Additive Manufacturing Metal and Polymer Powder Based Systems Process Requirements

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1. INTRODUCTION

Note: Nothing in this standard supersedes applicable laws and regulations.
Note: In the event of conflict between the English and domestic language, the English language shall take precedence.
Note: It is intentional that this document is NOT Confidential.

1.1 Scope / Purpose

This standard defines the minimum process requirements, manufacturing standards, and technical requirements for metal and polymer parts produced by additive manufacturing ("AM") using powder as a feedstock, with emphasis on raw material, build conditions, post processing, and finishing operations. The purpose of these requirements is to guide part Suppliers' preparation of global, common quotations, and subsequent incorporation into manufacturing planning and execution of a program at the assembly or part detail level.

Any deviations from this standard requested prior to sourcing are to be detailed and approved by Purchaser.

1.2 Applicability

This standard is applicable to the qualification and control of powder-based additive manufacturing processes for metals and polymers, including both powder bed fusion (PBF) and binder jetting (BJ). The requirements are based on

experience, best practices, and lessons learned– they are applicable to all Tiered AM Suppliers in the supply chain.

This standard is NOT intended to define the initial supplier qualification required prior to Technical Review or Request for Quote discussions. Those definitions will be outlined in a separate document.

1.3 Remarks

This standard is intended to ensure a Part Supplier's ability to produce additive manufacturing parts that meet the Purchaser's quality requirements. Emphasis is placed on the ability to supply a uniform and consistent part. While this standard details the requirements for global qualification of a Part Supplier, additional data and/or qualification submissions, including PPAP for production parts, may be requested by the Purchaser. Note: this Process Specific Statement of Requirements (Process SOR) is in addition to and not intended to replace any other requirements as outlined by the Purchaser.

1.4 Requirements Wording Conventions

The word "shall" states a mandatory, binding requirement for which verifiable proof shall be provided within 24 h upon request from the Purchaser. The word "should" denotes a highly recommended preference or desired conformance.

2. REFERENCES

2.1 External Standards/Specifications

IATF 16949	AIAG PPAP-4	AIAG FMEA-4	AIAG CQI-9
ASTM 52921	ASTM E3	ASTM E8	ASTM B215
ISO 527	ISO 179	NFPA 652	ASTM 52900

2.2 Standards/Specifications

Identification and Branding requirements as specified by the Purchaser shall be followed as specified.

2.3 Additional References

- AIAG Failure Mode and Effects Analysis, IATF 16949 Guidance Manual (AIAG CQI-16), AIAG CQI-19 Sub-Tier Supplier Management Process Guideline and Production Part Approval Process, available at URL: http://www.aiag.org/
- CAD and CAD Drawing Files
- Statement of Requirements (SOR)

3. DEFINITIONS

3.1 Additive manufacturing (AM): the process of joining materials to produce objects directly from 3D model data, usually layer upon layer. It is the opposite of subtractive manufacturing.

3.2 Powder bed fusion (PBF): a classification of additive manufacturing process by which thermal energy selectively fuses metallic or polymer powder layer by layer in a powder bed. Thermal energy may be provided via various sources including laser, electron beam, and infrared radiation.

3.3 Build platform: base of a build space which provides a solid surface upon which the powder is spread and fused to form the parts and supports through the build process. The build platform is fixed to the machine to facilitate the build.

3.4 Build envelope: the volume defined in the x, y, and z directions over which parts may be reliably built. The build envelope may be smaller than the full reach of the laser or dimensions of the build volume.

3.5 Build volume: the total usable volume available in the machine, including the space outside of the build envelope.

3.6 Support: sacrificial material produced in conjunction with the part to anchor the part to the build platform, or provide a foundation for downstream sintering or handling processes.

3.7 Powder lot: the totality of powder produced under traceable, controlled conditions, from a single powder manufacturing process cycle in a given size range appropriate for the AM technology.

3.8 Powder blend: a quantity of powder made by thoroughly intermingling powders originating from one or several powder lots of the same nominal composition. This blend can include a combination of virgin and recycled powders.

3.9 Recycle ratio: the ratio of virgin powder to used powder.

3.10 Build: all parts and supports, if applicable, constructed during a single run of the AM process within the AM machine's manufacturing envelope (i.e. build volume).

