



AEROSPACE RECOMMENDED PRACTICE

ARP7044™

Issued

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Powder History Metric and Labeling Schema

RATIONALE

Release of a new SAE Aerospace Recommended Practice (ARP) where none before had been published.

1. SCOPE

1.1 Purpose

This SAE Aerospace Recommended Practice (ARP) describes a method to measure, track, and characterize the history of powder feedstock when consumed in the production of parts via additive manufacturing (AM). The history captured as part of this ARP includes AM process exposure, feedstock consumption, blending, and losses associated with the totality of the AM workflow. This document also outlines a two-part metric schema for used powder feedstock consequential of its process exposure history. This metric schema also enables aligning risk determination and usage practices for used powder when based on a correlation between tabulated values in the schema and user-identified metrics. These correlated metrics with schema values may also be used when establishing powder blending workflows or identifying end-of-life for feedstock.

1.2 Application

This metric and labeling schema is best applied when used in combination with fixed practices and under control by associated process specifications. These specifications shall govern both the AM process to produce parts and the methods to recover, recondition, inspect, disposition, and blend used and virgin feedstock. The combined definition of both AM process and ex situ powder handling¹ establish controls throughout the powder feedstock lifecycle and maintain the integrity of tabulated metrics determined by this ARP document.

This document and its contents do not inherently or automatically establish requirements for implementation of an AM process or powder reuse process. Furthermore, the metric defined in subsequent sections does not serve as acceptance criteria nor does it supersede requirements described by virgin powder specifications when identified. However, requirements may be established at the discretion of a cognizant engineering organization (CEO) as a consequence of this document's usage.

This ARP is limited in scope to individual alloys described by a single powder specification and not intended to establish controls across various grades of a singular chemistry².

¹ Established by AMS7031 or similar process to batch prepare used powder for reuse.

² The following are examples of cases not intended to be covered by this document:

Example 1: Used AMS7017 (Ti-6Al-4V ELI/Gr. 23) is determined to no longer be conforming to requirements of weight percent oxygen and is topped off with virgin AMS7017 (Ti-6Al-4V ELI/Gr. 23) to return bulk chemistry measurements to meet requirements of AMS7017.

Example 2: AMS7015 (Ti-6Al-4V/Gr. 5) is topped off with virgin or used AMS7017 (Ti-6Al-4V ELI/Gr. 23) to extend reuse life.

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2. APPLICABLE DOCUMENTS

The issue of the following document in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier 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.

AMS7002	Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts
AMS7003	Laser Powder Bed Fusion Process
AMS7025	Metal Powder Feedstock Size Classifications
AMS7031	Batch Processing Requirements for the Reuse of Used Powder in Additive Manufacturing of Aerospace Parts

2.2 Terms and Definitions

The following definitions apply for the calculation of metric values, shorthand abbreviation in metric designations, and general usage of the metric.

UNIQUE LOT IDENTIFICATION: A sequence of letters and numbers that may be either intelligible or not when identifying a measurable mass of powder at any point during the additive manufacturing process, powder reuse process, or when stored for later usage. For the purpose of defining the metric, this unique lot identification will be referred to by the shorthand of:

AAA

BUILD CYCLE COUNTER: All powder that has entered into the volume considered to be the build envelope of an AM process and exposed to machine or process variables will denote the execution of a single build cycle. For the purpose of defining this metric, this build cycle counter will be an integer value describing the number of build cycles that the powder has seen exposure. When blending lots of powder, the resultant mixture or blend of powder will inherit the largest value from the constituents combined. No powder reuse process, blending of used and virgin powder, or reconditioning may alter this metric value. Virgin powder will maintain a build cycle counter of "000" until it meets the defined criteria described in this definition. The build cycle counter will be referred to by the shorthand of:

BBB

LOT MASS: The mass in kilograms of the lot or batch of powder. This unit of powder may already be assigned a calculated metric string. This value represents the current mass of the powder and may be adjusted should any powder be debited from the lot as part of future consumption or loss to outside of the AM or powder reuse processes. The lot mass will be referred to by the shorthand of:

DDD

RECOVERED FRACTION: The ratio of the mass of powder recovered and reconditioned (m_R) to the mass of the powder loaded (m_L) into a single build cycle of an AM process. The recovered fraction will be referred to by the shorthand and calculation of:

$$RF = \frac{m_R}{m_L}$$

The measured mass of powder recovered and reconditioned is indicative of powder that is determined to represent the mass of used powder that is conforming to the powder specification. Actions such as sieving during reconditioning may lower the effective mass and this debit shall be accounted for when establishing the RF ratio.

