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Standard Practice for Electromagnetic (Eddy-Current) Sorting of Nonferrous Metals[1]

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1. Scope

1.1 This practice describes a procedure for sorting nonferrous metals using the electromagnetic (eddy-current) method. The procedure is intended for use with instruments using absolute or comparator-type coils for distinguishing variations in mass, shape, conductivity, and other variables such as alloy, heat treatment, or hardness that may be closely correlated with the electrical properties of the material. Selection of samples to evaluate sorting feasibility and to establish calibration standards is also described.

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

2. Referenced Documents

2.1 *ASTM Standards:*

E 105 Practice for Probability Sampling of Materials[2]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[2]

E 1316 Terminology for Nondestructive Examinations[3]

3. Terminology Definitions

3.1 Definitions of terms relating to electromagnetic testing are given in Terminology E 1316.

4. Summary of Practice

4.1 The techniques that are primarily used in electromagnetic sorting employ the absolute (single-) and comparative (two-) coil methods using either encircling or probe coils. The decision of whether to use single-coil or two-coil operation is usually based on empirical data. In the absolute-coil method (encircling or probe), the equipment is calibrated by placing standards of known properties in the test coil. The value of the tested electrical parameter, which may be correlated with alloy, heat treatment temper, or hardness, is read on the display of an indicator. In the comparative coil method (encircling or probe coils), the test specimen in one coil is compared with a reference piece in a second coil to determine whether the test specimen is within or outside of the required limits.

4.1.1 *Absolute Coil Method*:

4.1.1.1 *Encircling Coil*—Samples of known classification (standards) are inserted consecutively in the test coil, and the controls of the instrument are adjusted to obtain appropriate response. Typically, three samples would be used representing the upper, lower, and mid-range for which calibration is required. The test is then conducted by inserting the specimens to be sorted into the test coil, and observing the instrument response.

4.1.1.2 *Probe Coil*—The probe coil is placed consecutively on the standards of known properties and the controls of the instrument are adjusted for appropriate response (see 4.1.1.1). The test is then conducted by placing the probe on the specimens to be sorted and observing the instrument response.

4.1.2 *Comparative Coil Method*:

4.1.2.1 *Encircling Coil*—Known reference pieces (standards) representing the minimum or maximum limits, or both, of acceptance or sorting category are inserted in the reference and test coil. The instrument controls are adjusted for appropriate responses. The test is then conducted by inserting specimens to be sorted in the test coil, leaving the known reference in the reference coil and observing the instrument response.

4.1.2.2 *Probe Coil*—Both probe coils are placed on the reference pieces (standard) representing the minimum or maximum limits, or both, of acceptance or sorting category. The instrument controls are adjusted for appropriate responses. The test is then conducted by placing the test probe on the specimens to be sorted (the other probe is left on the reference standard) and observing the instrument response.

4.2 The range of instrument response must be so adjusted in the initial step that the anticipated deviations will be within the range of readout.

4.3 Both absolute and comparative methods using encircling coil(s) require comparing the specimens to be tested with the reference piece(s). Two or more samples representing the limits of acceptance may be required. In the absolute method,

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

the electrical reference signal from the instrument is adjusted with the standard in the coil. In the comparative method, any electromagnetic condition, that is not common to the test specimen and the standard will produce an imbalance in the system. The comparative method is usually more stable since it suppresses most of the interferences.

4.4 The testing process may consist of manual insertion of one specimen after another into the test coil or an automated feeding and classifying mechanism may be employed. In automated setups, it is sometimes necessary to establish empirically the time required for the test specimen to remain in the test coil while the reading is being taken, especially if low frequencies are employed.

5. Significance and Use

5.1 Absolute and comparative methods provide a measure for sorting large quantities of nonferrous parts or stock with regard to composition or condition, or both.

5.2 The comparative or two-coil method is used when high-sensitivity testing is required. The advantage of this method is that it almost completely suppresses interferences.

5.3 The ability to accomplish these types of separations satisfactorily is dependent upon the relation of the electric characteristics of the nonferrous parts to their physical condition.

5.4 These methods may be used for high-speed sorting in a fully automated setup where the speed of testing may approach many specimens per second depending on their size and shape.

