
Additive manufacturing — Round robin testing — General guidelines

Fabrication additive — Essais interlaboratoires — Lignes directrices générales

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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 documents 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 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, and 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 outlines the steps with regard to aspects of design to conduct and run a round robin study (RRS) to assess the degree of variability in an additive manufacturing material or process.

The RRS can be used to study variations arising from the AM production process including feedstock, machine operation, process control, and post processing. The RRS plan can identify various aspects of the AM process to be considered to execute the study so that it is possible to maximize the consistency of the results based on the objective of the study.

Additive manufacturing is still a developing technology and round robin studies play an important role to help generate the information needed to populate materials engineering databases, determine design allowables, and improve processing and post-processing consistency in order to drive maturation.

The result of the RRS is a qualitative or quantitative assessment of the material used or the process variability, rather than the assessment of accuracy and precision of a specific test method from an inter-laboratory study. Additionally, RRS can involve other entities besides laboratories.

Round robin studies differ from normal research studies by having different participants, each trying to undertake a nominally identical process. The aim is to determine the effect of the desired variables on the process outcome. The output can be used for different applications such as the demonstration of process robustness or for derivation of material property data. A well-conducted RSS does not guarantee small variability, but ensures that any observed variability is indicative of the material or process, not poor study design.

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1 Scope

This document is focused on the management of the round robin study (RRS) and can provide guidance for the scope development, planning, and execution of the RRS study. It can provide guidance to identify the feedstock, machine operations, process controls, and post-processing operations prior to running the study. RR organizers can identify controlled and free parameters in the study. This document can also provide guidance on the selection and use of test methods that can be applicable. The RRS investigates the variations found in AM parts. The outcome of the study can be used to improve the maturation of AM technologies.

A RRS, as described in this document, is different from an inter-laboratory comparison because an inter-laboratory study establishes the variability in a measurement method when undertaken by multiple users on a well-controlled artefact.

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900, and the following apply.

ISO and IEC maintain terminological 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

process control document

document recording process variables, procedure followed, and building notes

4 RRS task force and RRS manager

The RR task force is the executive team responsible for establishing the goals and scope of the round robin study. The procedure presented in this guide can consist of sequences to help the RRS task force in preparing the RRS. Once the RRS has been developed, an RRS manager can be assigned to assist participants with operational questions.

The RRS task force can be the sole arbiter of technical issues.

5 Develop a round robin study

5.1 Suggested steps to develop a round robin study

Suggested steps in an RRS are given in [Table 1](#).

Table 1 — Sequence of a round robin study

Sequence	Procedure	Clause/subclause in this document
1	Determine goal and select the RRS task force	5.2
2	Determine scope of RRS	5.3
3	Develop a manufacturing plan	5.4
4	Process control document	5.5
5	Develop a measurement and testing plan	6
6	Solicit participants	7
7	Provide RRS plan	8
8	Pilot run (if needed)	9
9	Full scale run	10
10	Data handling	11
11	Prepare study report	12
12	Record keeping	13

5.2 Identify the goal of the study and select the round robin task force

Identifying the objective of the study is an important first step. Once the goal of the study is determined, an RRS task force can then be formed consisting of interested parties with relevant experience in AM. The RRS task force can name an RRS manager who is able to assist RRS participants during the pilot and full-scale runs. The RRS task force can then develop the RRS plan that includes:

- a) scope and purpose;
- b) manufacturing;
- c) measurement and testing plans,
- d) soliciting participants;
- e) guiding the study;
- f) collecting data;
- g) interpreting data;
- h) preparing a final report.

5.3 Prepare scope of round robin study

The RRS task force can determine process selections such as feedstock material, process parameters, and methods that are required to be controlled. It is possible that AM RRS can be a useful tool for determining the repeatability and reproducibility of an AM process, assessing production readiness, and populating material databases and material data sheets for design purposes. The output of the RRS can be a reporting of statistical variations in AM part properties.

5.4 Develop a manufacturing plan

A manufacturing plan sets forth the AM process, feedstock, process parameters and sequence of activities needed to produce a specific part. The following outline can provide a minimum guide of information that can be included in the plan, however, it is possible that the RRS can have more details than what is listed.

a) Part description (part geometry, including build platform and lattice structure).

