



SAE AEROSPACE STANDARDS – Additive Manufacturing Specifications

David Alexander
Director, SAE Aerospace Standards

Affiliate



Affiliate



Aerospace Council Organisational Chart

SAE Aerospace Council Organization Chart

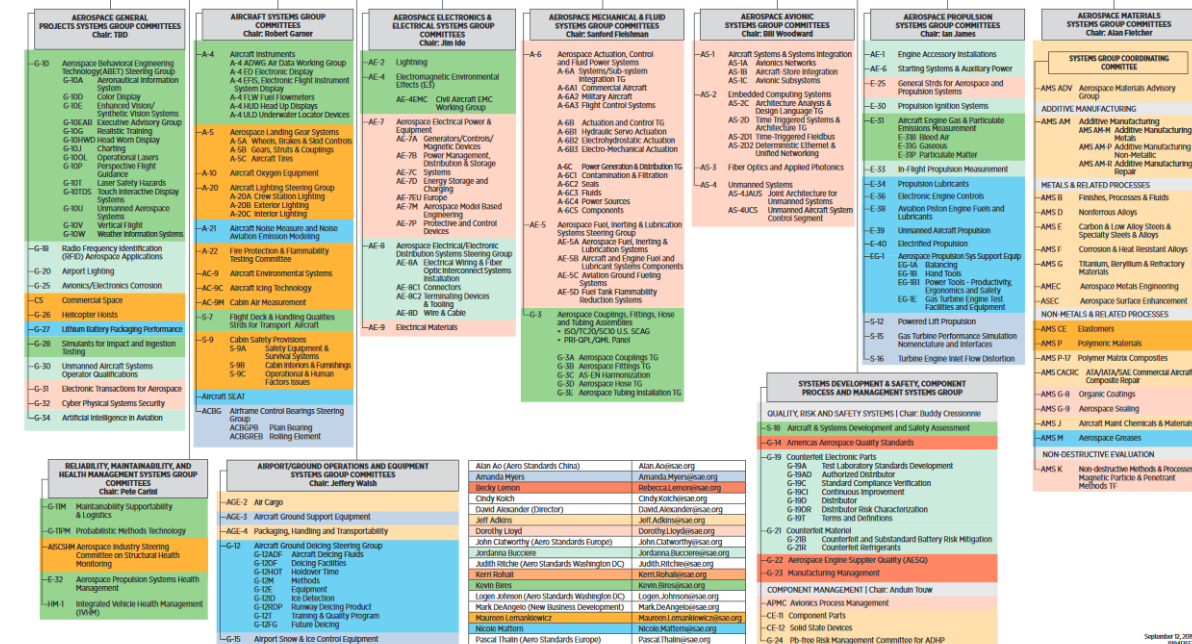
sae.org/standards



Americas
400 Commonwealth Drive
Warrendale, PA 15096 USA
+1 877 606 7323
+1 724 776 4930
CustomerService@sae.org

Europe
1 York Street
Wandsworth, W8 5PA, UK
+44 (0) 20 7034 1250

Asia
Room 2502, Litong Plaza,
No. 1350 North Sichuan Road
Hongkou District,
Shanghai, 200080, P.R. China
+86 21 6140 8900



Systems Groups 10

Steering Groups 3

Technical Committees 180+

Standards 7,800+

AS, AMS, ARP, AIR

Unique Participants 8,500+

Total Participation 17,600+

SAE Aerospace Council, Global Custodians: Oversight and Governance

Airbus

American Airlines

A4A

AVIC

BAE Systems

Bell

Boeing

CAPE

CIRA

COMAC

EASA

Embraer

FAA

Leonardo

GE Aviation

Gulfstream Aerospace (Chair)

Honeywell Aerospace

Lockheed Martin

Lufthansa Technik

Meggitt

Northrop Grumman

Pratt & Whitney / UTC

Rolls-Royce

Safran

Sikorsky

Textron Aviation

U.S. Department of Defense

UPS

Wichita State University

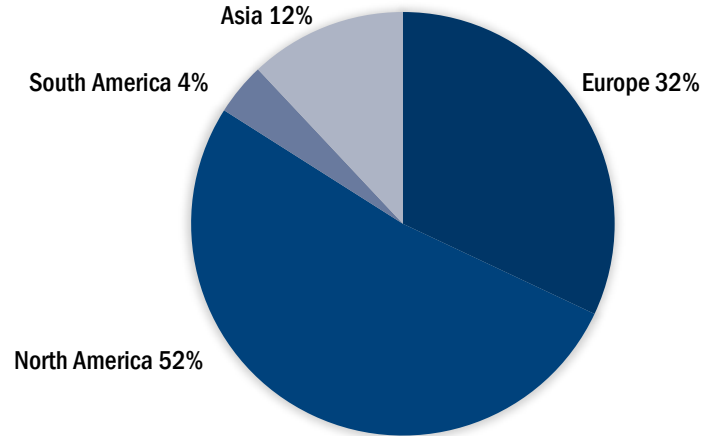
April 2018 meeting hosted by Safran, Saclay

Stakeholders:

Industry, Operators, Government, Research

ICAO Observer Role

Global Stakeholders: Matching the Industry



New SAE Committees 2014-19

G-22 Engine Supply Chain Quality

G-25 Electronics & Avionics Corrosion Protection*

G-26 Helicopter Hoists*

Electric Aircraft Steering Group (EASG)

AMS-AM Additive Manufacturing*

A-4 HWD – Head Worn Displays*

A-4 EFIS – Electronic Flight Information Displays*

G-27 Lithium Battery Packaging Performance*

G-28 Simulants for Engine Ingestion & Impact Testing

E-39 Unmanned Vehicle Propulsion Systems

SMC-PNT Position, Navigation, Timing

AC-9M Cabin Air Quality Measurement*

AE-9 Electrical Materials

G-30 UAS Operator Approvals

Digital & Data Steering Group

A-22 Fire Protection and Flammability Testing*

G-31 Electronic Transactions (Blockchain)

G-21B Counterfeit Batteries

E-40 Electrified Propulsion

AE-7D Aviation Battery Technology & Charging

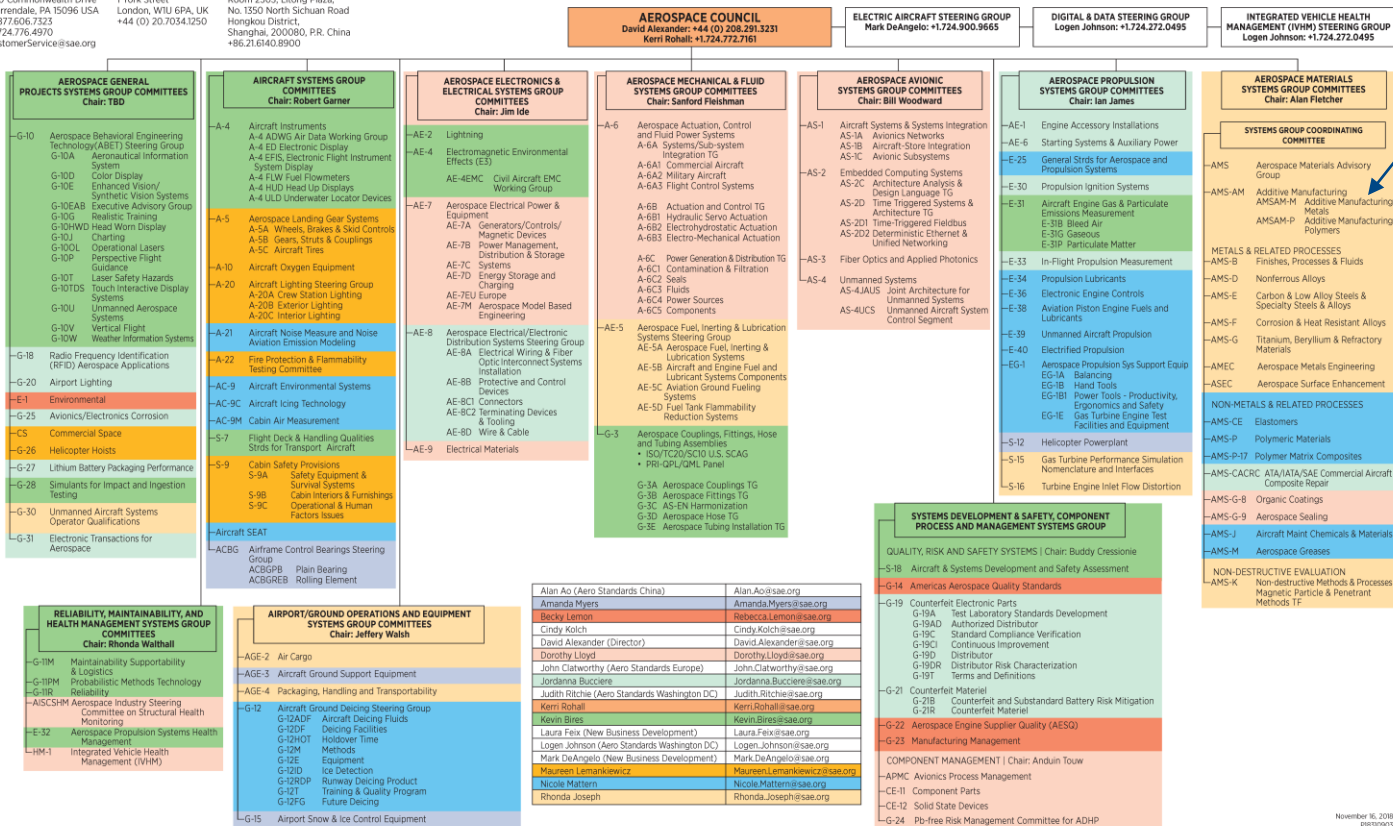
G-32 Cyber-physical Systems Security

G-34 Artificial Intelligence

* Authority/Agency/Association Request

SAE Aerospace Council Organization Chart

sae.org/standards



AMS-AM

SAE AMS Key Principles Support Aircraft Certification

AMS = Aerospace Material Specifications

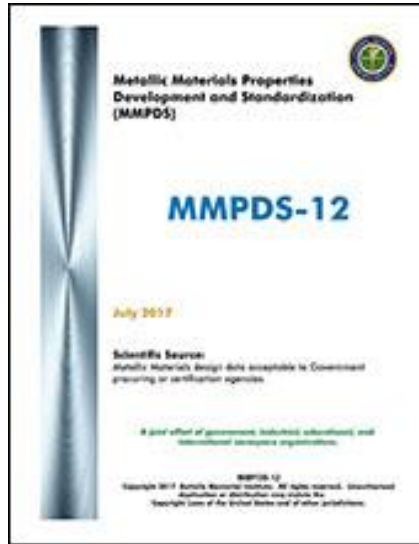
- Establish appropriate requirements and controls to ensure quality and consistency of final product
