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Standard Test Method for Measurement of Coating Thickness by the Beta Backscatter Method[1]

This standard is issued under the fixed designation B567; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers the beta backscatter gages for the nondestructive measurement of metallic and nonmetallic coatings on both metallic and nonmetallic substrate materials.

1.2 The test method measures the mass of coating per unit area, which can also be expressed in linear thickness units provided that the density of the coating is known.

1.3 The test method is applicable only if the atomic numbers or equivalent atomic numbers of the coating and substrate differ by an appropriate amount (see 6.2).

1.4 Beta backscatter instruments employ a number of different radioactive isotopes. Although the activities of these isotopes are normally very low, they can present a hazard if handled incorrectly. This standard does not purport to address the safety issues and the proper handling of radioactive materials. It is the responsibility of the user to comply with applicable State and Federal regulations concerning the handling and use of radioactive material. Some States require licensing and registration of the radioactive isotopes.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *activity*—the nuclei of all radioisotopes are unstable and tend to change into a stable condition by spontaneously emitting energy or particles, or both. This process is known as radioactive decay. The total number of disintegrations during a suitably small interval of time divided by that interval of time is called "activity." Therefore, in beta backscatter measurements, a higher activity corresponds to a greater emission of beta particles. The activity of a radioactive element used in beta backscatter gages is generally expressed in microcuries (1 μCi = 3.7×10^4 disintegrations per second).

2.1.2 *aperture*—the opening of the mask abutting the test specimen. It determines the size of the area on which the coating thickness is measured. This mask is also referred to as a platen, an aperture plate, a specimen support, or a specimen mask.

2.1.3 *backscatter*—when beta particles pass through matter, they collide with atoms. Among other things, this interaction will change their direction and reduce their speed. If the deflections are such that the beta particle leaves the body of matter from the same surface at which it entered, the beta particle is said to be backscattered.

2.1.4 *backscatter coefficient*—the backscatter coefficient of a body, R, is the ratio of the number of beta particles backscattered to that entering the body. R is independent of the activity of the isotope and of the measuring time.

2.1.5 *backscatter count:*

2.1.5.1 *absolute backscatter count*—the absolute backscatter count, X, is the number of beta particles that are backscattered during a finite interval of time and displayed by the instrument. X will, therefore, depend on the activity of the source, the measuring time, the geometric configuration of the measuring system, and the properties of the detector, as well as the coating thickness and the atomic numbers of the coating and substrate materials. X_0 is the count produced by the uncoated substrate, and X_s, that of the coating material. To obtain these values, it is necessary that both these materials are available with a thickness greater than the saturation thickness (see 2.1.12).

[1] This test method is under the jurisdiction of ASTM Committee B08 on Metallic and Inorganic Coatings and is the direct responsibility of Subcommittee B08.10 on Test Methods.

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2.1.5.2 *normalized backscatter*—the normalized backscatter, x_n, is a quantity that is independent of the activity of the source, the measuring time, and the properties of the detector. The normalized backscatter is defined by the equation:

$$x_n = \frac{X - X_0}{X_s - X_0}$$

where:

X_0 = count from the substrate,
X_s = count from the coating material, and
X = count from the coated specimen, and each count is for the same interval of time.

Because X is always $\geq X_0$ and $\leq X_s$, x_n can only take values between 0 and 1. (For reasons of simplicity, it is often advantageous to express the normalized count as a percentage by multiplying x_n by 100.)

2.1.5.3 *normalized backscatter curve*—the curve obtained by plotting the coating thickness as a function of x_n.

2.1.6 *beta particles*—beta particles or beta rays are high-speed electrons that are emitted from the nuclei of materials undergoing a nuclear transformation. These materials are called beta-emitting isotopes, beta-emitting sources, or beta emitters.

2.1.7 *coating thickness*—in this test method, coating thickness refers to mass per unit area as well as geometrical thickness.

2.1.8 *dead time or resolving time*—Geiger-Müller tubes used for counting beta particles have characteristic recovery times that depend on their construction and the count rate. After reading a pulse, the counter is unresponsive to successive pulses until a time interval equal to or greater than its dead time has elapsed.

2.1.9 *energy*—it is possible to classify beta emitters by the maximum energy of the particles that they release during their disintegration. This energy is generally given in mega-electronvolts, MeV.

2.1.10 *equivalent (or apparent) atomic number*— the equivalent atomic number of an alloy or compound is the atomic number of an element that has the same backscatter coefficient as the material.

2.1.11 *half-life, radioactive*—for a single radioactive decay process, the time required for the activity to decrease by half.

