



International
Standard

ISO 9924-3

**Rubber and rubber products —
Determination of the composition
of vulcanizates and uncured
compounds by thermogravimetry —**

**Part 3:
Hydrocarbon rubbers, halogenated
rubbers and polysiloxane rubbers**

*Caoutchouc et produits à base de caoutchouc — Détermination
de la composition des vulcanisats et des mélanges non vulcanisés
par thermogravimétrie —*

*Partie 3: Caoutchoucs hydrocarbonés, caoutchoucs halogénés et
caoutchoucs polysiloxanes*

**Second edition
2024-02**

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 45, *Rubber and rubber products*, Subcommittee SC 2, *Testing and analysis*.

This second edition cancels and replaces the first edition (ISO 9924-3:2009), which has been technically revised.

The main changes are as follows:

- extension of the scope by deleting the mandatory preliminary extraction;
- the result of 2006 ITP has been deleted, the result of 2022 ITP has been added in [Annex C](#).

A list of all parts in the ISO 9924 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Rubber and rubber products — Determination of the composition of vulcanizates and uncured compounds by thermogravimetry —

Part 3:

Hydrocarbon rubbers, halogenated rubbers and polysiloxane rubbers

WARNING 1 — Persons using this document should be familiar with normal laboratory practice. This document does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of any other restrictions.

WARNING 2 — Certain procedures specified in this document might involve the use or generation of substances, or the generation of waste, that could constitute a local environmental hazard. Reference should be made to appropriate documentation on safe handling and disposal after use.

1 Scope

This document specifies a thermogravimetric method for the determination of the main constituents of rubber compounds such as elastomer(s), carbon black and mineral filler.

It establishes the “fingerprint” of the tested material. However, the result does not always correspond exactly to the theoretical formula of the rubber.

This method applies to raw or compounded rubbers, vulcanized and unvulcanised, with or without extraction.

This method applies to rubbers with hydrocarbon backbones (NR, BR, SBR, IIR, EPDM, ACM, AEM, etc.) used alone or as mixtures. For the mixtures, the polymer content corresponds to the total rubber and it is not usually possible to identify individual polymers.

This method applies to rubbers with halogenated hydrocarbon backbones (CR, CSM, FKM, CM, CO, ECO, etc.) or containing nitrogen (NBR, HNBR, NBR/PVC, etc.), as well as to their mixtures. However, these rubbers often form carbonaceous residues which interfere with the analysis. Application of an appropriate procedure minimizes these interferences.

This method also applies to rubbers with a polysiloxane backbone (VMQ, etc.) and to rubbers not listed above.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at <https://www.iso.org/obp>

— IEC Electropedia: available at <https://www.electropedia.org/>

4 Principle

A weighed test portion is heated following a pre-set programme in a known atmosphere.

Initial pyrolysis in an inert atmosphere (nitrogen) is followed by combustion in an oxidizing atmosphere.

Generally, the reactions that generate mass variations are decompositions, oxidations or reactions volatilizing a constituent.

The loss in mass as a function of temperature indicates a quantitatively usable thermogram which is characteristic of the material.

5 Reagents

5.1 Nitrogen of minimal purity 99,995 % mass fraction, with an oxygen content of less than 10 mg/kg (ppm) and hydrocarbon content less than 1,5 mg/kg (ppm).

5.2 Dry air, with no detectable trace of oil.

The air used may be reconstituted nitrogen and oxygen of purity minimum 99,5 % mass fraction. In some cases, pure oxygen may be used.

6 Apparatus

6.1 Thermogravimetric analyser (TGA).

6.1.1 General. Various types of analyser are commercially available. The basic components of an analyser are listed in [6.1.2](#) to [6.1.8](#).

6.1.2 Thermogravimetric balance, comprising a microbalance provided with a pan made from a nonoxidizable material that can weigh up to 50 mg, is readable to the nearest 1 µg and equipped with an oven capable of being maintained at temperatures from room temperature to approximately 1 000 °C.

6.1.3 Appropriate enclosure, allowing the sample to be kept under a specified atmosphere.

6.1.4 Pan or crucible, of size suitable to accommodate the sample and small enough to reduce the influence of buoyancy.

6.1.5 Temperature-control system, allowing heating rates to be controlled from 10 °C/min to 50 °C/min.

6.1.6 Gas selector, allowing successive introduction of the inert gas and oxidizing gas while controlling the flow rate.

6.1.7 Measurement equipment, for gas flow rate in the range 10 cm³/min to 250 cm³/min.

6.1.8 Data acquisition and processing system.

7 Preparation of samples

7.1 Conditioning of samples

Test samples should be conditioned in standardized laboratory conditions of temperature and humidity in accordance with ISO 23529. These conditions are preferred, but are not mandatory.

In order to refine the centesimal composition, prior extraction of plasticizers and additives with an appropriate solvent might be useful. In this case, the method described in ISO 1407 can be applied. The thermogravimetric analysis shall then be carried out on the non-extractable part previously dried until constant weight.

7.2 Test portion

Prepare a test portion of $8 \text{ mg} \pm 3 \text{ mg}$ cut into a single piece.