- Traceable to statistically substantiated material property data
- Support public material property database with verifiable pedigree
- Downgrading the properties or characteristics of published AMS are not permitted
- Provide foundation for regulatory acceptance and certification processes

Minimum Tensile Properties

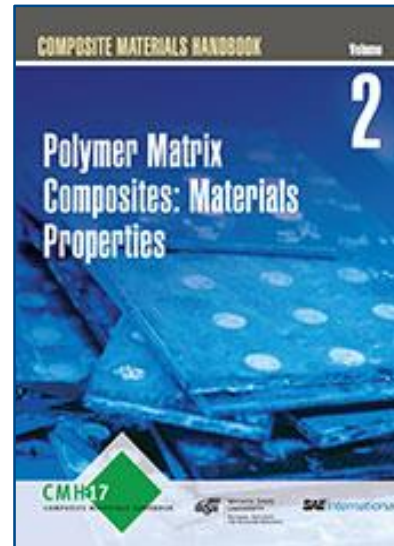
Section Size (In)	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)
Direction >>	Z	Z	Z
Up to 0.5	120	50	30

AMS Ties to Materials Properties Databases

SAE's aerospace material and process specifications therefore support material property databases with verifiable pedigree – such as...



References 1500+ AMS metals specs



References AMS composite specs

First Additive Manufacturing AMS Specification

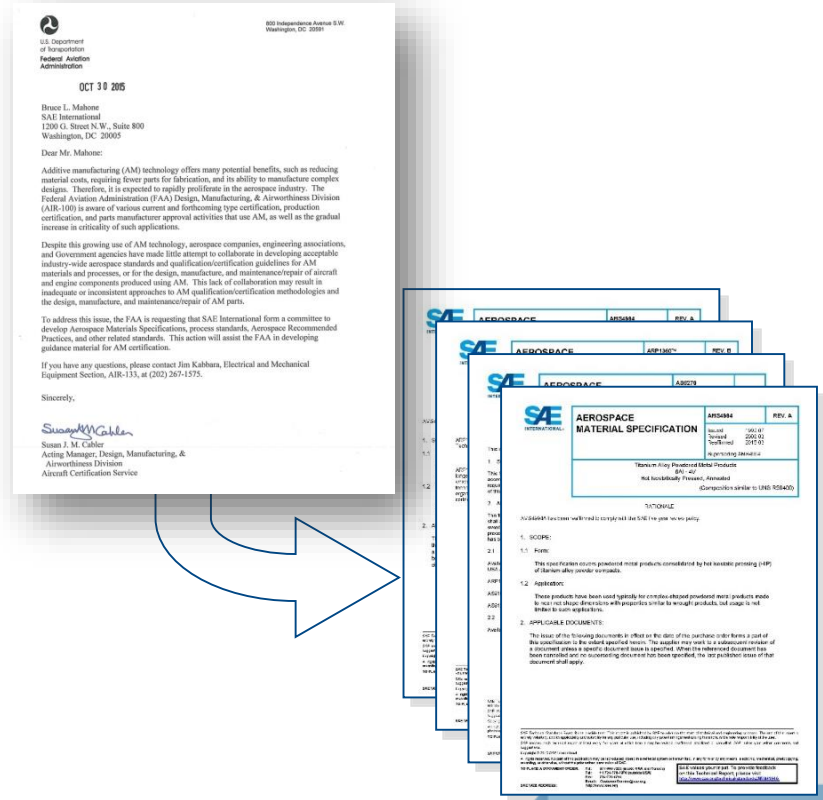
AMS4999, Titanium Alloy Direct Deposited Products 6Al - 4V Annealed

- 2002: Initial release by AMS-G, Titanium, Beryllium & Refractory Materials
- 2011: Revision – AMS4999A
- 2016: Reaffirmed
- 2017: Transferred from AMS-G to AMS-AM

Federal Aviation Administration (FAA) Task Request to SAE

- Signed October 30, 2015
- Requested SAE International
- ‘form a committee to develop Aerospace Materials Specifications, process standards, Aerospace Recommended Practices, and other related standards ...

to assist the FAA in developing guidance material for AM certification.’