2.1.12 *saturation thickness*—the minimum thickness of a material that produces a backscatter that is not changed when the thickness is increased. (See also Appendix X1.)

2.1.13 *sealed source or isotope*—a radioactive source sealed in a container or having a bonded cover, the container or cover being strong enough to prevent contact with and dispersion of the radioactive material under the conditions of use and wear for which it was designed.

2.1.14 *source geometry*—the spatial arrangement of the source, the aperture, and the detector with respect to each other.

3. Summary of Test Method

3.1 When beta particles impinge upon a material, a certain portion of them is backscattered. This backscatter is essentially a function of the atomic number of the material.

3.2 If the body has a surface coating and if the atomic numbers of the substrate and of the coating material are sufficiently different, the intensity of the backscatter will be between two limits: the backscatter intensity of the substrate and that of the coating. Thus, with proper instrumentation and if suitably displayed, the intensity of the backscatter can be used for the measurement of mass per unit area of the coating, which, if the density remains the same, is directly proportional to the thickness.

3.3 The curve expressing coating thickness (mass per unit area) versus beta backscatter intensity is continuous and can be subdivided into three distinct regions, as shown in Fig. 1. The normalized count rate, x_n, is plotted on the *X*-axis, and the logarithm of the coating thickness, on the *Y*-axis. In the range $0 \leq x_n \leq 0.35$, the relationship is essentially linear. In the range $0.35 \leq x_n \leq 0.85$, the curve is nearly logarithmic; this means that, when drawn on semilogarithmic graph paper, as in Fig. 1, the curve approximates a straight line. In the range $0.85 \leq x_n \leq 1$, the relationship is nearly hyperbolic.

3.4 Radiation other than the beta rays are emitted or backscattered by the coating or substrate, and may be included in the backscatter measurements. Whenever the term backscatter is used in this method, it is to be assumed that reference is made to the total radiation measured.

4. Significance and Use

4.1 The thickness or mass per unit area of a coating is often critical to its performance.

4.2 For some coating-substrate combinations, the beta backscatter method is a reliable method for measuring the coating nondestructively.

4.3 The test method is suitable for thickness specification acceptance if the mass per unit area is specified. It is not suitable for specification acceptance if the coating thickness is specified and the density of the coating material can vary or is not known.

5. Instrumentation

5.1 In general, a beta backscatter instrument will comprise: (*1*) a radiation source (isotope) emitting primarily beta particles having energies appropriate to the coating thickness to be measured (see Appendix X2), (*2*) a probe or measuring system with a range of apertures that limit the beta particles to the area of the test specimen on which the coating thickness is to be measured, and containing a detector capable of counting the number of backscattered particles (for example, a Geiger-Müller counter (or tube)), and (*3*) a readout instrument where the intensity of the backscatter is displayed. The display, in the form of a meter reading or a digital readout can be: (*a*) proportional to the count, (*b*) the normalized count, or (*c*) the coating thickness expressed either in thickness or mass per unit area units.

