AEROSPACE MATERIAL SPECIFICATION

AMS7010™	REV. A
Issued 2020-01 Revised 2021-10 Superseding AMS7010	

Laser Directed Energy Deposition Additive Manufacturing Process (L-DED)

RATIONALE

This is a revision to the specification for wire fed laser directed energy deposition additive manufacturing process to incorporate requirements for powder feedstock used in powder fed laser directed energy deposition additive manufacturing process in addition to wire feedstock.

1. SCOPE

1.1 Purpose

This specification establishes process controls for the repeatable production of preforms/parts using the laser directed energy deposition (L-DED-) process for additive manufacturing. Preforms are intended to be used to manufacture aerospace parts, but usage is not limited to such applications. Feedstock may be either wire (for L-DED-Wire) or powder (for L-DED-Powder).

1.2 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.

1.3 Classifications

Class A: Wire feed

Class B: Powder feed

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.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
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SAE WEB ADDRESS: **http://www.sae.org**

For more information on this standard, visit
https://www.sae.org/standards/content/AMS7010A/

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.

ARP1917 Clarification of Terms Used in Aerospace Metals Specifications

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

ASTM E2281 Standard Practice for Process Capability and Performance Measurement

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 Definitions

The following definitions apply in addition to those defined in ISO/ASTM 52900 and ARP1917A:

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

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

BUILD ENVELOPE: Largest external dimensions of the X, Y, and Z-axes within the build space where preforms/parts will be fabricated.

DEPOSITION FILE: The electronic file that is supplied to the L-DED machine for manufacturing one or more preforms/parts. This includes but is not limited to, preform/part geometry, location, orientation, and process parameters.

FEEDSTOCK: Wire or powder which is melted during the L-DED process to become a deposited bead and constitute the deposit.

FEEDSTOCK MANUFACTURER: The Company that manufactures the wire or powder to be used in the L-DED machine.

INTERRUPT: To break the continuity of the deposition process.

KEY PROCESS VARIABLES: 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).

LASER DIRECTED ENERGY DEPOSITION WITH WIRE (L-DED-Wire): Additive manufacturing process in which focused thermal energy supplied by one or more laser(s) is used to fuse wire by melting as it is being deposited to form three-dimensional shapes.

LASER DIRECTED ENERGY DEPOSITION WITH POWDER (L-DED-Powder): Additive manufacturing process in which focused thermal energy supplied by one or more laser(s) is used to fuse powder by melting as it is being deposited to form three-dimensional shapes.

L-DED MACHINE MANUFACTURER/INTEGRATOR: Company that manufactures the L-DED machine or integrates the component equipment to build the machine.

PREFORM/PART: The end-item which results from the laser-deposition of wire or powder feedstock onto a substrate.

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 L-DED process to produce preforms/parts.

PURCHASER: Organization that issues the Purchase Order to the producer.

SUBSTRATE: The base material utilized to initiate the deposition of L-DED material. The substrate may or may not remain a portion of the preform/part.

2.5 Acronyms

AM	Additive Manufacturing
CAD	Computer Aided Design
CEO	Cognizant Engineering Organization
L-DED	Laser Directed Energy Deposition
L-DED-Wire	Laser Directed Energy Deposition Wire
L-DED-Powder	Laser Directed Energy Deposition Powder
PCD	Process Control Documentation

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 considered to be 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 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 L-DED process:

3.1.1 Key Process Variables

3.1.1.1 The producer shall establish values, tolerances, and measurement frequency for all Key Process Variables of the L-DED 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 Key Process Variable 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 Key Process Variables 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 key process variables of the PCD, and authorized by the CEO.

3.1.2.1.1 To substantiate allowable process interruptions, the producer shall provide documentation demonstrated through testing or other suitable means that process interruptions do not affect the quality and performance of the preform/part.

3.1.3 Digital File and Software Configuration Control

The producer shall establish a configuration control system to ensure the correct software and files are used in the production of components using L-DED. This system shall include internal procedures to control electronic files, conversion settings, and machine parameters. All files shall be traceable through revision control and have access 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 L-DED 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 procedures 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 preform/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 L-DED 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 include all ancillary equipment required to meet the specified requirements.

