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Additive manufacturing — Environment, health and safety — Test method for the hazardous substances emitted from material extrusion type 3D printers in the non-industrial places

Fabrication additive — Environnement, santé et sécurité — Méthode d'essai pour les substances dangereuses émises par les imprimantes 3D de type à extrusion de matière dans les lieux non industriels

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Foreword

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The committee responsible for this document is ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM Committee F42, *Additive Manufacturing Technologies*, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on Additive Manufacturing, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 438, *Additive manufacturing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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.

Introduction

This document refers to the assessment of hazardous substances emitted during operation of material extrusion type AM machines, commonly known as “3D printers” installed in schools or public places for educational and hands-on purposes, and basic countermeasures for reducing the substances.

This document provides the necessary information and test procedures to reflect the characteristics of the AM process based on the previous international standards related to indoor air quality and to assess hazardous substances in the non-industrial places.

Operator, supervisor, and manager who are working at the non-industrial places will be able to use this document to measure and diagnose air quality. This document also includes appendices to help them try to reduce the hazardous substances emitted into the non-industrial spaces.

Additive manufacturing — Environment, health and safety — Test method for the hazardous substances emitted from material extrusion type 3D printers in the non-industrial places

1 Scope

This document specifies a test method for measuring hazardous substances emitted during the operation of material extrusion type AM machines commonly used in the non-industrial places and includes non-normative suggestions for ways to reduce them.

This document specifies some of the main hazardous substances emitted from this type of machine during operation for currently commonly used materials, it describes the additional information and the associated test method for measuring hazardous substances, and includes considerations for reducing the hazardous substances and basic countermeasures.

This document specifies how to measure concentrations of hazardous substances generated in the non-industrial places (school, public place and so on) in which this type of machines are installed, and to maintain an acceptable work environment by managing field facilities, machines, filaments, and additive manufactured products for the reduction of hazardous substances.

However, this document does not cover all gas-phase chemical emissions. Only a range of Volatile Organic Compounds (VOCs) from n-hexane to n-hexadecane, including aldehydes are included. Considerations for reducing chemical emissions and for improving the work environment are given in Annexes A and B.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 16000-2, *Indoor air — Part 2: Sampling strategy for formaldehyde*

ISO 16000-3, *Indoor air — Part 3: Determination of formaldehyde and other carbonyl compounds in indoor and test chamber air — Active sampling method*

ISO 16000-4, *Indoor air — Part 4: Determination of formaldehyde — Diffusive sampling method*

ISO 16000-5, *Indoor air — Part 5: Sampling strategy for volatile organic compounds (VOCs)*

ISO 16000-6, *Indoor air — Part 6: Determination of organic compounds (VVOC, VOC, SVOC) in indoor and test chamber air by active sampling on sorbent tubes, thermal desorption and gas chromatography using MS or MS FID*

ISO 16017-1, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 1: Pumped sampling*

ISO 16017-2, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 2: Diffusive sampling*

ISO 16200-1, *Workplace air quality — Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography — Part 1: Pumped sampling method*

ISO 16200-2, *Workplace air quality — Sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography — Part 2: Diffusive sampling method*

ISO/TR 27628, *Workplace atmospheres — Ultrafine, nanoparticle and nano-structured aerosols — Inhalation exposure characterization and assessment*

ISO 28439, *Workplace atmospheres — Characterization of ultrafine aerosols/nanoaerosols — Determination of the size distribution and number concentration using differential electrical mobility analysing systems*

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions from ISO/ASTM 52900 and the following are applied.

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/

3.1
volatile organic compound
VOC
organic compound that is emitted from the test specimen and all those detected in the chamber outlet air

Note 1 to entry: Due to practical reasons to be taken into account for test chambers, this definition differs from that defined in ISO 16000-6:2004. In ISO 16000-6, the definition is based on the boiling point range (50 °C to 100 °C) to (240 °C to 260 °C).

Note 2 to entry: The emission test method described in ISO 16000-9 is optimum for the range of compounds specified by the definition of total volatile organic compounds (TVOC).

[SOURCE: ISO 16000-9:2006, 3.15]

3.2
aldehydes
organic compounds containing formyl families

Note 1 to entry: Formaldehyde, acetaldehyde and vanillin are members of aldehyde families.

[SOURCE: ISO 21366:2019, 3.8]

3.3
ultrafine particles
UFP
particles with a particle diameter less or equal 0,1 µm

[SOURCE: ISO/IEC 28360-1:2021, 4.36]

3.4
breakthrough volume
volume of test atmosphere that can be passed through a sorbent tube before the concentration of eluting vapour reaches a predefined limit value of the applied test concentration

Note 1 to entry: For hazardous substances in air, 5 % of the applied test concentration is a generally applied limit value.

[SOURCE: ISO 16017-1:2000, 3.1, modified — The definition was slightly reworded.]

