittlement . Recommend surface wave technique.

d. **EDDY CURRENT TESTING METHOD.** Not recommended for detecting hydrogen embrittlement. Many variables inherent in the specific material may produce conflicting patterns.

e. **RADIOGRAPHIC TESTING METHOD.** Not recommended for detecting hydrogen embrittlement. The sensitivity required to detect hydrogen embrittlement is in most cases in excess of radiographic capabilities.

A DETAILED CRACK PATTERN OF HYDROGEN EMBRITTLEMENT

B HYDROGEN EMBRITTLEMENT UNDER CHROME PLATE



C HYDROGEN EMBRITTLEMENT PROPAGATED THROUGH CHROME PLATE

Figure 7-17. Hydrogen Embrittlement Discontinuity

718 INCLUSIONS

1. CATEGORY. Processing (Weldments)

2. MATERIAL. Ferrous and Nonferrous Welded Material

3. DISCONTINUITY CHARACTERISTICS

Surface and subsurface. Inclusions may be any shape. They may be metallic or non-metallic and may appear singly or be linearly distributed or scattered throughout the weldment. (See Figure 7-18.)

4. METALLURGICAL ANALYSIS

Metallic inclusions are generally particles of metals of different density as compared to the weld or base metal. Non-metallic inclusions are oxides, sulphides, slag or other non-metallic foreign material entrapped in the weld or between the weld metal and the base metal.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) This NDT method is universally used.

(2) Metallic inclusions appear on the radiograph as sharply defined, round, erratically shaped, or elongated white spots and may be isolated or in small linear or scattered groups.

(3) Non-metallic inclusions will appear on the radiograph as shadows of round globules or elongated or irregularly shaped contours occurring singly, linearly, or scattered throughout the weldment. They will generally appear in the fusion zone or at the root of the weld. Less absorbent material is indicated by a greater film density and more absorbent materials by a lighter film density.

(4) Foreign material such as loose scales, splatter, or flux may invalidate test results.

b. EDDY CURRENT TESTING METHOD

(1) Normally confined to thin wall welded tubing.

(2) Established standards may be required if valid results are to be obtained.

c. MAGNETIC PARTICLE TESTING METHOD

(1) Normally not used for detecting inclusions in weldments.

(2) Confined to machined weldments where the discontinuities are surface or near surface.

(3) The indications would appear jagged, irregularly shaped, individually or clustered, and would not be too pronounced.

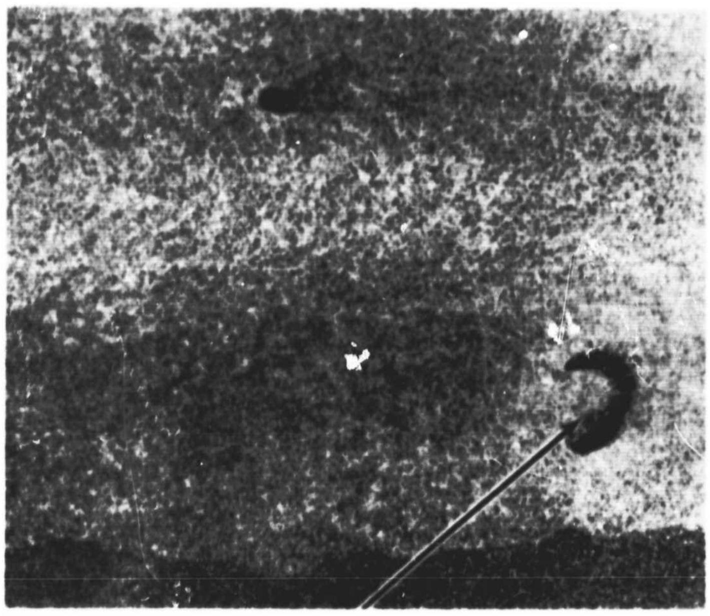
(4) Discontinuities may go undetected when improper contact exists between the magnetic particles and the surface of the article.

d. ULTRASONIC TESTING METHOD

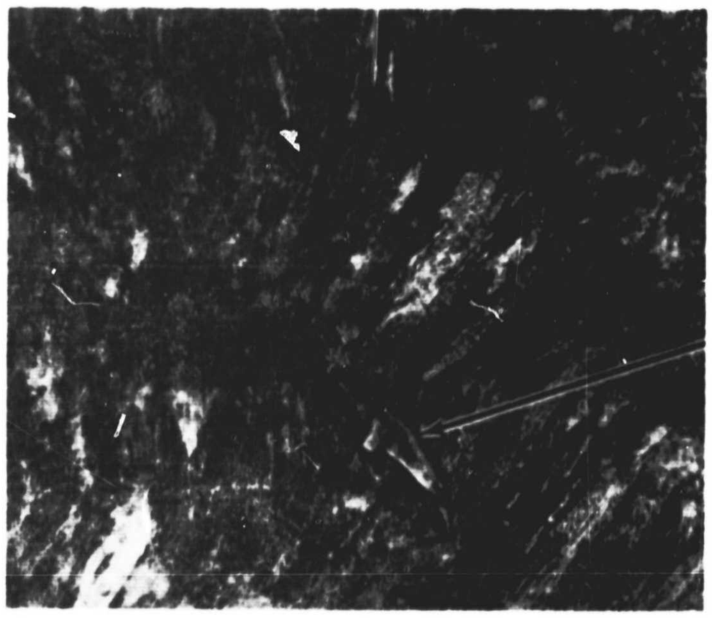
(1) Not normally used for detecting inclusions.

(2) Specific applications of design or of article configuration may require ultrasonic testing.

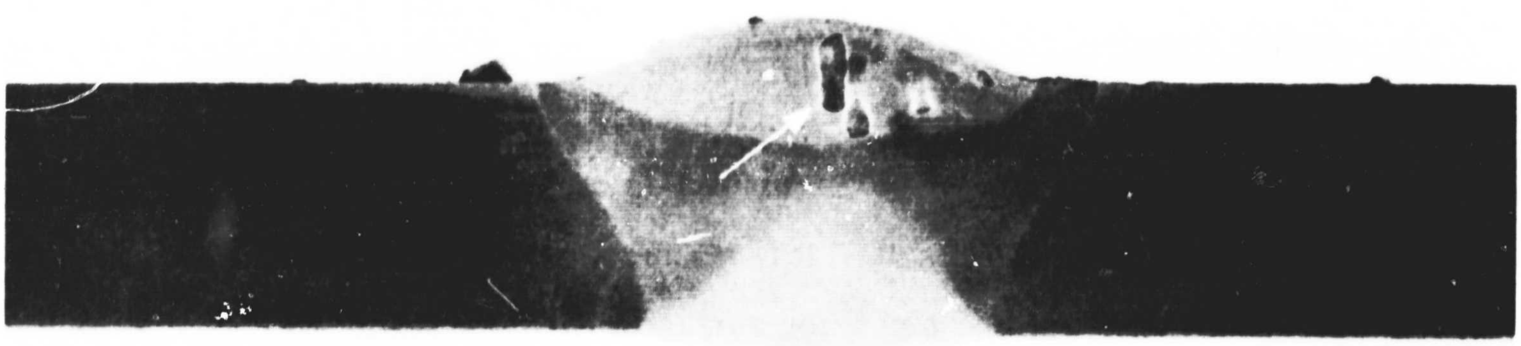
e. LIQUID PENETRANT TESTING METHOD. Not applicable. Inclusions are normally not open fissures.



A METALLIC INCLUSIONS



B INCLUSIONS TRAPPED IN WELD



C CROSS-SECTION OF WELD SHOWING INTERNAL INCLUSIONS

Figure 7-18. Weldment Inclusion Discontinuity

719 INCLUSIONS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Subsurface (original bar) or surface (after machining). There are two types: one is non-metallic with long straight lines parallel to flow lines and quite tightly adherent. Often short and likely to occur in groups. The other type is non-plastic, appearing as a comparatively large mass and not parallel to flow lines. Found in forged, extruded, and rolled material. (See Figure 7-19.)

4. METALLURGICAL ANALYSIS

Non-metallic inclusions (stringers) are caused by the existence of slag or oxides in the billet or ingot. Non-plastic inclusions are caused by particles remaining in the solid state during billet melting.

5. NDT METHODS APPLICATIONS AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Normally used to evaluate inclusions in wrought material.

(2) Inclusions will appear as definite interfaces within the metal. Small clustered condition or conditions on different planes causing a loss in back reflection. Numerous small scattered conditions cause excessive "noise".

(3) Inclusion orientation in relationship to ultrasonic beam is critical.

(4) The direction of the ultrasonic beam should be perpendicular to the direction of the grain flow whenver possible.

b. EDDY CURRENT TESTING METHOD

(1) Normally used for thin wall tubing and small diameter rods.

(2) Testing of ferro-magnetic materials can be difficult.

c. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used on machined surface.

(2) Inclusions will appear as a straight intermittent or as a continuous indication. They may be individual or clustered.

(3) The magnetic technique should be such that a surface or near surface inclusion can be satisfactorily detected when its axis is in any direction.

(4) A knowledge of the grain flow of the material is critical since inclusions will be parallel to that direction.

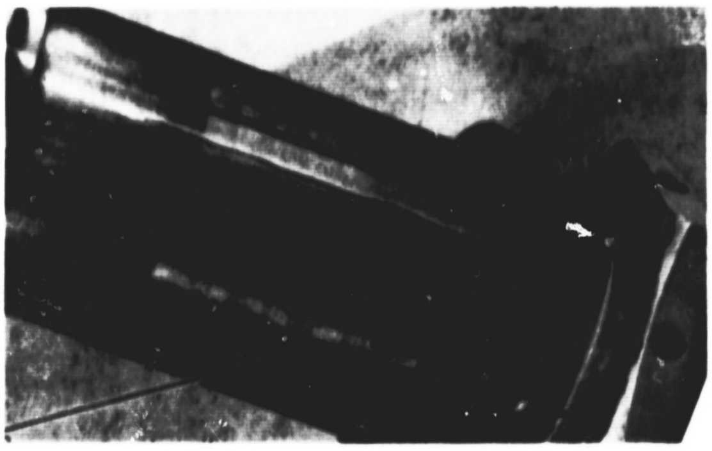
(5) Certain types of steels are more prone to inclusions than other.

d. LIQUID PENETRANT TESTING METHOD

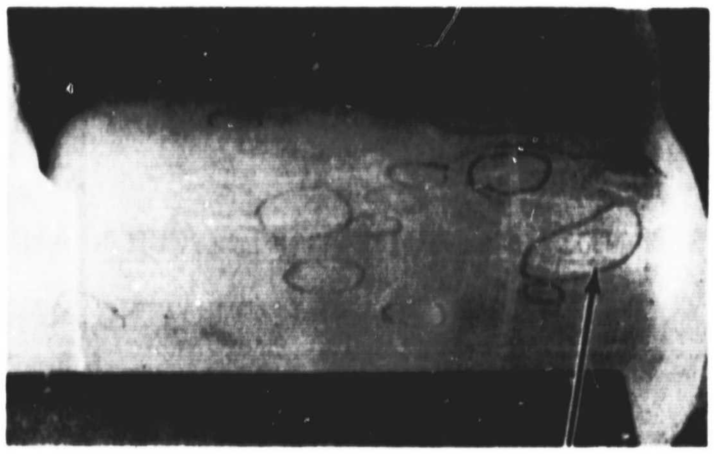
(1) Not normally used for detecting inclusions in wrought material.

