



AEROSPACE MATERIAL SPECIFICATION

AMS7022™

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Binder Jet Additive Manufacturing (BJAM) Process

RATIONALE

This Aerospace Materials Specification is intended to provide process requirements for production of aerospace parts via the binder jet additive manufacturing process. No such specification currently exists.

AMS7022 has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

1.1 Purpose

This specification establishes process controls for the repeatable production of sintered parts by binder jet additive manufacturing (BJAM). It is primarily intended to be used to manufacture metallic or ceramic aerospace parts, but usage is not limited to such applications.

1.2 Application

Requirements for printing are to be applied only to printing machine and process. Requirements for BJAM are applied to the entire process, from receiving through a fully sintered part. "Printing" is intentionally used instead of "binder jetting" or "binder jet printing" to differentiate the printing step from the entire BJAM process.

1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The producer may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2750 Pyrometry

ARP1917 Clarification of Terms Used in Aerospace Metals Specifications

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SAE WEB ADDRESS:

Full document details: SAE AMS7022

For more information on this standard, visit
<https://www.sae.org/standards/content/AMS7022/>

Documents

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2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E2281 Standard Practice for Process Capability and Performance Measurement

ASTM E2587 Standard Practice for Use of Control Charts in Statistical Process Control

2.3 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO/ASTM 52900 Additive Manufacturing - General Principles - Terminology

2.4 Terminology

2.4.1 Definitions

The following definitions apply in addition to those defined in ISO/ASTM 52900 (e.g., build space, build volume) and ARP1917 Rev. A:

ACCEPTABLE TO CEO: Does not require written approval from CEO prior to implementation into production. Any changes require notification to the CEO prior to sintered part shipment. This allows producer to decide and the CEO the right to disapprove the decision.

AUTHORIZED BY CEO: Requires prior written approval from the CEO.

BINDER CURING: Processing of the printed white state parts within the build volume to set the binding agent to fix form and increase part strength to permit depowdering from the build volume and subsequent handling. Curing may include drying or chemical reactions.

BINDER FEEDSTOCK SUPPLIER: The company that supplies the liquid binder to be used in the printing machine.

BINDER FEEDSTOCK: Liquid ejected from the print head to selectively bind the powder feedstock.

BINDER JET ADDITIVE MANUFACTURING (BJAM): Additive manufacturing process consisting of printing and post-printing steps necessary to achieve final pre-heat treatment, part density such as: curing, depowdering, debinding, sintering, and/or infiltration. A result of this process is a sintered part that may require additional heat treatment or finishing to achieve final material properties and form.

BUILD BOX: The container within which the printing process occurs. This volume includes the mechanism by which the build platform translates vertically with each subsequent layer. Atop the build platform exists the build volume, expanded throughout the printing process, and fully enclosed by the build box.

BUILD ENVELOPE: Largest external dimensions of the X-, Y-, and Z-axes within the build space where parts will be fabricated. The build envelope is inset from the internal limiting dimensions of the build volume by the part-to-wall offset.

BUILD: A single printing operation to produce one or many white or green parts within a single build box.

DEBINDING: Thermal processing to remove some or all of the binder from a green state part, prior to or combined with sintering.

DEPOWDERING: Removal of green state parts from within the unbound powder build volume, and removal of any unbound powder from the green state parts.

GREEN STATE PART: The state of the part after curing, but prior to debinding.

INFILTRATION: Thermal processing of debound parts to cause densification by liquid metal filling of interconnected porosity. Capillary forces drive a lower melting temperature metal to penetrate a partially sintered part and fill the aforementioned porosity.

INTERRUPT: Unplanned deviation from the pre-determined PCD of the BJAM process.

KEY PROCESS VARIABLES (KPV): Aspects of the manufacturing process that may impact the capability to meet the specified requirements. These include physical, chemical, metallurgical, mechanical, and dimensional properties (3.1.1).

POWDER FEEDSTOCK SUPPLIER: The company that supplies the powder to be used in the printing machine.

POWDER FEEDSTOCK: Powder that is layered and made available for selective binding during the printing process.

PRINTING FILE: The electronic file(s) supplied to the equipment as part of the printing process for manufacturing one or more white or green state parts. This may include but, is not limited to, part geometry, location, orientation, and parameters for printing.

PRINTING MACHINE MANUFACTURER/INTEGRATOR: Company that manufactures the printing machine or integrates the component equipment to build the machine.

PRINTING: A liquid agent is selectively dispersed into layers of powder to bind particles to create a white or green state part. ("Printing" is intentionally used instead of "binder jetting" or "binder jet printing" to differentiate the printing step from the entire BJAM process—printing through sintering.)

PROCESS CONTROL DOCUMENT (PCD): A collection of procedures and requirements that are used to document and to control variation of a product.

PRODUCER: The entity using the BJAM process to produce sintered parts.

PURCHASER: Organization that issues the purchase order to the producer.

RECOATER: The internal physical apparatus that performs recoating.

RECOATING: The act of spreading powder feedstock to create a uniform layer within the build envelope for subsequent binder agent deposition.