3.5
active sampling
active sampling method in which sampling for collecting chemical substances is performed within an hour

3.6
real-time sampling
real-time sampling method in which measuring the total number concentration of aerosol particles is performed consecutively

4 Hazardous substance targets and major factors

VOCs, aldehydes, and UFP are currently identified as some of the potentially hazardous substances emitted during operation of material extrusion type AM machines in schools and public places. The material extrusion type AM machines which are currently used for AM process with filaments (ABS, PA, PC, etc.) can change the concentration of hazardous substances depending on the process and environment of the non-industrial places. The risk of each hazardous substance can be confirmed by referring to the hazard statement of the MSDS of the substance.

Since the following factors can increase the concentration of hazardous substances in that place, appropriate countermeasures are needed. See Annex A for information on considerations to reduce the emission concentrations of hazardous substances in the non-industrial place.

The factors are specified as follows:

— printer-related factors (e.g. design - open frame, enclosed);

— feedstock-related factors (e.g. type of polymer, colour, infill materials);

— process-related factors (e.g. extruder temp, bed temp, infill density);

— environmental-related factors (e.g. room size, presence of doors/windows, ventilation, temperature, humidity).

5 Relevant test standards

This document covers three main classes (VOCs, aldehydes, and UFP) of hazardous substances that could be emitted in case of using material extrusion type 3D printers and filaments. Table 1 provides a list of these hazardous substances and the recommended sampling strategy and test methods for their analysis in a workplace or indoor environment. Users should be aware that each type of emission could vary individually depending on the duration of machine operation, type of filaments, temperature, humidity of the place, etc. As such they much each be monitored individually and proper care should be taken to ensure the monitoring plan covers the worst-case scenarios. Currently, there is no test method to measure VOCs, aldehydes, and UFP simultaneously or for an extended period (such as the entire additive manufacturing process). Therefore, the non-industrial places where material extrusion type 3D printers are in operation require an integrated analysis method to monitor each substance that is relevant to the process.

Table 1 — Relevant test standards for some hazardous substances

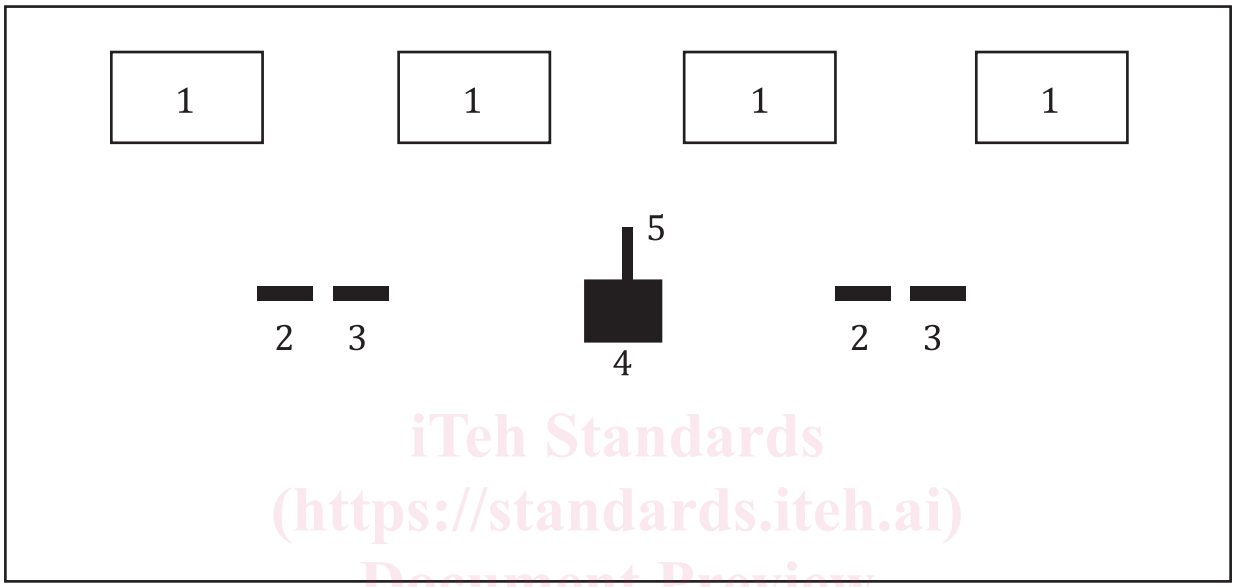
Requirements	VOCs	Aldehydes	UFPs
Sampling method	ISO 16000-5 ISO 16000-6 ISO 16017-1 ISO 16017-2 ISO 16200-1	ISO 16000-2 ISO 16000-3 ISO 16000-4 ISO 16200-2	ISO/TR 27628 ISO 28439
Analysis method	ISO 16000-6 ISO 16017-1 ISO 16017-2	ISO 16000-4	ISO/TR 27628 ISO 28439

6 Sampling conditions

6.1 Sampling location

Sampling of hazardous substances during the AM process shall be carried out simultaneously and the VOCs, aldehydes sampler and the UFP analysis equipment shall be placed in separate spaces to sample each of the substances. Figure 1 shows an example of one possible spacing of samplers relative to 3D printers. Two VOCs and aldehyde sampler shall be installed for cross-check. In addition, the sampler location is usually installed at the centre of the non-industrial place and is installed at 1,0 m to 1,8 m height from the floor.

