
**Implants for surgery — Ultra-high
molecular weight polyethylene —**

**Part 4:
Oxidation index measurement method**

*Implants chirurgicaux — Polyéthylène à très haute masse
moléculaire —*

Partie 4: Méthode de mesurage de l'indice d'oxydation



Reference number
ISO 5834-4:2005(E)

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Published in Switzerland

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 5834-4 was prepared by Technical Committee ISO/TC 150, *Implants for surgery*, Subcommittee SC 1, *Materials*.

ISO 5834 consists of the following parts, under the general title *Implants for surgery — Ultra-high molecular weight polyethylene*:

- *Part 1: Powder form*
- *Part 2: Moulded forms*
- *Part 3: Accelerated ageing methods*
- *Part 4: Oxidation index measurement method*
- *Part 5: Morphology assessment method*

Introduction

This part of ISO 5834 describes a method for the measurement of the relative extent of oxidation present in ultra-high molecular weight polyethylene (UHMWPE) intended for use in surgical implants. The material is analysed by infrared spectroscopy. The intensity of the carbonyl absorptions ($>C=O$) centred near $1\,720\text{ cm}^{-1}$ is related to the amount of chemically bound oxygen present in the material. Other forms of chemically bound oxygen (R_1OR_2 , R_1OOR_2 , ROH , etc.) are not detected by this method.

Although this method might give the investigator a means to compare the relative extent of carbonyl oxidation present in various UHMWPE samples, it is recognized that other forms of chemically bound oxygen can be important contributors to characteristics of these materials.

The applicability of the infrared method has been demonstrated by many literature reports. This particular method, using the intensity (area) of the C-H absorption centred near $1\,370\text{ cm}^{-1}$ to normalize for the sample's thickness, has been validated by an interlaboratory study (ILS).

Implants for surgery — Ultra-high molecular weight polyethylene —

Part 4: Oxidation index measurement method

1 Scope

This part of ISO 5834 specifies a method for the measurement of the relative extent of oxidation present in ultra-high molecular weight polyethylene (UHMWPE).

It is applicable to ultra-high molecular weight polyethylene (UHMWPE) intended for use in surgical implants.

2 Normative references

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

ISO 5834-2, *Implants for surgery — Ultra-high molecular weight polyethylene — Part 2: Moulded forms*

ISO 11542-1, *Plastics — Ultra-high-molecular-weight polyethylene (PE-UHMW) moulding and extrusion materials — Part 1: Designation system and basis for specifications*

ISO 11542-2, *Plastics — Ultra-high-molecular-weight polyethylene (PE-UHMW) moulding and extrusion materials — Part 2: Preparation of test specimens and determination of properties*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11542-1 and ISO 11542-2 and the following apply.

3.1 aperture size

L_a

length and width of a rectangular aperture, or the diameter of a circular aperture used by an infrared spectrometer to make spectral measurements

3.2 bulk oxidation index

$I_{ox,b}$

⟨sample⟩ mean of the oxidation indices collected over a range of about 1,5 mm near the centre of the sample's oxidation index profile

NOTE Typically this is a plateau region with the smallest oxidation indices. For samples less than about 8 mm to 10 mm thick, this central region might display the sample's highest oxidation indices, depending on its state of oxidation.

3.3
depth locator

d_i
measurement of the mean distance from the articular surface, or surface of interest, from which a spectrum was collected and a corresponding I_{ox} calculated

3.4
increment size

L_i
distance between two adjacent locations on a test film where sequential infrared spectra are collected

NOTE This distance is typically a constant for a given test specimen.

3.5
normalization peak area

A_{norm}
total area of the normalization peak(s) between 1 330 cm^{-1} and 1 396 cm^{-1}

NOTE This area is computed as the area between the baseline and the spectral trace, as shown in Figure 1.