The part description can provide full details of the part or parts, including tolerances of each part, support layout, lattice structures, and tolerances for any specified surface textures or embossed labelling. Depending on the study, the source file (CAD, scan, or other source type), part file or files, and build file may be supplied along with specified tolerances. Instructions on the placement and orientation of digital components within the AM systems build volume can be included.

b) Machine requirements (including make/model, software, maintenance, calibration, etc.).

The manufacturing plan can clearly define the AM machine requirements such as, but not limited to

- make/model,
- type of AM process being studied,
- platform,
- atmosphere,
- machine software version,
- last date of maintenance, and
- machine calibration.

c) Facility requirements (environment, stability, process gas, etc.).

The requirements of the facility where the machine is located. This can include environment (temperature and humidity), stability (e.g electrical, mechanical, magnetic), provision (process gas, cooling water, air etc).

d) Feedstock requirements (handling, storage, specification, etc.).

Since feedstock can produce significant variation of results, it is possible to accurately quantify and control the source, specifications, and traceability of the feedstock. Requirements can also include feedstock conditioning prior to component fabrication.

The RRS task force can define the following feedstock qualities:

- feedstock supply:
 - 1) RRS team acquires feedstock and distributes it to participants;
 - 2) RRS task force can define feedstock specification and quantities to procure by participants;
- feedstock batch properties: can be the same for all participants:
 - 1) chemical composition;
 - 2) physical properties;
 - 3) batch properties:
 - i) virgin;
 - ii) used: with limits on prior re-use;

iii) blend: defined by the RRS team;

— feedstock conditioning (if needed).

The RRS task force can provide participants with detailed instructions for the storage, safe handling and use of the feedstock. It is possible that this includes environmental exposure and any recycling/reprocessing steps that might be necessary during the production of the parts in the study. Detailed records of the material including all processing and environmental exposure it has undergone can be recorded in the process control document so that full traceability of the material is possible.

e) Hardware setup requirements (user training, operator proficiency, machine setup).

Instructions can be provided to participants for machine setup, and can include:

- user training, operator proficiency;
- environmental conditions (internal to the machine);
- machine performance validation (calibration and qualification);
- machine setup;
- machine cleaning;
- material handling;
- equipment maintenance and revalidation processes;
- after maintenance or servicing the machine can be validated.

f) Software setup requirements (programs, user training, operator proficiency, build file setup).

Specification of software to be used including version. Operators can be highly proficient with the build processing and machine software so it is possible for them to create job files from the part files provided by the RRS task force. They can also possess a fundamental understanding of the processes needed to use machine software to execute the build with the proper processing parameters.

g) In-process requirements (monitoring, data collection, environment).

AM machines have an increasing amount of in-process monitoring, data collection, environmental monitoring, and feedback control. As much of this data can be recorded as possible, even if it cannot be controlled, so that it can be correlated with the final part properties. Depending on the study design it is possible that the machine will use internal feedback control to maintain certain processing conditions. A record of the in-process monitoring can be retained.

h) Process completion (data reporting, sample numbering).

There is a possibility of the RRS manager providing guidance as to what to do if planned or unplanned build interruptions occur during the study. This can occur due to process errors, machine interruptions, or environmental changes. If the error is serious, the build can be terminated at the discretion of the RRS manager. If the build is interrupted and then restarted, the participant can record causation of the stoppage, build height, and procedures undertaken to restart the build. The RRS manager can be informed of any deviations or if there is a problem with completion of the manufacturing plan.

i) Post processing requirements (heat treatment, machining, sample numbering).

Most AM processes require some form of post-processing before the part can be used. Post-processing can include removal from the machine itself, the build platform, support removal, finish machining or thermal post processing. The RRS task force can specify the post-processing steps or they can collect test parts from each RRS participant prior to post-processing while still attached to the build platform. The RRS task force can have a single organization undertake all the post processing operations, or have multiple organizations perform them. The post-processing procedures along with facility performing

the tasks can be documented and shared with RRS participants, or they can be included in the final report.

5.5 Process control document

Develop process control documentation requirements: The process control document can be written along with the manufacturing plan. The process control document can outline the settings and parameters used in the process, define in-process monitoring data to be recorded, and any other information pertinent to the build, such as build interruptions and build anomalies. It is possible that this will enable the RRS manager to check the manufacturing plan has been followed correctly and enable a complete understanding of the manufacturing process. Any deviations from the manufacturing plan or unexpected issues can be communicated to the RRS manager as soon as possible.