UFP sampling tube shall consist of a conductive silicon tube or stainless steel, not exceeding 3 m in length, and avoid bends in the tube.



Key

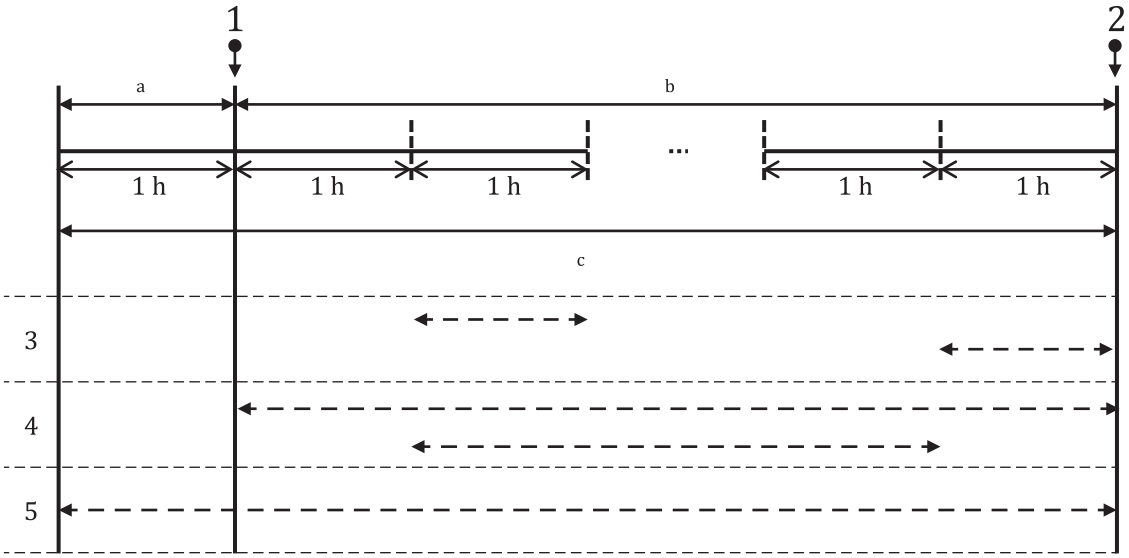
1 material extrusion 3D printer (example)
2 VOCs sampler
3 aldehyde sampler
4 UFP analytical equipment
5 UFP sampling tube

Figure 1 — Schematic diagram of the non-industrial place for sampling strategy

In case of UFP analytical equipment that condenses nanoparticles by using butanol, isopropanol, and other organic solutions, the substances could be spontaneously volatilized in the non-industrial place while the equipment is in operation. Accordingly the final concentration of VOCs would be affected. Therefore, UFP analytical equipment that uses organic solvents, should be placed outside the additive manufacturing site, ensuring no occurrence of cross-contamination from outside.

6.2 Sampling planning

The sampling conditions need requirements shown in Figure 2 according to the active, time-integrated and real-time sampling methods.



Key

1 start to operate the 3D printer
2 suspend the 3D printer
3 example of active method
4 example of time integrated
5 example of real-time method
a Pre-operation phase.
b Operation phase.
c Sampling phase.

Figure 2 — Sampling planning in the non-industrial place

a) Pre-operation phase

As a preparation step for feeding the filament before the operation of the 3D printer, it is necessary to open doors and windows and operate the ventilation system for 60 minutes or longer to emit the toxic substances released from this process. If external air quality is rather suspicious, the place should be ventilated through a forced circulation way or mechanical circulation equipment instead of opening the windows.

b) Operation phase

In the operation phase, where the 3D printers are running, all doors and windows shall be closed to prevent the external air from coming in. If there is a ventilation system or a heating or cooling facility in the non-industrial place, run the printer under the same condition as usual. However, if the test is expected to be conducted under the most adverse condition in the non-industrial place, the ventilation and air conditioning systems could be shut down during the evaluation.

c) Sampling phase

In this phase, each of the hazardous substances is sampled. This phase is divided into active, time-integrated, and real-time sampling methods according to the sampling strategy:

— active method.

The sampling of VOCs and aldehydes is performed only for one hour in a specific phase among the operation phase b) during the 3D printer operation.