(2) Inclusions are generally not openings in the material surface.

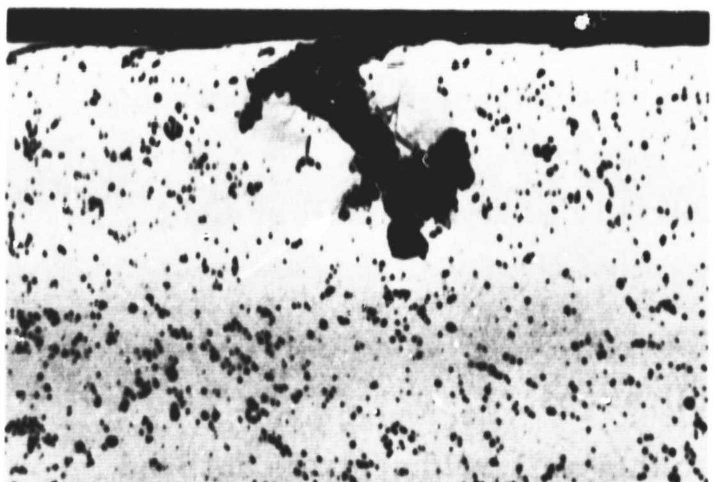
e. RADIOGRAPHIC TESTING METHOD. Not recommended. NDT methods designed for surface testing are more suitable for detecting surface inclusions.



A TYPICAL INCLUSION PATTERN ON MACHINED SURFACES



B STEEL FORGING SHOWING NUMEROUS INCLUSIONS



C MICROGRAPH OF TYPICAL INCLUSION

D LONGITUDINAL CROSS-SECTION SHOWING ORIENTATION OF INCLUSIONS

Figure 7-19. Wrought Inclusion Discontinuity

720 LACK OF PENETRATION

1. **CATEGORY.** Processing

2. **MATERIAL.** Ferrous and Nonferrous Weldments

3. **DISCONTINUITY CHARACTERISTICS**

Internal or external. Generally irregular and filamentary occuring at the root and running parallel with the weld. (See Figure 7-20.)

4. **METALLURGICAL ANALYSIS**

Caused by root face of joint not reaching fusion temperature before weld metal was deposited. Also caused by fast welding rate, too large a welding rod, or too cold a bead.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

a. RADIOGRAPHIC TESTING METHOD

(1) Used extensively on a wide variety of welded articles to determine the lack of penetration.

(2) Lack of penetration will appear on the radiograph as an elongated dark area of varying length and width. It may be continuous or intermittent and may appear in the center of the weld at the junction of multipass beads.

(3) Lack of penetration orientation in relationship to the radiographic source is critical.

(4) Sensitivity levels govern the capability to detect small or tight discontinuities.

b. ULTRASONIC TESTING METHOD

(1) Commonly used for specific applications.

(2) Complex weld configurations, or thin wall weldments do not lend themselves to ultrasonic testing.

(3) Lack of penetration will appear on the scope as a definite break or discontinuity resembling a crack and will give a very sharp reflection.

(4) Repeatability of ultrasonic test results is difficult unless equipment is standardized.

c. EDDY CURRENT TESTING METHOD

(1) Normally used to determine lack of penetration in nonferrous welded pipe and tubing.

(2) Eddy current can be used where other nonferrous articles can meet the configuration requirement of the equipment.

d. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used where backside of weld is visible.

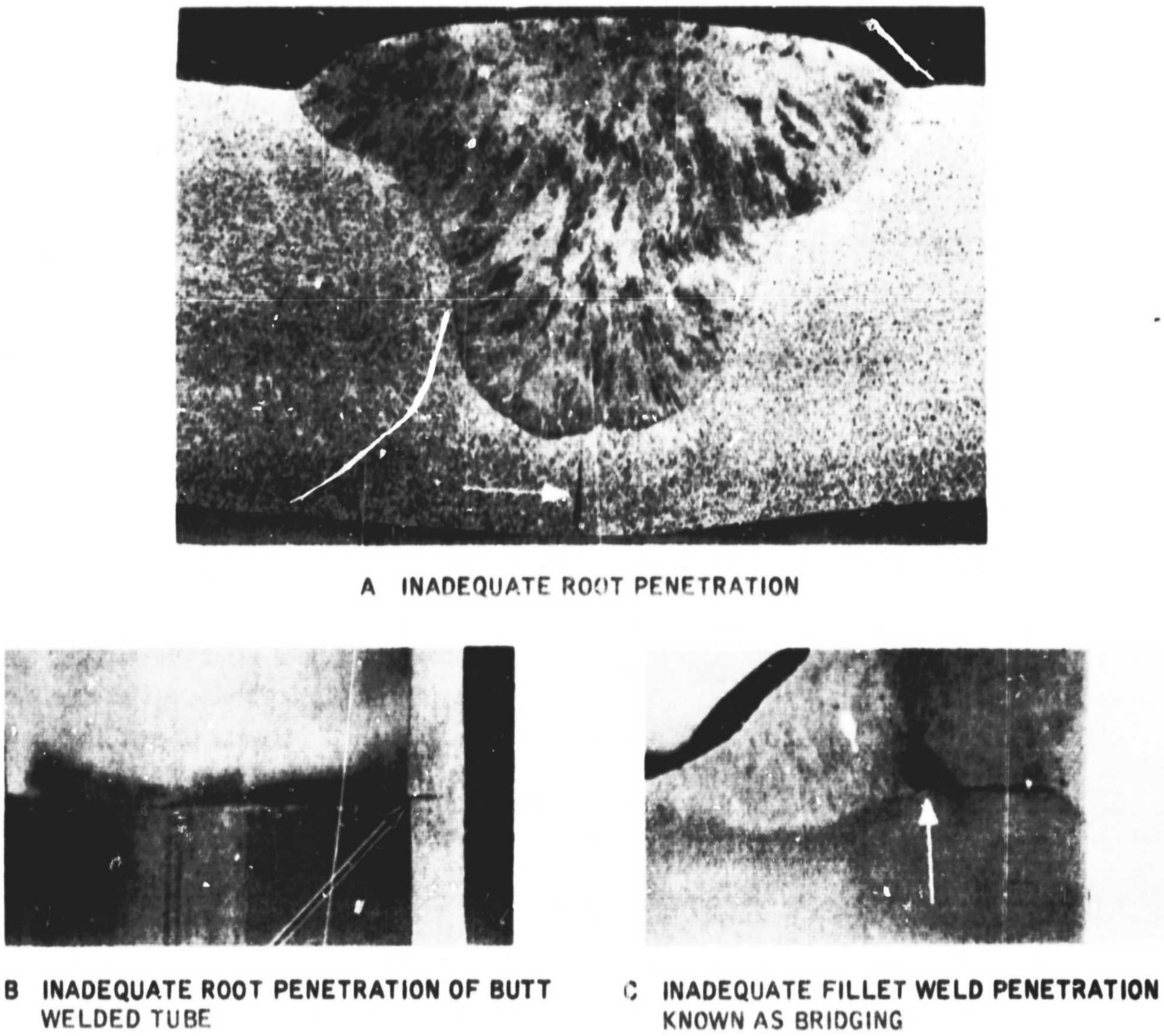
(2) Lack of penetration appears as an irregular indication of varying width.

e. LIQUID PENETRANT TESTING METHOD

(1) Normally used where backside of weld is visible.

(2) Lack of penetration appears as an irregular indication of varying width.

(3) Residue left by the penetrant and the developer could contaminate any re-welding operation.



A INADEQUATE ROOT PENETRATION

B INADEQUATE ROOT PENETRATION OF BUTT WELDED TUBE

C INADEQUATE FILLET WELD PENETRATION KNOWN AS BRIDGING

Figure 7-20. Lack of Penetration Discontinuity

721 LAMINATIONS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface and internal. Flat, extremely thin, generally aligned parallel to the work surface of the material. May contain a thin film of oxide between the surfaces. Found in forged, extruded, and rolled material. (See Figure 7-21.)

4. METALLURGICAL ANALYSIS

Laminations are separations or weaknesses generally aligned parallel to the work surface of the material. They may be the result of pipe, blister, seam, inclusions, or segregations elongated and made directional by working. Laminations are flattened impurities that are extremely thin.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) For heavier gauge material the geometry and orientation of lamination (normal to the beam) makes their detection limited to ultrasonic.

(2) Numerous wave modes may be used depending upon the material thickness or method selected for testing. Automatic and manual contact or immersion methods are adaptable.

(3) Lamination will appear as a definite interface with a loss of back reflection.

(4) Through transmission and reflection techniques are applicable for very thin sections.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Articles fabricated from ferrous materials are normally tested for lamination by magnetic particle.

(2) Magnetic indication will appear as a straight, intermittent indication.

(3) Magnetic particle testing is not capable of determining the over-all size or depth of the lamination.

c. LIQUID PENETRANT TESTING METHOD

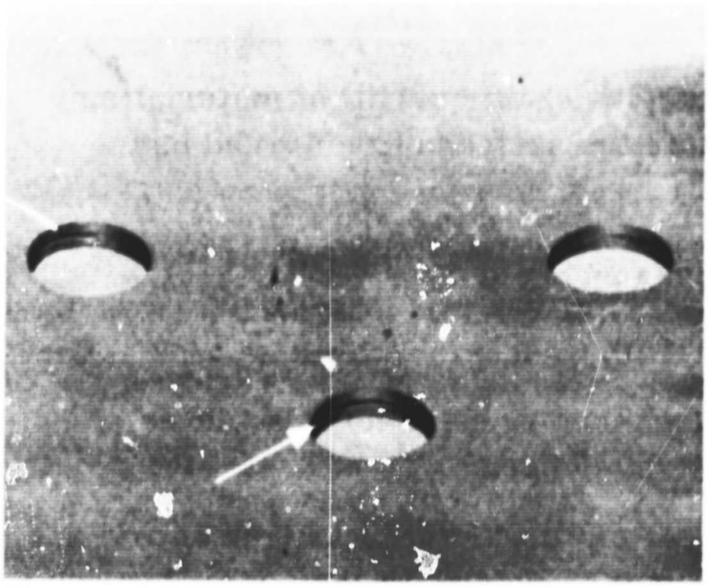
(1) Normally used on nonferrous materials.

(2) Machining, honing, lapping, or blasting may smear surface of material and thereby close or mask surface lamination.