3.6
oxidation

incorporation of oxygen into another molecule (e.g. UHMWPE) by means of a chemical covalent bond

3.7
oxidation index

I_{ox}
ratio of the area of the absorption peak(s) between 1 650 cm^{-1} and 1 850 cm^{-1} (A_{ox}) to the area of the absorption peak(s) between 1 330 cm^{-1} and 1 396 cm^{-1} (A_{norm})

See Figure 1.

3.8
oxidation index profile

graphical representation of variation of the sample's oxidation index with distance from its articular surface or the surface of interest

NOTE This is a plot of I_{ox} against d_i . Typically the graph will show the profile through the entire thickness of the sample.

3.9
oxidation peak area

A_{ox}
total area of the absorption peak(s) between 1 650 cm^{-1} and 1 850 cm^{-1}

NOTE This area is computed as the area between the baseline and the spectral trace, as shown in Figure 1.

3.10
surface oxidation index

$I_{ox,s}$
<sample> mean of the oxidation indices from the sample's articular surface, or the surface of interest, to a depth of 3 mm subsurface

4 Test articles

The test articles shall be made from UHMWPE moulded material and classified as Type 1, Type 2 or Type 3 in accordance with ISO 5834-2.

NOTE The UHMWPE finished products for this application are not equipped with light stabilizers and therefore need to be protected against UV influence.

5 Materials and apparatus

5.1 Materials

The test articles for oxidation index measurements shall be made from UHMWPE moulded forms complying with the requirements of ISO 5834-2.

5.2 Apparatus

5.2.1 Infrared spectrometer, calibrated, capable of recording a transmission absorption spectrum over the range of about $1\,200\text{ cm}^{-1}$ to about $2\,000\text{ cm}^{-1}$, using 0,15 mm to 0,25 mm thick films at a resolution of 4 cm^{-1} and an aperture of about $0,2\text{ mm} \times 0,2\text{ mm}$. An increment size of 0,2 mm is recommended.

Other modes of collection [i.e. percent reflection, attenuated total reflection (ATR), etc.], and aperture and increment sizes may be used to generate the sample's absorption spectrum provided they can be demonstrated to produce equivalent results. Too large an aperture can result in a loss of profile accuracy.

When a Fourier transform infrared (FTIR) spectrometer is used, a minimum of 32 scans shall be collected per spectrum. The FTIR instrument and sample compartment should be purged with a moisture- and carbon-dioxide-free inert gas (e.g. nitrogen, helium, or argon) to minimize spectral interference from these components.

5.2.2 Specimen holder, consisting of equipment capable of accurately positioning the sample under the aperture.

5.2.3 Microtome, consisting of equipment capable of producing 0,15 mm to 0,25 mm thick slices (films) of a sample perpendicular to the articular surface or the surface of interest.

6 Significance and use

The methods described in this part of ISO 5834 may be used to measure the oxidation indices of UHMWPE components under real-time conditions such as shelf ageing and after implantation and accelerated oxidative challenges.

7 Procedure

7.1 Preparation of test specimens

Using a microtome, or other appropriate device, prepare a thin slice of the sample 0,15 mm to 0,25 mm thick. The slice shall typically be taken near the centre of the sample's articular surface or the surface of interest. The orientation of the slice shall typically be perpendicular to the articular surface or the surface of interest.

7.2 Configuration of test specimen in the spectrometer

The test film (slice) shall be first configured in the spectrometer (after an appropriate background spectrum has been collected) so that the aperture is positioned over the first 0,2 mm of the film starting at the articular surface. Subsequent spectra shall be collected sequentially at about 0,2 mm increments from the articular surface across the width of the film to the opposite surface. Larger increment sizes may be used, however too large an increment size can result in a loss of profile accuracy.

7.3 Preparation of the infrared spectrometer

Prepare the infrared spectrometer for collection of a transmission absorption spectrum from a thin film of the UHMWPE sample, according to the manufacturer's recommendations and the conditions described in 7.1. Collect the sequence of spectra according to 7.2.

