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Determination of the film thickness of coatings using an ultrasonic gage

Détermination de l'épaisseur du feuil de revêtement par mesurage ultrasons

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Foreword

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The committee responsible for this document is ISO/TC 35, *Paints and varnishes*, Subcommittee SC 9, *General test methods for paints and varnishes*.

Determination of the film thickness of coatings using an ultrasonic gage

1 Scope

This Technical Specification describes a method for determining the film thickness of coatings on metallic and non-metallic substrates using an ultrasonic gauge.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4618, *Paints and varnishes — Terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4618 and the following apply.

3.1
ultrasonic wave
acoustic wave having a frequency higher than the range of audibility of the human ear, generally taken as higher than 20 kHz

[SOURCE: EN 1330-4:2010, 3.1.1]

3.2
longitudinal wave
compressional wave
wave in which the particle motion in a material is in the same direction as the propagation of the wave

[SOURCE: EN 1330-4:2010, 2.3.1]

3.3
echo
ultrasonic pulse reflected to the probe

[SOURCE: EN 1330-4:2010, 5.5.2]

3.4
echo height
echo amplitude
height of an *echo* (3.3) indication on the screen

[SOURCE: EN 1330-4:2010, 5.5.5]

3.5
ultrasonic impulse
short-lived ultrasound signal

3.6
ultrasonic sensor
ultrasonic probe
device for sending and receiving *ultrasonic waves* (3.1), mostly based on piezoelectric materials

3.7
acoustic impedance
Z
product of sound velocity and density of a material

3.8
reflection coefficient
ratio of total reflected sound pressure to incident sound pressure at a reflecting surface

[SOURCE: EN 1330-4:2010, 3.4.11]

Note 1 to entry: For a wave the reflection coefficient R is calculated from the *acoustic impedances* (3.7) Z_1 and Z_2 of the bordering media, for which 1 is the medium of the incoming sound:

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

For a negative reflection coefficient the *phase* (3.9) of the reflected signal is changed by 180°.

3.9
phase
fraction of a complete wave cycle, expressed as an angle

[SOURCE: EN 1330-4:2010, 2.2.5]

3.10
interface
boundary between two media, in acoustic contact, having different *acoustic impedances* (3.7)

[SOURCE: EN 1330-4:2010, 3.4.1]

3.11
sound path travel time
time needed for the sound path travel distance

[SOURCE: EN 1330-4:2010, 5.6.3]

3.12
couplant
coupling film
medium interposed between the probe and the object under examination to enable the passage of *ultrasonic waves* (3.1)between them

[SOURCE: EN 1330-4:2010, 5.3.2]

3.13
A-scan presentation
display of the ultrasonic signal in which the X-axis represents the time and the Y-axis the amplitude

[SOURCE: EN 1330-4:2010, 5.5.16]

Note 1 to entry: Ultrasonic film thickness measuring devices, besides the numerical values of the obtained film thicknesses, normally display A-scans for checking the echo forms and echo sequences on a screen as well.

3.14
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with *adjustment of a measuring system* (3.15), often mistakenly called "self-calibration", nor with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: ISO/IEC Guide 99:2007, 2.39]

3.15
adjustment of a measuring system
adjustment
set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment and span adjustment (sometimes called "gain adjustment").

Note 2 to entry: Adjustment of a measuring system should not be confused with *calibration* (3.14), which is a prerequisite for adjustment.

Note 3 to entry: After adjustment of a measuring system, the measuring system normally should be recalibrated.

[SOURCE: ISO/IEC Guide 99:2007, 3.11]

3.16
working standard
standard which is traceable to the national standard

[SOURCE: EN 60731:2007, 3.4.1.2]