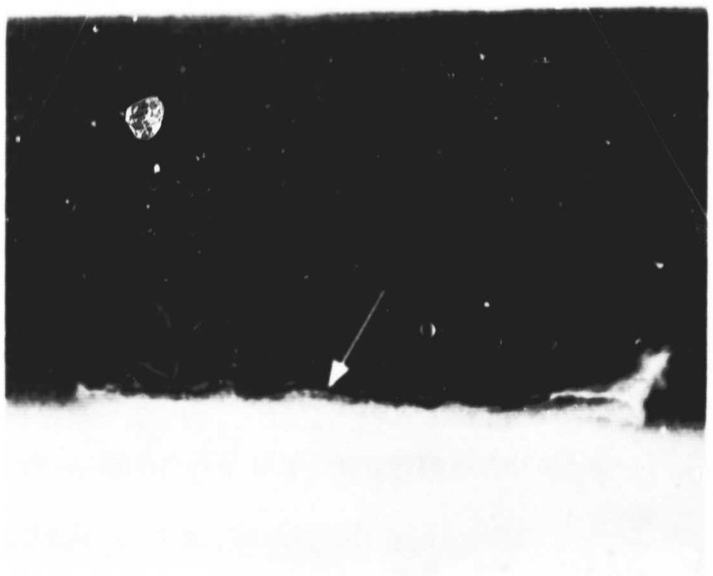
(3) Acid and alkalines seriously limit the effectiveness of liquid penetrant testing. Thorough cleaning of the surface is essential.

d. EDDY CURRENT TESTING METHOD. Not normally used to detect laminations. If used, the method must be confined to thin sheet stock.

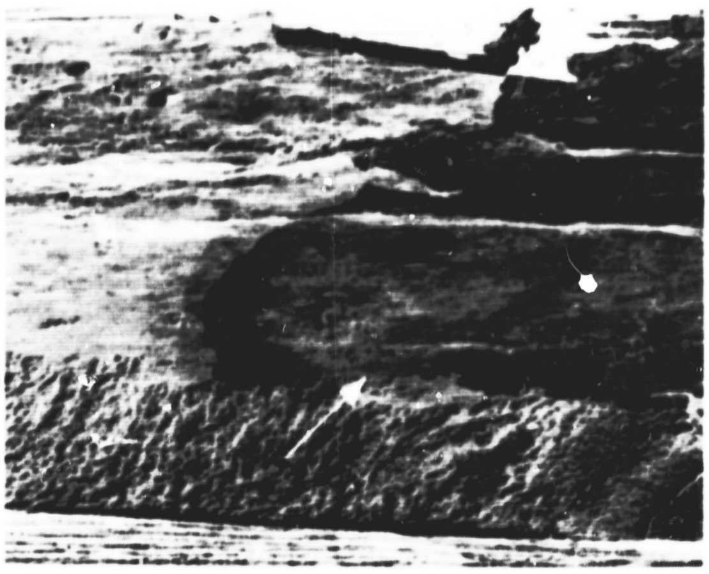
e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laminations Laminations have very small thickness changes in the direction of the X-ray beam, thereby making radiographic detection almost impossible.



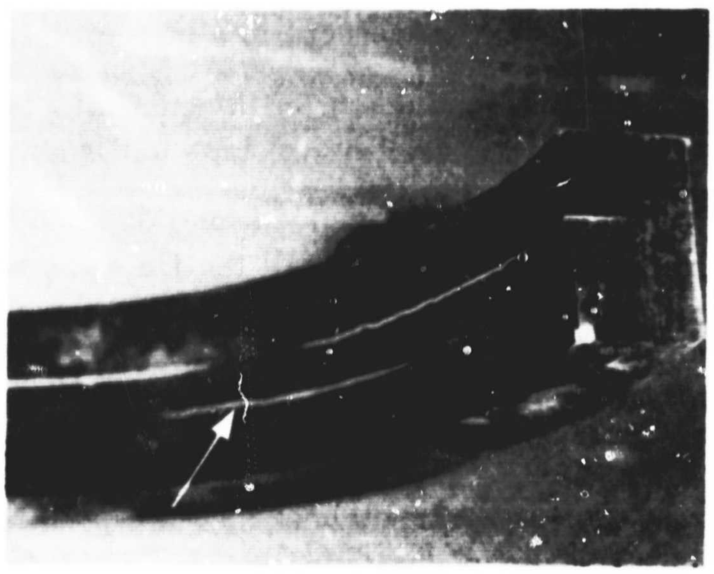
A LAMINATION IN 0.250 IN. PLATE



B LAMINATION IN 0.040 TITANIUM SHEET



C LAMINATION IN PLATE SHOWING SURFACE ORIENTATION



D LAMINATION IN 1 IN. BAR SHOWING SURFACE ORIENTATION

Figure 7-21. Lamination Discontinuity

722 LAPS AND SEAMS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Rolled Threads

3. DISCONTINUITY CHARACTERISTICS

Surface. Wavy lines, often quite deep and sometime very tight, appearing as hairline cracks. Found in rolled threads in the minor, pitch, and major diameter of the thread, and in direction of rolling. (See Figure 7-22.)

4. METALLURGICAL ANALYSIS

During the rolling operation, faulty or oversized dies or an overfill of material may cause material to be folded over and flattened into the surface of the thread but not fused.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Compatibility with both ferrous and nonferrous materials makes fluorescent liquid penetrant the first choice.

(2) Liquid penetrant indications will be circumferential, slightly curved, intermittent or continuous indications. Laps and seams may occur individually or in clusters.

(3) Foreign material may not only interfere with the penetration of the penetrant into the discontinuity but may cause an accumulation of penetrant in a nondefective area.

(4) Surface of threads may be smeared due to rolling operation, thereby sealing off laps and seams.

(5) Fluorescent and dye penetrants are not compatible. Dye penetrants tend to kill the fluorescent qualities in fluorescent penetrants.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Magnetic particle indications would generally appear the same as liquid penetrant.

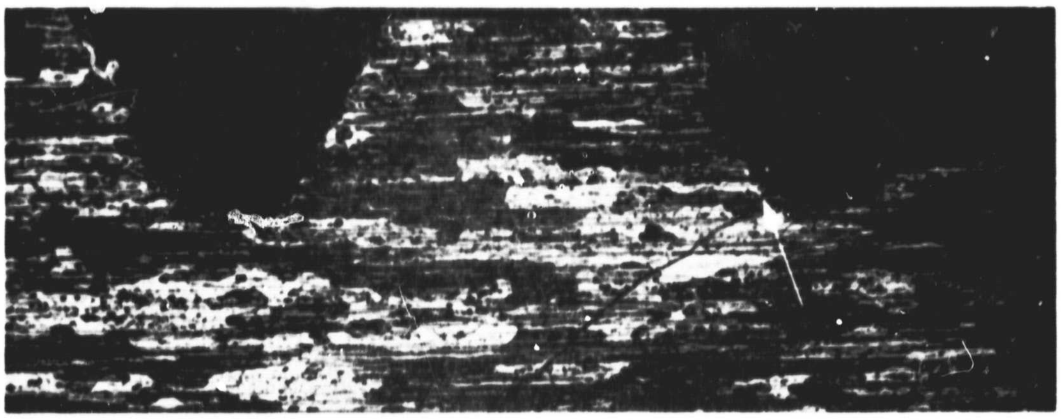
(2) Irrelevent magnetic indications may result from the thread configuration.

(3) Questionable magnetic particles indications can be verified by liquid penetrant testing.

c. **EDDY CURRENT TESTING METHOD.** Not normally used for detecting laps and seams. Article configuration is the restricting factor.

d. **ULTRASONIC TESTING METHOD.** Not recommended for detecting laps and seams. Thread configurations restrict ultrasonic capability.

e. **RADIOGRAPHIC TESTING METHOD.** Not recommended for detecting laps and seams. Size and orientation of discontinuities restricts the capability of radiographic testing.



A TYPICAL AREAS OF FAILURE LAPS AND SEAMS

B FAILURE OCCURRING AT ROOT OF THREAD

C AREAS WHERE LAPS AND SEAMS USUALLY OCCUR

Figure 7-22. Laps and Seams Discontinuity in Rolled Threads

723 LAPS AND SEAMS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

   a. Lap Surface. Wavy lines usually not very pronounced or tightly adherent since they usually enter the surface at a small angle. Laps may have surface openings smeared closed. Found in wrought forgings, plate, tubing, bar, and rod. (See Figure 7-23.)

   b. Seam Surface. Lengthy, often quite deep and sometimes very tight, usually parallel fissures with the grain and at times spiral when associated with rolled rod and tubing.

4. METALLURGICAL ANALYSIS

Seams originate from blowholes, cracks, splits, and tears introduced in earlier processing and elongated in the direction of rolling or forging. The distance between adjacent innerfaces of the discontinuity is very small.

Laps are similar to seams and may result from improper rolling, forging, or sizing operations. During the processing of the material, corners may be folded over or an overfill may exist during the sizing resulting in material being flattened into the surface but not fused. Laps may occur on any part of the article.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. MAGNETIC PARTICLE TESTING METHOD

      (1) Magnetic particle is recommended for ferrous material.

      (2) Surface and near-surface laps and seams may be detected by this method.

      (3) Laps and seams may appear as a straight, spiral, or slightly curved indication. They may be individual or clustered and continuous or intermittent.

      (4) Magnetic buildup of laps and seams is very small. Therefore, a magnetizing current greater than that used for the detection of a crack is necessary.

      (5) Correct magnetizing technique should be used when examining for forging laps since the discontinuity may lie in a plane nearly parallel to the surface.

b. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is recommended for nonferrous material.

(2) Laps and seams may be very tight and difficult to detect especially by liquid penetrant.

(3) Liquid penetrant testing of laps and seams can be improved slightly by heating the article before applying the penetrant.

c. ULTRASONIC TESTING METHOD

(1) Normally used to test wrought material prior to machining.

(2) Surface wave technique permits accurate evaluation of the depth, length, and size of laps and seams.

