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**Non-destructive testing - Test method for measuring
industrial computed tomography (CT) density**

无损检测 工业计算机层析成像（CT）密度测量方法

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Table of Contents

Foreword 3

1 Scope 4

2 Normative references 4

3 Terms and definitions..... 4

4 Basic requirements..... 4

5 Test method 6

6 Test technology..... 8

7 Measurement process 10

8 Test record and report 12

Appendix A (Informative) Fabrication specifications of the density comparison
test specimen 13

Appendix B (Informative) Mass attenuation coefficient of typical substances
under different energies..... 15

Appendix C (Informative) Calculation method of equivalent energy 16

Non-destructive testing - Test Method for Measuring Industrial Computed Tomography (CT)

1 Scope

This Standard specifies the methods to use industrial computed tomography (CT) to measure the density of objects.

This Standard is applicable to industrial CT systems, of which the energy range is 200keV ~ 10 MeV, and which perform density-measurement of common metal and non-metallic materials.

2 Normative references

The following documents are indispensable for the application of this document. For dated references, only the dated version applies to this document. For undated references, the latest edition (including all amendments) applies to this document.

GB/T 9445 Non-destructive testing - Qualification and certification of NDT personnel (GB/T 9445-2015, ISO 9712:2012, IDT)

GB/T 29069 Non-destructive testing. Test method for measurement of industrial computed tomography (CT) system performance

GB/T 29070 Non-destructive testing. Industrial computed tomography (CT) testing. General requirements

GB/T 34365 Non-destructive testing. Terminology. Terms used in industrial computed tomography testing

3 Terms and definitions

Terms and definitions determined by GB/T 34365 and the following ones are applicable to this document.

4 Basic requirements

4.1 Test personnel

4.1.1 Personnel engaged in industrial CT density measurement shall meet the

ρ -- density value of the to-be-test sample, in grams per cubic centimeter (g/cm^3);

μ -- linear attenuation coefficient;

μ_m -- mass attenuation coefficient.

This method requires the mass attenuation coefficient of a known substance; THEREFORE, it cannot measure a substance of an unknown component or a polymer substance which is difficult to measure the mass attenuation coefficient. The mass attenuation coefficient is different under different energies; THEREFORE, the equivalent energy of the CT system needs to be determined first when this method is used. See Appendix C for the calculation method of equivalent energy. When the equivalent energy is 200 keV ~ 2 MeV, the mass attenuation coefficient hardly changes with the change of energy. THEREFORE, if the mass attenuation coefficient of the to-be-test substance is unknown, THEN, the mass attenuation coefficient of a known substance which has similar density can be used instead.

5.2 Method 2

Select a density standard sample in the density comparison test specimens as the density reference sample of density measurement. According to the average CT density $\bar{f}_0$ of the specified area of the density reference sample AND the proportionality coefficient K which is set by the CT system (generally 1000 ~ 5000 according to the overall parameters of the CT system), perform normalization to the average CT density $\bar{f}$ of the designated area of each density comparison test specimen according to Formula (3), so as to obtain the average CT value $\bar{\mu}$ in the area:

$$\bar{\mu} = \frac{\bar{f} - \bar{f}_0}{\bar{f}_0} \times K \quad \dots\dots\dots (3)$$

Where:

$\bar{\mu}$ -- average CT number of the specified area of the density comparison test specimen;

$\bar{f}$ -- average CT density of the specified area of the density comparison test specimen;

$\bar{f}_0$ -- average CT density of the specified area of the density standard sample;

K -- proportionality coefficient that is set by the CT system.

Use the average CT number $\bar{\mu}$ of the specified area of each density comparison test specimen AND the known density ρ of the standard sample;

detection, errors which are introduced by CT artifacts and ray hardening shall be minimized; the measurement range shall be selected to avoid the areas which are affected by artifacts; and the selected pixels shall be valid pixels; if necessary, filtering shall be used to remove invalid pixels.

7.3 Density measurement

7.3.1 Select the same density reference sample that is used in the density calibration (the density comparison test specimen that is closest to the density of the to-be-test substance); place the density reference sample near the test area of the to-be-test object to perform CT scan, at the same time, as the measured object; or place the density reference sample individually at the same scanning position (with the test area of the to-be-test object), and use the same processing parameters as the to-be-test object, to scan the density comparison test specimen separately.

7.3.2 CT scanning process conditions of density measurement, such as specimen placement, scanning mode, scanning parameters (tube voltage, tube current, focus size, filtering method, slice thickness, diameter of the field of view, scan matrix, sampling time, etc.) and reconstruction parameters, shall be exactly the same as those of the density comparison test specimens.

7.3.3 In consideration of the stability of the equipment itself, in the actual detection process, according to the situation, periodically re-scan the density comparison test specimen; determine the change of the CT value of the density comparison test specimen; if necessary, modify the functional relation between the CT number and the density, so as to improve the detection accuracy.

7.3.4 Obtain the average CT density $\bar{f}$ of the specified area (the number of pixels in the specified area should not be less than 100 and not more than 2/3 of the entire standard sample image area) from the CT image of the density reference sample.

7.3.5 Obtain the average CT density $\bar{f}$ of the to-be-test area (the number of pixels in the area should be not less than 100) from the CT image of the to-be-test object. If Method 2 is used to perform the density measurement, perform normalization according to Formula (3) to obtain the average CT number $\bar{\mu}$ of the to-be-test area.

7.3.6 Obtain the average material density of the area according to the average CT number of to-be-test area and the calibrated functional relation.

7.3.7 Repeat the measurement of different areas of the same uniform material for at least 5 times; use the average value of the densities which were measured from 5 times as the density value of the material; and calculate the standard deviation of the density measurement.

Appendix C

(Informative)

Calculation method of equivalent energy

C.1 Calculation process

C.1.1 Set the detection parameter to the highest density resolution, and use industrial CT to detect the density comparison test specimen.

C.1.2 For the measurement of the average CT number of each density standard sample of the density comparison test specimens in a certain range (the measurement range should be a circular area; the number of pixels in each circular area should be no less than 100, but no more than 2/3 of the entire standard sample image area; the number of measurements should not be less than 5), it is recommended to use the least squares to establish the functional relation [Formula (1)] between the average CT number and the linear attenuation coefficient;

C.1.3 Multiply the density of each sample by the mass attenuation coefficient to obtain the linear attenuation coefficient μ_1 of the sample, and respectively select the mass attenuation coefficient of a set of energy ranges (the range shall include the equivalent energy of the system) to calculate the linear coefficient of each sample, so as to obtain the linear attenuation coefficient of each sample at different energies.

C.1.4 Use the functional relation [Equation (1)] to calculate the linear attenuation coefficient μ_2 of each sample; respectively calculate the correlation coefficient BETWEEN the linear attenuation coefficient μ_1 AND the linear attenuation coefficient μ_2 under different energies.

C.1.5 Select the energy corresponding to the maximum value of the correlation coefficient as the equivalent energy of the CT system.

C.2 Calculation example

Use the industrial CT system of 9 MeV to measure the density of three substances, namely methyl methacrylate ($\text{H}_8\text{C}_5\text{O}_2$), tetrafluoroethylene (C_2F_4) and aluminum (aluminum, Al); and respectively measure the average CT number of the three substances; use the least squares to calculate the coefficients k and c of Formula (1); THEN use Formula (1) to calculate the linear attenuation coefficient μ_1 of each substance; check the table to gain the mass attenuation coefficient of each substance at 3 700 keV ~ 4 000 keV; THEN multiply the corresponding density to gain the linear attenuation coefficient μ_2

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