Penetrating Radiation Inspection—SAE J427b

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LAND SEA AIR SPACE

PREPRINT

PENETRATING RADIATION INSPECTION—SAE J427b

SAE Information Report

Report of Iron and Steel Technical Committee approved June 1960 and last revised June 1978.

Purpose—The purpose of this report is to provide basic information on penetrating radiation, as applied in the field of nondestructive testing, and to supply the user with sufficient information so that he may decide whether penetrating radiation methods apply to his particular inspection need. Detailed information references are listed in the Bibliography.

General—Penetrating radiation is a versatile nondestructive test method used in modern industry. The use of penetrating x-rays, gamma rays, thermal neutrons, and other forms of radiation which do not affect the material being inspected, provide the basic information by which soundness can be determined. Radiography provides a permanent record on film of internal conditions. Fluoroscopy differs from radiography in that the radiation image is projected on a fluorescent screen or other readout monitor and observed visually rather than recorded on a film. Penetrating radiation enables industry to monitor a variety of products for a number of types of imperfections. Objects inspected range in size from micro-miniature electronic parts to very large components in a wide range of manufactured forms (for example; castings, weldments, assemblies).

Principles—X-rays, gamma rays, and neutrons possess the capability of penetrating materials, even those that are opaque to light. In passing through matter, some of these rays are absorbed or scattered. Materials absorb x-rays and gamma rays in proportion to their mass. Neutron absorption, on the other hand, is not related directly to atomic number or mass; neighboring elements can differ in neutron absorption by factors of 100 or more. Differential absorption of the radiant energy passing through the object due to the presence of voids, discontinuities, or density variations caused by inhomogeneity or internal construction is recorded on radiographic film or observed directly by fluoroscopic methods. With acceptable conditions of technology and equipment, it is generally agreed that discontinuities can be detected which present to the axis of radiation a minimum dimension of 1–2% of the thickness of the object undergoing radiographic examination, or 2–6% for fluoroscopic examination. Two-dimensional imperfections, such as cracks and cold shuts, are not detectable unless they present an effective thickness difference of the above magnitude, or greater.

Procedure

1. Radiographic Film Technique—A radiographic film is a photographic record produced by the passage of x-rays, gamma rays, or neutrons through an object onto a film. When film is exposed to a radiation source or light, an invisible change is produced in the film emulsion. The areas so exposed become dark when the film is immersed in a developing solution; the amount of darkening depends upon the degree of exposure. Image formation is usually enhanced through use of thin metal screens in intimate contact with the film. Lead screens are used in x-ray exposures made with energy above 100 kV and in gamma ray exposures. Screens are necessary for film detection of thermal neutrons. Gadolinium metal screens are normally used for this purpose. The developing, fixing, and washing of exposed film may be done either manually or in an automatic film processor. The exposed, processed, and dried radiographic film is examined under transmitted light. Interpretation of the image is performed in accordance with established codes, specifications, or acceptance criteria.

The finished radiograph should be viewed under conditions which provide for the best visualization of detail combined with maximum comfort and minimum fatigue for the observer. A high-intensity illuminator with adjustable intensity is almost a necessity for optimum radiographic observation and interpretation. Penetrameters are used to indicate the image quality which exists in a radiograph. The type generally used in the United States is a small rectangular plate of the same material as the object being x-rayed. It is uniform in thickness (usually 2% of the object thickness) and has holes drilled through it. ASTM specifies hole diameters 1, 2, and 4 times the thickness of the penetrameter. Step, wire, and bead penetrameters are also used. (See ASTM E 94, Recommended Practice for Radiographic Testing.) For neutron radiography, image quality indicators provide a measure of the relative exposure due to gamma rays, higher energy neutrons, and scattered neutrons. Additional image quality indicators are suggested to provide measures of contrast and resolution capability. (See ASTM E 545.)

ADVANTAGES—Film radiography provides a permanent, visible record of the internal condition of the subject. Preservation of films is a common practice in industry.

DISADVANTAGES—High cost is the chief objection to film radiography. One-half of the average inspection cost is the radiographic film cost. X-ray paper products reduce this disadvantage when maximum performance capability is not required.

Inspection results are not available until radiographic film has been exposed, processed, and interpreted.

