ASTM INTERNATIONAL

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Standard Guide for
Examination and Evaluation of Pitting Corrosion[1]

1. Scope

1.1 This guide covers the selection of procedures that can be used in the identification and examination of pits and in the evaluation of pitting (See Terminology G15) corrosion to determine the extent of its effect.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate* ~~safety~~ *safety, health, and* ~~health~~*environmental practices and determine the applicability of regulatory limitations prior to use.*

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
E3 Guide for Preparation of Metallographic Specimens
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]
G16 Guide for Applying Statistics to Analysis of Corrosion Data
2.2 *National Association of Corrosion Engineers Standard:*
NACE RP-01-73 Collection and Identification of Corrosion Products[4]

3. Significance and Use

3.1 It is important to be able to determine the extent of pitting, either in a service application where it is necessary to predict the remaining life in a metal structure, or in laboratory test programs that are used to select the most pitting-resistant materials for service.

4. Identification and Examination of Pits

4.1 *Visual Inspection*—A visual examination of the corroded metal surface is usually beneficial, and this is done under ordinary light, with or without the use of a low-power magnifying glass, to determine the extent of corrosion and the apparent location of pits. It is often advisable to photograph the corroded surface at this point so that it can be compared with the clean surface after the removal of corrosion products.

4.1.1 If the metal specimen has been exposed to an unknown environment, the composition of the corrosion products may be of value in determining the cause of corrosion. Follow recommended procedures in the removal of particulate corrosion products and reserve them for future identification (see NACE RP-01-73).

4.1.2 To expose the pits fully, use recommended cleaning procedures to remove the corrosion products and avoid solutions that attack the base metal excessively (see Practice G1). It may be advisable during cleaning to probe the pits with a pointed tool to determine the extent of undercutting or subsurface corrosion (Fig. 1). However, scrubbing with a stiff bristle brush will often enlarge the pit openings sufficiently by removal of corrosion products, or undercut metal to make the pits easier to evaluate.

(a) Narrow, Deep   (b) Elliptical   (c) Wide, Shallow

(d) Subsurface   (e) Undercutting
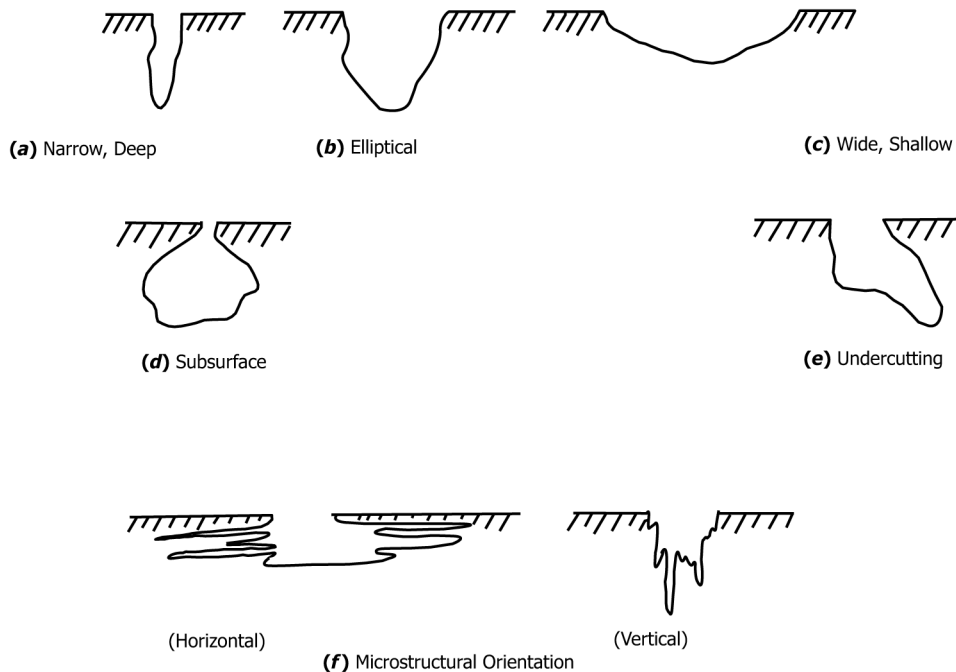
(Horizontal)   (Vertical)

(f) Microstructural Orientation

FIG. 1 Variations in the Cross-Sectional Shape of Pits

4.1.3 Examine the cleaned metal surface under ordinary light to determine the approximate size and distribution of pits. Follow this procedure by a more detailed examination through a microscope using low magnification (20×).