SAE AMS-AM Committee – Then

Inaugural meeting July 21-22, 2015 in Atlanta

- Created subcommittees and initiated specification projects
- First Face-to-Face Meetings Cincinnati (GE), Bristol (Air
- 150+ registered members
 - 4 Subcommittees
 - 1 sponsored specification
 - LPBF 625
 - 2 proposed specifications
 - LPBF 625 Powder Feedstock, LPBF Process



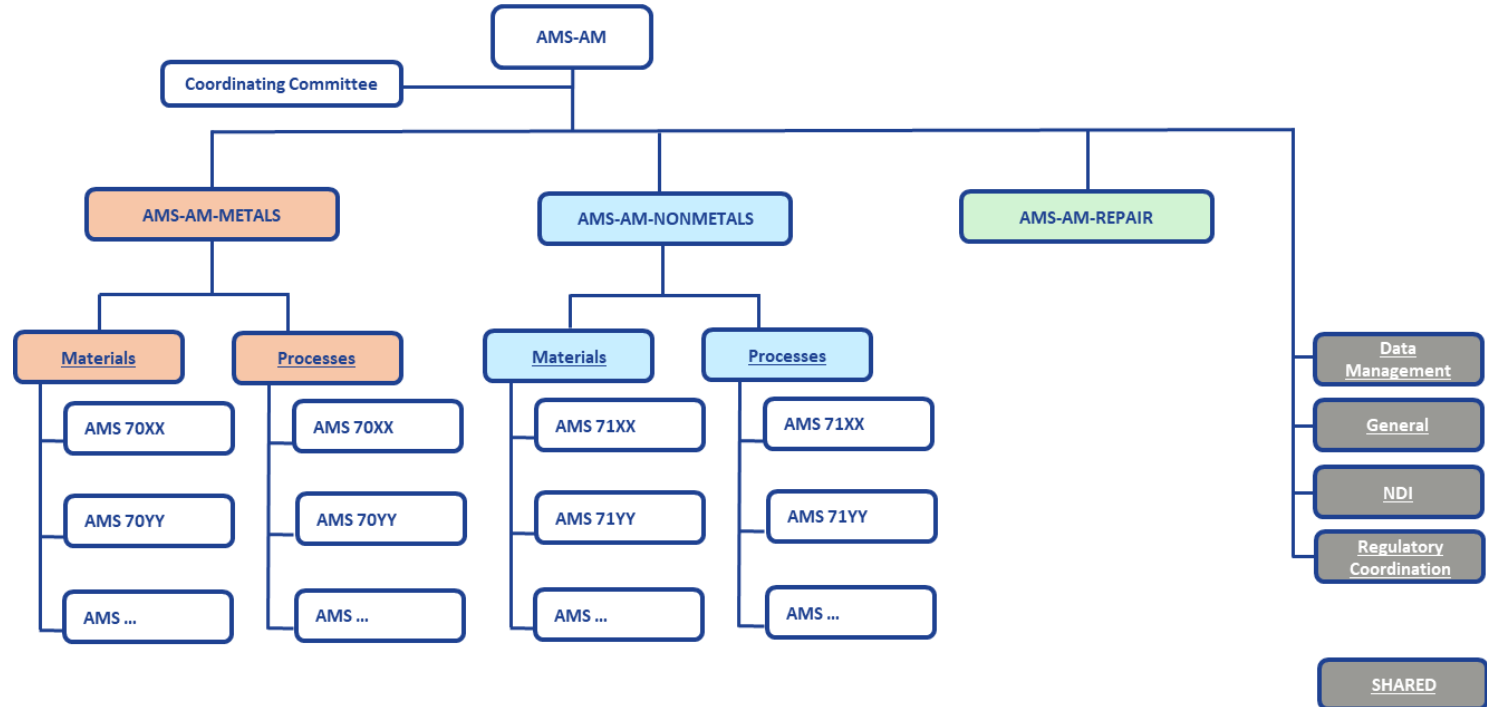
SAE AMS-AM Committee – Now

- 500+ members from 20+ countries
- Airlines, MRO, aircraft/spacecraft/engine OEMs, Tier 1 & 2 suppliers, component manufacturers, machine suppliers, material suppliers, feedstock, service providers, test laboratories, defense agencies, regulatory authorities
- 7 Subcommittees
- 10 published specs
- 22 specs under development
- Expansion into Nonmetals & Repair
- New frontiers...