5.5 Successful sorting of nonferrous material depends mainly on the variables present in the sample and the proper selection of frequency and fill factor.

5.6 The accuracy of a sort will be affected greatly by the coupling between the test coil field and the tested part during the measuring period.

6. Interferences

6.1 The influence of the following variables must be considered for proper interpretation of the results:

6.1.1 The correlation shall be established so that electrical properties of various groups do not overlap and are well defined in the calibration procedure used.

6.1.2 The test frequency must be selected to provide a well-defined separation of variables.

6.1.3 The temperature of the standard and test specimen shall be controlled within limits that will permit a well-defined range of conductivity or permeability, or both, for which the correlation of the group or groups is valid. Cooling of the test standard when high field strengths are used or allowing test specimens to cool or heat to an established ambient range, or both, may be required.

6.1.4 The geometry, mass, and thickness of the standard and test specimen shall be controlled within limits that will permit sorting.

6.1.5 Magnetic permeability variations can interfere when sorting paramagnetic materials.

6.1.6 Signal response can result from a change in relative motion between the test specimen and the test coil, such as the length of time the specimen is in a test coil (see 4.4).

6.1.7 Conductivity has an unambiguous relationship to hardness for certain alloys. However, when alloys are mixed, identical conductivity does not necessarily indicate the same hardness.

6.1.8 Care must also be exercised in using conductivity to sort overheated parts quenched at a high temperature as the conductivity reading for acceptable parts may repeat at a large increase in temperature.

6.1.9 Lift-off can result in a change in the test system output with probe coils. This effect is a change in the magnetic coupling between the test specimen and probe coil. Care must be exercised to prevent this effect from interfering with test results; either mechanical or electronic compensation must be used.

6.1.10 For certain heat-treatable (aluminum) alloys, conductivity values can also repeat themselves during the aging cycle at a constant temperature. Thus, for such alloys, conductivity is not unique as a monitor of temper, etc.

7. Apparatus

7.1 *Electronic Apparatus*—The electronic apparatus shall be capable of energizing the test coils with alternating currents of suitable frequencies and power levels and shall be capable of sensing changes in the electromagnetic response of the coils. Equipment may include any suitable signal-processing devices (phase discriminator, filter circuits, etc.) and the output may be displayed by meter, oscilloscope, recorder, signaling devices, or any suitable combination required for the particular application.

7.2 Test coils may be of the encircling or probe-coil type and shall be capable of inducing an electromagnetic field in the test specimen and standard, and sensing changes in the electric or magnetic characteristics of the test specimen.

7.2.1 When selecting the test coil, the objective should be to obtain a coil fill factor as large as possible. This means that the inside of the test coil should be filled by the test specimen as much as possible. This is of primary importance for tests requiring high sensitivity.

7.2.2 For complicated test specimen shapes, a corresponding insert shall be provided to ensure that each test specimen can be placed in the same position within the test coil. These inserts, as well as any other accessories, should consist of nonferromagnetic, electrically nonconductive material.

7.3 *Mechanical Handling Apparatus*— A mechanical device for feeding and sorting the test specimens may be used to automate a particular application.

8. Sampling

8.1 Sampling (see Practices E 105 and E 122) is a method to obtain assurance that materials are of satisfactory quality. Instead of 100 % inspection, a portion of the material is examined to show evidence of the quality of the whole. There are two important needs for this approach: first, in the final inspection or tests made to assure that products delivered are in conformance with specification requirements; second, to control parts and assemblies while they are being processed. Statistical acceptance sampling tables and statistical process-control sampling tables have been developed to meet these needs.

8.2 Acceptance sampling may be conducted on an accept/reject (or attributes) basis; that is, determining whether or not the units of the sample meet the specification. Examination of the samples may also be conducted on a measurements (or variables) basis; that is, determining actual readings on the units in the sample. The majority of acceptance sampling is carried out on a sampling by attributes basis and the usual acceptance sampling table is designed for accept/reject.