NOTE The preparation of the test portion can influence the kinetics of the phenomena.

8 Procedure

8.1 General

Considering the variety of the decomposition modes linked to the nature of polymers, two procedures are defined:

- procedure A for carbon rubbers;
- procedure B for polysiloxane and fluorocarbon rubbers.

If procedure A does not result in a thermogram that achieves constant mass at $600 \text{ }^\circ\text{C}$, procedure B shall apply.

A non-exhaustive list of the recommended procedures for each of the various rubber families is given in [Table A.1](#).

8.2 Description of the procedures

[Table 1](#) gives details of the operating steps for procedures A and B.

Table 1 — Operating steps

Step	Units	Procedure A	Procedure B
Initial temperature	$^\circ\text{C}$	35 ± 10	35 ± 10
Heating rate under nitrogen	$^\circ\text{C}/\text{min}$	20	20
Target temperature under nitrogen	$^\circ\text{C}$	600	800
Maintenance time at target temperature under nitrogen	min	0	5
Cooling under nitrogen	$^\circ\text{C}$	600 to 400	800 to 400
Temperature at the change of atmosphere	$^\circ\text{C}$	400	400
Maintenance time at atmosphere change temperature under air	min	2	2
Heating rate under air	$^\circ\text{C}/\text{min}$	20	20
Final temperature under air according to the equipment ^a	$^\circ\text{C}$	800 to 850	800 to 850
Maintenance time at the final temperature under air	min	10 to 20	10 to 20

^a If procedures do not result in a thermogram that achieves constant mass at final temperature under air, maintain the final temperature condition until constant mass is achieved.

8.3 Test procedures

8.3.1 Connect the apparatus and adjust (6.1.6) the gas flow to a rate between 20 cm³/min and 250 cm³/min (6.1.7). Set the parameters according to the chosen process.

The recommended flow rate is 100 cm³/min.

8.3.2 Before the test, ensure that the pan (6.1.4) or the crucible is clean and empty.

8.3.3 Close the thermobalance oven (6.1.2), purge with a nitrogen (5.1) flow at the preset rate. Wait until stabilization. Adjust the zero to compensate for the mass of the pan or the crucible.

8.3.4 Place the test piece prepared in accordance with 7.2 in the pan or the crucible and weigh it under the conditions specified in 8.3.3. Record the mass, m_0 .

8.3.5 Conduct the test by following the operating steps specified in Table 1.

8.3.6 At the end of the test, allow the oven to cool to room temperature, open it and clean the pan or the crucible.

9 Expression of results

9.1 Recordings

Make two different types of recording to enable the necessary calculations to be made:

- a plot of the percentage variation in mass fraction, w , versus temperature or time;
- a derivative plot, dw/dT .

These will be used to derive the content of the various compound ingredients.

9.2 Calculation of the mass change from curves

An example of a thermogram is given in Figure B.1.

The derivative plot shall be used to define particular points on the mass variation plot as follows.

Identify on the derivative plot the minima A'_0 , A'_1 , A'_2 , and A'_3 , corresponding to the closest points to return to zero of the derived function. Note these points on the main curve of mass change. Report A_0 , A_1 , A_2 , and A_3 on the ordinate and read the corresponding masses m_0 , m_1 , m_2 , and m_3 ,

where

- m_0 is the initial mass of the test piece;
- m_1 is the mass of the test piece remaining after pyrolysis;
- m_2 is the mass of the test piece remaining after pyrolysis and carbon black combustion;
- m_3 is the mass of the residue yield.

The percentage mass fraction loss, $w_1 + w_2$, due to pyrolysis is given by [Formula \(1\)](#):

$$w_1 + w_2 = \frac{m_0 - m_1}{m_0} \times 100 \quad (1)$$

The percentage mass fraction loss, w_5 , due to carbon black combustion is given by [Formula \(2\)](#):

$$w_5 = \frac{m_1 - m_2}{m_0} \times 100 \quad (2)$$

The percentage mass fraction loss, w_7 , due to partial or total decomposition of mineral components is given by [Formula \(3\)](#):

$$w_7 = \frac{m_2 - m_3}{m_0} \times 100 \quad (3)$$

The percentage mass fraction, w_8 , corresponding to the residue yield, is given by [Formula \(4\)](#):

$$w_8 = \frac{m_3}{m_0} \times 100 \quad (4)$$

The sum of the percentage mass fractions, $w_1 + w_2 + w_5 + w_7 + w_8$, shall correspond to 100 % (not including the analytical errors).

NOTE These operations can be calculated by computer.

9.3 Interpretation

9.3.1 General

A simple interpretation of the thermogram shall give pyrolysable, non-pyrolysable mass fraction losses and the residue.

9.3.2 Rubbers with hydrocarbon backbones (Figures B.2 and B.3)

a) Under nitrogen

The first loss in mass fraction, w_1 , corresponds to organic compounds of low molecular weight and volatile matter.

The second loss in mass fraction, w_2 , corresponds to the pyrolysis of one or several polymers. The end of the polymer decomposition is arbitrarily taken at the end of the heating step under nitrogen.