SAE AMS-AM Committee

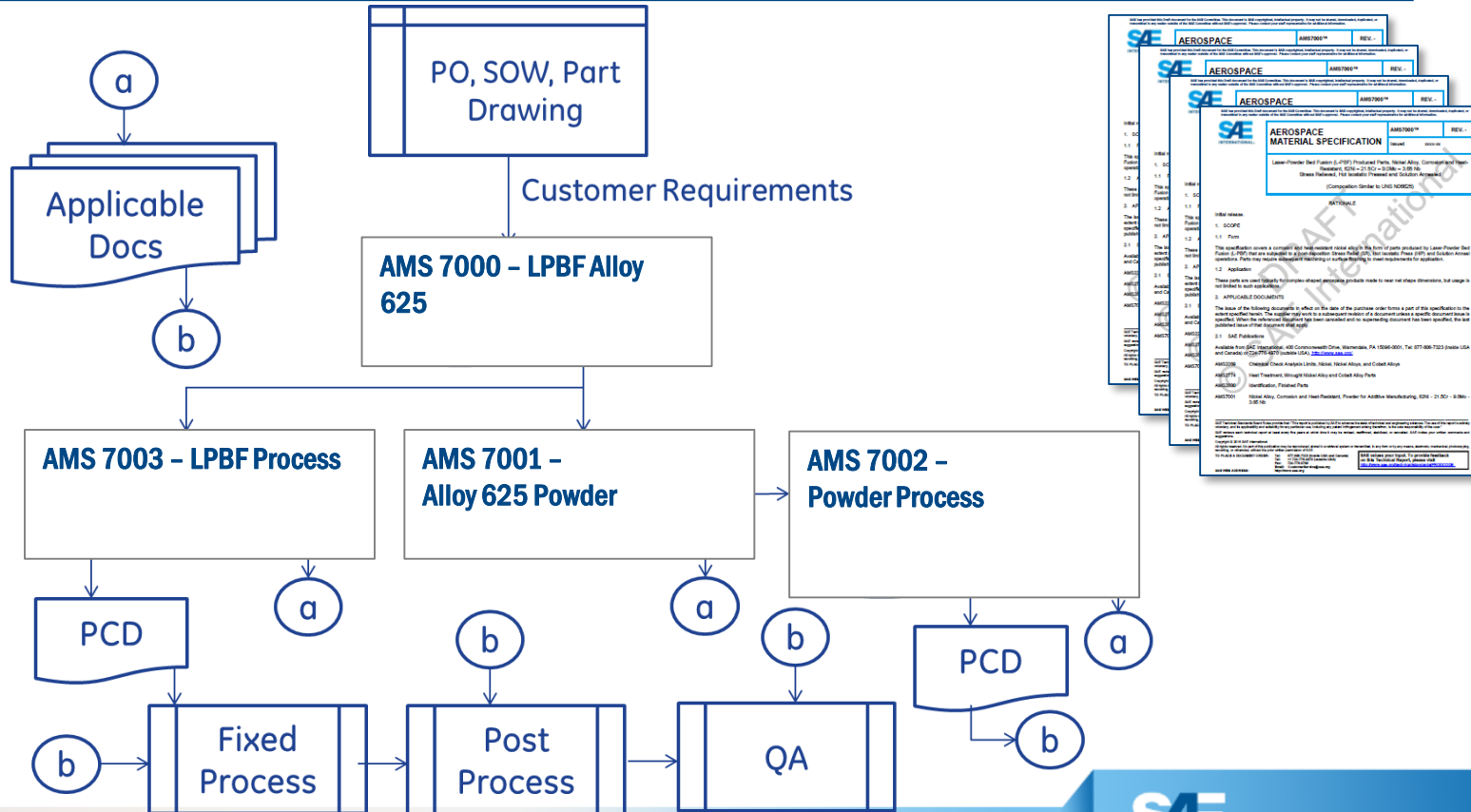
Scope: To develop and maintain aerospace material and process specifications for additive manufacturing...



2018 Published AMS-AM Specifications – Metals

Standard	Title	Type
AMS7000	Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni -21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed	Final Material Spec
AMS7001	Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 62Ni - 21.5Cr - 9.0Mo - 3.65 Nb	Powder Material Spec
AMS7002	Process Requirements for Production of Powder Feedstock for Use in Laser Powder Bed Additive Manufacturing of Aerospace Parts	Powder Processing Spec
AMS7003	Laser Powder Bed Fusion Process	Process Spec

Specification Hierarchy Applied to First AMS-AM Specifications



2019 Published AMS-AM Specifications – Metals

Standard	Title	Type
AMS7004	Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved	Final Material Spec
AMS7005	Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process	Process Spec
AMS7008	Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe	Powder Material Spec
AMS7013	Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La	Powder Material Spec
AMS7014	Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo	Powder Material Spec

Additional Metallic AM Documents Under Development (1/2)

Type	Topics
Material (Powder)	718 (AMS7006) 17-4 Powder (AMS7012) Ti 6-4 Grade 5 (AMS7015) Ti 6-4 ELI Grade (AMS7017) AlSi10Mg (AMS7018) Aluminum Alloy Powder (AMS7020) 15-5PH Powder (AMS7021) Ti-48Al-2Nb-2Cr Powder (AMS7023) Powder Feedstock Size Classifications (AMS7025)
Material (PBF Finished Part)	17-4PH H1025 Alloy Laser Powder Bed Fusion (AMS7016) Inconel 718 L-PBF Material specification (AMS7024)

Additional Metallic AM Documents Under Development (2/2)

Type	Topics
Process	<p>Process Requirements for Production of Metal Powder (AMS7002A)</p> <p>Laser Powder Bed Fusion Process (AMS7003A)</p> <p>Electron Beam Powder Bed Fusion (AMS7007)</p> <p>Ti 6-4 with Laser Wire Deposition (AMS7009)</p> <p>Laser Wire DED (AMS7010)</p> <p>Ti 6-4 Electron Beam Powder Bed Fusion (AMS7011)</p> <p>Binder Jetting Process (AMS7022)</p>
General	<p>Part Qualification Guidelines (AIR7352)</p>