8.3 Process control sampling may be conducted on material during the course of production to prevent large quantities of defective parts being found in the acceptance tests. Many parts and materials are subjected to several successive machining or processing operations before they become finished units. Parts can be most effectively controlled during production by examining small samples of these parts at frequent regularly scheduled intervals. The object of this process check is to provide a continuous picture of the quality of parts being produced. This helps prevent production of defective parts by stopping and correcting the problem as soon as it begins to appear in the manufacturing process and thereby keeping the process in control. Sampling may be by attributes or by variables and process control sampling tables are used. The measurements (variables) control chart is by far the most effective process control technique.

8.4 Statistical sampling tables have four definite features: *(1)* specification of sampling data—that is, the size of the samples to be selected, the conditions under which the samples are to be selected, and the conditions under which the lot will be accepted or rejected; *(2)* protection afforded—that is, the element of risk that the sampling schedules in a given table will reject good lots or accept bad ones; *(3)* disposal procedure—that is, a set of rules that state what is to be done with lots after sampling has been completed; and *(4)* cost required—that is, average inspection cost required to accept or reject a lot.

9. Test Specimen or Sample (Calibration Standards)

9.1 Two known samples of the precise size and configuration of the product to be tested are usually used to set up for sorting by the absolute coil method (see 10.2). Three known samples of the precise size and configuration are usually used for sorting by the comparative coil (see 10.3) method.

9.2 Three known samples are usually required for a three-way mix (see 10.4).

9.3 The sample should be selected to represent the extremes of acceptable and unacceptable groups or a range of hardness or conductivity to assure no overlap in the sort.

9.4 Other arrangements can be used and are acceptable but are not described in this procedure.

10. Calibration and Standardization

10.1 The electromagnetic sorting method is primarily one of comparison between specimens. Empirical data and physical tests on samples representing properties to be separated determine the validity of the sort. The calibration and standardization procedure shall be based on the properties of the sample requiring separation. The sort may require more than one test operation.

10.2 When using the absolute coil method (encircling), insert the known acceptable calibration standard to a fixed position in the coil and adjust the test instrument to get an on-scale meter or oscilloscope reading, or both. Replace the acceptable standard with a known unacceptable standard in the same exact position and adjust the sensitivity of the instrument to maximize the indicated difference reading without exceeding 90 % of the available scale range.

10.3 When using the comparative coil method (encircling), select a reference piece (usually one that falls within the acceptable limits of the specimens being tested), place it in the reference coil and set this coil and piece in a location so that it will not be accidentally disturbed during the sorting operation. For this method, when used with a two-way mix, choose two calibrated standards, one of which represents the acceptable and the other the unacceptable group. Place the acceptable calibration standard at a fixed position in the test coil coinciding with the position of the reference piece in the reference coil and balance the instrument. Replace this acceptable calibration standard with one representing the unacceptable group and adjust the test instrument's phase, sensitivity, and coil current, to maximize the indicator reading without exceeding 90 % of the available scale range. Reinsert the acceptable standard and alternately readjust the instrument controls to retain a null value for the acceptable standard and maximum indication for the unacceptable standard.

10.4 For a three-way sort, it is best to have three calibration standards, two of which represent the high and low limits of acceptability for one group or one each of the two unacceptable groups. The third standard represents the acceptable lot of material.

10.4.1 A typical case of high and low limits of acceptability standards is in measurements where standards representing maximum and minimum acceptable hardness are required. In this instance, insert the third standard representing the acceptable lot into the test coil and adjust the instrument for a null or zero reading. Then adjust the controls to maximize the indications without exceeding ±90 % of the available scale range from the null for each of the other two standards (maximum and minimum). Alternate readjustment of the controls may be necessary to retain the null reading, as well as the maximum and minimum limits for acceptance.

10.4.2 For a three-way sort when three dissimilar grades of material become mixed, place the third standard (acceptable group) into the test coil and null. Then successively insert into the test coil the two standards representing the other two grades and adjust the instrument's controls to maximize the indications without exceeding ±90 % of the available scale range from the null for each of the other two standards. Alternate readjustment of the controls may be necessary to retain the null reading as well as the indication for the other two standards.

10.5 A similar procedure to that used with encircling coils is used with probe coils (10.2-10.4). Instead of placing standards in the coil(s), position the probe(s) in a suitable location on the standard(s).