3.1.5.5 All maintenance performed shall be recorded via manual or electronic 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 Substrate and Feedstock Material Handling and Storage Plan

Procedures for handling and storage of substrate and feedstock materials shall be established, substantiated, and authorized by the CEO to meet the requirements defined by the finished preform/part material. At a minimum, the substrate and feedstock material handling plan shall include the following items as defined by class.

3.1.6.1 Class A plan must include:

- The procedure to substantiate that the substrate and feedstock used in the L-DED machine complies with the specified requirements including the inspection procedures.
- Storage conditions for the substrate and feedstock.
- Substrate and feedstock lot traceability and tracking to maintain traceability compliant with the requirements of the CEO.
- Conveyance and transport from any storage location to the L-DED machine.
- Methods for substrate preparation and cleaning.

3.1.6.2 Class B plan must include:

- All requirements for 3.1.6.1 (Class A).
- The procedure to collect and process used powder (if powder reuse is allowed).
- The procedure to identify feedstock blending process, ensuring all independent feedstock lots meet the feedstock specification.
- The procedure to identify feedstock usage (such as virgin or reuse) including the maximum number of uses.

Additional recommended elements of a material 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, foreign material, or both that would change the performance of the items produced in the L-DED process. The producer shall identify potential sources of contamination throughout all aspects of the L-DED process, including feedstock storage and handling, L-DED machine, L-DED consumables, and ancillary equipment, and establish procedures to minimize the sources of such contamination.

3.2 L-DED Machine Approval

For each individual L-DED machine, the producer shall demonstrate that the items fabricated in that machine conform to all 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 preform/part built within the extents of the build envelope defined in the PCD and orientations in the x-y plane and z direction.

3.3 L-DED Process Approval

Process approval moves beyond machine approval and incorporates all key process variables of the PCD including final preform/part geometry in the finalized deposition layout. The CEO shall approve the requirements (i.e., how many preforms/parts, how many machines, how many feedstock lots, required testing, etc.) and the producer shall demonstrate the capability to meet those requirements. This substantiation shall be authorized by the CEO prior to implementation of the process for production.

3.4 Statistical Process Control (SPC)

Statistical process control shall be used to demonstrate process control and be performed per the methods defined in ASTM E2587 and ASTM E2281. The Key Process Variables identified in the ”SPC Required” column of Appendix A shall be maintained in a control chart with established limits. The producer shall have a reaction plan, authorized by the CEO, in-place to respond to variations detected in process control charts.

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 L-DED process is executed in accordance with the PCD. At a minimum, this procedure shall include:

- Selecting the correct deposition file
- Selecting the correct machine settings and parameters
- Pre-deposition machine check procedure per the key process variables defined in the PCD
- Substrate installation and fixturing requirements
- Feedstock loading requirements
- Substrate material and preparation requirements

4.5 L-DED 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 key process variables defined in the PCD
- Preform/Part or witness coupon rejection caused by the L-DED process; specimen failure cause shall be concurred by the CEO
- Changing the machine location or environment
- Feedstock material change from one specification or material type to another
- Change in feedstock supplier
- Machine repair involving critical system components or subsystems including, but not limited to, the laser, the optical train, the feedstock delivery system, the positioning system, and the inert environment system; critical system components or subsystems and requalification procedures for the components shall be identified within the PCD and agreed upon between the Supplier and CEO

4.6 Preform/Part Quality Report

4.6.1 The producer shall maintain a deposition tracking system that establishes a record for each build performed on the L-DED machine.

4.6.2 The preform/part quality report shall include evidence that the key process variables meet the requirements of the PCD.

4.7 Digital File Traceability

The process for conversion of the data file to a deposition file, including conversion software and conversion settings that will affect file conversion, shall be controlled and documented to maintain configuration control. Recommendations for parameters that should be included in the traceability document are listed in Appendix D.

4.8 Training Requirements

4.8.1 The producer shall establish a training program covering all elements of the specification in relation to the L-DED process. Recommended subject areas for a training program can be found in Appendix C.

4.8.2 The producer shall be responsible for ensuring that employees demonstrate competence in operating the process. Additional training and validation of understanding of the individual PCD may be required.

4.8.3 The producer shall be responsible for creating and maintaining the necessary documentation to ensure personnel continue to demonstrate competence in the required subject areas.

5. PREPARATION FOR DELIVERY

Not applicable.

6. ACKNOWLEDGMENT

Not applicable.