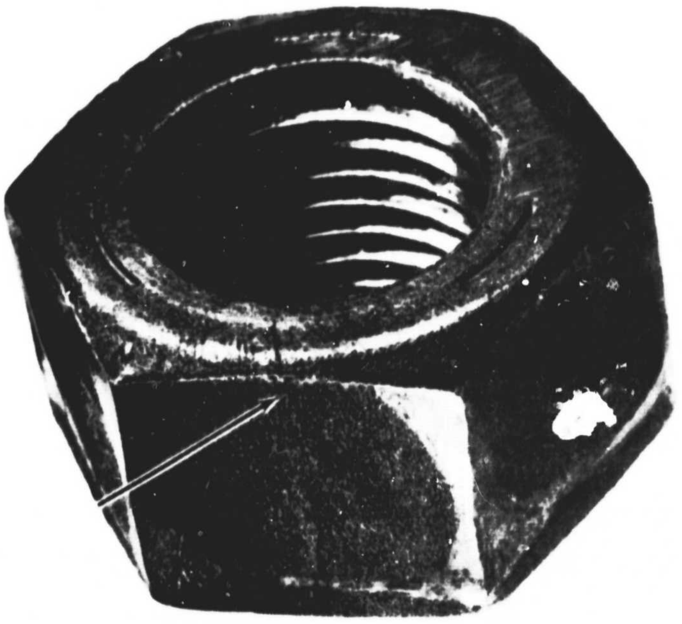
(3) Ultrasonic indication of laps and seams will appear as definite inner faces within the metal.

d. EDDY CURRENT TESTING METHOD

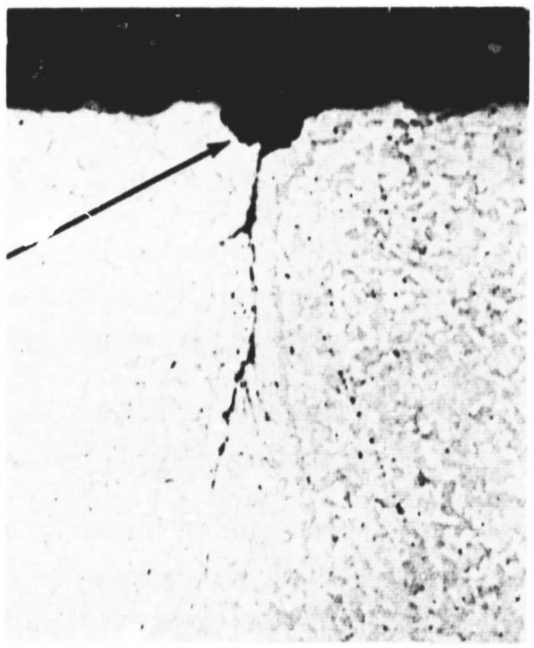
(1) Normally used for the evaluation of laps and seams in tubing and pipe.

(2) Other articles can be screened by eddy current where article configuration and size permit.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laps and seams in wrought material. Although the ratio between the discontinuity size and the material thickness exceeds 2% of sensitivity in most cases, discontinuities have a very small thickness change in the direction of the X-ray beam, thereby making radiographic detection almost impossible.



A TYPICAL FORGING LAP



B MICROGRAPH OF A LAP

Figure 7-23. Laps and Seams Discontinuity in Wrought Material

724 MICRO-SHRINKAGE

1. CATEGORY. Processing

2. MATERIAL. Magnesium Casting

3. DISCONTINUITY CHARACTERISTICS

Internal. Small filamentary voids in the grain boundaries appear as concentrated porosity in cross section. (See Figure 7-24.)

4. METALLURGICAL ANALYSIS

Shrinkage occurs while the metal is in a plastic or semi-molten state. If sufficient molten metal cannot flow into different areas as it cools, the shrinkage will leave a void. The void is identified by its appearance and by the time in the plastic range it occurs. Micro-shrinkage is caused by the withdrawal of the low melting point constituent from the grain boundaries.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Radiography is universally used to determine the acceptance level of micro-shrinkage.

(2) Micro-shrinkage will appear on the radiograph as an elongated swirl resembling feathery streaks or as dark irregular patches, which are indicative of cavities in the grain boundaries.

b. LIQUID PENETRANT TESTING METHOD

(1) Normally used on finished machined surfaces.

(2) Micro-shrinkage is not normally open to the surface. These conditions will, therefore, be detected in machined areas.

(3) The appearance of the indication depends on the plane through which the condition has been cut. The appearance varies from a continuous hairline to a massive porous indication.

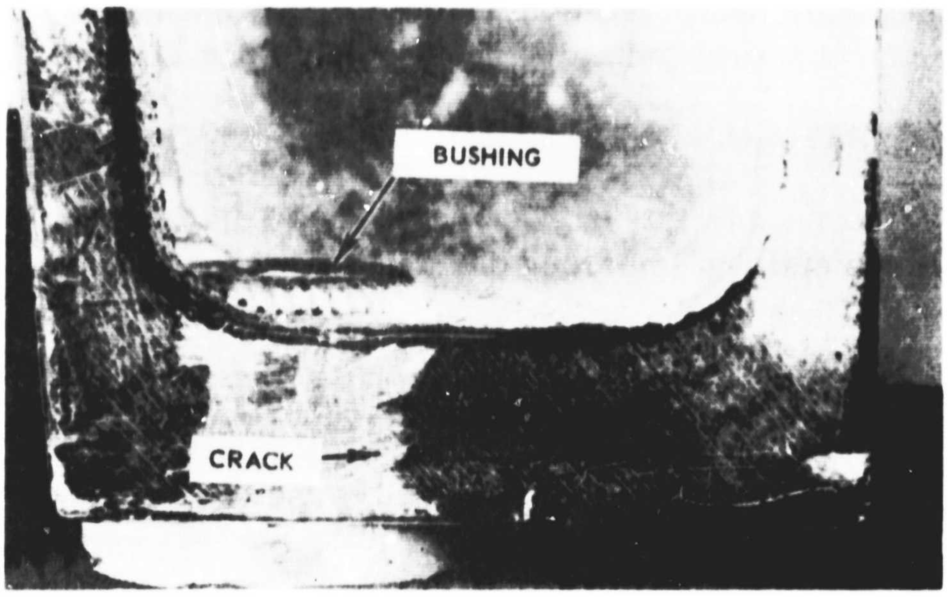
(4) Penetrant may act as a contaminant by saturating the micro porous casting affecting their ability to accept a surface treatment.

(5) Serious structural and a dimensional damage to the article can result from the improper use of acids or alkalies. They should never be used unless approval is obtained.

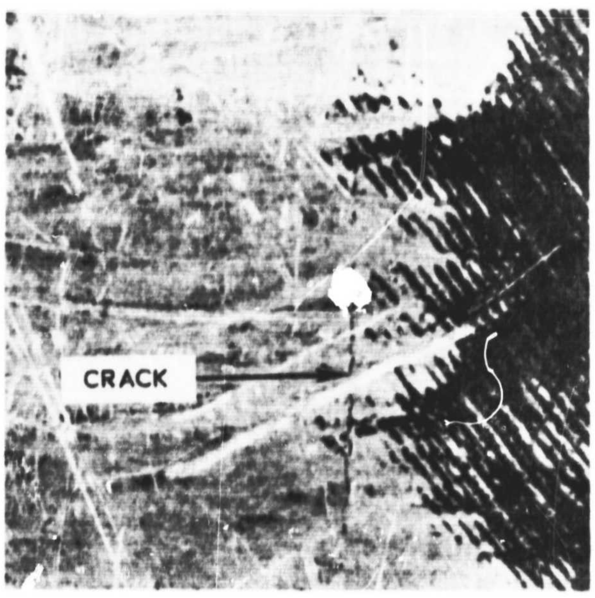
c. EDDY CURRENT TESTING METHOD. Not recommended for detecting micro-shrinkage. Article configuration and type of discontinuity do not lend themselves to eddy current.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting micro-shrinkage. Cast structure and article configuration are restricting factors.

e. MAGNETIC PARTICLE TESTING METHOD. Not applicable. Material is nonferrous.



A CRACKED MAGNESIUM HOUSING



B CLOSE-UP VIEW OF (A)

C MICROGRAPH OF CRACKED AREA

Figure 7-24. Micro-Shrinkage Discontinuity

725 GAS POROSITY

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Weldments

3. DISCONTINUITY CHARACTERISTICS

Surface or subsurface. Rounded or elongated, teardrop shaped with or without a sharp discontinuity at the point. Scattered uniformly throughout the weld or isolated in small groups. May also be concentrated at the root or toe. (See Figure 7-25.)

4. METALLURGICAL ANALYSIS

Porosity in welds is caused by gas entrapment in the molten metal, too much moisture on the base or filler metal, or improper cleaning or preheating.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHY TESTING METHOD

(1) Radiography is the most universally used NDT method for the detection of gas porosity in weldments.

(2) The radiographic image of a 'round' porosity will appear as ov l shaped spots with smooth edges, while 'elongated' porosity will appear as oval shaped spots with the major axis sometimes several times longer than the minor axis.

(3) Foreign material such as loose scale, flux, or splatter will affect validity of test results.

b. ULTRASONIC TESTING METHOD

(1) Ultrasonic testing equipment is highly sensitive, capable of detecting micro-separations. Established standards should be used if valid test results are to be obtained.

(2) Surface finish and grain size will affect the validity of the test results.

c. EDDY CURRENT TESTING METHOD

(1) Normally confined to thin wall welded pipe and tube.

(2) Penetration restricts testing to a depth of more than one-quarter inch.

d. LIQUID PENETRANT TESTING METHOD

(1) Normally confined to in-process control of ferrous and nonferrous weldments.

(2) Liquid penetrant testing, like magnetic particle, is restricted to surface evaluation.

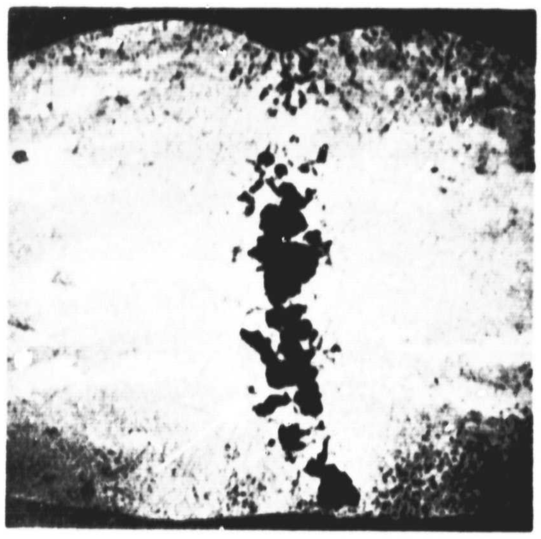
(3) Extreme caution must be exercised to prevent any cleaning material, magnetic (iron oxide), and liquid penetrant materials from becoming entrapped and contaminating the rewelding operation.

e. MAGNETIC PARTICLE TESTING METHOD

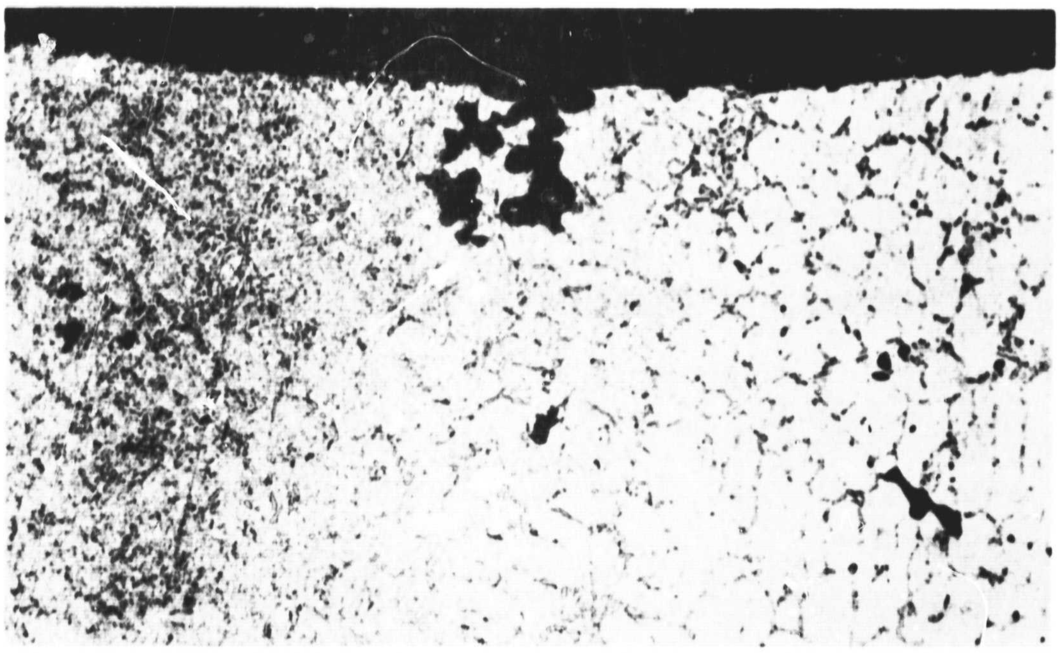
(1) Not normally used to detect gas porosity.