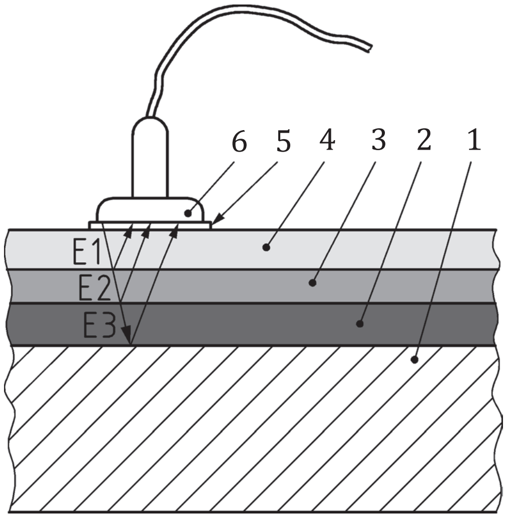
4 Principle

The method described in this Technical Specification determines single film thicknesses from the times of flight of an ultrasonic impulse that is partially reflected at the interfaces of the coating system. The strengths and weaknesses of the method are shown by measuring data for the different film-substrate combinations that are relevant in practice.

5 Physical principles of the measuring method and of the application

When measuring the film thickness using ultrasound, longitudinal waves are used because they can be easily generated and can be coupled into a work piece with almost every liquid. As shown in Figure 1, a sensor (6) consists of a piezoelectric disc, for sound generation and for reception, and of a "delay path". The ultrasonic impulse generated in the sensor first passes the delay path and then spreads through layers 1 to 3 down to the substrate (1) and beyond.

On each interface, a fraction of the impinging ultrasonic wave is reflected as a new ultrasonic impulse, while another fraction passes through. The first reflection occurs in the ultrasonic sensor when the ultrasonic impulse impinges on layer 1 (4).



Key

1 substrate

2 layer 3

3 layer 2

4 layer 1

5 couplant (liquid)

6 ultrasonic sensor (sender and receiver)

E echo 1, 2, 3

Figure 1 — Ultrasonic method

Ultrasonic impulses are recorded when they are received in the ultrasonic sensor. The distances of time between the ultrasonic impulses correspond to the sound path travel times T_i (i = 1, 2, 3) in the three individual layers. The amplitude or echo height of the ultrasonic impulse reflected on each interface depends on the respective reflection factors. If the sound velocity in each single layer is known, the respective film thickness can be calculated by means of the times of flight. For each layer, Formula (1) applies:

$$v = \frac{t_\mathrm{d}}{T/2} \qquad (1)$$

where

v is the sound velocity;

t_d is the dry film thickness;

T is the sound path travel time in the layer (back and forth).

In order to be able to resolve echoes with short intervals of sound path travel times with the naked eye (e.g. 20 ns in a 20 µm thick coating), the ultrasonic impulses shall be at least just as short. For this, the ultrasonic frequencies shall be respectively high (at least the reciprocal of half of the time of flight) or the A-scan shall be generated from lower frequencies by means of digital signal processing. For an example of an A-scan, see Figure 2.

When layers are too thin, the echoes of the individual layers merge into each other. In this case, an optic control of the evaluation in the A-scan presentation is no longer possible.

In cases where the A-scan presentation shows positive and negative half-waves, it shall be taken into account that for a negative reflection factor ($Z_2 < Z_1$) the phase of the ultrasonic impulse changes by 180°. If this is ignored, a relative time delay of a half wavelength can occur.

The precondition for ultrasonic impulses with signal amplitudes sufficiently high for evaluation forming at the interface of two layers is

— a sufficiently high reflection coefficient or respectively different acoustic impedances *Z*, and

— a clearly defined intersection between the materials.

Otherwise, the reflections can become too low for detection. This can also occur with curved work pieces where, due to geometry, not all sound fractions simultaneously re-impinge from the interface on the sensor.

Key

T sound path travel times for layers 1, 2, 3

E echo for layers 1, 2, 3

Figure 2 — Example of an A-scan presentation

6 Apparatus and materials

6.1 Ultrasonic film thickness measuring device

A device with an ultrasonic sensor for sending and receiving ultrasonic impulses and an evaluation unit for determining the film thickness over the time of flight (see Figure 1).

NOTE The ultrasonic sensors used for measuring the film thickness generate ultrasonic signals (longitudinal waves), which spread perpendicularly to the surface of the work piece and the coating. In the schematic diagram in Figure 1, a slant representation of the sound propagation was selected only for illustrating the sound generation.