2. Fluoroscopic Inspection Technique—Fluoroscopy is the process of examining an object by direct observation of the fluorescence of a screen caused by radiation transmitted through an object. The arrangement of the x-ray source, object, and imaging plane is identical to that used in radiography. The fluorescent screen, image intensifier tube, television camera, and similar electronic imaging devices convert x-rays to visible light for further signal processing and operator interpretation.

ADVANTAGES—Production line inspection systems are available. These can result in low cost per part inspected and can meet the inspection requirements of high-volume production.

DISADVANTAGES—The sensitivity of the fluoroscopic process is not as great as that of radiography, 2–6% being routine. The lack of a permanent record of the examination may be a disadvantage. For systems employing television detection, however, magnetic recording can be used, or photographs may be taken of the television image.

Application—The ability of high energy radiation to penetrate all engineering materials and the differential rates of absorption for different materials is responsible for the extensive use of this nondestructive inspection technique throughout industry. Accordingly, penetrating radiation inspection methods are extensively used for flaw detection in the following areas:

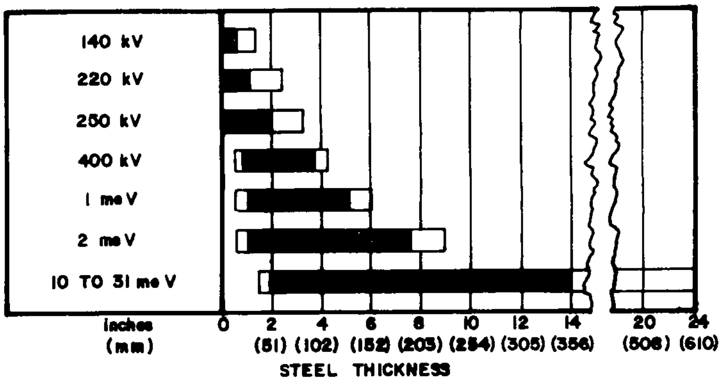
1. Castings—The increasingly wide use that penetrating radiation inspection methods enjoy in the castings field result from the fact that most of the flaws and discontinuities inherent in ferrous and nonferrous castings can be readily detected by this inspection medium. Shrinkage, gas porosity, inclusions, hot tears, cold cracks and shuts, core shifts, and major surface irregularities may be detectable by radiographic or fluoroscopic inspection techniques. In addition, the following discontinuities which are peculiar to light metal (aluminum and magnesium) castings are detectable: gas holes, dross inclusions, segregation, micro-shrinkage, hydrogen porosity, microporosity, shrinkage, sponge, cold shuts, and other discontinuities common to light metal castings.

2. Weldments—Penetrating radiation inspection of weldments is an accepted procedure for the detection of internal discontinuities. It is used in the establishment of welding procedures to qualify welders and especially to control quality of welded joints in finished products. The following imperfections or discontinuities are detectable by radiography: porosity, cracks, poor penetration and fusion, inclusions, and other discontinuities common in welded joints.

3. Finished Assemblies—Penetrating radiation techniques are applicable to the inspection of fabricated assemblies relative to placement of internal components, such as electronic devices, mufflers, fuel tanks, bonded honeycomb, and tires. Electrical connections as well as the position of bolts and nuts in finished enclosures are frequently checked by radiography. Neutron radiography of assemblies provides a capability to verify proper placement of hydrogen-containing materials in metal assemblies. By this method rubber *O* rings, plastic parts, propellants, fluid levels, and similar materials can be visualized even when these objects are inside metallic containers.

4. Miscellaneous Applications—Less frequent use is made of radiographic techniques in the inspection of forgings, powder metal parts, and of nonmetallic materials such as plastic, rubber, ceramic, and solid propellant. The limited use of this inspection medium for forgings is

The ϕ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.



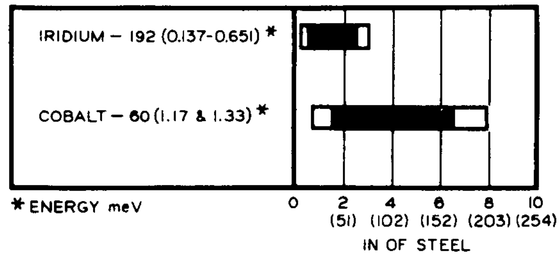
THE SHADED PORTIONS OF THE BAR REPRESENT THICKNESSES WHERE 1% SENSITIVITY IS OBTAINED. THE UNSHADED PORTION AT BAR ENDS REPRESENT 2% SENSITIVITY.

