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SURFACE VEHICLE INFORMATION REPORT

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Carbon Steel Tubing for General Use - Understanding Nondestructive Testing for Carbon Steel Tubing

RATIONALE

SAE J2592 Information Report provides a means for the average lay person not directly associated with the manufacturing of bulk steel tubing, a better understanding of the various methods to evaluate the molecular integrity of steel tubing without the need of destructing the tubing. This July 2011 project provides five year review with only the following editorial changes.

1. SCOPE

This SAE information report provides a means to understand the various methods of evaluating the integrity of steel tubing without the need of destroying the tubing. This report describes eddy current testing, flux leakage testing, ultrasonic testing, and magnetic particle testing of steel tubing. The primary purpose of these methods of testing steel tubing is to look for flaws in the tubing, such as discontinuities, seams, cracks, holes, voids and other imperfections characteristic to the specific construction of the tubing.

1.1 Purpose

This information report is written so the average person can understand its meaning, even though they might not be familiar with steel tube mill activities and manufacturing processes.

When agreed upon between the user and the manufacturer, nondestructive testing is used in lieu of hydrostatic pressure proof testing, which is a destructive test.

The nondestructive testing systems described in this document are currently being used in the U.S. tubing industry to monitor steel tubing manufactured to the SAE tubing standards listed in the related publications section.

These SAE standard tubing materials are primarily intended for mobile/stationary industrial equipment and automotive applications. Aircraft and Aerospace applications were not considered during the preparation of this document.

2. REFERENCES

2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J356 Welded Flash Controlled Low-Carbon Steel Tubing Normalized for Bending, Double Flaring and Beading

SAE J358 Non-Destructive Tests

SAE J420 Magnetic Particle Inspection

SAE J425 Electromagnetic Testing by Eddy Current Methods

SAE J428 Ultrasonic Inspection

SAE J524 Seamless Low-Carbon Steel Tubing Annealed for Bending and Flaring

SAE J525 Welded and Cold Drawn Low-Carbon Steel Tubing Annealed for Bending and Flaring

SAE J526 Welded Low-Carbon Steel Tubing Suitable for Bending, Flaring, Beading, Forming and Brazing

SAE J527 Brazed Double Wall Low-Carbon Steel Tubing

SAE J1677 Tests and Procedures for Carbon Steel and Low Alloy Steel Tubing

SAE J2435 Welded Flash Controlled, SAE 1021 Carbon Steel Tubing, Normalized for Bending, Double Flaring, and Beading

SAE J2467 Welded and Cold-Drawn, SAE 1021 Carbon Steel Tubing Normalized for Bending and

SAE J2551 Recommended Practices for Fluid Conductor Carbon and Alloy Steel Tubing Applications

SAE J2613 Welded Flash Controlled, High Strength (500 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Sub-Critically Annealed for Bending, Double Flaring, and Beading

SAE J2614 Welded and Cold-Drawn, High Strength (500 MPa Tensile Strength) Low Alloy Steel Hydraulic Tubing, Sub-Critically Annealed for Bending and Flaring

SAE J2658 Carbon and Steel Alloy Tube Conductor Assemblies for Fluid Power and General Use - Test Methods for Hydraulic Fluid Power Metallic Tube Assemblies

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel:212-642-4900, www.ansi.org.

ISO 3304 Plain end seamless precision steel tubes - Technical conditions for delivery

ISO 3305 Plain end welded precision steel tubes - Technical conditions for delivery

ISO 8434 Metallic tube connections for fluid power and general use

ISO 10763 Plain-end, seamless and welded steel tubes - Dimensions and nominal working pressures

EN 10305-2 Welded Cold Drawn Steel Tubes for Precision Applications

EN 10305-4 Seamless Cold Drawn Steel Tubes for Hydraulic and Pneumatic Power Systems

JIS G 3454 Welded Carbon Steel Pipes for Pressure Service

JIS G 3455 Seamless Carbon Steel Pipes for Pressure Service

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

ASTM A 254 Standard Specification for Copper Brazed Steel Tubing

ASTM A 268 Standard Specification for Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service

ASTM A 450/A 450M Standard Specifications for General Requirements for Carbon, Ferritic Alloy and Austenitic Alloy Steel Tubing

ASTM A 500 Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes

ASTM A 501 Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing

ASTM A 513 Standard Specification for Electric- Resistance-Welded Carbon and Alloy Steel Mechanical Tubing

ASTM A 519 Standard Specification for Seamless Carbon and Alloy Steel Mechanical Tubing

ASTM A 539 Standard Specification for Electric- Resistance-Welded Coiled Steel Tubing for Gas and Fuel Oil Lines

ASTM A 618 Standard Specification for Hot-Formed Welded and Seamless High-Strength Low-Alloy Structural Tubing

ASTM A 822 Standard Specification for Seamless Cold-Drawn Carbon Steel for Hydraulic System Service