3.11 X-axis of the machine: the x-axis of the machine coordinate system is defined as running parallel to the front of the machine and perpendicular to the y-axis and z-axis.

3.12 Y-axis of the machine: the y-axis of the machine coordinate system is defined as running perpendicular to the x-axis and z-axis and lies in plane with the x-axis.

3.13 Z-axis of the machine: the z-axis of the machine coordinate system is defined as running perpendicular to the x-axis and y-axis and is parallel to the height of the build.

4. POWDER FEEDSTOCK REQUIREMENTS

4.1 Virgin Powder Requirements

4.1.1 The manufacturing Supplier shall have a feedstock specification. The Supplier shall specify the acceptable limits for each Key Performance Indicator (KPI) of the feedstock specification.

4.2 Powder Feedstock Requirements

4.2.1 Incoming Inspection. An incoming inspection procedure shall be performed by the Supplier to verify Material Supplier's certificate of analysis (CoA) meets Supplier's feedstock specification.

4.2.2 Storage and Packaging. Powder shall be packaged and stored with clearly identifiable material names and lot numbers on each container for virgin powder, recycled powder, and partially used powder containers. The atmosphere for powder storage shall be controlled for humidity, temperature, and inert atmosphere as necessary; and should include desiccant packs. Powder containers shall be specific to alloy type to prevent cross contamination.

4.2.3 Powder Sampling. Powder sampling shall follow the guidelines provided by ASTM B215.

4.2.4 Powder Blending. Powder may be blended by the Supplier provided that each individual lot meets the requirements of section 6.1 of the Supplier's specification including SPC where specified.

4.2.5 Recycled Powder. Recycled powder is acceptable for use but shall have a robust quality system in place to ensure build quality. The Supplier shall provide the recycling plan to the purchaser prior to building during the request for quote process (RFQ).

5. MANUFACTURING EXECUTION PLAN

5.1 A manufacturing plan is required prior to building. The manufacturing plan will serve as a control plan that outlines the production process, standardized work, and statistical process monitoring.

5.2 Parameters established during Production Part Approval Process (PPAP) for each machine, material, and parameter set shall be implemented unchanged for production. Any changes to machine, material, or parameter set will require PPAP to be repeated. Statistical process control with upper and lower process control limits should be used to track variation in the process and to remedy observed process shifts. A joint effort between the Supplier and Purchaser will determine what the key process inputs to be monitored will include. Statistical

methods will follow those listed in the AIAG manual. The Supplier shall supply evidence to the Purchaser that ongoing process monitoring of identified key variables is occurring upon request.

5.3 The details of the machine setup, machine subsystems, and lasers, shall be included in the manufacturing plan and reviewed by the operator to facilitate a successful build that meets all the customers required metrics. Any deviations to the standard manufacturing plan shall be submitted to and approved by the Purchaser prior to any shipment of parts.

5.4 **Metals Manufacturing Plan**

5.4.1 The Supplier shall establish a procedure for depowdering parts and verifying parts are sufficiently depowdered.

5.4.2 The Supplier shall establish a procedure for removing support structures.

5.4.3 Machining stock addition and/or part compensation shall be included in the manufacturing plan.

5.4.4 The post processing heat treatment method shall be determined during the initial quotation process and agreed upon by the Purchaser and the Supplier. Any thermal processing shall include but is not limited to control for: temperature, hold times, heating and cooling rates, atmosphere, and pressure. All heat treat providers shall be CQI-9 compliant and/or approved by the Purchaser.

5.4.5 Post-machining of the build or parts in the build shall follow an agreed upon plan. The procedures approved during PPAP must be followed during production.

5.4.6 The Supplier shall develop a plan to achieve required final part surface finish via post-print processing or other means.

5.5 **Polymer Manufacturing Plan**

5.5.1 The Supplier shall establish a procedure for depowdering parts and verifying parts are sufficiently depowdered.

5.5.2 The Supplier shall establish a procedure for removing support structure.

5.5.3 The Supplier shall develop a plan to determine the maximum allowable percentage of recycled material included in the build.

5.5.4 The Supplier shall establish a procedure for cooling the parts after production to maintain final part dimensions to the required tolerances.