8 Calculations

8.1 General

The results obtained from the following calculations can be useful for describing the oxidation characteristics of a sample or comparing the oxidation characteristics of one sample with another.

8.2 Oxidation peak area

For each absorbance spectrum, calculate the total area of the peak absorptions between $1\,650\text{ cm}^{-1}$ and $1\,850\text{ cm}^{-1}$ (Figure 1, A_{ox}). This is the area below the sample's absorption curve and above the straight baseline drawn between the same starting and ending points, namely: $1\,650\text{ cm}^{-1}$ and $1\,850\text{ cm}^{-1}$.

8.3 Normalization peak area

For each absorbance spectrum, calculate the total area of the peak absorptions between $1\,330\text{ cm}^{-1}$ and $1\,396\text{ cm}^{-1}$ (Figure 1, A_{norm}). This is the area below the sample's absorption curve and above the straight baseline drawn between the same starting and ending points, namely: $1\,330\text{ cm}^{-1}$ and $1\,396\text{ cm}^{-1}$.

8.4 Oxidation index

For each absorbance spectrum, calculate its I_{ox} by dividing the area of its oxidation peak (8.1) by the area of its normalization peak (8.2), as shown in Figure 1.

8.5 Depth locator

Calculate the mean distance from the articular surface (d_i) for each spectrum and its corresponding I_{ox} from the following equation:

$$d_i = 0,5L_a + nL_i$$

where

L_a is the size of the aperture in micrometers in the step direction;

n is the number of steps (increments) by which the aperture is moved from its initial location at the articular surface;

L_i is the step (increment) size in micrometers.

NOTE The absorbance recorded by the instrument corresponds to the area of the sample (aperture) being illuminated by the IR beam. The $0,5L_a$ factor in the equation allows for the calculation of the position of the centre of the aperture relative to the starting point or edge of the sample film.