6 Develop a measurement and testing plan

Develop measurement and testing plan: Once the parts are manufactured and processed, measurements and tests can be required that will assess the products from the RRS. The measurement and testing plan can assess the geometric dimensioning and tolerancing, mechanical, thermo-physical, microstructural, electronic, or other property. A list of potentially applicable test methods for AM materials is given in ISO/ASTM 52927.

The number of samples can also be considered to ensure sufficient statistical confidence in the results obtained from the study. Given the greater variability in AM materials as well as typically higher surface texture, anisotropy, and the presence of unintentional internal defects, the spread of results can be greater than for standardized manufacturing processes. Therefore, the number of samples to produce adequate statistical significance can be greater than for standardized manufacturing processes.

The test methods can be used which are applicable to AM materials and processes so that it is possible to obtain relevant test results. According to best practice, tests can be undertaken by a single, accredited laboratory (ISO/IEC 17025) so that it is possible to provide estimates of the measurement uncertainty. If measurements are undertaken by multiple parties, then the quantification of measurement uncertainty is important for the interpretation of the measurement results. Any measurement failures or non-conformities can be identified and notified to the RRS manager. Measurement methods can be used that do not follow internationally agreed standards; instead, the RRS manager can fully document the procedure, testing, measurement results, and variability of the test method.

7 Solicit participants

The RRS task force can write and provide a brief outline of the study that defines the aims and scope of the round robin study and the requirements for participation. A list can be developed that allows the RRS task force to understand the capabilities, experience, proficiency, and qualifications of potential participants. This can include a proposed timescale for participation, so that expectations can be set, and delays can be avoided. The task force can decide to ask further questions to better understand the capabilities and interest of RRS participants.

8 Send the manufacturing plan to participants

The RRS task force can send the manufacturing plan to the RRS participants. The RRS task force can check that participants have reviewed the manufacturing plan to ensure that they are able to satisfy the requirements. Feedback from participants can be requested in case the manufacturing plan needs to be adjusted. Any adjustments to the manufacturing plan can be adjudicated by the task force and shared by all RRS participants. If it is possible, a strict change log and version control of the manufacturing plan can be kept, so that it is clear exactly which version has been used by participants.

9 Execute a pilot run with select participants

A short, small scale pilot run of the study can be undertaken with a few selected RRS participants to check for unexpected issues. This can include all aspects of the RRS including testing. Based on feedback during the pilot run, it is possible to adjust the manufacturing plan and process control document. The RRS task force can maintain all documentation from the pilot run so that any changes to the RRS are noted.

10 Execute a full scale production run

a) Part design and part files.

The design files can be prepared and distributed to RRS participants according to the manufacturing plan. If it is possible, consideration can be given to assure that the files are genuine and not accidentally or deliberately altered. RRS Participants can keep a copy of the files generated and used in the study.

b) Feedstock.

The feedstock for the study can be obtained and prepared according to the manufacturing plan, with specified measurements undertaken. All material sent is packaged according to applicable standards, rules, and regulations for shipping potentially hazardous or export controlled material. All applicable safety data sheets can be included with them.

c) Execute the study.

Once the manufacturing phase of the study has been started, it is important that the RRS manager can maintain regular communications with the participants to ensure the timely completion of the study. If there are any problems encountered by participants, it is possible to reschedule parts of the RRS or participants can be removed from the study. If participants identify any deviation from the manufacturing plan, this can be communicated to the RRS task force or RRS manager. The task force can determine the impact on the study and include this in the report.

d) Examine all process control documents.

After executing the study (see item list c) above) RRS participants can send their completed process control document to the task force prior to commencing any post-processing activities or shipping the parts. The task force can assess all the process control documents and identify any cases where the manufacturing plan was not followed, information was not recorded, measured parameters lay outside of defined tolerances, and other deviations outside of the manufacturing plan. Follow up discussions between the task force and RRS participants can occur prior to commencing post processing and shipping.

The RRS task force can decide to remove participants from the study due to deviations from the manufacturing plan, or they can decide to allow participants to continue and simply annotate the deviations in the final report.

e) Shipping.

The RRS task force can specify how the parts are shipped between participants. This can include requirements packaging to ensure that components properties do not change or get damaged during shipping. Considerations can be made for customs, freight charges, and export control.

f) Post-processing.

Post-processing operations can be carried out on the samples in accordance with the RRS plan. The post-processing can be performed individually by each RRS participant, or at one site as chosen by the task force. All records and processing conditions can be added to the process control document for the samples.

g) Measurements after post-processing.