5.5.5 The Supplier shall develop a plan to achieve required final part surface finish via post-print processing or other means.

6. MANUFACTURING REQUIREMENTS

6.1 **Data Integrity.** The Supplier shall establish a procedure for export of part CAD geometry to AM-compatible file types (STL, 3MF, AMF, etc.) that maintains critical feature resolution, surface artifacts, and overall CAD geometry within acceptable tolerances.

6.2 **AM Build Setup.** The Supplier shall be responsible for the complete setup of the AM build, including parts layout, spacing, orientation, packing, and support structures (if applicable) using the appropriate OEM and 3rd party AM build setup software(s). The Supplier shall optimize the build layout to achieve cost, throughput, performance, and dimensional targets provided by the Purchaser. The Supplier should consider the AM requirements provided by the Purchaser during the quotation stage.

6.3 **AM Process Parameters.** The Supplier shall be responsible for selecting the optimal AM machine and material parameter set combination to achieve cost, throughput, performance, and dimensional targets provided by the Purchaser. The Supplier should consider the AM requirements provided by the Purchaser during the quotation stage.

6.4 **Pre-Build Checklist.** A pre-build checklist shall be established prior to each build which includes, but is not limited to, the following: a maintenance/qualification log, the correct feedstock material and quantity for the build, presence of a properly prepared build platform/chamber, presence of a properly prepared re-coater, verification of the drawing revision number to the part file, verification of the build orientation and build platform location, part quantity for the build, and verification of the correct machine parameter settings per approved manufacturing plan.

6.5 **Process Control Plan**. The Supplier shall develop and review their process control plan with the Purchaser as part of Advanced Product Quality Planning (APQP) and PPAP utilizing and matching the steps, frequencies, and detection methods specified in the Process Failure Modes and Effects Analysis (PFMEA). Any parts with a process change (or a deviation from any specification) from the PPAP approved process control plan requires approval from the Purchaser PRIOR to shipment including proper labeling and shipping methods from the deviation. Subsequently, if the change/deviation is agreed by both parties to continue, it will require a new PPAP (with the level to be defined by the Purchaser.)

6.6 **Training and Work Instructions.** Documented process procedures and specifications shall be defined as part of the end-to-end additive

manufacturing process, including digital file creation and build setup, to assure quality parts can be manufactured at each step of the process. These shall include the equipment to be used as well as approved process steps.

From these procedures, operator training with standard work instructions which are properly written to explain the correct method of performing the operator job functions shall be developed. The Supplier shall ensure operators are cross trained to perform various job functions. The Supplier shall have training plans and a method to certify each of the Supplier's employees. Tracking and performance must be available to the Purchaser upon request.

6.7 Polymers and Metals Manufacturing Requirements

6.7.1 Where applicable, the Supplier shall have a build platform specification which includes, but is not limited to, the appropriate build platform material, geometry, parallelism, and surface finish. The build platform shall be inspected to ensure qualification prior to building. Material for the build platform shall be selected for the appropriate heat conductivity, absorbability, strength, stiffness, and material.

6.7.2 The re-coater system shall be inspected for chips, scratches, or debris that could cause detrimental defects during the build process. The re-coater is required to be consistent with the manufacturer's recommendation in assembly and material type.

6.7.3 Machines shall be operated in a controlled atmosphere where a monitoring system for humidity and temperature is present, verified for accuracy, and calibrated on a scheduled basis. Sensors shall be placed within the build chamber to facilitate the most accurate measurement possible. The build shall not be started until the atmosphere within the chamber has been reached for the appropriate feedstock material.

6.7.4 The fusing mechanism(s), if applicable, and accessories shall be calibrated and checked for accuracy prior to build.

6.7.5 The inkjet nozzles, if applicable, shall be purged and checked for clogging prior to build.

6.7.6 The Supplier shall be responsible for applying the correct scaling factors and processing parameters to produce the final part to required tolerances.