The percentage w_1 shall only be considered if the derivative returns to the origin. Otherwise, the overall percentage of organic compounds $w_1 + w_2$ shall be determined.

b) Under oxidizing atmosphere

- 1) w_5 is the loss in mass fraction, due to carbon black combustion (if any is present in the compound).
- 2) w_7 is the loss in mass fraction, due to the partial or total decomposition of mineral components (e.g. CaCO_3), (see Figure B.3).
- 3) w_8 is the residue yield at 800 °C.
- 4) w_6 is the mineral content, equal to $w_7 + w_8$.

NOTE 1 Extraction with a suitable solvent is used to separate organic compounds of low molecular weight and volatile matter from the polymer.

NOTE 2 Once the rubber has been extracted, it is no longer possible to determine w_1 on the thermal diagram. The percentage of extractable compounds in the calculation of the percentages is taken into account.

9.3.3 Rubbers with a nitrogenous hydrocarbon backbone (Figure B.4)

For nitrogen-containing hydrocarbon rubbers, the thermogram produced while nitrogen is flowing is similar to that described in 9.3.2. However, during pyrolysis, carbonaceous residues may be generated. These residues usually oxidize at lower temperatures than carbon black. If the resolution of the derivative plot allows, the corresponding mass fraction loss, w_3 , shall be added to the pyrolysate yield, w_2 .

NOTE NOTE 2 of 9.3.2 is also applicable.

9.3.4 Rubbers with a halogenated hydrocarbon backbone (Figure B.5)

For rubbers with a halogenated hydrocarbon backbone, the pyrolytic decomposition of the polymer takes place in several steps, in particular with:

- a) generation of volatile halogenated fragments;
- b) formation of carbonaceous residues.

The percentage mass fraction lost of halogenated volatile components, w_4 , shall be taken into account for the calculation of the content of polymer which is then equal to $w_4 + w_2$.

As the carbonaceous residues cannot be distinguished from the carbon black, the total content of carbon black shall be taken as $w_3 + w_5$.

NOTE NOTE 2 of 9.3.2 is also applicable.

9.3.5 Rubbers with a hydrocarbon, nitrogenous and oxygenated backbone

The thermogram is expressed in a similar way as for some rubbers with a nitrogenous hydrocarbon backbone (see 9.3.3).

9.3.6 Rubbers with a hydrocarbon and sulfurated backbone

The thermogram is expressed in a similar way as for some rubbers with a hydrocarbon backbone (see 9.3.2).

9.3.7 Rubbers with a polysiloxane backbone (Figure B.6)

The exploitation of a thermogram is specific to a polysiloxane-containing formulation.

During pyrolysis, this type of silicon-based polymer partially decomposes into silica, which then becomes part of the mineral residue yield. As a result, the polymer content is evaluated by default and the content of any mineral fillers is evaluated in excess.

NOTE NOTE 2 of 9.3.2 is also applicable.

9.4 Expression of results

9.4.1 Result obtained from the TGA curve

Thermograms can be interpreted in two different ways:

- the simple exploitation of the thermogram gives the contents of pyrolysable compounds, non-pyrolysable compounds and mineral residue;
- the detailed exploitation uses the following conventional values:
 - a) w_1 content lost due organic compounds of low molecular weight and volatile matters;

- b) w_2 content lost due to pyrolysable part of polymer(s);
- c) w_3 content lost due to combustion of any carbonaceous residues;
- d) w_4 content lost due to driving off any halogenated volatile fragments;
- e) w_5 content lost due to combustion of carbon black;
- f) w_6 content of mineral fillers and metallic salts;
- g) w_7 content lost due to mineral filler decomposition;
- h) w_8 mineral residue yield at 800 °C or 850 °C under air.

NOTE The different cases of Figures B.2 to B.6 are given with both interpretations.

9.4.2 Correction for extract in calculated percentage mass fractions of material

In the case of preliminary extraction, take into account the amount of extract in the calculation of the percentages. Calculate the extract-corrected mass fractions, w'_n , using the [Formula \(5\)](#):

$$w'_n = \frac{w_n (100 - w_1)}{100} \quad (5)$$

where

n is 2 to 8 (for definitions of the individual parameters, see [9.4.1](#));

w_1 is the extractable matter content, as a percentage mass fraction, determined by solvent extraction.

10 Test report

The test report shall contain at least the following information:

- a) sample details:
 - 1) full description of the sample and its origin,
 - 2) conditions of preparation of the sample,
 - 3) the extraction solvent with the method used;
- b) test method:
 - 1) a full reference to the test method used, i.e. the number of this document (ISO 9924-3:2024),
 - 2) the procedure used (A or B);
- c) test details:
 - 1) the laboratory temperature,
 - 2) the time and temperature of conditioning prior to test,
 - 3) the temperature of test, if other than standard laboratory temperature,
 - 4) type of equipment used,
 - 5) details of any procedures not specified in this document as well as the possible incidents;
- d) test results:
 - 1) the number of test pieces used,

- 2) the individual test results,
- 3) the date of test.

11 Precision

See [Annex C](#).