4.1.4 Determine the size, shape, and density of pits.

4.1.4.1 Pits may have various sizes and shapes. A visual examination of the metal surface may show a round, elongated, or irregular opening, but it seldom provides an accurate indication of corrosion beneath the surface. Thus, it is often necessary to cross section the pit to see its actual shape and to determine its true depth. Several variations in the cross-sectioned shape of pits are shown in Fig. 1.

4.1.4.2 It is a tedious job to determine pit density by counting pits through a microscope eyepiece, but the task can be made easier by the use of a plastic grid. Place the grid, containing 3 to 6-mm squares, on the metal surface. Count and record the number of pits in each square, and move across the grid in a systematic manner until all the surface has been covered. This approach minimizes eyestrain because the eyes can be taken from the field of view without fear of losing the area of interest.

4.1.5 *Metallographic Examination*—Select and cut out a representative portion of the metal surface containing the pits and prepare a metallographic specimen in accordance with the recommended procedures given in Methods E3. Examine microscopically to determine whether there is a relation between pits and inclusions or microstructure, or whether the cavities are true pits or might have resulted from metal dropout caused by intergranular corrosion, dealloying, and so forth.

4.2 *Nondestructive Inspection*—A number of techniques have been developed to assist in the detection of cracks or cavities in a metal surface without destroying the material (**1**).[5] These methods are less effective for locating and defining the shape of pits than some of those previously discussed, but they merit consideration because they are often used in situ, and thus are more applicable to field applications.

4.2.1 *Radiographic*—Radiation, such as X rays, are passed through the object. The intensity of the emergent rays varies with the thickness of the material. Imperfections may be detected if they cause a change in the absorption of X rays. Detectors or films are used to provide an image of interior imperfections. The metal thickness that can be inspected is dependent on the available energy output. Pores or pits must be as large as ½ % of the metal thickness to be detected. This technique has only slight application to pitting detection, but it might be a useful means to compare specimens before and after corrosion to determine whether pitting has occurred and whether it is associated with previous porosity. It may also be useful to determine the extent of subsurface and undercutting pitting (Fig. 1).

4.2.2 *Electromagnetic:*

4.2.2.1 Eddy currents can be used to detect defects or irregularities in the structure of electrically conducting materials. When a specimen is exposed to a varying magnetic field, produced by connecting an alternating current to a coil, eddy currents are

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[5] The boldface numbers in parentheses refer to the list of references at the end of this practice.

induced in the specimen, and they in turn produce a magnetic field of their own. Materials with defects will produce a magnetic field that is different from that of a reference material without defects, and an appropriate detection instrument is required to determine these differences.

4.2.2.2 The induction of a magnetic field in ferromagnetic materials is another approach that is used. Discontinuities that are transverse to the direction of the magnetic field cause a leakage field to form above the surface of the part. Ferromagnetic particles are placed on the surface to detect the leakage field and to outline the size and shape of the discontinuities. Rather small imperfections can be detected by this method. However, the method is limited by the required directionality of defects to the magnetic field, by the possible need for demagnetization of the material, and by the limited shape of parts that can be examined.

4.2.3 *Sonics:*

4.2.3.1 In the use of ultrasonics, pulses of sound energy are transmitted through a couplant, such as oil or water, onto the metal surface where waves are generated. The reflected echoes are converted to electrical signals that can be interpreted to show the location of flaws or pits. Both contact and immersion methods are used. The test has good sensitivity and provides instantaneous information about the size and location of flaws. However, reference standards are required for comparison, and training is needed to interpret the results properly.