6.7.7 The chamber of the printer shall be clean and free from debris prior to build.

6.7.8 A minimum part spacing shall be established between parts and away from the extremities of the print chamber.

6.7.9 The airflow system within the machine chamber shall be calibrated and checked against limits for each build.

6.7.10 Part layout in the build chamber shall be established by the Supplier to provide a build free of defects and to maximize part quality and approved by the purchaser. Changes to the part layout after the Production Part Approval Process (PPAP) will require approval by the Purchaser and may require additional PPAP.

7. POST PRINT PROCESSING

7.1 All metal parts shall have a stress relief or heat treatment plan approved by the Purchaser. All heat treatment procedures including heat treatment and stress relief must have a heat treatment conformance report including hardness testing before and after heat treatment. Other requirements apply per section 4.4.4.

7.2 A debinding and sintering process shall be established by the supplier and approved by the purchaser, where applicable. All debinding and sintering processes must be maintained from PPAP through the production of components. Any deviations to the approved process must be reviewed and approved by the purchaser.

7.3 Support structures shall be removed from the part. All metal parts shall be free from burrs or sharp edges that may cause injury.

7.4 Parts shall be cleaned to remove any unsintered powder or material which is not present on the CAD model.

7.5 Surface texture shall be defined during quotation in accordance with ISO 1302 and may be defined as a constant value for the part and further specified by specific part location as determined by the Purchaser.

7.6 Part tolerances shall be specified in accordance with ISO 2768 and shall be agreed upon between the Supplier and Purchaser during the time of part quotation.

7.7 Additional surface finishing, sealing, appearance, and cosmetic processes may be required per purchaser requirements and shall be agreed upon during quotation.

8. QUALITY REQUIREMENTS

8.1 Reference IATF 16949 for AIAG quality requirements.

8.2 **Build Interruptions.** All unplanned and planned interrupted builds shall be reported to the Purchaser. Approval is needed from the Purchaser prior to releasing a planned or unplanned interrupted build. The Supplier shall have an action plan for build failure that addresses build failure prevention and the corrective action taken if a build failure occurs.

8.3 **Material Misfeeds.** The Supplier shall have in place a plan to identify misfeeds/shortfeeds of powder that may occur during the building process. Approval is needed from the purchaser prior to releasing a build with misfeeds.

8.4 **Part Identification.** The supplier shall have a method for uniquely identifying each individual part in a given build, and through the production run, which is approved by the purchaser. For instances in which a proper identification is not feasible, a review with the purchaser must be performed.

8.5 **Traceability.** All parts are expected to have complete electronic traceability throughout the entirety of the process via its unique identifier. Parts should be traceable at a minimum to the following:

a. Part CAD (or other applicable software) file, including approved release revision
b. AM file (STL, AMF, 3MF, etc.)
c. Build layout file
d. Parameter set
e. Feedstock certification
f. AM build report
g. Verification that all process steps were completed with agreed upon quality requirements per control plan prior to shipment of parts
h. Dimensional and final inspection data
i. Equipment maintenance records

8.6 **Part Verification Requirements.** The Part Supplier shall ensure and verify part conformance to all applicable specification requirements. The Part Supplier shall have calibrated/certified checking instruments/equipment on site. The Part Supplier shall notify the Purchaser at Strategic Sourcing Process (SSP) the type of equipment (Coordinate Measuring Machine (CMM), Scanning, etc.), the Supplier will utilize for their part verification. Testing on every build shall be performed until the process is determined to be in control as measured by successful completion of non-saleable part requirements Action Plan and

saleable PPAP. For the purpose of this requirement, a lot shall be defined as a build. Inspection frequency shall be documented in the Part Supplier process control plan and shall not be altered without the Purchaser's approval. Data taken from testing and inspection frequencies shall be documented and monitored per the agreed upon process control plan.

8.7 **Reporting.** Table 3 shown below lists a summary of required documentation to be submitted to the purchaser as part of the request for quote process or shall be available upon request.