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Annex A
(informative)

Recommended procedures

Table A.1 — Recommended procedures according to rubber families (non-exhaustive list)

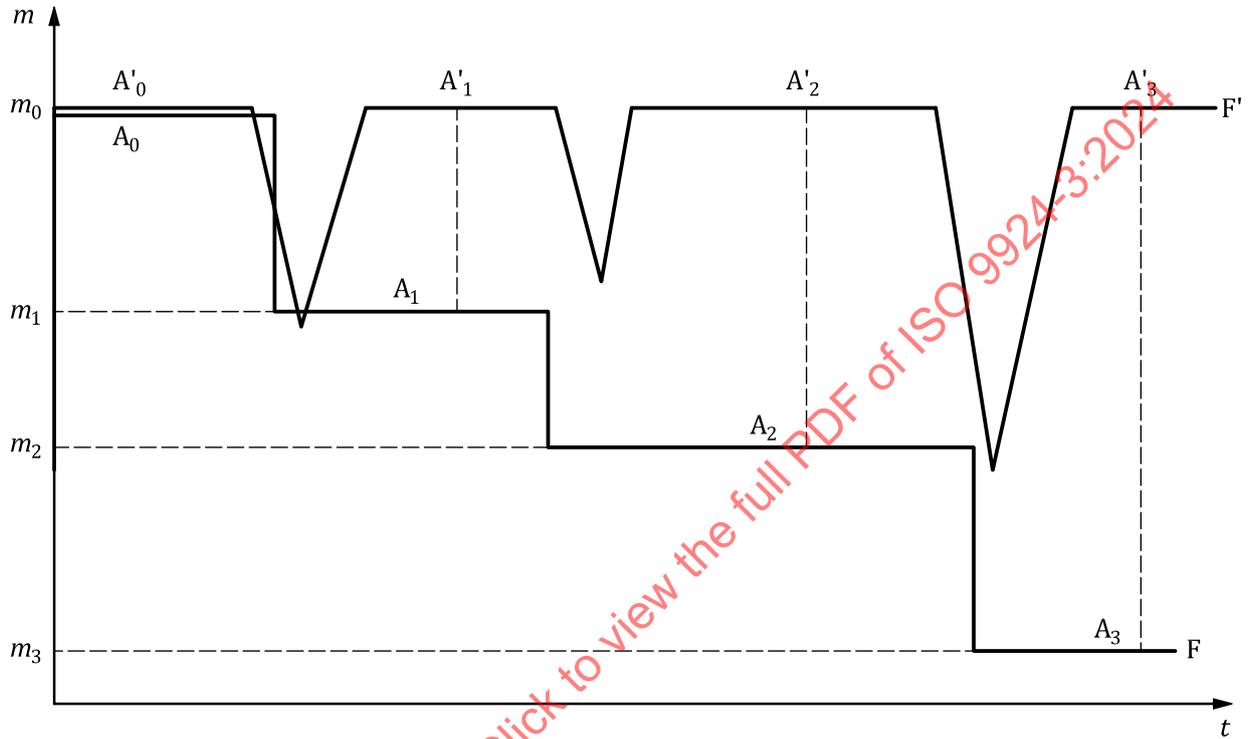
Rubber families	Procedure
Rubbers with a hydrocarbon backbone	
Natural rubber (NR) or synthetic isoprene rubber (IR)	A
Polybutadiene (BR)	A
Styrene-butadiene rubber (SBR)	A
Isobutene-isoprene rubber (IIR)	A
Ethylene-propylene-diene terpolymer (EPDM)	A
Copolymer of ethyl acrylate or other acrylates (ACM)	A
Copolymer of ethyl acrylate or other acrylates and ethylene (AEM)	A
Copolymer of ethylene and vinyl acetate (EVM)	A
Rubbers with a nitrogenous hydrocarbon backbone	
Acrylonitrile-butadiene rubber (NBR)	A
Hydrogenated acrylonitrile-butadiene rubber (HNBR)	A
Carboxylic acrylonitrile-butadiene rubber (XNBR)	A
Rubbers with a halogenated hydrocarbon backbone	
Chloroprene rubber (CR)	A
Chlorosulfonylpolyethylene (CSM)	A
Chloropolyethylene (CM)	A
Alkyl chlorosulfonylpolyethylene (ACSM ^a)	A
Polychloromethyloxirane (CO)	A
Copolymer of ethylene oxide and chloromethyloxirane (ECO)	A
Acrylonitrile-butadiene rubber/polyvinylchloride blend (NBR/PVC)	A
Isobutene-isoprene rubber brominated or chlorinated (BIIR or CIIR)	A
Fluorocarbon rubbers (FKM)	B
Rubbers with a hydrocarbon, nitrogenous and oxygenated backbone	
Polyester urethane or polyether urethane (AU or EU)	A
Rubbers with a hydrocarbon and sulfurated backbone	
Polysulfide rubber (T)	A
Rubbers with a polysiloxane backbone	
Polymethylvinylsiloxane (VMQ)	B
Polymethylfluorosiloxane (FMQ)	B

^a Name and abbreviated term do not appear in ISO 1629.