ASTM A 847 Standard Specification for Cold-Formed Welded and Seamless, Low Alloy Structural Tubing with Improved Atmospheric Corrosion Resistance

ASTM E 213 Standard Practice for Ultrasonic Examination of Ferro Magnetic Steel Tubular Products

ASTM E 273 Standard Practice for Ultrasonic Examination of Longitudinal Welded Pipe and Tubing

ASTM E 309 Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation

ASTM E 570 Standard Practice for Flux Leakage Examination of Ferro Magnetic Steel Tubular Products

ASTM E 1316 - 02a Standard Terminology for Nondestructive Examinations

3. TYPES OF NONDESTRUCTIVE TESTING

3.1 Eddy Current Testing

Eddy currents are the motion of electrons in a tube caused by a magnetic field generated by an alternating current in a nearby coil. In most applications where tubing is being tested, the tubing is passed through or nearby the coil arrangement, which can be encircling, in a semi-circle or a probe coil. As the tubing passes, the eddy currents are influenced by the characteristics of the metal, which include, conductivity, magnetic permeability, geometry, mass and homogeneity. Defects and flaws are detected by abnormal interruptions of the features being monitored and the electromagnetic system records the abnormalities as flaws. In most tube mill operations, the detection of a flaw in the tubing being manufactured automatically shuts down the mill, the flaw is removed, a correction action is determined and initiated, and then the mill is restarted.

3.1.1 Direct Sensing Method or Absolute Method

The strength of the eddy currents in the tubing being tested are exponentially proportional to the fill factor or lift-off factor (the amount of the area inside of the generating coil or the distance of the coil from the tubing being tested) and the excitation frequency. Once the flaw breaks the flow of electrons (eddy current), a sensing coil detects the difference, therefore resulting in the detection of the flaw. The characteristic that the eddy current senses can be studied by changes in amplitude (strength of signal), distribution and phase of the eddy currents. This method is preferred to detect long or continuous defects. Short or abrupt flaws might not be detected with the absolute method.

3.1.2 Comparison or Differential Method

Eddy current testing systems can be arranged to compare one section of tubing being tested to a section of tubing with known acceptable characteristics directly adjacent to it, therefore, providing an acceptable or an unacceptable comparison or differential. This method is preferred to find short or abrupt flaws.

3.1.3 Surface Phenomenon

Eddy current flow is generally more of a surface phenomenon and the sensitivity to finding flaws below the surface decreases with depth. The depth of penetration also decreases exponentially with increase in frequency. Frequency excitation, magnetic saturation and filtering can be used to increase sensitivity to subsurface flaws.

3.1.4 Maximizing Eddy Current Setup

In any eddy current test setup, it can be difficult to separate flaw signals from noise or vibration. The eddy current setup can be maximized by the following:

3.1.4.1 Proper coil setup.

3.1.4.2 Selection of the proper settings (test frequency, magnetic saturation and filtering).

3.1.4.3 Selection of the proper analysis circuit.

3.1.4.4 Proper testing location in the manufacturing process.

3.1.4.5 Demagnetization of the tubing is preferred after eddy current testing to prevent any shavings, chips or other ferrous particles from being attracted to the tubing. The most common way to demagnetize the tubing is draw it through a high intensity alternating current solenoid.

3.1.5 Advantages of Eddy Current Testing

3.1.5.1 Not dependent on defect orientation.

3.1.5.2 Suitable for high production of small diameter and light wall steel tubing.

3.1.5.3 Well suited for detection of short bond-plane weld defects.

3.1.5.4 Detection of subsurface cracks.

3.1.5.5 No couplant required.

3.1.6 Disadvantages of Eddy Current Testing

3.1.6.1 Can be influenced by non-injurious attributes such as hardness, surface condition, grain size, etc.

3.1.6.2 Lacks subsurface sensitivity in heavy wall tube.

3.1.6.3 Can require demagnetization after testing.

3.1.6.4

3.1.6.5 Permeability variations.

3.2 Flux Leakage Testing

Flux leakage testing is used to detect surface or near surface flaws such as pits, holes, cracks or seams in ferromagnetic tube materials only. Flux leakage testing is performed by magnetizing the tubing, which produces a north and south pole at each side of the flaw. When the flaw is present, the magnetic flux lines are forced to travel through the air at the location of the flaw, causing a leakage of flux. The magnetic flux field is induced into the tubing by applying an electric current into the tube by means of encircling coil or probe coil. The magnetic field induced into the tube needs to be perpendicular to the anticipated flaw. Any discontinuity in the tubing creates a leakage of flux at the surface of the part. The flaws are detected by the following two types of sensors.

3.2.1 Coil Type Sensor

Used to detect short flaws.

3.2.2 Hall Element

Used to detect gradual flaws.

3.2.3 Demagnetization

Demagnetization of the tubing is preferred and is usually required after flux leakage testing to prevent any shavings, chips or other ferrous particles from being attracted to the tubing. The most common way to demagnetize the tubing is draw it through a high intensity alternating current solenoid.