4.2.3.2 An alternative approach is to use acoustic emissions in detecting flaws in metals. Imperfections, such as pits, generate high-frequency emissions under thermal or mechanical stress. The frequency of emission and the number of occurrences per unit time determine the presence of defects.

4.2.4 *Penetrants*—Defects opening to the surface can be detected by the application of a penetrating liquid that subsequently exudes from the surface after the excess penetrant has been removed. Defects are located by spraying the surface with a developer that reacts with a dye in the penetrant, or the penetrant may contain a fluorescent material that is viewed under black light. The size of the defect is shown by the intensity of the color and the rate of bleed-out. This technique provides only an approximation of the depth and size of pits.

4.2.5 None of these nondestructive test methods provide satisfactory detailed information about pitting. They can be used to locate pits and to provide some information about the size of pits, but they generally are not able to detect small pits, and confusion may arise in attempting to differentiate between pits and other surface blemishes. Most of these methods were developed to detect cracks or flaws in metals, but with more refined development they may become more applicable to pitting measurements.

5. Extent of Pitting

5.1 *Mass Loss*—Metal mass loss is not ordinarily recommended for use as a measure of the extent of pitting unless general corrosion is slight and pitting is fairly severe. If uniform corrosion is significant, the contribution of pitting to total metal loss is small, and pitting damage cannot be determined accurately from mass loss. In any case, mass loss can only provide information about total metal loss due to pitting but nothing about depth of penetration. However, mass loss should not be neglected in every case because it may be of value; for example, mass loss along with a visual comparison of pitted surfaces may be adequate to evaluate the pitting resistance of alloys in laboratory tests.

5.2 *Pit Depth Measurement:*

5.2.1 *Metallographic*—Pit depth can be determined by sectioning vertically through a pre-selected pit, mounting the cross-sectioned pit metallographically, and polishing the surface. The depth of the pit is measured on the flat, polished surface by the use of a microscope with a calibrated eyepiece. The method is very accurate, but it requires good judgment in the selection of the pit and good technique in cutting through the pit. Its limitations are that it is time consuming, the deepest pit may not have been selected, and the pit may not have been sectioned at the deepest point of penetration.

5.2.2 *Machining* (**2, 3**):

5.2.2.1 This method requires a sample that is fairly regular in shape, and it involves the destruction of the specimen. Measure the thickness of the specimen between two areas that have not been affected by general corrosion. Select a portion of the surface on one side of the specimen that is relatively unaffected; then machine the opposite surface where the pits are located on a precision lathe, grinder, or mill until all signs of corrosion have disappeared. (Some difficulty from galling and smearing may be encountered with soft metals, and pits may be obliterated.) Measure the thickness of the specimen between the unaffected surface and subtract from the original thickness to give the maximum depth of pitting. Repeat this procedure on the unmachined surface unless the thickness has been reduced by 50% 50 % or more during the machining of the first side.

5.2.2.2 This method is equally suitable for determining the number of pits with specific depths. Count the visible pits; then machine away the surface of the metal in measured stages and count the number of visible pits remaining at each stage. Subtract the number of pits at each stage from the count at the previous stage to obtain the number of pits at each depth of cut.

5.2.3 *Micrometer or Depth Gage:*

5.2.3.1 This method is based on the use of a pointed needle attached to a micrometer or calibrated depth gage to penetrate the pit cavity. Zero the instrument on an unaffected area at the lip of the pit. Insert the needle in the pit until it reaches the base where a new measurement is taken. The distance traveled by the needle is the depth of the pit. It is best to use constant-tension instruments to minimize metal penetration at the base of the pit. It can be advantageous to use a stereomicroscope in conjunction with this

technique so that the pit can be magnified to ensure that the needle point is at the bottom of the pit. The method is limited to pits that have a sufficiently large opening to accommodate the needle without obstruction; this eliminates those pits where undercutting or directional orientation has occurred.