Annex B
(informative)

Examples of thermogram

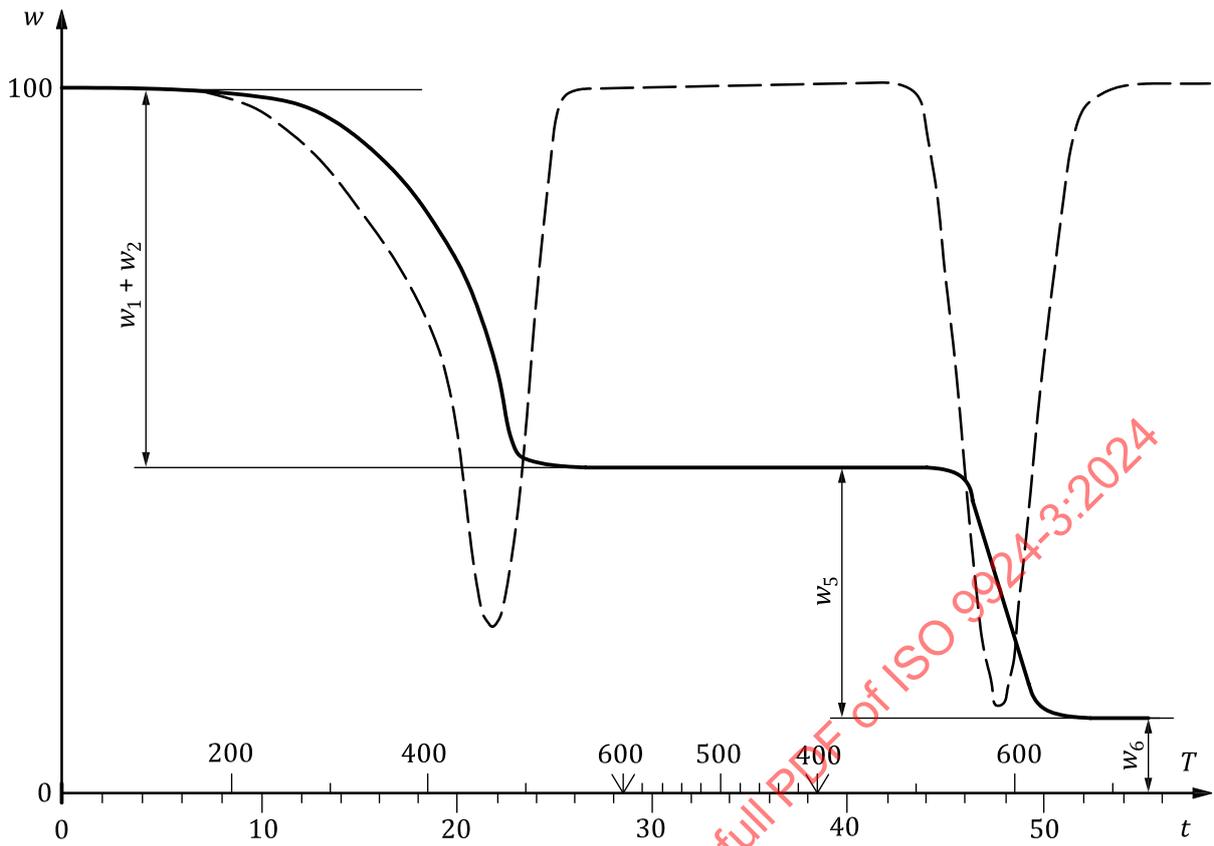
Examples of various thermograms are illustrated in [Figures B.1](#) to B.6.



Key

A_0, A_1, A_2, A_3	absolute minima	m_0	initial test piece mass
A'_0, A'_1, A'_2, A'_3	derivative minima	m_1	test piece mass after pyrolysis
F	main curve	m_2	test piece mass after pyrolysis and carbon black combustion
F'	derivative curve	m_3	residue yield mass
m	mass	t	time