(2) Only surface porosity would be evident. Near surface porosity would not be clearly defined since it is neither strong or pronounced.

A TYPICAL SURFACE POROSITY



B CROSS-SECTION OF (A) SHOWING EXTENT OF POROSITY



C MICROGRAPH OF CROSS-SECTION SHOWING TYPICAL SHRINKAGE POROSITY

Figure 7-25. Gas Porosity Discontinuity

726 UNFUSED POROSITY

1. **CATEGORY.** Processing

2. **MATERIAL.** Aluminum

3. **DISCONTINUITY CHARACTERISTICS**

Internal. Wafer-thin fissures aligned parallel with the grain flow. Found in wrought aluminum which is rolled, forged, or extruded. (See Figure 7-26.)

4. **METALLURGICAL ANALYSIS**

Unfused porosity is attributed to porosity which is in the cast ingot. During the rolling, forging, or extruding operations it is flattened into wafer-thin shape. If the internal surface of these discontinuities is oxidized or is composed of a foreign material, they will not fuse during the subsequent processing, resulting in an extremely thin interface or void.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

   a. ULTRASONIC TESTING METHOD

      (1) Used extensively for the detection of unfused porosity.

      (2) Material may be tested in the wrought as received configuration.

      (3) Ultrasonic testing fixes the location of the void in all three directions.

      (4) Where the general direction of the discontinuity is unknown, it may be necessary to test from several directions.

      (5) Method of manufacture and subsequent article configuration will determine the orientation of the unfused porosity to the material surface.

   b. LIQUID PENETRANT TESTING METHOD

      (1) Normally used on nonferrous machined articles.

      (2) Unfused porosity will appear as a straight line of varying lengths running parallel with the grain. Liquid penetrant is restricted to surface evaluation.

      (3) Surface preparations such as vapor blasting, honing, or sanding may obliterate by masking the surface discontinuities, thereby restricting the reliability of liquid penetrant testing.

      (4) Excessive agitation of powder in a large container may produce foaming.

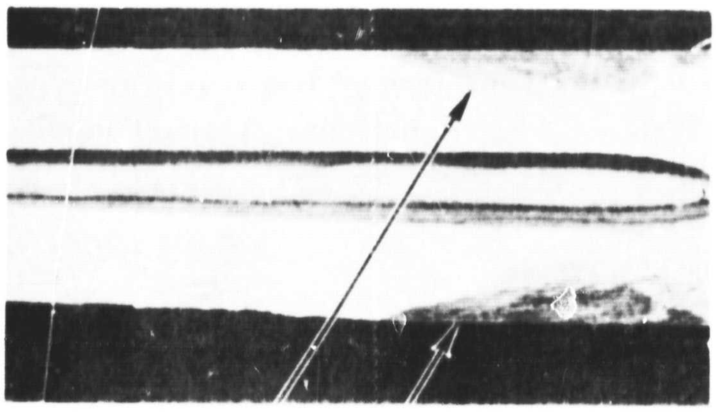
c. **EDDY CURRENT TESTING METHOD.** Not normally used for detecting unfused porosity.

d. **RADIOGRAPHIC TESTING METHOD**

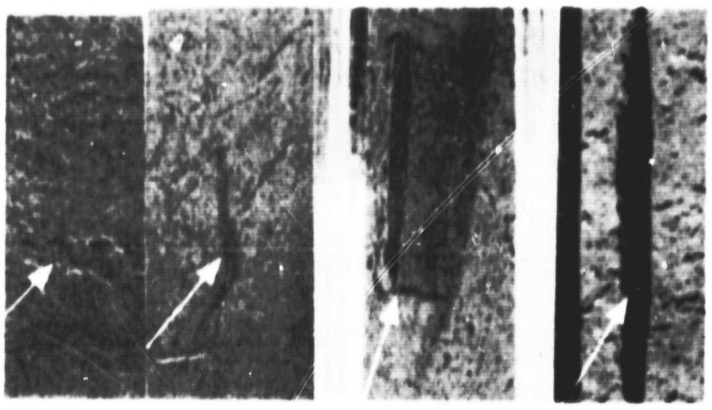
(1) Not normally used for detecting unfused porosity.

(2) Wafer-thin discontinuities are difficult to detect by a method which measures density or which requires that the discontinuity be parallel and perpendicular to the X-ray beam.

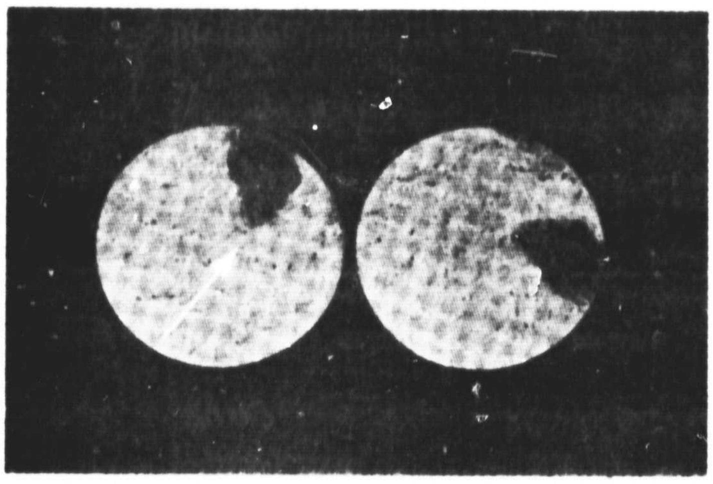
e. **MAGNETIC PARTICLE TESTING METHOD.** Not applicable. Material is nonferrous.



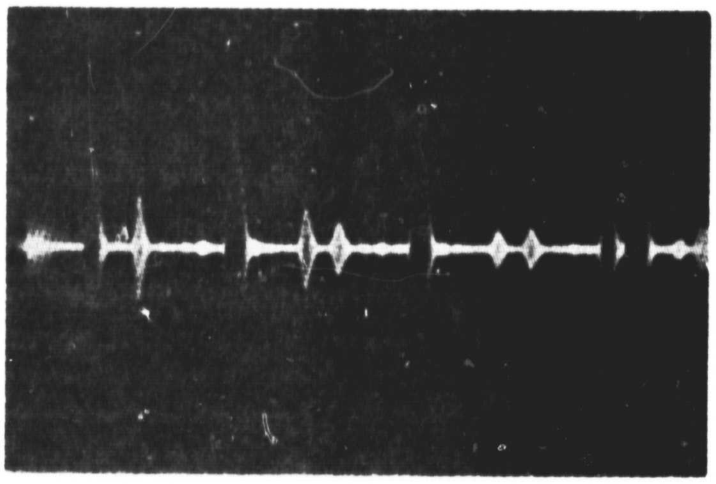
A FRACTURED SPECIMEN SHOWING UNFUSED POROSITY



B UNFUSED POROSITY EQUIVALENT TO 1/64, 3/64, 5/64 AND 8/64 (LEFT TO RIGHT)



C TYPICAL UNFUSED POROSITY



D ULTRASONIC SCOPE PATTERN OF (C)

Figure 7-26. Unfused Porosity Discontinuity

727 STRESS CORROSION

1. **CATEGORY.** Service

2. **MATERIAL.** Ferrous and Nonferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Range from shallow to very deep, and usually follow the grain flow of the material; however transverse cracks are also possible. (See Figure 7-27.)

4. **METALLURGICAL ANALYSIS**

Three factors are necessary for the phenomenon of stress corrosion to occur: 1) a sustained static tensile stress, 2) the presence of a corrosive environment, and 3) the use of a material that is susceptible to this type of failure. Stress corrosion is much more likely to occur faster at high levels of stress than at low levels of stress. The type of stresses include residual (internal) as well as those from external (applied) loading.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

a. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is normally used for the detection of stress corrosion.

(2) In the preparation, application, and final cleaning of articles, extreme care must be exercised to prevent over spraying and contamination of the surrounding articles.

(3) Chemical cleaning immediately before the application of liquid penetrant may seriously affect the test results if the solvents are not given time to evaporate.

(4) Service articles may contain moisture within the discontinuity which will dilute, contaminate, and invalid results if the moisture is not removed.

b. EDDY CURRENT TESTING METHOD

(1) Not normally used to detect stress corrosion.

(2) Eddy current equipment is capable of resolving stress corrosion where article configuration is compatible with equipment limitations.

c. ULTRASONIC TESTING METHOD

(1) Not normally used to detect stress corrosion.