5.2.3.2 In a variation of this method, attach the probe to a spherometer and connect through a microammeter and battery to the specimen (3, 4). When the probe touches the bottom of the pit, it completes the electrical circuit, and the probe movement is a measurement of pit depth. This method is limited to very regularly shaped pits because contact with the side of the pit would give a false reading.

5.2.4 *Microscopical*—This method is particularly valuable when pits are too narrow or difficult to penetrate with a probe type of instrument. The method is amenable to use as long as light can be focused on the base of the pit, which would not be possible in the case of example (*e*) in Fig. 1.

5.2.4.1 Use a metallurgical microscope with a magnification range from 50 to 500× and a calibrated fine-focus knob (for example, 1 division = 0.001 mm). If the latter is not available, a dial micrometer can be attached to the microscope in such a way that it will show movement of the stage relative to the microscope body.

5.2.4.2 Locate a single pit on the metal surface and center under the objective lens of the microscope at low magnification (for example, 50×). Increase the objective lens magnification until the pit area covers most of the field under view. Focus the specimen surface at the lip of the pit, using first the coarse and then the fine-focusing knobs of the microscope. Record the initial reading from the fine-focusing knob. Refocus on the bottom of the pit with the fine-focusing knob and record the reading. The difference between the initial and the final readings on the fine-focusing knob is the pit depth.

5.2.4.3 Repeat the steps in 5.2.4.2 to obtain additional measurements or until satisfactory duplication has been obtained. The repeatability of pit depth measurements on a single pit at four magnifications is shown in Annex A1.

5.2.4.4 A variation of the microscopical technique employs the use of an interference microscope. A beam of light is split, and one portion is projected on the specimen and the other on a reference mirror surface. The reflected light from these two surfaces is recombined, and interference fringes are formed that provide a topographical map of the specimen surface. These fringes can be used to measure vertical deviations on the metal surface. However, the method is limited to the shallower pits, that is, less than 25 μm, because the number of fringes increases to the point where they are difficult to count.

6. Evaluation of Pitting

6.1 There are several ways in which pitting can be described, given a quantitative expression to indicate its significance, or used to predict the life of a material. Some of the more commonly used methods are described in this section, although it is often found that no single method is sufficient by itself.

6.2 *Standard Charts* (3):

6.2.1 Rate the pits in terms of density, size, and depth on the basis of standard charts, such as those shown in Fig. 2. Columns A and B relate to the extent of pitting at the surface of the metal (that is, Column A is a means for rating the number of sites per unit area and Column B a means for showing the average size of these sites). Column C rates the intensity or average depth of attack. A typical rating might be A-3, B-2, C-3, representing a density of 5×10^4 pits/m^2, an average pit opening of 2.0 mm^2, and an average pit depth of 1.6 mm.

6.2.2 This method offers an effective means of communication between those who are familiar with the charts, and it is a simple means for storing data for comparison with other test results. However, it is tedious and time consuming to measure all pits, and the time is usually not justified because maximum values (for example, pit depths) usually have more significance than average values.

6.3 *Metal Penetration:*

6.3.1 Measure the deepest pits and express metal penetration in terms of the maximum pit depth or the average of the ten deepest pits, preferably both. This type of measurement is particularly significant when the metal is associated with an enclosure for a gas or liquid, and a hole could lead to a loss of fluid.

6.3.2 Metal penetration can also be expressed in terms of a pitting factor. This is the ratio of the deepest metal penetration to the average metal penetration, determined from weight loss, as shown in the following relationship:

$$\text{Pitting Factor} = \frac{\text{deepest metal penetration}}{\text{average metal penetration}} \qquad (1)$$

A pitting factor of one represents uniform corrosion; the larger the number, the greater the depth of penetration. The factor does not apply in those cases where pitting or general corrosion is very small because values of zero or infinity can readily be obtained when dealing with a ratio.

6.4 *Statistical:*

6.4.1 The application of statistics to the analysis of corrosion data is covered in detail in Guide G16. The subject is discussed briefly in this standard to show that statistics have a bearing on the evaluation of pitting data; more detailed information can be obtained from other publications.