Figure B.1 — Thermal diagram

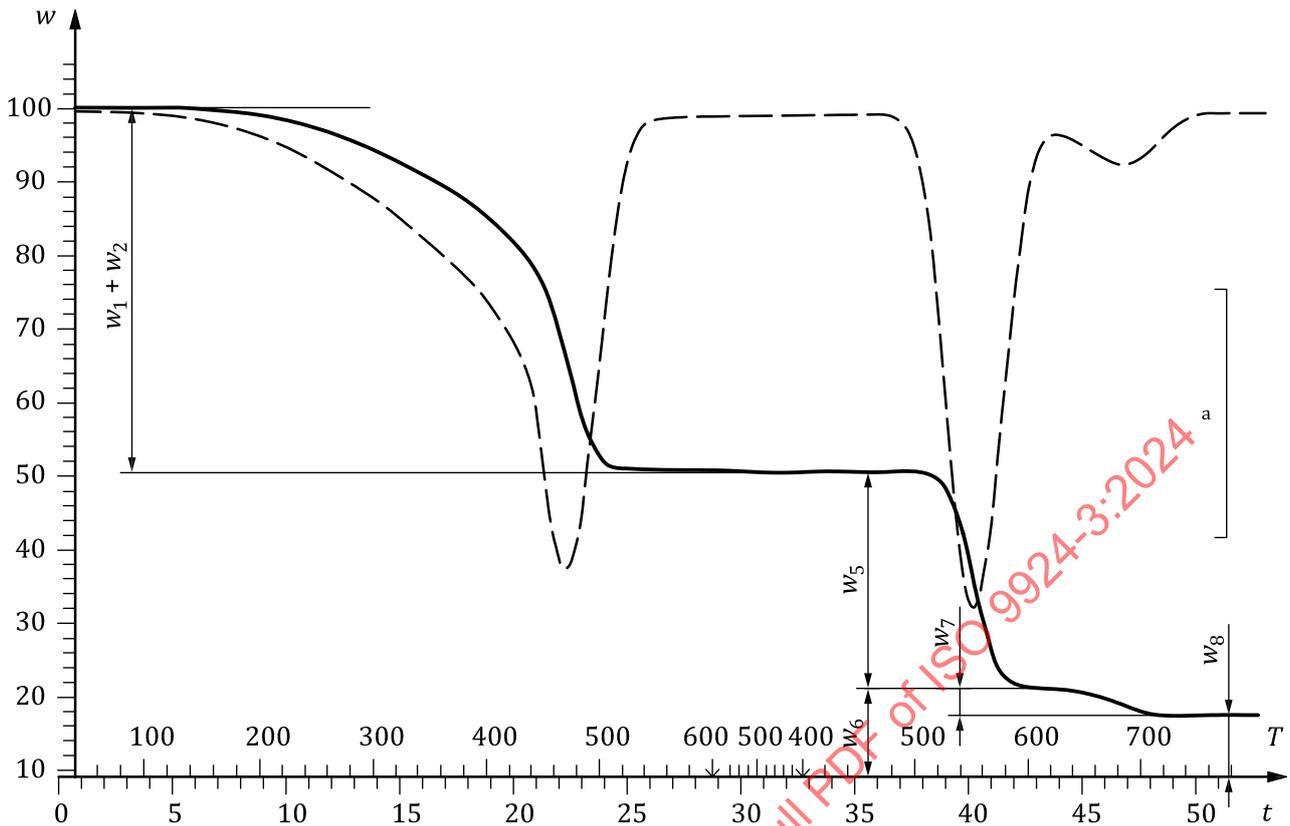


Key

- t time
- T temperature
- w mass fraction (content)

Detailed exploitation		Simple exploitation
w_1	content of organic compounds of low molecular weight and volatile matters	pyrolysable compounds
w_2	content of pyrolysable part of polymer(s)	
w_5	content of carbon black	non-pyrolysable compounds
w_6	content of mineral fillers and metallic salts	mineral residue