(2) Discontinuities are perpendicular to surface of material and require surface technique.

d. **MAGNETIC PARTICLE TESTING METHOD**

(1) **Not normally used to detect stress corrosion.**

(2) **Configuration of article and usual nonmagnetic condition exclude magnetic particle testing.**

e. **RADIOGRAPHIC TESTING METHOD**

(1) **Not normally used to detect stress corrosion.**

(2) **Surface indications are best detected by NDT method designed for such application. However, radiography can and has shown stress corrosion with the use of the proper technique.**

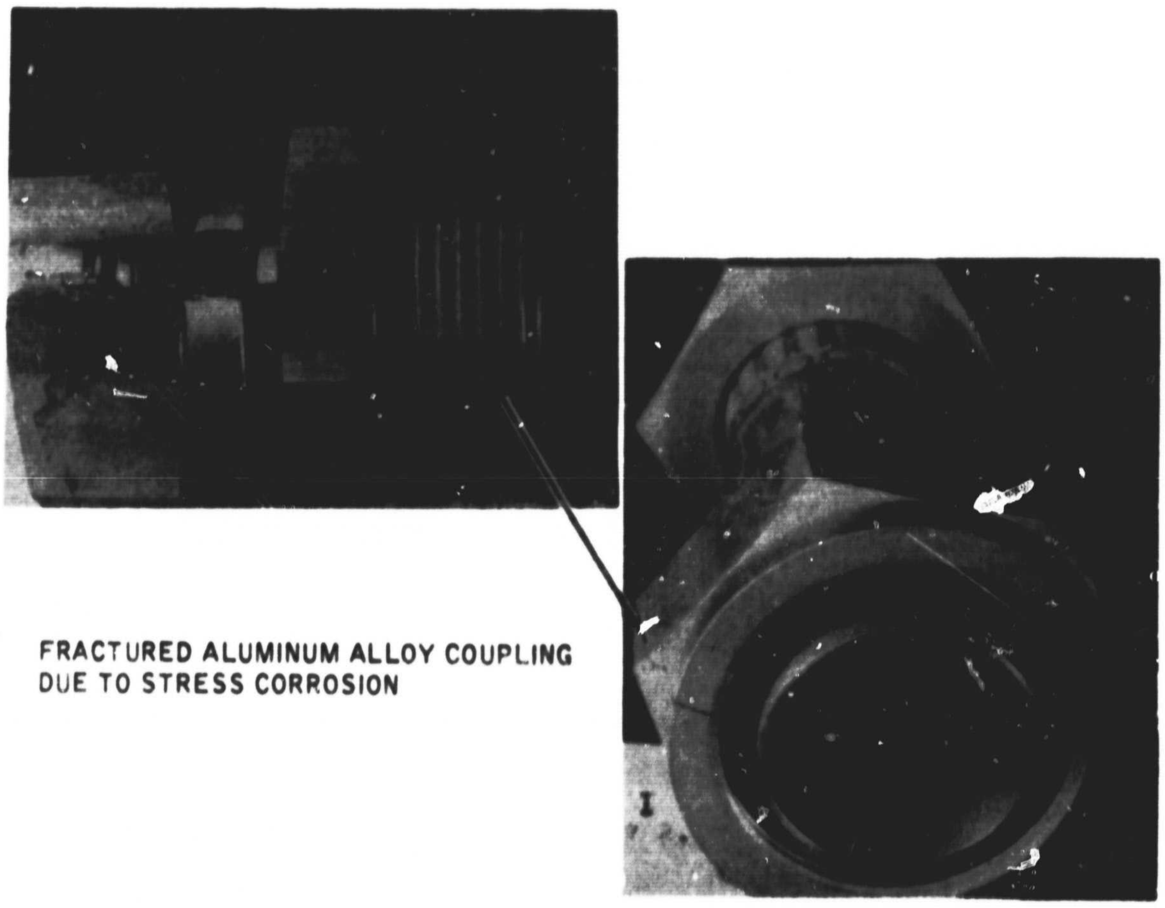


Figure 7-27. Stress Corrosion Discontinuity

728 HYDRAULIC TUBING

1. CATEGORY. Processing and Service

2. MATERIAL. Aluminum 6061-T6

3. DISCONTINUITY CHARACTERISTICS

Surface and internal. Range in size from short to long, shallow to very tight and deep. Usually they will be found in the direction of the grain flow with the exception of stress corrosion, which has no direction. (See Figure 7-28.)

4. METALLURGICAL ANALYSIS

Hydraulic tubing discontinuities are usually one of the following:

a. Foreign material coming in contact with the tube material and being embedded into the surface of the tube.

b. Laps which are the result of material being folded over and not fused.

c. Seams which originate from blowholes, cracks, splits and tears introduced in the eariler processing, and then are elongated during rolling.

d. Intergranular corrosion which is due to the presence of a corrosive environment.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. EDDY CURRENT TESTING METHOD

(1) Universally used for testing of nonferrous tubing.

(2) Heavier walled tubing (0.250 and above) may not be successfully tested due to the penetration ability of the equipment.

(3) The specific nature of various discontinuities may not be clearly defined.

(4) Test results may not be valid unless controlled by known standards.

(5) Testing of ferro-magnetic material may be difficult.

(6) All material should be free of any foreign material that would invalid the test results.

b. LIQUID PENETRANT TESTING METHOD

(1) Not normally used for detecting tubing discontinuities.

(2) Eddy current is more economical, faster, and with established standards is more reliable.

c. ULTRASONIC TESTING METHOD

(1) Not normally used for detecting tubing discontinuities.

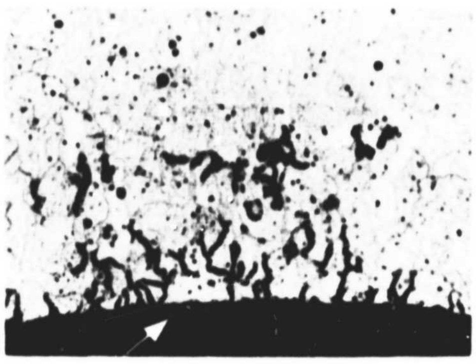
(2) Eddy current is recommended over ultrasonic testing since it is faster and more economical for this range of surface discontinuity and non-ferrous material.

d. RADIOGRAPHIC TESTING METHOD

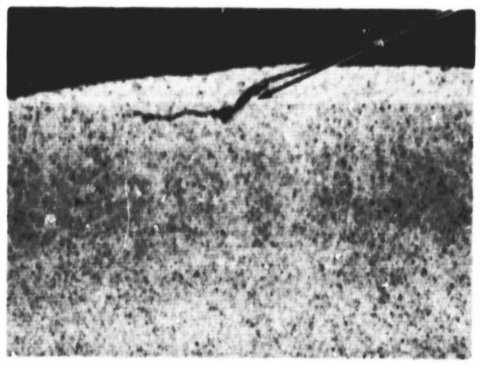
(1) Not normally used for detecting tubing discontinuities.

(2) The size and type of discontinuity and the configuration of the article limit the use of radiography for screening of material for this group of discontinuities.

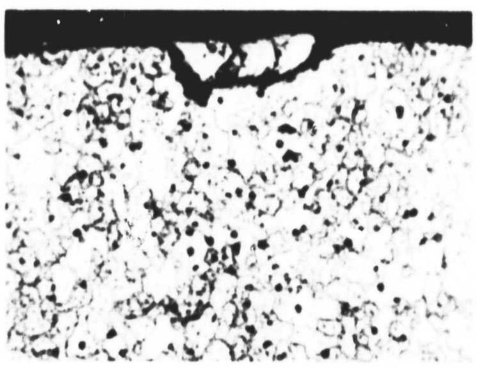
e. MAGNETIC PARTICLES TESTING METHOD. Not applicable. Material is nonferrous.



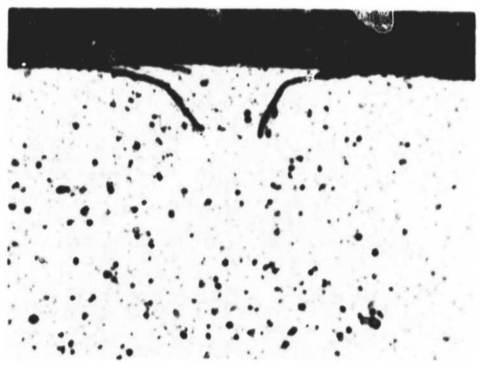
A INTERGRANULAR CORROSION



B LAP IN OUTER SURFACE OF TUBING



C EMBEDDED FOREIGN MATERIAL



D TWIN LAPS IN OUTER SURFACE OF TUBING

Figure 7-28. Hydraulic Tubing Discontinuity

729 MANDREL DRAG

1. CATEGORY. Processing

2. MATERIAL. Nonferrous Thick-Wall Seamless Tubing

3. DISCONTINUITY CHARACTERISTICS

Internal surface of thick-wall tubing. Range from shallow even gouges to ragged tears. Often a slug of the material will be embedded within the gouged area. (See Figure 7-29.)

4. METALLURGICAL ANALYSIS

During the manufacture of thick-wall seamless tubing, the billet is ruptured as it passes through the offset rolls. As the piercing mandrel follows this fracture, a portion of the material may break loose and be forced over the mandrel. As it does the surface of the tubing may be scored or have the slug embedded into the wall. Certain types of material are more prone to this type of failure than others.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. EDDY CURRENT TESTING METHOD

(1) Normally used for the testing of thin-wall pipe or tube.

(2) Eddy current testing may be confined to nonferrous materials.

(3) Discontinuities are qualitative, not quantative indications.

(4) Several factors simultaneously affect output indications.

b. ULTRASONIC TESTING METHOD

(1) Normally used for the screening of thick-wall pipe or tube for mandrel drag.

(2) Can be used to test both ferrous and nonferrous pipe or tube.

(3) Requires access from one side only.

(4) May be used in support of production line since it is adaptable for automatic instrumentation.

(5) Configuration of mandrel drag or tear will produce very sharp and noticeable indications on the scope.

c. RADIOGRAPHIC TESTING METHOD

(1) Not normally used although it has been instrumental in the detection of mandrel drag during examination of adjacent welds.

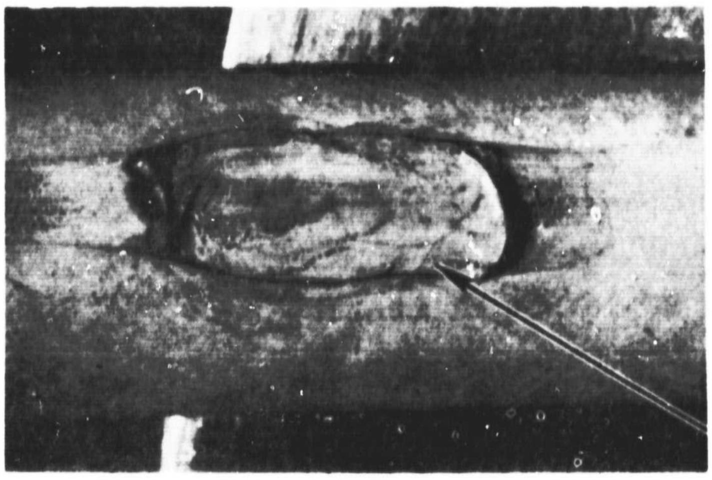
(2) Complete coverage requires several exposures around the circumference of the tube.

(3) This method is not designed for production support since it is very slow and costly for large volumes of pipe or tube.