7. REJECTIONS

Material or preforms/parts produced in a manner not compliant with all specified requirements are subject to rejection.

8. NOTES

8.1 Revision Indicator

A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars are (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE AMS AM ADDITIVE MANUFACTURING METALS COMMITTEE

APPENDIX A - KEY PROCESS VARIABLES REQUIRED FOR LASER-DIRECTED ENERGY DEPOSITION

Variable	L-DED Process		Description	Control Type	Impact to Process	SPC Required
	CL-A: Wire	CL-B: Powder				
Laser Power	X	X	The amount of laser power delivered to the melt pool	Range	Melt pool characteristics, deposition properties, and material performance	X
Laser Spot Size	X	X	The diameter of the laser beam at workpiece	Range	Melt pool characteristics, deposition properties/microstructure, and material performance	
Other Process Heat Input	X	X	The amount of other heat energy delivered to the substrate and/or wire	Range	Melt pool characteristics, deposition properties, and material performance	
Preheat Conditions	X	X	The thermal condition of the workpiece prior to start of deposition	Range	Distortion, material performance	
Interpass Temperature	X	X	The thermal condition of the workpiece during deposition	Range	Melt pool characteristics, deposition properties/microstructure, and material performance	
Feedstock Specification	X	X	Material specification for the material to be used for this application that defines the physical characteristics and method of manufacture	Range	Fundamental to application, deposit finish, properties/microstructure, and material performance	
Feedstock Manufacturer	X	X	The company producing the feedstock material	Discrete	Variation in material between producers can impact the characteristics of the feedstock material	
Planned Process Interruption	X	X	Location in the build where a planned process interruption (break in the continuity of the deposition process) has been authorized by the CEO	Range	Deposition properties/microstructure and material performance	
L-DED Machine Manufacturer, Model Number, Serial Number	X	X	The overall configuration of the L-DED system	Discrete	Hardware configuration, deposition properties/microstructure, and material performance	
Integrated Control System Configuration	X	X	The hardware, software, firmware, and programmable control modules that allow operation and control of the system	Discrete	Deposition properties/microstructure and material performance	
Deposition Strategy	X	X	Deposition order and direction, bead width and height, bead overlap, cooling rates, energy input	Discrete	Product quality and consistency	
Traverse Speed	X	X	The rate of relative movement between the laser system and the workpiece	Range	Melt pool characteristics, melt rate, and deposition bead profile	X
Build Chamber Gas Composition	X	X	The gas composition inside the build chamber during the deposition	Range	Deposition properties/microstructure and material performance	
Build Chamber Oxygen Content	X	X	The oxygen content inside the build chamber during the deposition	Range	Deposition properties/microstructure and material performance	X

Variable	L-DED Process		Description	Control Type	Impact to Process	SPC Required
	CL-A: Wire	CL-B: Powder				
Build Chamber Moisture Content	X	X	The moisture content inside the build chamber during the deposition	Range	Deposition properties/microstructure and material performance	X
Substrate Condition	X	X	The material, dimensions, tolerances, and surface finish of the substrate	Range	Distortion, material performance	
Substrate Cleaning and Preparation	X	X	Preparation and cleaning of the substrate prior to the start of deposition	Range	Deposition properties/microstructure and material performance, particularly at the deposition-to-substrate interface	
Feedstock Diameter	X		The diameter of the wire allowed for the process	Discrete	Melt pool characteristics, melt rate, and deposition bead profile	
Wire Entry into Melt Pool	X		Position and angle of the wire relative to the melt pool	Range	Melt pool characteristics, deposition properties/microstructure, and material performance	
Wire Feed Speed	X		The Wire is fed to the melting zone at an established speed	Range	Melt pool characteristics, melt rate, and deposition bead profile	X
Wire Feed Direction Relative to Travel Direction	X		Position of the wire relative to the travel direction of the motion system	Range	Melt pool characteristics, melt rate, and deposition bead profile	
Feedstock Particle Size Distribution (PSD)		X	The particle size distribution of the powder for the process	Discrete	Melt pool characteristics, melt rate, and deposition bead profile	
Powder Delivery Type		X	Delivery type (coaxial or multi-stream feed), including angle and position of the powder relative to the melt pool	Discrete	Melt pool characteristics, deposition properties/microstructure, and material performance	
Powder Nozzle Configuration		X	The material, dimensions, tolerances, surface finish of the nozzle	Discrete	Powder delivery, melt pool characteristics, deposition properties/microstructure, and surface finish	
Powder Feed Rate		X	The Powder is fed into the melt pool at an established rate	Range	Melt pool characteristics, melt rate, and deposition bead profile	X
Nozzle Standoff Distance		X	The distance measured from the tip of the processing head to the workpiece	Discrete	Melt pool characteristics, melt rate, and deposition bead profile	
Powder Jet Focal Point		X	The distance from the tip of the powder nozzle to the waist of the powder jet	Discrete	Melt pool characteristics, melt rate, and deposition bead profile	
Carrier Gas Composition		X	The chemical composition of gas carrying the powder from the powder feeder to the melt pool	Discrete	Deposition properties/microstructure and material performance	
Carrier Gas Flow Rate		X	The volumetric flow rate of gas carrying the powder from the hopper to the melt pool	Range	Powder jet shape, melt pool characteristics, capture efficiency	