Figure B.2 — Example of a rubber with a hydrocarbon backbone

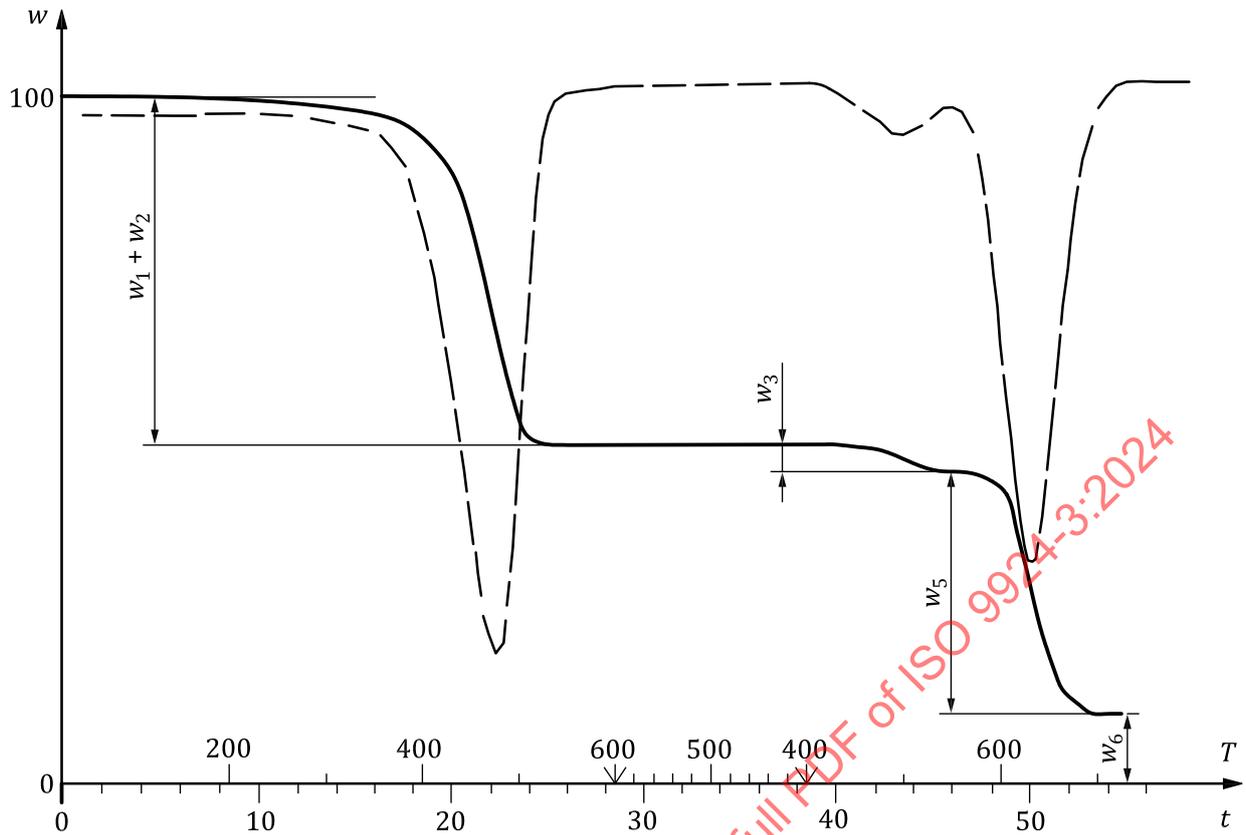


Key

- t time
- T temperature
- w mass fraction (content)
- a % min. $\begin{matrix} 5 \\ -1 \end{matrix}$

Detailed exploitation		Simple exploitation
w_1	content of organic compounds of low molecular weight and volatile matters	pyrolysable compounds
w_2	content of pyrolysable part of polymer(s)	
w_5	content of carbon black	non-pyrolysable compounds
w_7	content of mineral filler decomposition	mineral residue
w_8	mineral residue yield at 800 °C or 850 °C under air	
	w_6	content of mineral fillers and metallic salts

Figure B.3 — Example of a rubber with a hydrocarbon backbone containing calcium carbonate

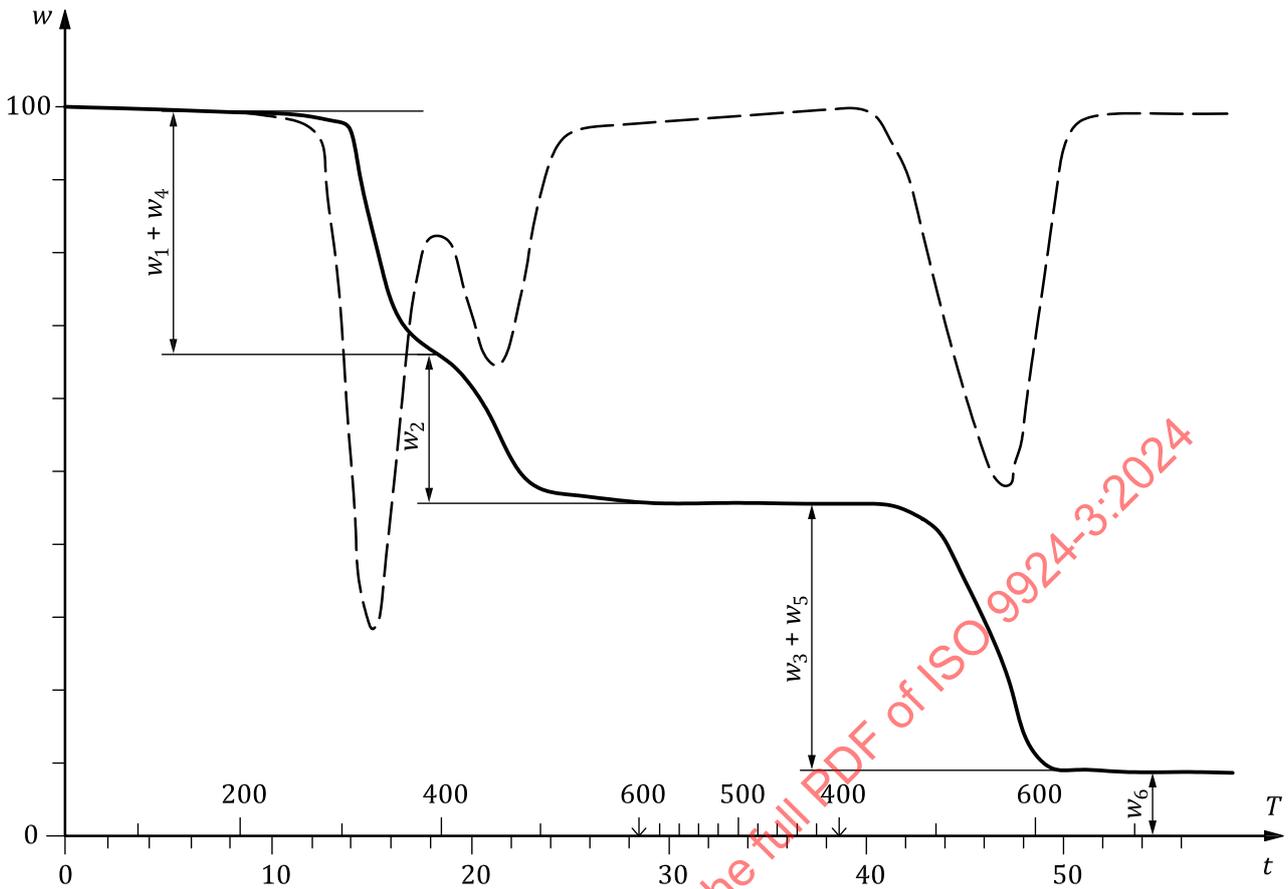


Key

- t time
- T temperature
- w mass fraction (content)