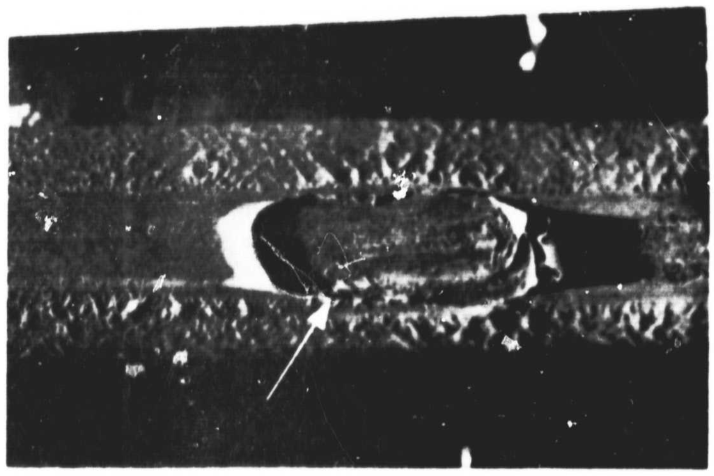
(4) Radiograph will disclose only two dimensions and not the third.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting mandrel drag since discontinuity is internal and would not be detectable.

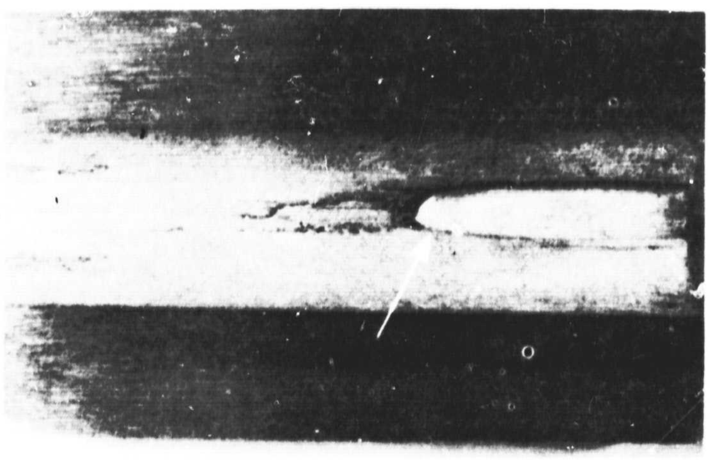
e. MAGNETIC PARTICLE TESTING METHOD. Not recommended for detecting mandrel drag. Discontinuities are not close enough to the surface to be detectable by magnetic particles. Most mandrel drag will occur in seamless stainless steel.



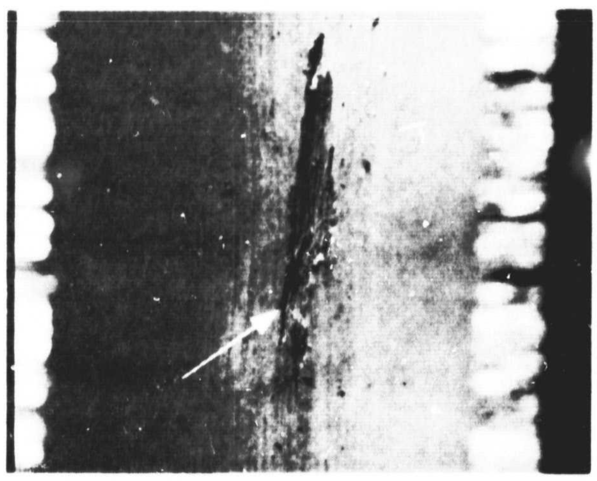
A EMBEDDED SLUG SHOWING DEEP GOUGE MARKS



B SLUG BROKEN LOOSE FROM TUBING WALL



C ANOTHER TYPE OF EMBEDDED SLUG



D GOUGE ON INNER SURFACE OF PIPE

Figure 7-29. Mandrel Drag Discontinuity

730 SEMICONDUCTORS

1. CATEGORY. Processing and Service

2. MATERIAL. Hardware

3. DISCONTINUITY CHARACTERISTICS

Internal. Appear in many sizes and shapes and various degrees of density. They may be misformed, aligned, damaged, or broken internal hardware. Found in transistors, diodes, resistors, and capacitors. (See Figure 7-30.)

4. METALLURGICAL ANALYSIS

Semiconductor discontinuities such as loose wire, weld splash, flakes, solder balls, loose leads, inadequate clearance between internal elements and case, and inclusions or voids in seals or around lead connections are the product of processing errors.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Universally used as the NDT method for the detection of discontinuities in semiconductors.

(2) The configuration and internal structure of the various semiconductors limit the NDT method to radiography.

(3) Semiconductors that have copper heat sinks may require more than one technique due to the density of the copper.

(4) Internal wires in semiconductors are very fine and may be constructed from materials of different density such as copper, silver, gold and aluminum. If the latter is used with the others, special techniques may be needed to resolve its reliability.

(5) Micro-particles may require the highest sensitivity to resolve.

(6) The complexity of the internal structure of semiconductors may require additional views to exclude the possibility of non-detection of discontinuities due to masking by hardware.

(7) Positive positioning of each semiconductor will prevent invalid interpretation.

(8) Source angle should give minimum distortion.

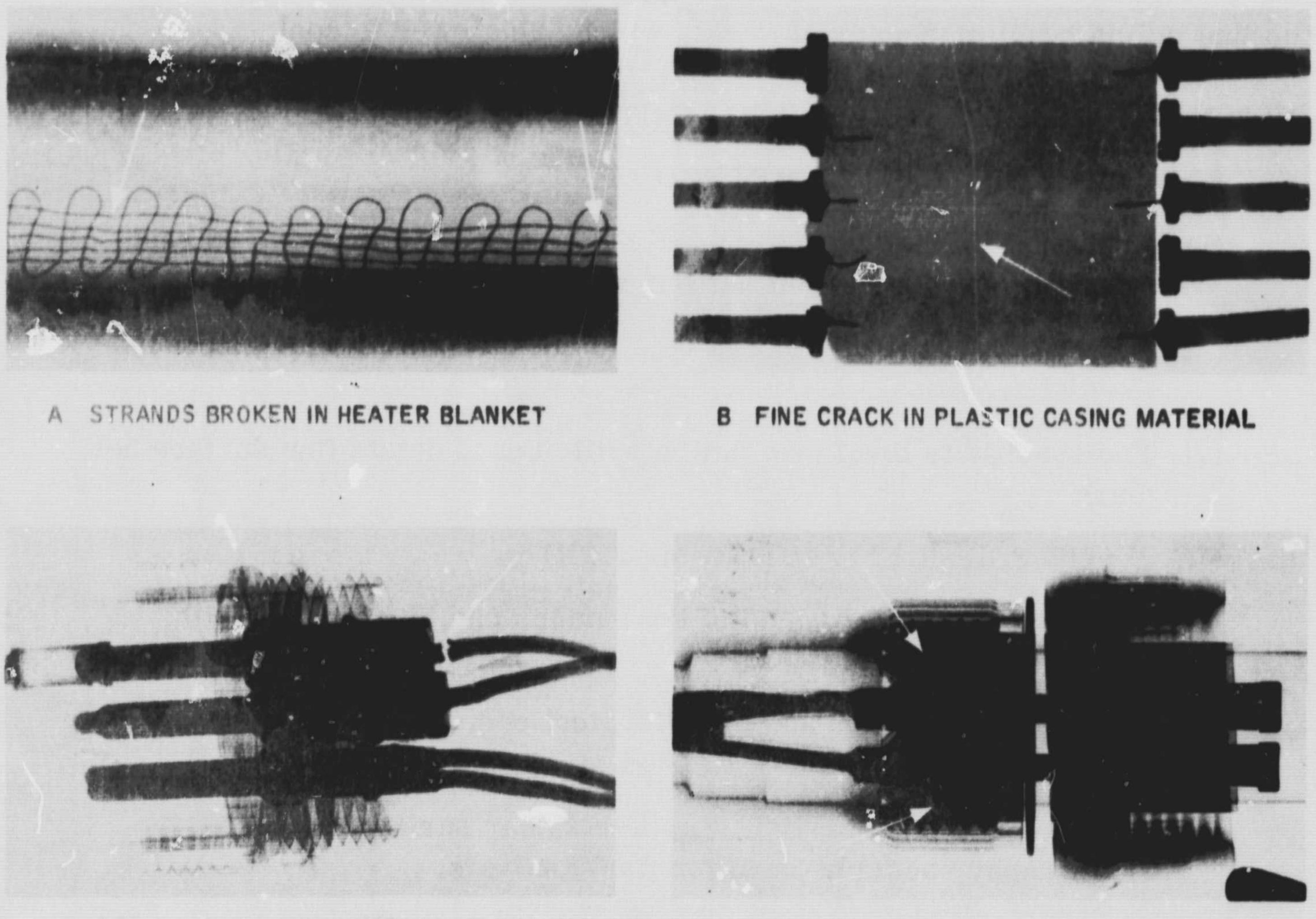
(9) Preliminary examination of semiconductors may be accomplished using a vidcon system that would allow visual observation during 360 degree rotation of the article.

b. **EDDY CURRENT TESTING METHOD. Not recommended for detecting semiconductor discontinuities. Nature of discontinuity and method of construction of the article do not lend themselves to this form of NDT.**

c. **MAGNETIC PARTICLE TESTING METHOD. Not recommended for detecting semiconductor discontinuities.**

d. **LIQUID PENETRANT TESTING METHOD. Not recommended for detecting semiconductor discontinuities.**

e. **ULTRASONIC TESTING METHOD. Not recommended for detecting semiconductor discontinuities.**



A STRANDS BROKEN IN HEATER BLANKET

B FINE CRACK IN PLASTIC CASING MATERIAL

C BROKEN ELECTRICAL CABLE

D FOREIGN MATERIAL WITHIN SEMICONDUCTOR

Figure 7-30. Semiconductor Discontinuity

731 HOT TEARS

1. **CATEGORY.** Inherent

2. **MATERIAL.** Ferrous Castings

3. **DISCONTINUITY CHARACTERISTICS**

Internal or near surface. Appear as ragged line of variable width and numerous branches. Occur singly or in groups. (See Figure 7-31.)

4. **METALLURGICAL ANALYSIS**

Hot cracks (tears) are caused by non-uniform cooling resulting in stresses which rupture the surface of the metal while its temperature is still in the brittle range. Tears may originate where stresses are set up by the more rapid cooling of thin sections that adjoin heavier masses of metal, which are slower to cool.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

a. RADIOGRAPHIC TESTING METHOD

(1) Radiographic testing is the first choice since the material is cast structure and the discontinuities may be internal and surface.

(2) Orientation of the hot tear in relation to the source may influence the test results.

(3) The sensitivity level may not be sufficient to detect fine surface hot tears.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Hot tears that are exposed to the surface can be screened with magnetic particle method.

(2) Article configuration and metallurgical composition may make demagnization difficult.

(3) Although magnetic particle can detect near surface hot tears, radiography should be used for final analysis.

(4) Foreign material not removed prior to testing will cause an invalid test.

c. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is recommended for nonferrous cast material.

(2) Liquid penetrant is confined to surface evaluation.