RECOVERED FRACTION METRIC: The value assigned to the powder and used in labeling and bookkeeping of its relative exposure history. A recovered fraction metric shall be tabulated after every build, blending of individual lots of powder. The recovered fraction metric represents a cumulative consumption metric that approximates fractional build cycle printed volume as a proxy for a powder lot's exposure to a build cycle environment. The less powder recovered from a build cycle, the more powder is considered to have been consumed, and consequently the more energy imparted to that process's build cycle.

For powder recovered from an AM process, its new RFM value is calculated as the product of the recovered fraction of powder from the build cycle and recovered fraction metric of the powder used as feedstock for that build cycle. For virgin material, the recovered fraction metric shall be denoted by a value of 1.000.

$$RFM_{output} = RFM_{input} * RF_{build\ cycle}$$

For example, a build cycle where the feedstock loaded maintains an RFM of 0.900 and loaded mass (m_L) of 80 kg, and the mass of powder recovered (m_R) is 68 kg, the RFM output value shall be tabulated as:

$$RFM_{output} = 0.900 * \left(\frac{68\ kg}{80\ kg} \right)$$

$$RFM_{output} = 0.765$$

MASS WEIGHTED RECOVERED FRACTION METRIC: When blending lots of powder with different histories, the recovered fraction metric value shall be weighted by the mass of the powder acting as a constituent to a larger mixture or blend. The mass weighted recovered fraction metric shall be referred to by the shorthand and calculation shown where " m " refers to the mass of the powder with the recovered fraction metric and the subscript of " i " describes a single constituent to the mixture or blend:

$$MWRFM_i = m_i * RFM_i$$

POWDER STATUS PREFIX: A modified prefix is used ahead of the unique lot identification string to denote if the powder is either in the virgin, reuse, or non-compliant state. This is only used to aid in the identification of powder condition and may be found at the beginning of the powder history and metric string. For the purpose of shorthand reference, the prefix will carry the placeholder of:

p

And be located at the beginning of a unique lot identification:

$pAAA$

If a prefix is to be used, it may be either of the following:

V : Virgin powder

R : Reuse powder

NC : Non-compliant powder

NON-COMPLIANT POWDER: Powder determined to have properties or characteristics that are outside limits established by an associated powder specification. This term may also be used to identify powder that meets some pre-determined criteria of usage history when assessed using this ARP.

REUSE POWDER: Powder prepared in accordance with AMS7031, or similar, and determined to be in conformance with requirements established by an associated powder specification. Until conformance to a powder specification is established, used powder is not designated as reuse powder.

3. POWDER HISTORY METRIC AND LABELING SCHEMA

3.1 Background

Requirements within virgin powder specifications are used for the procurement of feedstock for AM processes. In the absence of standardized requirements for reuse powder, these same specifications are commonly considered the acceptance criteria when determining if reuse powder is fit for continued AM workflows. However, many of the standard test methods and acceptance limits for characteristics of powder feedstocks are established at size scales that cannot efficiently or cost-effectively measure with sufficient precision non-conforming or deleterious attributes at individual particle levels. This type of degraded feedstock cannot be meaningfully improved by reconditioning operations. Bulk inspection techniques designed for acceptance of virgin powder may be unable to properly discriminate between reuse feedstock fit and unfit for specific applications. Additionally, unappreciated or yet-identified forms of degradation may accumulate in a powder feedstock with its continued usage. For AM processes used to produce high-value or high-consequence parts, the uncertainties associated with powder reuse strategies may be too great for an organization and its parts' applications.

3.2 Implementation

This ARP proposes a schema to be applied on used powder as a means to collect powder process exposure history and correlate it with measurable material properties or performance of interest. Such data and its association may then further serve as criteria to quarantine used powder or realign used powder for narrowly determined applications. The implementation of this practice is considered to be most accurate when applied with an AM process controlled by a single process control document (PCD); however, usage of this schema is not limited to such single-process applications.

To minimize the burden at implementation, the measurement and metric schema proposed in this document reduces a complicated manufacturing process and its effects on powder feedstocks into simplified inputs and outputs. It is acknowledged that this reduction in complexity may overlook, under-account, or over-account the degradation AM processes may impart. It is for this reason that the metric schema includes several tracking metrics that may be used collectively or individually when determining the best method to track and assess a feedstock's usability when managing process and part risk. Other commercially available processes and tools may be available to address this measurement and powder assessment use case.

The powder history and metric schema in this document was intended to be used in AM workflows that are powder-bed technologies operated as batch processes with lot identification and control. However, this schema may find utility with other AM processes and can be adapted at the discretion of CEO.

The following sections define this metric, provide examples of its usage, and identify its shortcomings in practice.

3.3 Utility Limits

Powder lots that use this metric are intended to also be labeled with such information. This metric is only useful when its values are maintained throughout the implementation of the associated AM process PCD, storage of used and unused powder, and adjusted as a consequence of the blending that occurs throughout each execution of a powder reuse process (refer to AMS7031).