FIG. 1–APPROXIMATE PRACTICAL THICKNESS RANGES OF STEEL FOR VARIOUS X-RAY KILOVOLTAGES

explained by the fact that forging defects are smaller in size and unsuitably oriented for good detection.

Equipment–There are a number of factors which affect the use of penetrating radiation to varying extents. These factors can be grouped into three general categories: source of radiation, object or material to be examined, and detecting or recording medium.

Sources for neutron radiography include nuclear reactors, accelerators, and radioactive isotopes. These sources can be moved (in a truck, for example) but most neutron radiographic inspection is done by bringing the inspection object to the source. Radiation sources for other types of radiography involve either x-ray generators or one of several radio isotyopes. X-rays are produced when high-velocity electrons impinge upon target atoms. The energy of the x-radiation produced is a function of the velocity of the impinged electrons, which in turn is dependent upon the applied anode voltage (kV or meV). The practical thickness range of steel which can be inspected by x-ray units is proportional to their radiation energy, as shown in Fig. 1. The usefulness of Fig. 1 can be extended to other materials by referring to Table 1, which gives equivalence factors for various other materials as compared to steel.



NOTE: DIMENSIONS ARE IN (mm)

THE SHADED PORTIONS OF THE BAR REPRESENT THICKNESSES WHERE 2% SENSITIVITY IS OBTAINED. THE UNSHADED PORTION AT BAR ENDS REPRESENT POORER SENSITIVITY IN THE PRACTICAL RANGE.

FIG. 2–APPROXIMATE PRACTICAL THICKNESS OF STEEL FOR VARIOUS RADIOACTIVE ISOTOPE SOURCES

The radiographic isotopes emit gamma radiation of known energy levels. The approximate practical thickness range of the most commonly used radioisotopes for steel is included in Fig. 2. The energy level of the gamma radiation for each isotope determines its equivalence factor for materials other than steel (included in Fig. 2). Table 1 can be utilized to approximate these equivalence factors by averaging the energy values for a given source and using the closest energy level column in the table.

Other factors such as economics, flexibility, sensitivity, maintenance costs, and portability must of necessity be considered when deciding the type of unit to be used.

Generally, x-ray film is used as the detecting medium. Various types of film are commercially available. These differ in speed, grain, and contrast. The selection of a film is interrelated with the type and energy of the radiation, and the material and thickness of the object to be inspected. Factors such as sensitivity required and exposure time are also considerations. Industrial x-ray paper may be used as a detecting medium. This stabilization paper offers several advantages: lower material cost, increased processing speed, darkroom simplicity, and space savings. Consideration should be given to this process if maximum sensitivity and long periods of radiographic print storage are not required. Other detecting media are available, such as Polaroid film, and Xeroradiography.

TABLE 1–APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS FOR SEVERAL METALS IN RELATION TO STEEL[a] (ADAPTED FROM ASTM E 94)

Metal	Density	Radiographic Equivalence Factor					
		140 kV	220 kV	250 kV	400 kV	1 meV	2 meV
Aluminum	2.7	0.083	0.24	0.24	–	–	–
Magnesium	1.7	0.05	0.08	0.08	–	–	–
Steel	7.8	1.0	1.0	1.0	1.0	1.0	1.0
Stainless (18.8)	7.9	1.0	1.0	1.0	1.0	1.0	1.0
Copper	8.9	1.8	1.4	1.4	1.4	–	–
Zinc	7.1	–	1.3	1.3	1.3	–	–
Brass	8.4	–	1.3	1.3	1.3	1.2	–
Lead	11.3	–	11.0	–	–	5.0	2.5

[a]Note: To determine upper practical limit for materials listed other than steel, divide the value given for steel by the proper equivalence factor. Table 1 may be extended to apply to radioisotopes by taking the average of the energy values given in Fig. 2, and using the nearest size x-ray unit in the table.