Non-Metallic Additive Manufacturing

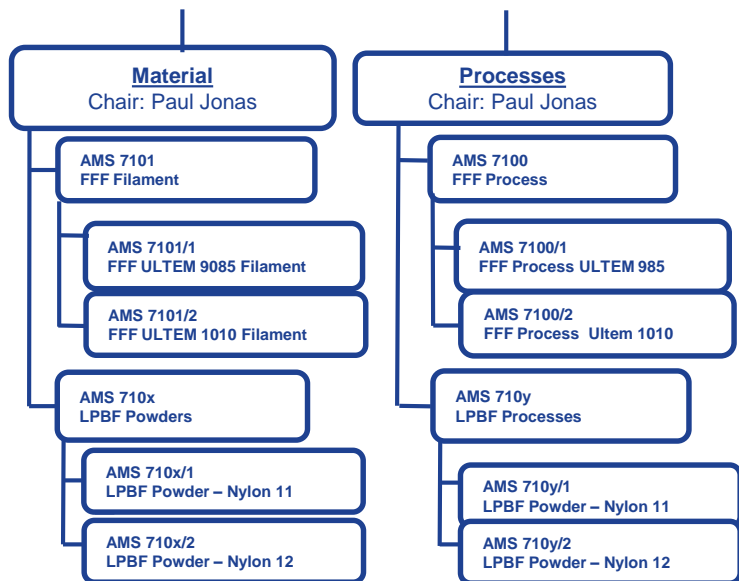
AMS-AM P Non-Metallic Additive Manufacturing Subcommittee

- Initiated in 2017 at IATA's request to meet aviation regulatory requirements for quality and consistency of polymeric additive manufactured parts
- AMS7100 Series
- Provides traceability to NCAMP material property data
- Unique framework for nonmetal material & process specifications
- First 2 aerospace AM polymer specs published in October 2019

AMS-AM Polymer – Published & In-Process Specifications

Number	Title	Description	Status
AIR7300	<i>Polymers Data Submission Guidelines</i>	Explains the procedure and testing schematic needed to establish the specification minimum values and preliminary test estimate	In revision
AMS7101	<i>Material for Fused Filament Fabrication Process</i>	General Requirements needed to establish minimum values for FFF Feedstock	Published ✓
AMS7100	<i>Fused Filament Fabrication Process</i>	General Requirements needed to establish a FFF System (machine/materials/software)	Published ✓
AMS7101/1	<i>Material for Fused Filament Fabrication- Type 1, Class 1, Grade 1, Natural Material</i>	Specific Requirements and Acceptance Criteria for this type of FFF Feedstock	In Ballot
AMS7100/1	<i>Stratasys Fortus 900mc Plus with Type 1, Class 1, Grade 1, Natural Material</i>	Specific Settings/Requirements details to Achieve the Minimum Specification Values and Full Qualification	Dec 1 st Final Draft for Ballot
AMS7102	<i>Laser Powder Bed Fusion</i>	General Process Specification for the L-PBF process	Draft Due in 2019
AMS7102/1	<i>L-PBF EOS Machine Specific Process Specification</i>	Specific Process Specification to the machine and material	Draft Due in 2019
AMS7103	<i>L-PBF Material</i>	General Specification defining requirements for the L-PBF process	Draft Due in 2019
AMS7103/1	<i>A Specific Material for the L-PBF Process</i>	Specific Requirements for a unique material for the L-PBF Process	Draft Due in 2019
ARP XXX	<i>Material Recycling Recommended Practices</i>	Standard practices used for powder handling and storage/recycling. Used in the data generation of 7102/1 & 7103/1	Draft Due in 2019

Multiple Slash Sheets

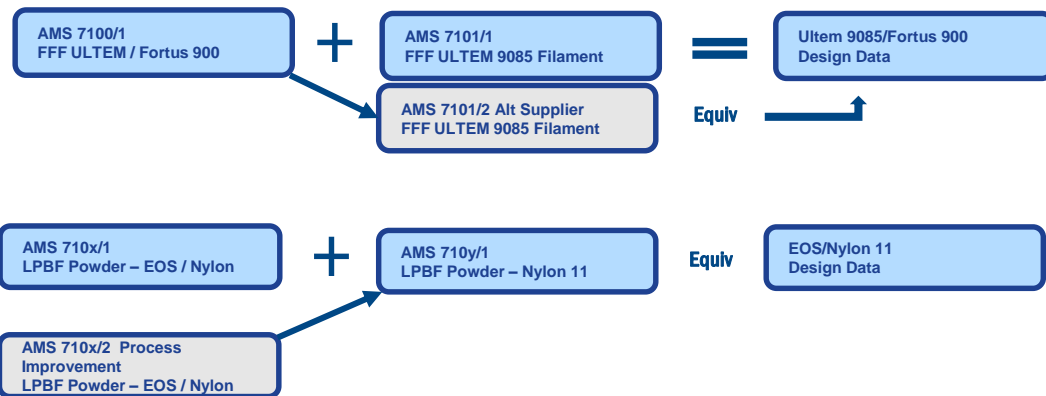


A different Process (Machine) requires a different slash sheet -

To be able to utilize the approved design data;

Equivalence would need to be shown

Equivalence – Is statistical Equivalence (not \geq)



Obtaining the AMS-AM Specifications

Usual channels – Direct to SAE or 3rd party resellers

SAE Mobilus - AMS-AM Specs

The screenshot displays the SAE MOBILUS website interface. At the top, the SAE MOBILUS logo is visible, along with a 'Select Language' dropdown and a 'Help' button. Below the logo, a navigation bar includes links for 'SAE MOBILUS Home', 'Search', 'Dashboard', 'Learning Center', 'Knowledge Hubs', 'Browse', and 'Standards Committees'. A search bar is present with the placeholder text 'Enter keyword, authors, product code...' and a dropdown menu set to 'Metadata + Full Text'. A 'Search' button and a link to 'Advanced Search' are also visible.