SETTER: A fixture to provide support and control the distortion of the part as it undergoes debinding and sintering.

SINTERING: Thermal processing of debound parts to cause a consolidation (i.e., removal of pores/voids) and an increase in density. Sintering results in dimensional shrinkage. Sintering may occur via solid state processes or may include a phase change to the liquid state.

WHITE STATE PART: Uncured or partially cured parts present in the build volume, after printing, but prior to final curing of binding agent and depowdering. Parts in this state typically do not have sufficient mechanical properties to permit handling.

2.4.2 Acronyms

AM	Additive Manufacturing
BJAM	Binder Jet Additive Manufacturing process
CAD	Computer-Aided Design
CEO	Cognizant Engineering Organization
PCD	Process Control Documentation
KPV	Key Process Variable

3. TECHNICAL REQUIREMENTS

3.1 Process Control Documentation (PCD)

The PCD shall be established by the producer, substantiated with respect to the specified requirements, and authorized by the Cognizant Engineering Organization (CEO). Once authorized, all aspects of the PCD are a fixed process and any changes to the PCD shall require substantiation prior to the change being implemented into production. Changes to the PCD that can affect a key process variable (KPV) must be authorized by the CEO. All other changes to the PCD must be acceptable to the CEO. The PCD shall address the following aspects of the BJAM process:

3.1.1 Key Process Variables

3.1.1.1 The producer shall establish values, tolerances, and measurement frequency for all KPVs of the BJAM process including, but not be limited to, the variables defined in Appendix A. These values and tolerances shall be substantiated with respect to the specified requirements and be authorized by the CEO. Any change to a KPV shall be authorized by the CEO.

3.1.1.2 Process variables may be omitted from the PCD when substantiated by the producer and authorized by the CEO.

3.1.1.3 The values of any KPVs considered proprietary by the producer may be assigned a code designation and recorded by the producer in an internal document. Each variation in such variable value shall be assigned a modified code designation.

3.1.2 Process Interruption

3.1.2.1 Process interruptions are not permitted, unless previously substantiated by the producer, incorporated into the KPVs of the PCD, and authorized by the CEO.

3.1.2.2 To substantiate allowable process interruptions, the producer shall demonstrate through documented testing or other suitable means that process interruptions do not affect the quality and performance of the sintered part. This documentation shall be provided to the CEO prior to acceptance.

3.1.3 Digital File and Software Configuration Control

The producer's configuration management process shall establish configuration control to ensure the correct software and files are used in the production of components using BJAM. This system shall include internal procedures to control electronic files, conversion settings, and machine parameters. All files' configurations shall be managed including revision control.

3.1.4 Calibration and Verification Plan

3.1.4.1 Procedures for calibration and verification shall be established and substantiated by the producer to measure and adjust, at a minimum, all variables required by the printing machine manufacturer/integrator, as well as those identified as required in Appendix B. The plan shall include procedures, values, tolerances, and frequency of verification of each variable specific to the application.

3.1.4.2 All calibrations and verifications performed shall be recorded via manual or electronic means and maintained for a period compliant with requirements of the ordering documents.

3.1.4.3 When authorized by the CEO, calibration and verification variables may be omitted when substantiated to have no impact on the ability for the sintered part produced to meet the specified requirements.

3.1.5 Maintenance Plan

- 3.1.5.1 Procedures for maintenance shall be established and substantiated that include a checklist of activities, instructions to perform each activity, and the frequency by which that activity shall be completed.
- 3.1.5.2 At a minimum, maintenance plans shall include all activities and instructions that are required by the printing machine manufacturer/integrator.
- 3.1.5.3 Additional maintenance items unique to the installation, facility, or specific application shall also be documented and included in the maintenance plan.
- 3.1.5.4 The maintenance plan shall also include all equipment beyond the printer required to meet the specified requirements for the sintered part.
- 3.1.5.5 All maintenance performed shall be recorded via physical or digital means and maintained for a period compliant with requirements of the ordering documents.
- 3.1.5.6 Maintenance plans shall include all wear and life limited items that have been determined critical to consistent and reliable production.

3.1.6 Binder Feedstock and Powder Feedstock Handling and Storage Plan

Procedures for handling and storage of binder and powder feedstocks shall be established and substantiated to meet the requirements defined by the finished sintered part material. At a minimum, the binder and powder feedstock handling plan shall include the following:

- The procedure(s) to substantiate that the binder and powder feedstocks used in the printing machine comply with the specified requirements. This includes procedures for sampling and testing or verification of supplier's certification of sampling and testing.
- Storage conditions for the binder and powder feedstocks. The requirements do not have to be the same for both the binder and powder feedstocks.
- Binder feedstock and powder feedstock lot traceability to maintain traceability compliant with the requirements of the CEO.
- Conveyance, transport, and handling and loading procedures for feedstocks from any storage location into the printing machine.
- Process for removal of powder from the printing machine that will be used in a subsequent build.
- Process for collection of powder from de-powdering and conveyance and transport to re-conditioning or recovery systems.
- Plan for powder reconditioning and reuse, including: sieving, blending or mixing of virgin powder with reclaimed powder, maximum number of reuses of a single lot, and allowance for mixing multiple powder lots.
- Process for ensuring that used powder feedstock that exceeds any limitation defined in the PCD (e.g., size, composition, moisture content, maximum number of uses, etc.) is labeled as non-conforming, quarantined, and not loaded into the printing machine.