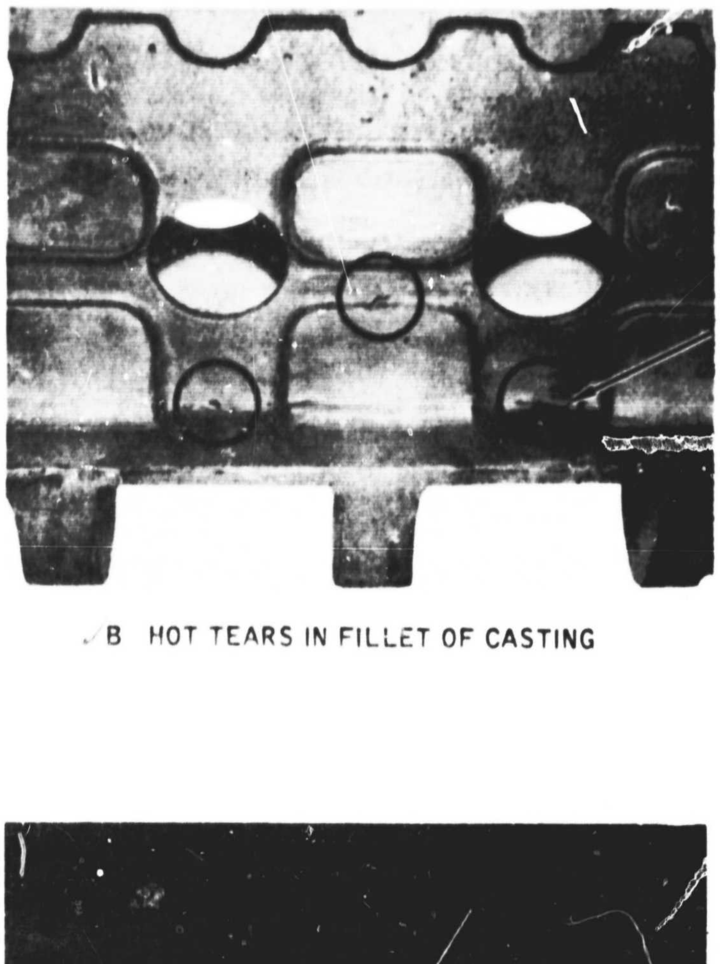
(3) The use of penetrants on castings may act as a contaminant by saturating the porous structure and affect the ability to apply surface finish.

(4) Repeatability of indications may be poor after a long period of time.

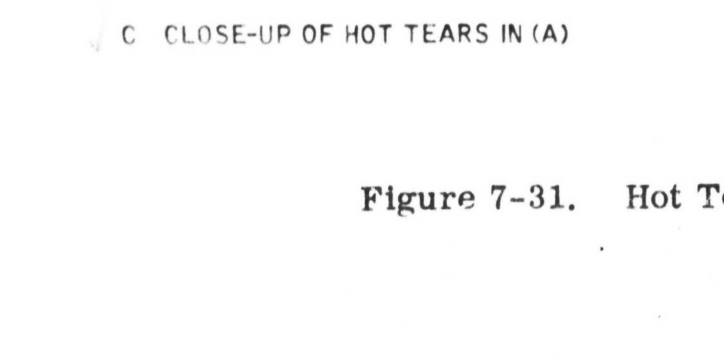
d. **ULTRASONIC TESTING METHOD.** Not recommended for detecting hot tears. Discontinuities of this type when associated with cast structure do not lend themselves to ultrasonic testing.

e. **EDDY CURRENT TESTING METHOD.** Not recommended for detecting hot tears. Metallurgical structure along with the complex configurations do not lend themselves to eddy current testing.

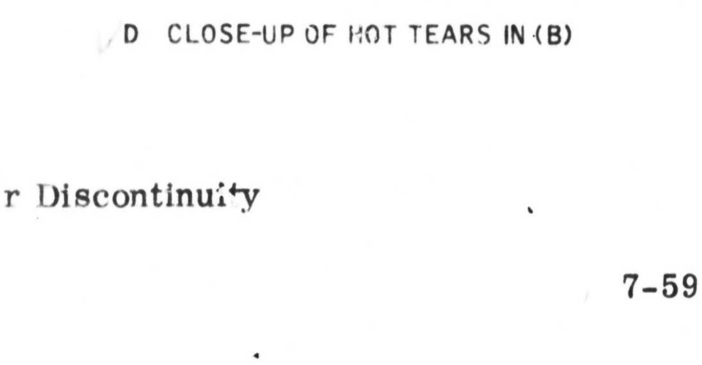
A TYPICAL HOT TEARS IN CASTING



B HOT TEARS IN FILLET OF CASTING



C CLOSE-UP OF HOT TEARS IN (A)



D CLOSE-UP OF HOT TEARS IN (B)

Figure 7-31. Hot Tear Discontinuity

732 INTERGRANULAR CORROSION

1. CATEGORY. Service

2. MATERIAL. Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface or internal. A series of small micro-openings with no definite pattern. May appear singly or in groups. The insidious nature of intergranular corrosion results from the fact that very little corrosion or corrosion product is visible on the surface. Intergranular corrosion may extend in any direction following the grain boundaries of the material. (See Figure 7-32.)

4. METALLURGICAL ANALYSIS

Two factors that contribute to intergranular corrosion are:

a. Metallurgical structure of the material that is prone to intergranular corrosion such as unstabilized 300 series stainless steel.

b. Improper stress relieving or heat treat may create the susceptibility to intergranular corrosion. Either of these conditions coupled with a corrosive atmosphere will result in intergranular attack.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is the first choice due to the size and location of this type of discontinuity.

(2) Chemical cleaning operations immediately before the application of liquid penetrant may contaminate the article and seriously affect the test results.

(3) Cleaning in solvents may release chlorine and accelerate intergranular corrosion.

(4) Trapped penetrant solution may present a cleaning or removal problem.

b. RADIOGRAPHIC TESTING METHOD

(1) Intergranular corrosion in the more advanced stages has been detected with radiography.

(2) Sensitivity levels may prevent the detection of fine intergranular corrosion.

(3) Radiography may not determine on which surface the intergranular corrosion will occur.

c. EDDY CURRENT TESTING METHOD

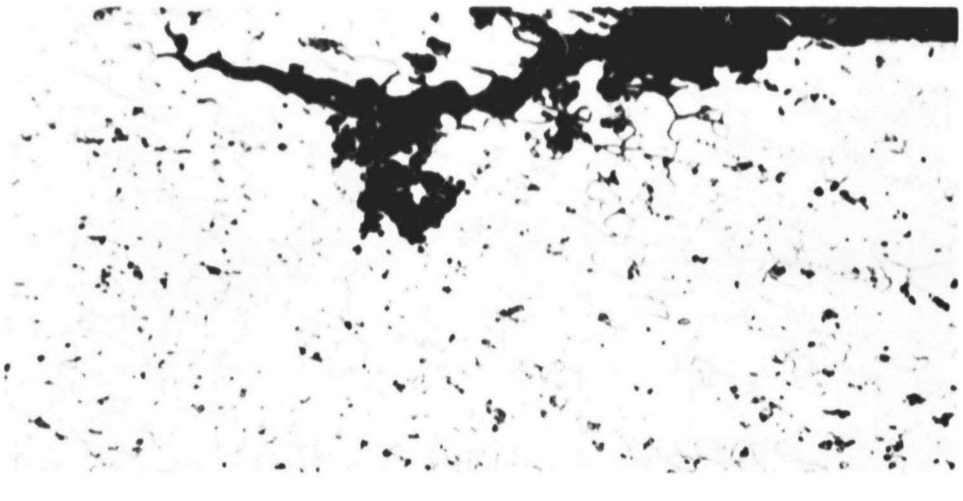
(1) Eddy current can be used for the screening of intergranular corrosion.

(2) Tube or pipe lend themselves readily to this method of NDT testing.

(3) Metallurgical structure of the material may seriously affect the output indications.

d. ULTRASONIC TESTING METHOD. Not normally used although the equipment has the capability to detect intergranular corrosion.

e. MAGNETIC PARTICLES TESTING METHOD. Not recommended for detecting intergranular corrosion. Type of discontinuity and material restrict the use of magnetic particles.



A MICROGRAPH OF INTERGRANULAR CORROSION SHOWING LIFTING OF SURFACE FROM SUBSURFACE CORROSION

B MICROGRAPH SHOWING NATURE OF INTERGRANULAR CORROSION. ONLY MINOR EVIDENCE OF CORROSION IS EVIDENT FROM SURFACE

Figure 7-32. Intergranular Corrosion Discontinuity

CHAPTER 8: SAFETY PRECAUTIONS
TABLE OF CONTENTS

CHAPTER 8: SAFETY PRECAUTIONS

800 GENERAL

Liquid penetrant testing uses a variety of materials that have distressing and often hazardous characteristics. Except for water, the liquids used are usually flammable and some, upon contact, can cause skin irritation. The developing powders used are non toxic but, in confined spaces, can become a health hazard. The black lights used with fluorescent penetrants are in the ultra-violet spectrum of light rays that can cause physiological damage (sunburn, etc.). All of these hazards can be avoided or minimized by observing the precautionary measures mentioned in the following paragraphs.

801 FIRE

Flashpoint is the lowest temperature at which vapors above a volatile combustible substance ignite in air when exposed to flame. Some penetrant materials have very low flashpoints and their use is avoided. The higher the flashpoint of a material the less fire hazard it presents. Safe practice requires that penetrant materials used in open tanks have a flashpoint of greater than 120° F. Because most penetrant materials burn readily, smoking is forbidden in or near test areas. Penetrant materials are never stored near heat or open flame, and exhaust fans are used to disperse vapors.

802 SKIN IRRITATION

The oil base of liquid penetrant materials has a drying action on the skin. Because of this, the materials may cause unpleasant, if not dangerous, irritations. To prevent unnecessary contact with penetrant materials care is taken to avoid splashing; protective hand creams are used; aprons and neoprene gloves are worn; and soap and water are used to immediately remove any penetrant materials that have come in contact with the skin.

803 AIR POLLUTION

The developing powders used in penetrant testing are non-toxic but inhalation of excessive amounts can be a health hazard. To avoid unhealthful concentrations of powder in the atmosphere, exhaust fans are installed in confined areas where dry developers are used. Fans are also used to remove the vapors from liquid penetrant materials out of the test area.

804 BLACK LIGHT

The black light used to cause fluorescence of penetrant materials has a frequency of approximately 3650 angstroms. This frequency is at the lower end of the ultra-violet frequency spectrum, the least harmful portion of the spectrum. The higher frequency ultra-violet rays are harmful to many forms of life including humans since they cause sunburn and are injurious to the eyes. The filters used with penetrant test black lights filter out the harmful ultra-violet rays generated by the mercury arc lamp as well as the visible light rays. Cracked, chipped, or broken filters are to be replaced prior to use of the light.