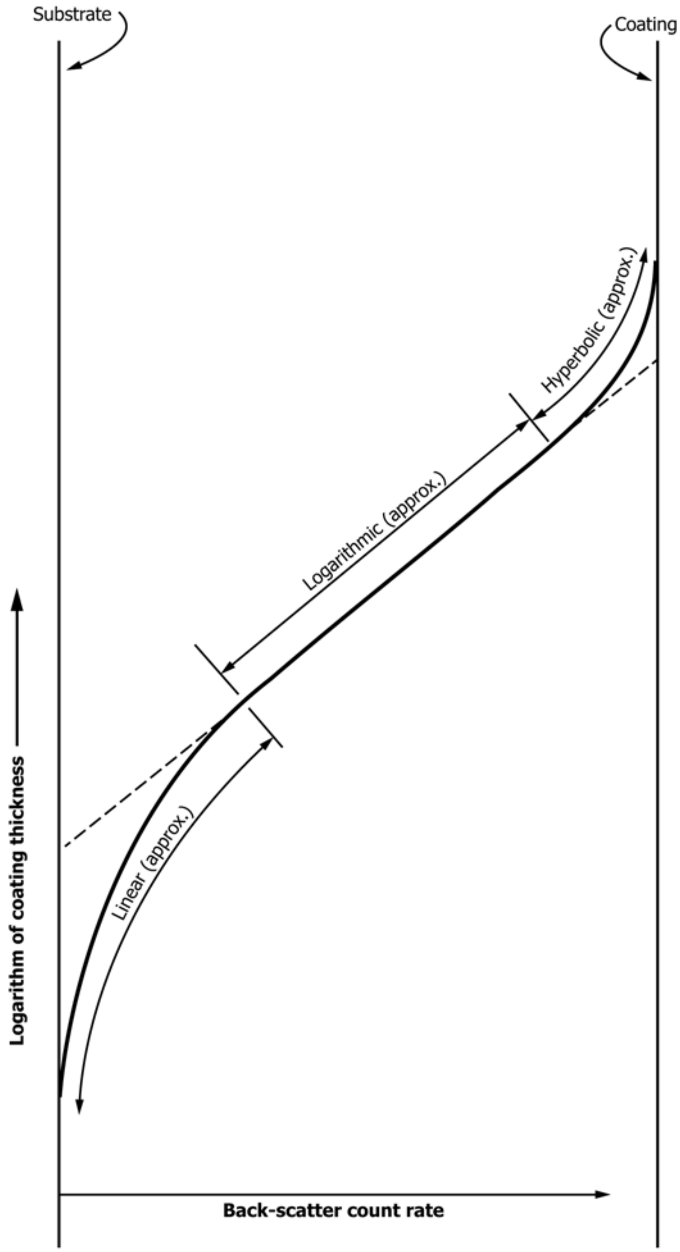

FIG. 1 Normalized Backscatter

6. Factors Affecting the Measuring Accuracy

6.1 *Counting Statistics:*

6.1.1 Radioactive disintegration takes place randomly. Thus, during a fixed time interval, the number of beta particles backscattered will not always be the same. This gives rise to statistical errors inherent to radiation counting. In consequence, an estimate of the counting rate based on a short counting interval (for example, 5 s) may be appreciably different from an estimate based on a longer counting interval, particularly if the counting rate is low. To reduce the statistical error to an acceptable level, it is necessary to use a counting interval long enough to accumulate a sufficient number of counts.

6.1.2 At large total counts, the standard deviation (σ) will closely approximate the square root of the total count, that is $\sigma = \sqrt{X}$; in 95 % of all cases, the true count will be within $X \pm 2\sigma$. To judge the significance of the precision, it is often helpful to express the standard deviation as a percentage of the count, that is, $100\sqrt{X}/X$, or $100/\sqrt{X}$. Thus, a count of 100 000 will give a value ten times more precise than that obtained with a count of 1000. Whenever possible, a counting interval should be chosen that will provide a total count of at least 10 000, which corresponds to a statistical error of 1 % for the count rate. It should be noted, however, that a 1 % error in the count rate can correspond to a much larger percentage error in the thickness measurement, the relative error depending on the atomic number spread or ratio between coating and substrate materials.

6.1.3 Direct-reading instruments are also subject to these statistical random errors. However, if these instruments do not permit the display of the actual counting rate or the standard deviation, the only way to determine the measuring precision is to make a large number of measurements at the same coated location on the same coated specimen, and calculate the standard deviation by conventional means.

NOTE 1—The accuracy of a thickness measurement by beta backscatter is generally poorer than the precision described in 5.1, inasmuch as it also depends on other factors that are described below. Methods to determine the random errors of thickness measurements before an actual measurement are available from some manufacturers.

6.2 *Coating and Substrate Materials*—Because the backscatter intensity depends on the atomic numbers of the substrate and the coating, the repeatability of the measurement will depend to a large degree on the difference between these atomic numbers; thus, with the same measuring parameters, the greater this difference, the more precise the measurement will be. As a rule of thumb, for most applications, the difference in atomic numbers should be at least 5. For materials with atomic numbers below 20, the difference may be reduced to 25 % of the higher atomic number; for materials with atomic numbers above 50, the difference should be at least 10 % of the higher atomic number. Most plastics and related organic materials (for example, photoresists) may be assumed to have an equivalent atomic number close to 6. (Appendix X3 gives atomic numbers of commonly used coating and substrate materials.)

6.3 *Aperture:*

6.3.1 Despite the collimated nature of the sources used in commercial backscatter instruments, the backscatter recorded by the detector is, nearly always, the sum of the backscatter produced by the test specimen exposed through the aperture and that of the aperture plate(n). It is, therefore, desirable to use a material with a low atomic number for the construction of the platen and to select the largest aperture possible. Measuring errors will be increased if the edges of the aperture opening are worn or damaged, or if the test specimen does not properly contact these edges.

6.3.2 Because the measuring area on the test specimen has to be constant to prevent the introduction of another variable, namely the geometrical dimensions of the test specimen, it is essential that the aperture be smaller than the coated area of the surface on which the measurement is made.

6.4 *Coating Thickness:*