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SURFACE VEHICLE INFORMATION REPORT

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(R) DETECTION OF SURFACE IMPERFECTIONS IN FERROUS RODS, BARS, TUBES, AND WIRES

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

1. *Scope*—This SAE Information Report provides a summary of several methods that are available for detecting, and in some instances detecting and measuring, surface imperfections in rods, bars, tubes, and wires. References relating to detailed technical information and to specific applications are enumerated in 2.2.

2. *References*

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the lastest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J420—Magnetic Particle Inspection
SAE J425—Eddy Current Testing by Electromagnetic Methods
SAE J426—Liquid Penetrant Test Methods
SAE J428—Ultrasonic Inspection

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

J. M. Mandula and E. S. Monk, "NDT Systems for Steel Billets, Bars, and Tubes." Materials Evaluation, Vol. 34 (10), October 1976, pp. 230–236.
W. A. Black, "Evaluation of Surface Defects by Nondestructive Testing - A Progress Report." Journal of Metals, October 1965, pp. 1136–1140.
J. M. Mandula, "Billetscan - A New Eddy Current Device for Total Surface Inspection of Square Billets." Materials Evaluation, Vol. 30 (3), March 1972, pp. 49–54.
T. W. Judd, "Orbitest for Round Tubes." Materials Evaluation, Vol. 28 (1), Jan. 1970, pp. 8–12.
C. E. Betz, "Principles of Penetrants." Second Edition, Magnaflux Corporation, Chicago, IL.
Metals Handbook, Ninth Edition, Vol. 17, Nondestructive Evaluation and Quality Control, 1989, ASM International, Metals Park, OH 44073.
W. J. McGonnagle, "Nondestructive Testing." Second Edition, Gordon and Breach, Science Publishers, Inc., New York, 1969.

R. C. McMaster, "Nondestructive Testing Handbook." Second Edition, Vol. 2, Liquid Penetrant Tests, 1982, ASM International, Metals Park, OH 44073.
C. E. Betz, "Principles of Magnetic Particle Testing." Magnaflux Corporation, Chicago, IL, 1985.
H. L. Libby, "Introduction to Electromagnetic Nondestructive Test Methods." John Wiley & Sons, New York, 1971.
"Nondestructive Testing." (NASA SP-5113), National Aeronautics and Space Administration, Washington, DC, 1973.
Nondestructive Testing Handbook, Vol. 4, Electromagnetic Testing, 1986, American Society for Nondestructive Testing, Columbus, OH 43228.
Tool and Manufacturing Engineer's Handbook, Vol. 4, Quality Control and Assembly, 1987, Society of Manufacturing Engineers, Dearborn, MI 48121.

3. ***Limitations***—Imperfections which are open to the surface of ferrous rods, bars, tubes, or wires are the only types considered. Such imperfections include:

a. Longitudinal types (seams and laps)
b. Point types (pits)
c. Mechanical types (scratches, nicks, and gouges)

4. *Test Methods for Detection*

4.1 Visual Examination—Depending upon end product requirements, visual inspection, with or without the aid of magnification, is in some cases adequate to detect the surface imperfections under consideration. Conditions which limit the size and nature of the imperfections as well as surface qualities are factors to be considered in its application. Visual examination may be aided by using surface preparations such as buffing, light grinding, pickling, or blast cleaning using a small particle grit or sand. Sometimes pickling is used in conjunction with blast cleaning.

4.2 Liquid Penetrant—SAE J426 briefly describes the equipment and techniques for detecting surface imperfections using a liquid penetrant. The method is generally used for inspecting nonmagnetic materials, but it can also be used on ferrous materials. Being a test involving a penetrating liquid, it is insensitive to the directional aspects of surface flaws; consequently, it will detect laps, seams, cracks, and similar surface imperfections without regard to their orientation. Good indications, however, are dependent upon surface cleanliness, and the ability of the imperfection to admit and retain the penetrating liquid.

4.3 Magnetic Particle Inspection—The methods available, recommended usage for types of surface discontinuities, and inspection techniques are described in SAE J420. The sensitivity level to be achieved is dependent upon the system employed. Magnetic particle inspection is especially useful to find laps, seams, cracks, inclusions, and some mechanical flaws in ferromagnetic materials, but it has limited value when inspecting for gouges and pits that are circular in nature or too broad to induce a magnetic leakage field. Although a clean surface is important for satisfactory indications, the shape of the cross section and straightness of the test specimens are inconsequential in obtaining satisfactory results. However, if magnetic particle inspection is to be applied to coiled materials, it must be performed on representative samples cut from the coils.

4.4 Electromagnetic—Electromagnetic methods are used for the detection of surface imperfections. Eddy current and fringe flux techniques are discussed here. SAE J425 gives general information relative to the nature and use of eddy currents in the broad field of nondestructive testing. This discussion gives additional information on electromagnetic methods as they apply to the detection of surface imperfections in ferrous bars, tubes, rods, and wires.

A distinct advantage of electromagnetic testing is that it can give information as to the severity of surface imperfections. This makes it possible to establish a quality level of the material being tested by accepting that with imperfection not detrimental to the end use of the material and by rejecting that with more severe imperfections. The minimum surface imperfection which can be detected by electromagnetic methods is determined by:

a. The surface condition of the material;
b. The type and size of the test coil used;
c. The test frequency used;
d. The discriminating capabilities of the test instrumentation;
e. The smoothness of operation of the material handling equipment.

4.4.1 Eddy Current—Eddy current testing is a method of electromagnetic testing in which eddy current flow is induced in the material under test by an exciting coil energized with an alternating current. Changes in the flow caused by variations in the material are reflected into a sensing coil or coils for subsequent analysis by suitable instrumentation and techniques.