Table 3: Summary of Deliverables

E11 Ref.	Deliverable	When to Submit		
		RFQ Response / Tech Review	PPAP	Completion of Production Build
4.1	Manufacturing Plan	X	X	
5.5	Process Control Plan	X	X	
6.1	Powder Feedstock Specification	X		
6.2	Powder Recycling Plan	X	X	
8.	Batch Acceptance Test			X
9.2	Interrupted Builds Action Plan		X	
9.3	Material Misfeeds Plan		X	
9.5	Part Traceability Summary	X	X	
10.1	Dust Hazard Analysis	X	X	
12.	Maintenance Plan	X	X	
13.	Design Review	X		

9. SAFETY

9.1 **Dust Hazard Analysis.** A Dust Hazard Analysis (DHA) for the AM facility (Manufacturing DUNS site) shall be completed per NFPA 652 Standard on the Fundamentals of Combustible Dust or other equivalent recognized combustible dust standard, prior to the RFQ Technical Review. If a DHA is not complete or has expired at the RFQ Technical Review stage, a plan to conduct a DHA shall be submitted with a Technical Review package. A current, valid DHA report shall be submitted as part of PPAP approval.

9.2 **Personal Protective Equipment.** During all operations where hazards are present, operators shall wear Personal Protective Equipment (PPE). Typical examples include, but are not limited to, respirators, fire retardant jackets/suits, gloves, safety glasses, electrostatic dissipative shoes, etc.

9.3 **Hazardous Waste**. All waste generated during the loading, running, depowdering, sieving, and post-processing steps shall be labeled and disposed as hazardous waste, where no current national, state, and/or local safety regulations currently exist.

9.4 Refer to all national, state, and local safety regulations and Supplier recommendations for additional safety requirements.

10. MAINTENANCE PLAN

10.1 A Total Preventative Maintenance (TPM) plan shall be established and shall specify the frequency of all system checks and the method of documentation. Where machines are not under service contract, a critical spare parts list shall be developed and any personnel working on "breakdown or non-preventative" items shall be trained by the OEM machine manufacturer or certified to the OEM standards.

The preventative maintenance plan should include but is not limited to the following where applicable by machine type:

a. Beam generation, position, and alignment of all components.
b. Platform position within the system and any other mechanical components.
c. The cooling and chiller system.
d. The filter system and gas purge system.
e. Compressed air and dryer system.
f. Gas supply to the processing chamber including regulators.
g. Sensor calibration- oxygen, temperature, flow rate, and pressure.
h. System calibration- beam, galvanometers, servos, sensors, lenses, optics.
i. Power level after the laser beam has passed through the system optics.
j. Evaluation of wear components.
k. Cleaning procedure in accordance with OEM operations manual.
l. Any inspection required by state, local, or federal government body.
m. A laser power curve must be established and reconfigured to ensure the laser power is within the specification limit.

11. TECHNICAL REVIEW/REQUEST FOR QUOTE (RFQ) PROCESS.

11.1 The Purchaser and the prospective Supplier will have an open dialog to establish all manufacturing, testing, qualification, part classification, and reporting for the quoted additively manufactured part. Agreement between

the Supplier and the Purchaser shall be established prior to the commencement of the build.

11.2 During the quotation process, the Purchaser requires that the Supplier submit a Manufacturing Execution Plan.

11.3 The purchaser will request the manufacturing plan and master qualification plan for review with the Supplier. All documents listed in Table 3 are required to be submitted to the purchaser for RFQ. A summary of the manufacturing plan will be presented to the purchaser to give an overview of the process. Specific documents pertaining to the manufacturing plan shall be available for submission at the request of the purchaser for clarification.

11.4 A design review of the part to be printed with the anticipated build information shall be included with the following:

a. Design for Additive Manufacturing feedback
b. Complete build layout, including total number of parts, part locations and orientations, and support structure if applicable.
c. Total printed material volume, and support structure volume, if applicable
d. Total build height.
e. Total number of layers.
f. Total build time- including warm up, fusion time, and cool down time.
g. Powder consumed for each build and the unused powder recovered.
h. Polymers- packing density of the parts in chamber, powder considered as waste in addition to powder consumed for each build and powder recovered, the detailing and fusing agent consumed for build (where applicable to the process used).
i. Support structures.
j. Method for compensation of shrinkage and distortion throughout process.

CHANGE LOG

This Change Log lists all approved changes implemented in this document since the last published version.

Paragraph Affected	Description of Change	Change Date	Version
All	Initial Publication	14APR2020	1
All	Version update to V2	05MAY2020	2
All	Refinements via USCAR collaboration	15DEC2021	3.0