11. Procedure

11.1 Connect the required test coil to the instrument. Place insert(s) or other positioning fixture in the coil(s) if required.

11.2 Switch on the instrument and allow it to warm up for at least the length of time recommended by the manufacturer.

11.3 Make all necessary setup and control adjustments in accordance with the manufacturer's recommendation. Adjust frequency, field strength, sensitivity, and other necessary controls to values determined for the electromagnetic sort.

11.4 Calibrate the sorting system in accordance with 10.2 when using the absolute coil method, 10.3 when using the comparative coil method, or 10.5 when using probe coils. Calibrate at the start of the test run and at least once every hour of continuous operation or whenever improper functioning of the system is suspected (see 11.7).

11.5 For manual operation, insert the test specimens manually in the test coil.

11.5.1 Read the test results on an indicator.

11.5.2 Manually remove the specimens from the test coil.

11.6 For automatic sort, transmit the test specimens continuously through the test coil.

11.6.1 In passing through the coil, each test specimen is analyzed by the test instrument.

11.6.2 A signal, corresponding to the conductivity of the respective test specimen, is sent to a sorting gate where the tested specimens are automatically sorted into preselected groups.

11.7 Verify the calibration of the instrument at the end of testing each lot. If the calibration is found to have changed since the last check so that it affects the sort, recalibrate the system and retest all of the material tested since the last check.

12. Interpretation of Results

12.1 The results of most nondestructive testing procedures are based on the comparison of an unknown with a standard. Unless the significant interrelationships of material or product properties are understood and measurable for both standard and unknown samples, erroneous test results may be obtained.

12.2 Electromagnetic sorting is best used for repetitive tests on material that has the same shape, composition, and metallurgical structure; that is, it is not generally used for tests on grossly different materials. Electromagnetic sorting is generally not useful if there is limited knowledge of the properties of the unknown or test material.

12.3 Interpretation of data depends upon the degree to which the test materials compare with the reference materials. It is necessary to have all variables, except that one selected as a basis for sorting, under control if the measured variation is to be properly interpreted. Results can often be interpreted or explained by a processing change, such as temperature, composition, and inclusions, when the measured property is known to be a function of the processing procedures.

12.4 When products with different shapes, alloys, or conductivities are to be sorted, only a qualitative interpretation of results can be made. The materials can be said to be different, but the reason for the difference may not be understood.

12.5 When the spread in value of the measured variable is sufficient, electromagnetic sorting can be 100 % effective. However, there may be cases where a single test will not show a clear separation. Often a second test or procedure can be used to further define the separation of materials. For example, a different test frequency may show the effect of a second variable.

12.6 Shape and surface variations can mask the test results. If surface hardness is desired as the basis for sorting, all material should have composition and surface roughness under sufficient control so that the effects of variations in hardness can be separated.

13. Report

13.1 The written report of an electromagnetic sort should contain any information about the test setup that will be necessary to duplicate the test at the same or some other location, plus such other items as may be agreed upon by the using parties. The following information should be recorded:

13.1.1 Description of apparatus:
13.1.1.1 Type of equipment.
13.1.1.2 Model number.
13.1.1.3 Serial number.
13.1.2 Recorder (if used):
13.1.2.1 Type.
13.1.2.2 Model number.
13.1.2.3 Serial number.
13.1.3 Coil:
13.1.3.1 Size.
13.1.3.2 Type.
13.1.4 Other interconnecting apparatus.
13.1.5 Reference standards.
13.1.6 Test frequency.
13.1.7 Description of materials:
13.1.7.1 Geometry.
13.1.7.2 Chemistry.
13.1.7.3 Heat treatment.
13.1.8 Method of calibration.
13.1.9 Scanning speed.
13.1.10 Temperature of the standard.
13.1.11 Temperature of the test specimen.
13.1.12 Test method.

14. Precision and Bias

14.1 Measurement bias depends upon factors that include equipment, techniques, temperature control of parts and standard, geometry, types of materials, and operator. Variations in these factors can affect the bias of the sort.

15. Keywords

15.1 electromagnetic (eddy current) testing; nonferrous metals; sorting

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