6.4.2 The probability that pits will initiate on a metal surface is dependent on a number of factors, such as the pitting tendency of the metal, the corrosivity of the solution, the specimen area, and the time of exposure. A pitting probability test can be conducted
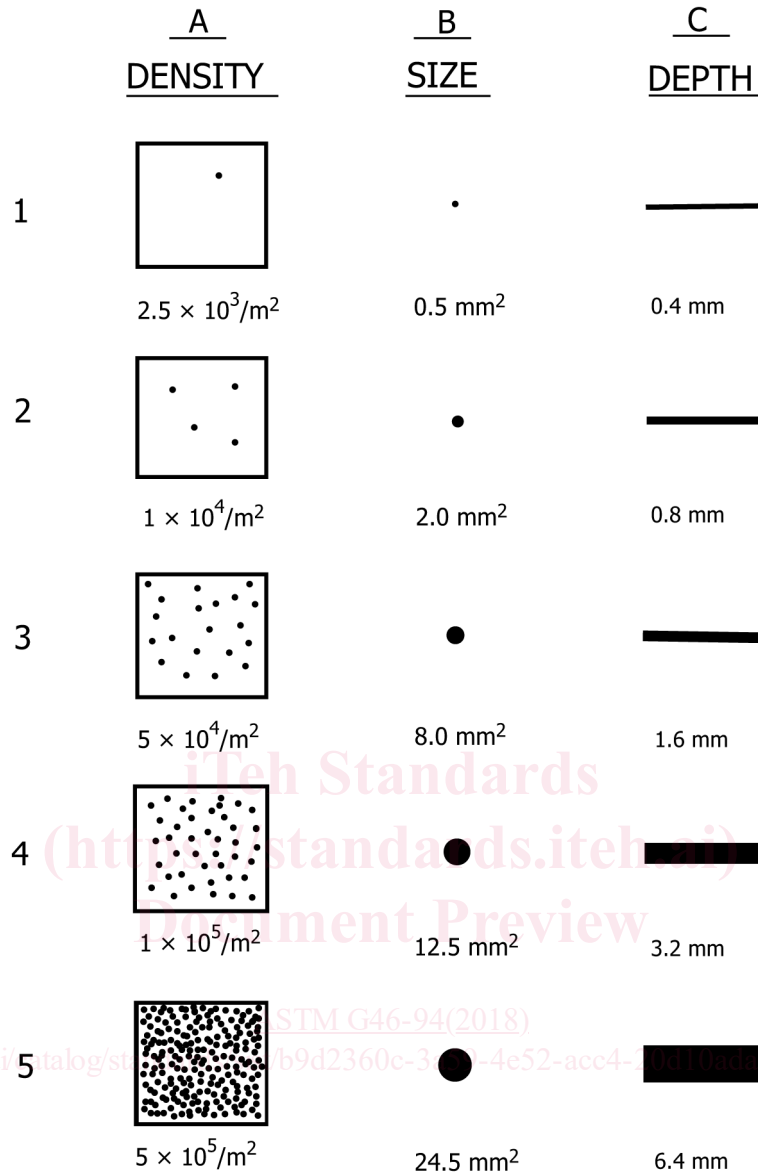
	A DENSITY	B SIZE	C DEPTH
1	$2.5 \times 10^3/m^2$	0.5 mm²	0.4 mm
2	$1 \times 10^4/m^2$	2.0 mm²	0.8 mm
3	$5 \times 10^4/m^2$	8.0 mm²	1.6 mm
4	$1 \times 10^5/m^2$	12.5 mm²	3.2 mm
5	$5 \times 10^5/m^2$	24.5 mm²	6.4 mm

FIG. 2 Standard Rating Charts for Pits

to determine the susceptibility of metals to pitting, but it will not provide information about the rate of propagation, and the results are only applicable to the conditions of exposure. The pitting probability (*P*) in % after the exposure of a number of specimens to a particular set of conditions can be expressed as follows (**5, 6**):

$$P = \frac{N_p}{N} \times 100 \qquad (2)$$

where:

N_p = number of specimens that pit, and
N = total number of specimens.