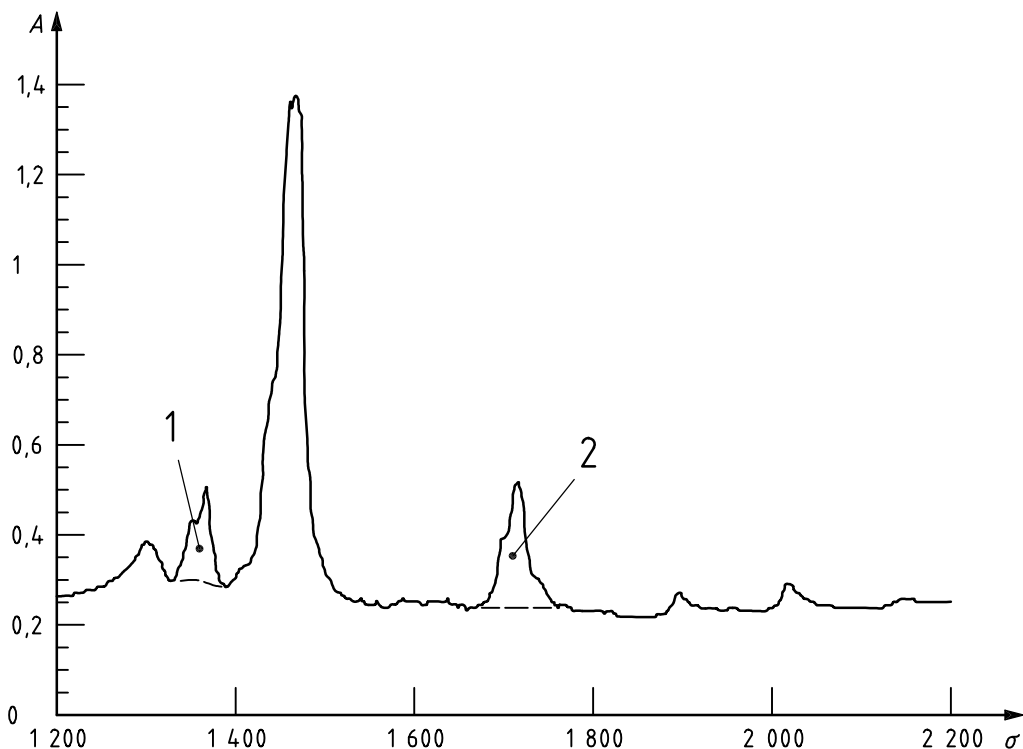
8.6 Sample's surface oxidation index

Calculate a sample's $I_{\text{ox},s}$ by calculating the mean average of the sample's oxidation indices (I_{ox}) with depth locator (d_i) values between 0 mm and 3 mm.

NOTE The first 3 mm of material subsurface to an articular surface typically experiences the greatest degree of real time oxidation and the greatest stresses during real time use. The $I_{\text{ox},s}$ is one way of representing the sample's oxidative state in this important region.

8.7 Sample's bulk oxidation index

Calculate a sample's $I_{\text{ox},b}$ by calculating the mean of the sample's oxidation indices (I_{ox}) corresponding to about the centre 1,5 mm of material.



Key

A absorbance

σ wavenumber, cm^{-1}

1 normalization peak area, A_{norm} ($1\,370\text{ cm}^{-1}$)

2 oxidation peak area, A_{ox}

$$I_{\text{ox}} = A_{\text{ox}}/A_{\text{norm}}$$

Figure 1 — Typical FTIR spectra of oxidized UHMWPE, showing the definition of an area-based oxidation index based on normalization using the $1\,370\text{ cm}^{-1}$ peak

8.8 Sample's oxidation index profile

Construct a plot of a sample's oxidation indices (I_{ox} , y -axis) versus their corresponding depth locators (d_i , x -axis).

9 Reports

9.1 General

It is important that details regarding the preparation of the test samples, the prior history of the material and the spectrometer operating parameters be recorded. Report the following minimum information in 9.2 to 9.8.

9.2 Information concerning the material

The resin type and resin lot number shall be reported along with its consolidation method(s), manufacturer and manufacturer lot number. Any special post consolidation treatments, e.g. hot isostatic pressing (HIP), annealing, sterilization, cross-linking, stabilization, accelerated ageing, and storage conditions shall also be reported.

9.3 Sample information

Each sample shall be clearly identified as an orthopaedic implant or explant or as a laboratory test specimen. The specimen's general geometry shall be described clearly detailing the orientation of the test specimen film relative to the sample geometry. Any special post-treatments of the original test sample, e.g. annealing, sterilization, cross-linking, stabilization, accelerated ageing, and storage conditions shall be stated.

The test film thickness and total width shall be reported together with any special post-treatments of the test films, e.g. annealing, sterilization, cross-linking, stabilization, accelerated ageing, mechanical treatments and storage condition.

9.4 IR spectrometer parameters

The manufacturer and model number of the spectrometer shall be reported along with the aperture dimensions, increment size, spectral resolution, and number of scans used.

9.5 Calculation methods

The methods used to calculate any reported I_{OX} , $I_{OX,s}$, $I_{OX,b}$, and I_{OX} profiles shall be clearly described.

9.6 Sample's calculated surface oxidation index

Each sample's surface oxidation index shall be reported.

9.7 Sample's calculated bulk oxidation index

Each sample's bulk oxidation index shall be reported.

9.8 Sample's calculated oxidation index profile

Each sample's calculated oxidation index profile shall be reported.

Bibliography

- [1] ISO 5834-1, *Implants for surgery — Ultra-high molecular weight polyethylene — Part 1: Powder form*
- [2] ISO 5834-3, *Implants for surgery — Ultra-high molecular weight polyethylene — Part 3: Accelerated ageing methods*
- [3] ISO 14242 (all parts), *Implants for surgery — Wear of total hip-joint prostheses*
- [4] ISO 14243 (all parts), *Implants for surgery — Wear of total knee-joint prostheses*

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