The principle of eddy current testing, simply stated, is mutual induction. Mutual induction is the development of an induced emf in one circuit by the change of current in another. Thus, if a piece of metal is placed in the field of an exciting coil carrying alternating current, eddy currents will be induced in the metal.

Testing is performed by passing the bar, rod, tube, or wire lengthwise through or near the inspection coil, which may contain separate exciting and sensing coils or a single coil that may be used for both purposes. The exciting coil is energized with alternating current of one or more frequencies. The electrical impedance of the sensing coil is modified by the proximity of the material under test. The extent of this modification is determined by the distance between the coil and the material, and the electrical conductivity and magnetic permeability of the material. The presence of metallurgical or mechanical discontinuities on the surface of the material will alter the apparent electrical impedance of the coil. During passage of the material being tested, the test coil induces eddy currents in the material and senses changes in amplitude and/or phase of these eddy currents. These changes produce electrical signals which are amplified and modified so as to actuate a suitable signalling device. If variations in magnetic permeability exist in the test material, they may cause spurious signals with some types of eddy current tests. These signals are generally eliminated by saturating the test piece with a uniform magnetic field at the test coil.

Two general coil types will be discussed here. One coil type is the encircling or feed-through type where the coil or coils are stationary while the material is fed through by means of a suitable transport mechanism. Either absolute or differential coil arrangements can be used. The differential coil arrangement is particularly sensitive to short imperfections such as pits, silvers, or nicks. Longitudinal imperfections, such as cracks or seams, may be indicated if they are variable. The absolute arrangement is sensitive to variables such as material properties, size, shape, and imperfections.

The other type is the probe coil. This type can be made to rotate around the material, or the coil can be held stationary while the material is rotated and traversed longitudinally in close proximity to the coil. The probe coil type is reliable and lends itself to mechanization of round product testing. The advantages are that no material saturation is necessary; that it is sensitive to continuous, uniform, longitudinal type imperfections; and that very shallow surface imperfections can be detected.

4.4.2 FRINGE FLUX—Fringe (or leakage) flux testing is a nondestructive method for detecting cracks and other discontinuities at or near the surface in ferromagnetic materials. The method consists of the following steps:

a. The part is magnetized immediately prior to or during the test to a proper level approaching saturation.
b. A flux sensor containing magnetic transducers is placed on the surface in the magnetized area.
c. The part or the magnetic flux sensor is moved progressively at a constant speed so the entire surface is scanned by the sensor.
d. Each magnetic transducer in the flux sensor is connected to an electronic console which amplifies, filters, and electronically processes the signals such that significant discontinuities are indicated (visually and audibly), then marked with paint or automatically removed from the production line, or both.

The fringe flux test is somewhat similar to a magnetic particle test with the flux sensor replacing the magnetic particles. It is somewhat similar to eddy current testing in the scanning and capability. The severity of the discontinuity can be estimated and a rejection level set with respect to the magnitude of the electromagnetic indication produced by the discontinuity.

If properly applied, this method is capable of detecting the presence and location of significant discontinuities such as pits, scabs, slivers, gouges, roll-ins, laps, seams, cracks, holes, and imperfections in welds.

4.5 Ultrasonic—Ultrasonic test methods, as described in SAE J428, can be used for the detection of surface discontinuities in bar and tube products. Various adaptations of the basic method are employed. The choice is influenced by factors such as cross-sectional area of the bar and the size and nature of the imperfections sought. Under proper conditions, ultrasonic waves can be propagated on and just below the surface of the bar. This test mode is particularly well suited to surface inspection. However, surface roughness and cleanliness must be controlled to prevent false determinations.

In general, ultrasonic inspection is limited to bars and wires greater than 2.5 mm (0.1 in) in diameter.

5. Methods of Measurement—Electromagnetic (eddy current or fringe flux) and ultrasonic testing may be considered quantitative in that acceptance standards can be established, and the equipment set to reject materials having surface imperfections exceeding the predetermined acceptable conditions. Actual deviations from an acceptance standard can be interpreted quantitatively, after acquiring experience with the material being tested and gaining familiarity with the signal changes resulting from the type of imperfection or imperfections being investigated.

Only the surface length of an imperfection can usually be determined from liquid penetrant testing, magnetic particle testing, and visual examination and are usually interpreted qualitatively. However, some indication of the depth of surface discontinuities is sometimes possible on hot rolled products if a fluorescent powder is used when inspecting by the magnetic particle method (see Principles of Magnetic Particle Testing, p. 354).

Methods of actual depth measurement that are easy to use will either destroy the initial evidence or are a destructive test method. Those commonly used are as follows:

5.1 File or Grind and Inspect—Depth is often determined by merely filing or grinding the imperfection until it disappears visually. When using magnetic particle inspection, the material is ground or filed and then magnetic particle inspected again to determine if the imperfection is completely removed. The depth of the resulting groove to the point of complete removal of the discontinuity, can then be measured.

5.2 Macroexamination—Depth can be determined by cutting and grinding a section perpendicular to the direction of the imperfection and macroetching the sample. The depth is measured by a suitable means which could be a scale, Brinell glass, or low power microscope.

5.3 Microexamination—A very accurate method of measuring depth is by cutting and metallographically polishing a section perpendicular to the direction of the imperfection and measuring the depth microscopically.

5.4 Macroetching—If all conditions, including acid concentration, temperature, and time are controlled, a surface discontinuity of a section can be exaggerated by macroetching. The depth of the etched imperfection can be estimated and a rough approximation made of the original imperfection depth since the amount of material removed can be determined by measuring the cross section before and after etching. Subtracting this difference from the estimated depth of the etched surface imperfection gives the rough estimate.

6. Notes

6.1 Marginal Indicia—The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

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