A yellow banner message states: 'The SAE MOBILUS platform will be unavailable from 7:00am EST to 12:00pm EST on Saturday November 9, 2019 due to planned maintenance. We apologize for the inconvenience. View Details'.

The main content area is divided into two sections. On the left, under 'Your Selections', there is a filter for 'AMS AM Additive Manufacturing Metals'. Below this, there are buttons for 'Apply', 'Reset', and 'Save'. A 'Show Only' section includes checkboxes for 'Newly Added Content', 'My Access', and 'Full Text Content'. A 'Filters' section includes a 'Collections' dropdown and a 'File Formats' section with checkboxes for 'HTML (11)' and 'PDF (11)'.

On the right, the 'Search Results(11)' section is displayed. It shows 'Displaying results 1-10 of about 11'. The results are sorted by 'Relevance' and are displayed 'Per Page 10'. The first two results are:

- ☐ **Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe**
AMS AM Additive Manufacturing Metals
Current
Published 2019-03-26 by SAE International in United States
Aerospace Material Specification
AMS7008
This specification covers a corrosion and heat-resistant nickel alloy in the form of pre-alloyed powder.
- ☐ **Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo**
AMS AM Additive Manufacturing Metals
Current
Published 2019-03-11 by SAE International in United States
Aerospace Material Specification
AMS7014

Upcoming SAE AMS-AM Meetings

Monthly Virtual TG/Spec Meetings

SAE AMS-AM Additive Manufacturing Committee

Meeting Dates: May 11-14, 2020

Hosted by: Additive Industries

Meeting location: Additive Industries b.v.
Achtseweg Zuid 155
NL 5651 Eindhoven
The Netherlands

- Register online at www.sae.org
- Contact jeff.adkins@sae.org



SAE GROUP

Affiliate



Affiliate



SAE ITC PROGRAMS

Mission

SAE Industry Technologies Consortia (SAE ITC) enables organizations to **connect, collaborate and positively impact global industries** by empowering implementation of **precompetitive solutions** and **innovative technologies**.

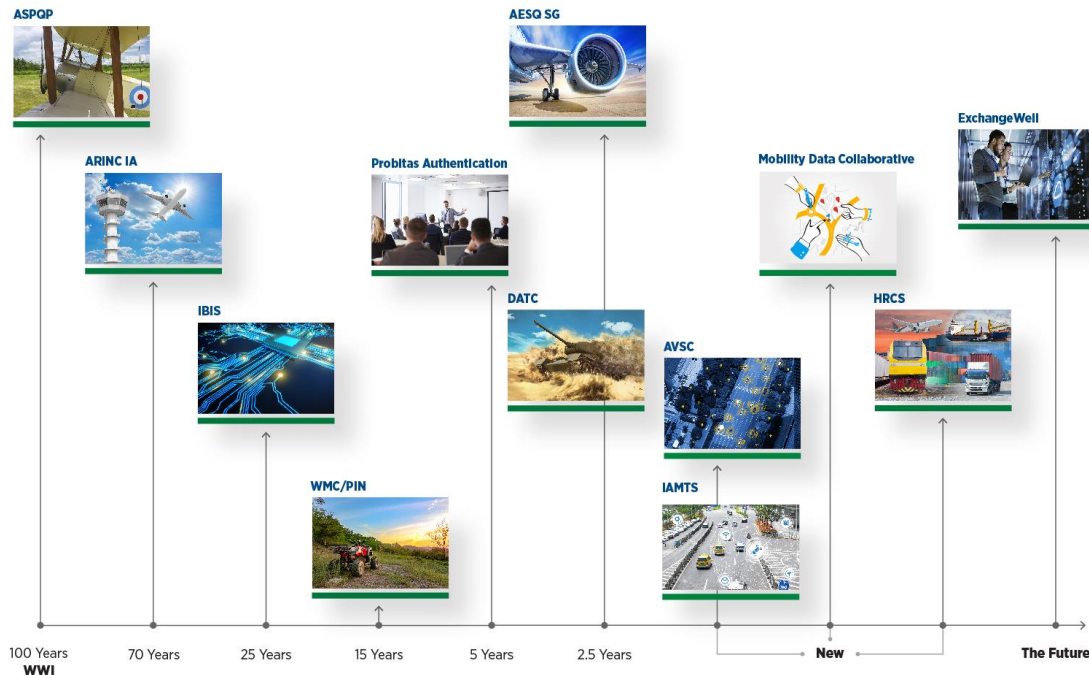
Vision

We are a trusted global leader in consortia-based **collaborative tools and services** for highly technical industries' research, design, operations and supply chains.