Additional recommended elements of a binder feedstock and powder feedstock handling and storage plan can be found in Appendix E.

3.1.7 Moisture and Contamination Control Plan

- 3.1.7.1 Procedures shall be implemented to minimize the risk of moisture and foreign material that would change the performance of the items produced in the BJAM process. The producer shall identify potential sources of contamination throughout all aspects of the BJAM process, including binder and powder feedstock storage and handling, printing machine, printing consumables, and ancillary equipment, and establish procedures to minimize the sources of such contamination.

3.2 Printing and Ancillary Equipment Machine Approval

3.2.1 Printing Machine and Curing Equipment Approval

The following requirements in this section only pertain to the BJAM process steps through de-powdering. For each individual printing machine, the producer shall demonstrate that the green state parts fabricated in that machine conform to all relevant PCD requirements including variables listed in Sections A.1, A.2, and A.3 and all calibration requirements in Sections B.1, B.2, and B.3. The CEO shall define the requirements (number of specimens, analysis method, and acceptance criteria) and the producer shall meet those requirements. This substantiation shall be authorized by the CEO prior to implementation into production. Each machine shall meet the following requirements at a minimum:

- Calibration and verification plan is executed and complies with the requirements of 3.1.4.
- Preventive maintenance is performed, documented, and complies with the requirements of 3.1.5.
- Material testing is performed using specimens extracted from green parts built within the extent of the build envelope defined in the PCD including the extremes of the x, y, and z positions and orientations in the x-y plane and z direction.

3.2.2 Debinding and Sintering Equipment Approval

The requirements following in this section only pertain to the subsequent BJAM process steps after curing and depowdering. The producer shall demonstrate that the items fabricated conform to all relevant requirements of the applicable material specification. The CEO shall define the requirements (number of specimens, analysis method, and acceptance criteria) and the producer shall meet those requirements. This substantiation shall be authorized by the CEO prior to implementation into production. Each machine shall meet the following requirements at a minimum:

- Calibration and verification plan is executed and complies with the requirements of 3.1.4.
- Preventive maintenance is performed, documented, and complies with the requirements of 3.1.5.
- Material testing is performed using specimens extracted from debound and sintered parts that have already met the requirements outlined in 3.2.1 as defined in the PCD.

3.3 BJAM Process Approval

Process approval moves beyond machine approval and incorporates all KPVs of the PCD including final part orientation, part to part spacing, part to wall spacing, and debind and sinter procedures. Debind and sinter procedures may include, but are not limited to furnace time and temperature profile, process environment, part orientation and spacing, geometric distortion compensation strategy, and setter design and support strategy. The CEO shall approve the requirements (e.g., how many parts, how many machines, how many feedstock lots, required testing, etc.) and the producer shall demonstrate the capability to meet those requirements through each step of the BJAM process. This substantiation shall be authorized by the CEO prior to implementation of the BJAM process for production.

3.4 Statistical Process Control (SPC)

Statistical process control shall be used to quantify and reduce variation, improve, and monitor the BJAM process. This includes use of process capability and performance measurement per ASTM E2281 and use of control charts in SPC programs per ASTM E2587. The producer shall have a reaction plan authorized by the CEO in place to respond to actions, improve the overall process, and identify special causes of variation. The KPVs identified in the SPC Required column of Appendix A shall be controlled and maintained.

4. QUALITY ASSURANCE PROVISIONS

4.1 Calibration and Verification

The producer shall maintain documentation of all activities performed per the calibration and verification plan defined in 3.1.4.

4.2 Maintenance

The producer shall maintain documentation of all activities performed per the maintenance plan defined in 3.1.5 as well as any unplanned maintenance.

4.3 Feedstock Handling and Storage

The producer shall maintain evidence that feedstock material complies with the material handling and storage plan defined in 3.1.6.

4.4 Process Setup Verification

The producer shall have a procedure to ensure and document that the BJAM process is executed in accordance with the PCD. At a minimum, this procedure shall include:

- Selecting the correct build file
- Selecting the correct machine settings and parameters
- Pre-Printing machine check procedure per the KPVs defined in the PCD
- Build box installation and fixturing requirements
- Verification of adequate buildbox cleanliness
- Powder feedstock loading requirements
- Binder feedstock loading requirements
- Print head cleaning agent loading requirements
- Selecting the correct post-printing curing profile
- Selecting the correct debind and sinter furnace profile
- Sintering setters installation and verification requirements
- Verification of correct furnace part layout

4.5 BJAM Process Requalification

After initial machine and process approval, the producer shall demonstrate capability per 3.3, and as defined by the CEO, following the occurrence of any of the following events:

- A change to any of the KPVs defined in the PCD
- Sintered part or witness coupon rejection caused by the BJAM process; specimen failure cause shall be concurred by the CEO
- Changing the equipment location or environment