Detailed exploitation		Simple exploitation
w_1	content of organic compounds of low molecular weight and volatile matters	pyrolysable compounds
w_2	content of pyrolysable part of polymer(s)	
w_3	content of carbonaceous residues	non-pyrolysable compounds
w_5	content of carbon black	
w_6	content of mineral fillers and metallic salts	mineral residue

Figure B.4 — Example of a rubber with a backbone containing hydrocarbon and nitrogen

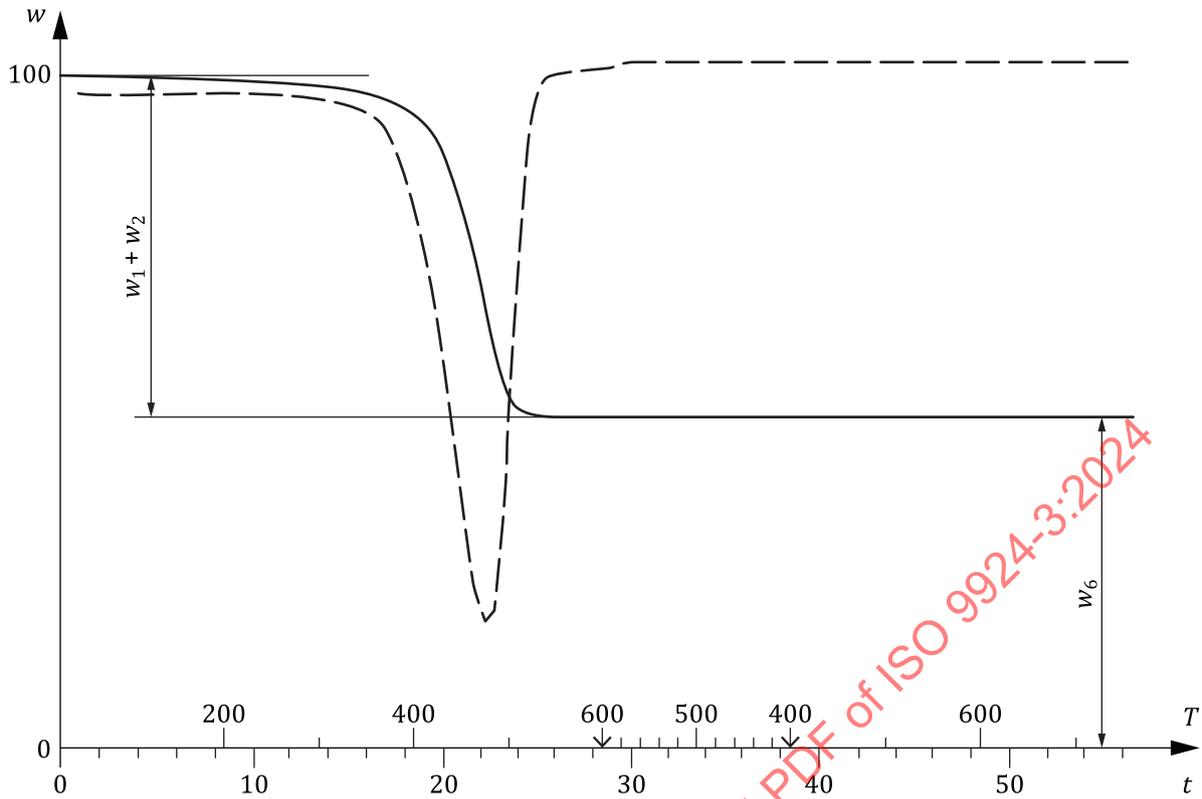


Key

- t time
- T temperature
- w mass fraction (content)

Detailed exploitation		Simple exploitation
w_1	content of organic compounds of low molecular weight and volatile matters	pyrolysable compounds
w_2	content of pyrolysable part of polymer(s)	
w_4	content of halogenated volatile fragments	
	polymer(s)	non-pyrolysable compounds
w_3	content of carbonaceous residues	
w_5	content of carbon black	mineral residue
w_6	content of mineral fillers and metallic salts	

Figure B.5 — Example of a rubber with a halogenated hydrocarbon backbone



Key

- t time
- T temperature
- w mass fraction (content)

Detailed exploitation		Simple exploitation
w_1	content of organic compounds of low molecular weight and volatile matters	pyrolysable compounds
w_2	content of pyrolysable part of polymer(s)	
w_6	content of mineral fillers and metallic salts	mineral residue ^a

^a The mineral residue also includes the silica generated by the pyrolysis of the polymer.

Figure B.6 — Example of a rubber with a polysiloxane backbone