6.4.3 The relationship between pit depth and area or time of exposure may vary with the environment, the metal exposed, and other variables. The relationships cited in 6.4.3.1 and 6.4.3.2 are examples that have been found to apply under certain exposure conditions.

6.4.3.1 The following relationship was found between the maximum pit depth (*D*) and the area (*A*) of a pipeline exposed to soil (**7, 8, 9**):

$$D = bA^a \qquad (3)$$

where *a* and *b* > 0, and *a* and *b* are constants that were derived from the slope and the *y*-intercept of a straight line curve obtained when the logarithms of the mean pit depth for successively increasing areas on the pipe were plotted against the logarithms of the

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corresponding areas. The dependence on area is attributed to the increased chance for the deepest pit to be found when the size of the sample of pits is increased through an increased area of corroded surface.

6.4.3.2 The maximum pit depth (*D*) of aluminum exposed to various waters was found to vary as the cube root of time (*t*), as shown in the following relationship **(5, 10)**:

$$D = Kt^{1/3} \tag{4}$$

K is a constant that is a function of the composition of the water and alloy. This relationship has been found to apply to several aluminum alloys exposed to different waters.

6.4.4 Extreme value probability statistics **(11, 12)** have been applied successfully to maximum pit depth data to estimate the maximum pit depth of a large area of material on the basis of examination of a small portion of that area **(3, 5, 10)**. The procedure is to measure maximum pit depths on several replicate specimens that have pitted, and then arrange the pit depth values in order of increasing rank. A plotting position for each order of ranking is obtained by substituting in the relation, $M/(n+1)$, where M = order of ranking, and n = total number of specimens or values. For example, the plotting position for the second value out of 10 would be $2/(10+1) = 0.1818$. These values are plotted on the ordinate of extreme value probability paper versus their respective maximum pit depths. If a straight line is obtained, it shows that extreme value statistics apply. Extrapolation of the straight line can be used to determine the probability that a specific depth will occur or the number of observations that must be made to find a particular pit depth.

6.5 *Loss in Mechanical Properties*—If pitting is the predominant form of corrosion and the density of pitting is relatively high, the change in a mechanical property may be used advantageously to evaluate the degree of pitting. Typical properties that are considered for this purpose are tensile strength, elongation, fatigue strength, impact resistance, and burst pressure **(13, 14)**.

6.5.1 The precautions that must be taken in the application of these mechanical test procedures are covered in most standard methods, but it must be stressed that it is important to use as nearly replicate specimens as possible for both the exposed and unexposed specimens. Thus, consideration should be given to edge effects, direction of rolling, surface conditions, and so forth.

6.5.2 Representative specimens of the metal are exposed to the same conditions except for the corrosive environment. The mechanical properties of the exposed and unexposed specimens are measured after the exposure; the difference between the two results is attributed to corrosion.

6.5.3 Some of these methods are more properly suited to the evaluation of other forms of localized corrosion, such as intergranular or stress corrosion, so their limitations must be considered. The often erratic nature of pitting and the location of pits on the specimen can affect results. In some cases the change in mechanical properties due to pitting may be too small to provide meaningful results. Probably one of the most difficult problems is to separate the effects due to pitting from those caused by some other form of corrosion.

7. Report

7.1 The report should include as much detailed information as possible, such as the following:

7.1.1 Metallurgical treatment of the metal, surface preparation, and final surface finish before exposure to test,

7.1.2 Environmental conditions and duration of exposure,

7.1.3 Appearance of the corroded surface before and after cleaning,

7.1.4 Identification of corrosion products,

7.1.5 Characterization of pits to include: size, shape, density, uniformity of distribution, depth (average and maximum), and location of pits with reference to microstructure, face, edge, crevice, and so forth,

7.1.6 Change in mechanical properties as the result of corrosion, and the method by which determined, and

7.1.7 Statistical information.

8. Keywords

8.1 metallographic inspection; pit density; pit depth; pit morphology; pitting corrosion; visual inspection