Variable	L-DED Process		Description	Control Type	Impact to Process	SPC Required
	CL-A: Wire	CL-B: Powder				
Shield Gas Composition		X	The chemical composition of gas used to shield the melt pool from the ambient environment	Discrete	Deposition properties/microstructure and material performance	
Shield Gas Flow Rate		X	The volumetric flow rate of gas used to shield the melt pool and protect optical components	Range	Melt pool size, melt pool characteristics, microstructure, capture efficiency	

APPENDIX B - CALIBRATION AND VERIFICATION REQUIREMENTS

Minimum Measurement Elements	L-DED Process	
	CL-A: Wire	CL-B: Powder
Laser focal distance	X	X
Laser spot size	X	X
Laser power and stability	X	X
Other heat input power and stability	X	X
Motion equipment positioning and accuracy	X	X
Inert environment sensing equipment	X	X
Data acquisition subsystems	X	X
Wire feed speed and stability	X	
Laser to wire alignment	X	
Powder feed rate and stability		X
Laser to powder stream alignment		X
Gas flow rates (Shielding/Carrier)		X

APPENDIX C - TRAINING PROGRAM CURRICULUM RECOMMENDATIONS

C.1 DIGITAL FILE TRACEABILITY

Personnel should have an understanding of how to maintain the integrity of the build file through the various stages of the manufacturing process.

C.2 PROCESS CAPABILITY

Personnel should have completed and documented company-defined training which covers the full capability and limitations of the AM equipment and process, including: materials (alloys and properties), geometric features, surface finish, digital files, post-processing impacts, process parameters, and others as specified by the organization.

C.3 PROCESS MONITORING (ABILITY TO DETECT ISSUES WHILE BUILD IS RUNNING)

Personnel should be trained in, and demonstrate an understanding of common defects, build errors, and likely causes of failure associated with the L-DED process. They should also be trained in the associated mitigation techniques to ensure failures are avoided, contained, or minimized.

C.3.1 Qualification

Personnel should be trained in both industry and the organization's standards and qualification procedures and be able to demonstrate knowledge of this essential function.

C.3.2 Feedstock and Substrate Material Handling

Personnel should be trained in and demonstrate the capability to execute all elements of the feedstock and substrate material handling and storage plan defined by the producer.

C.3.3 Machine Calibration and Verification

Personnel should be trained in and demonstrate the capability to execute all elements of the Calibration and Verification plan defined by the producer.

C.3.4 Machine Maintenance

Personnel should be trained in and demonstrate the capability to execute all elements of the Maintenance plan defined by the producer.

C.3.5 Machine Setup, Operation, and Preform/Part Removal

Personnel should be trained in and demonstrate the capability to operate the L-DED process in accordance with all technical requirements defined by Section 3 of this specification.

C.3.6 Documentation and Configuration Management

Personnel should be trained in and demonstrate the capability to maintain all documentation necessary to meet the requirements specified by the CEO.

C.3.7 EH&S

Personnel should be trained in and demonstrate competency in appropriate EH&S procedures as specified by the equipment manufacturer/integrator and the organizations standards or procedures. Particular attention should be given to laser safety as it relates to the operation of the machine.

C.3.8 Moisture and Contamination Control

Personnel should be trained in and demonstrate the capability to meet all requirements of the Moisture and Contamination Control plan defined by the producer.