6.2 Couplant

An acoustic contact between probe and test specimen with sufficient coupling shall be enabled. Commonly, a liquid (e.g. water or oil) or a gel couplant is applied.

6.3 Calibration standards

For checking the function of a measuring device, a working standard shall be used.

For checking the measuring method and for adjusting the device prior to use, a working measurement standard shall be used; one which largely corresponds to the respective test object to be measured with regard to film thickness, coating system, substrate and thicknesses of the layers.

7 Calibration, adjustment and checking of the measuring device

7.1 Calibration

Calibrate the device in accordance with the manufacturer's information.

NOTE Primarily, the time of flight of a signal is measured with the measuring devices. This time of flight can be checked, if necessary, with a calibration standard with defined thickness and known sound velocity.

7.2 Adjustment

Adjust the device in accordance with the manufacturer's information.

When adjusting the entering of sound velocities, it is recommended to use test specimens that are based on the minimum and maximum film thicknesses that would be expected for the determination of these sound velocities. Using the ultrasonic film thickness measuring device, the time of flight of the ultrasonic impulse and the sound velocities, in accordance with Formula (1), are determined in the same measuring area in which the film thickness was or will be determined with an alternative method.

The determination of the time of flight is carried out repeatedly on each test specimen and the mean is taken for each test specimen.

When selecting the test specimens to use for the determination of the sound velocity, it should be considered that the thinner the test specimens and the lower the sound path travel times, the more imprecise the determination of the sound velocity from time of flight and thickness.

When calculating, it shall be observed that the data are entered in the units used by the manufacturer of the device and, after a calculation in SI units, that these have been converted.

7.3 Checking the adjustment

Prior to recording the measurements, after turning the device on, and for alterations of the coating system or substrate of the test object, the adjustment of the measuring device shall be checked by means of a working standard.

All the device settings should always be done in accordance with the manufacturer's information.

After the adjustment, device settings that influence the ultrasonic signals shall not be changed. When exchanging the probe or changing the device settings another adjustment shall be carried out.

8 Procedure of measurement

Operate the device in accordance with the manufacturer's information.

Apply some couplant to the coating and measure its film thickness. Lay the sensor perpendicularly onto the coating and press so that the film of couplant becomes as thin as possible. Keep the probe calmly in the measuring position until a stable measuring value is displayed.

9 Temperature influence during the measurement

Most of the probes are intended to be used between −20 °C and +60 °C. However, it is recommended to carry out ultrasonic film thickness measurements, preferably in the range of common ambient temperatures, in order to keep the test object, couplant and probe at an equilibrium temperature during measuring. Temperature gradients in the delay path of the probe or in the test object influence the measuring results due to uncontrollable changes and fluctuations of the sound velocity.

In all materials the sound velocity depends more or less on the temperature.

NOTE For polymers, the changes are typically in the range of 0,1 % to 0,3 % per °C for a negative temperature coefficient.

In order to minimize errors due to temperature changes, constant temperature conditions should be observed. Adjusting and subsequent measuring shall be carried out at the same temperature. In cases where there are prolonged breaks between the measurements and changes of the ambient temperature the adjustment shall be checked.

10 Precision

10.1 General

For further information on the determination of precision see Annex B.

10.2 Repeatability limit

The repeatability limit *r* is the value below which the absolute difference between two test results (each the mean of three valid determinations) can be expected to lie when this method is used under repeatability conditions. In this case, the test results are obtained on identical material by one operator in one laboratory within a short interval of time using the described test method. The repeatability limit *r* in accordance with this specification, calculated with a probability of 95 %, corresponds to the values given in Tables 1 and 2.

Table 1 — Repeatability limit (*r*) for individual test specimens

Test specimen	Film thickness µm	Repeatability limit (*r*) µm
Spruce veneered	100	4
Spruce sanded	100	6
Beech veneered	100	6
Beech sanded	100	6
Aluminium	22	3
Aluminium	44	4
Carbon-fibre composite	22	3
Carbon-fibre composite	44	3
PP (polypropylene)	22	4
PP (polypropylene)	44	4
SMC (sheet moulding compound)	22	5
SMC (sheet moulding compound)	44	9
Steel	22	3
Steel	44	4