3.2.4 Advantages of Flux Leakage Testing

3.2.4.1 Not dependent on defect orientation.

3.2.4.2 Suitable for high production of small diameter and light wall steel tubing.

3.2.4.3 Well suited for detection of short bond-plane weld defects.

3.2.4.4 Well suited for detection of subsurface cracks.

3.2.4.5 No couplant required.

3.2.5 Disadvantages of Flux Leakage Testing

3.2.5.1 Can be influenced by non-injurious attributes such as hardness, surface condition, grain size, etc.

3.2.5.2 Lacks subsurface sensitivity in heavy wall tube.

3.2.5.3 Can require demagnification after testing.

3.2.5.4 Not well suited for short, small cracks.

3.2.5.5 Permeability variations.

3.3 Ultrasonic Testing

Ultrasonic testing is made possible due to the ability of solid materials to transmit high frequency sound waves. The amount of sound that a material can transmit is based on different physical properties such as density, modulus and grain size. Ultrasonic tests involve introducing controlled sound waves or ultrasonic energy into the tubing and observing how the passage of the sound is affected. Any defect in the tubing reflects or disperses energy. These reflections or dispersions of energy are detected by the ultrasonic system and are recorded as flaws.

3.3.1 Types of Ultrasonic Testing

3.3.1.1 Pulse Echo

Emits short burst of energy into the tubing, measures the amount of energy reflected back to the transducer. If the transducer receives energy, from a certain point, then a flaw is detected. The minimum thickness that the pulse can scan is 0.254 mm.

3.3.1.2 Through Testing

A continuous amount of ultrasonic energy is emitted into the tubing and a secondary transducer compares the energy transmitted, also known as the pitch and catch method.

3.3.1.3 Liquid Couplant Contact Testing Technique

Contact testing requires the transducer be placed directly on the tubing with a liquid couplant placed between the transducer and tubing. This requires a smooth finish on the tubing.

3.3.2 Advantages of Ultrasonic Testing

3.3.2.1 Excellent subsurface sensitivity in heavy wall tubular products.

3.3.2.2 Well suited to detect longitudinal weld line flaws in tubing.

3.3.2.3 Can analyze size, geometry and position of flaws.

3.3.2.4 Highly portable for field use.

3.3.2.5 Very sensitive to cracks.

3.3.3 Disadvantages of Ultrasonic Testing

3.3.3.1 Probes position in respect to the flaw is critical.

3.3.3.2 Difficult to use for surface flaws.

3.3.3.3 Difficult to use on light wall tubing.

3.3.3.4 Very dependent on defect orientations.

3.3.3.5 Requires use of couplant.

3.3.3.6 Limited by geometry; sample shall be smooth.

3.4 Magnetic Particle Testing

Finely divided magnetic particles (iron filings) can be introduced which causes a visible accumulation on the surface of the tube which readily identifies the flaw. This type of testing is not commonly used for production tube manufacturing. Most commonly used for inspecting small quantities of tubing in a non-production environment.

High Intensity Black Light

When fluorescent magnetic particles (iron filings) are being used, an operator using a high intensity black light is helpful to visually inspect the tubing for any indication of flaws.

4. TEST PROCEDURES

Setup requires a clean environment, free from dirt, grease, noise and electronic disturbances. The tube/line speed at which the testing is being performed needs to be compatible with the testing system; including frequency, filtering and full body coverage. In most batch testing processes some sort of end suppression can be used. This is an auto-sensing feature for the ends of the cut length tube that auto-activates the test system.

5. REFERENCE STANDARDS (KNOWN ACCEPTABLE MATERIAL SAMPLES)

The reference standards (known acceptable material samples) used to calibrate the test apparatus shall be on the same material type, temper and free of any discontinuities. The sample shall be a sufficient length to allow for the spacing of material discontinuities. The reference standard shall be tested at the same speed as the production settings.

5.1 Notches

Notches can be produced by electric discharge process, milling or saw cutting. The notches shall be placed in the transverse, longitudinal or a specified plane - such as an angle to the longitudinal axis of the tube. The depth, size, shape and configuration of the notch on the tube, affect the response of the testing system to the notches.

5.2 Drilled Holes

Drilled holes are typically specified by the purchaser and are defined as a percentage of the nominal tubing wall thickness or a diameter of 0.76 mm may be used. Drilled holes are commonly drilled through the entire wall of the tubing, although varying depths of 50% to 100% of the wall thickness drilled 20 mm from each other can be useful in determining a more dynamic calibration of the testing apparatus. Holes of varying depth and diameter used to calibrate the equipment can also provide useful results, depending on the final usage and construction of the tubing.

NOTE: When calibrating double-walled tubing, be aware of where the artificial discontinuities are placed. For maximum effectiveness, the discontinuities should be placed 180º from the seam or seams, unless otherwise specified by the purchaser.