SAE Industry Technologies Consortia (SAE ITC) is a collection of global consortia programs made up of public, private, academic, non-profit and government organizations, which **connect and collaborate** in neutral, pre-competitive forums. SAE ITC provides a legal infrastructure, proven processes, tools and resources enabling industry to **innovate and implement** strategic business improvements to achieve common benefits no one organization could develop independently.

For more information visit: sae-itc.com



SAE AMS-AM Material Properties for Spec Mins and Design Values



1. Near term:

- Industry managed Process Control Document (PCD)
- Focus on S-basis -> spec mins, lot acceptance, quality assurance
- Supplier IP protected

2. Long term:

- Design Values, MMPDS A, B-basis, or similar
- Data security, anonymization, storage, analysis and access leverage best practices in the industry
- Permissioned access to raw data (supplier IP protected)

SAE AMS-AMDC™ Additive Manufacturing Data Consortium

SAE AMS-AM Material Properties for Spec Mins and Design Values

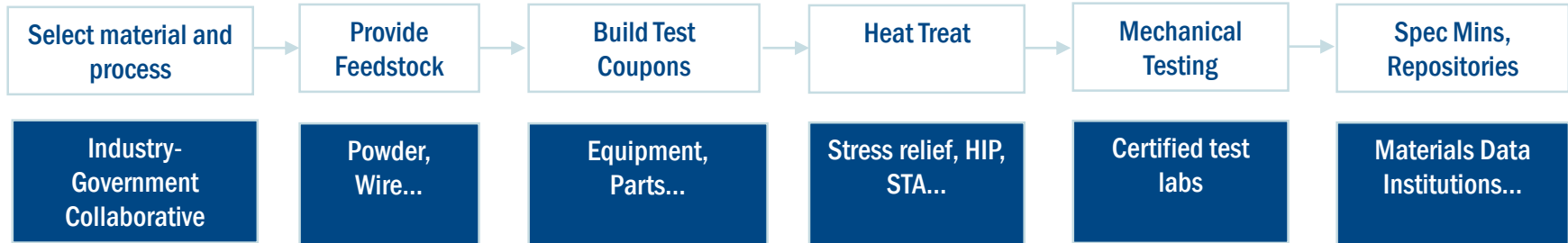
AMS-AM:

- Develop **specifications** for materials and processes
- Provide 'aerospace grade' procedure for generating mechanical property data

SAE AMS-AMDC™

- Obtain resources for generating **mechanical property data**
- Coordinates data creation
- Oversees collection and storage of data
- Provides necessary data for spec mins to AMS-AM
- Oversees and acts as repository for mechanical property data as applicable

SAE AMS-AMDC™ - Collaboration across value chain



- Collaboration across value chain to support specifications – power of collective
- Formalise & streamline data process through in-kind contributions
- Industry and government support
- Process can accommodate data generated by other institutions
- Call for interest/participation!
 - David Alexander
 - Info@sae-itc.org

SAE GROUP

Affiliate



Affiliate





Nadcap update on AM David Alexander on behalf of PRI

Background - Nadcap

- Nadcap is an Industry Managed program administered by the Performance Review Institute (PRI)
- Utilized by the majority of Aerospace Subscribers to manage the Special Processes of their Supplier network

Background – Additive Manufacturing (AM)

- The Welding Task Group were assigned responsibility for AM in 2015
- Checklist to assess laser and electron beam powder-bed process was developed (AC7110/14)
- In the absence of Industry Standards, the initial checklist (Revision NA) was based on requirements imposed in Subscriber specifications
- This checklist revision was issued in Q4 2016
- First accreditation – April 2017

Background – Additive Manufacturing (AM)

- Task Group reviewed feedback from Suppliers, Auditors, Subscribers, Equipment Manufacturers and introduced Rev A of the checklist in June 2018
- Limited number of audits performed to date
- In general, Suppliers who have been assessed have performed well

Audits / Accreditations to date

- 13 Audits conducted
- 8 Suppliers accredited
 - 4 in Europe
 - 4 in US
- 6 Suppliers new to Nadcap
- 2 Suppliers, AM is additional scope to existing process capability

Next Steps

- Task Group are working on Rev B
 - Utilizing feedback as before
 - Verifying that requirements in Industry Standards are included
 - Expected to be issued Mid-2020
 - No current plans to develop checklists for other AM variants
- Working with the Metallic Materials Manufacturing Task Group to develop a checklist for the assessment of Powder manufacture

How to access the checklist

- Register on eAuditNet.com
- Checklist is located via Resources / Documents / Audit Criteria / Welding
- Supporting Handbook that provides question intent and what can be presented as acceptable objective evidence is also available in eAuditNet
 - Resources / Documents / Audit Criteria / Welding / Handbooks and Guides

Contacts

If you have any Questions, please contact:

- Ian Simpson – Program Manager – Welding
isimpson@p-r-i.org Tel: +44 1332 869272
- Gabe Kustra – Staff Engineer
gkustra@p-r-i.org Tel +1 724 772 8673

QUESTIONS?

David Alexander

Director, SAE Aerospace Standards

1 York Street, London W1U 6PA, UK

m +44 7525 687909

david.alexander@sae.org