

DEPARTMENT OF THE NAVY NAVAL SEA SYSTEMS COMMAND 1333 ISAAC HULL AVE SE WASHINGTON NAVY YARD DC 20376-0001

IN REPLY REFER TO 4870 Ser 05T/2018-024 17 Aug 2018

From: Commander, Naval Sea Systems Command (SEA 05)

Subj: GUIDANCE ON THE USE OF ADDITIVE MANUFACTURING

- Ref:
- (a) NAVSEAINST 4870.10, Policy on the Adoption and Use of Additive Manufacturing
 - (b) DOD-STD-2101, Classification of Characteristics
 - (c) NAVSEAINST 5400.95F, Waterfront Engineering and Technical Authority Policy
 - (d) NAVSEA 5100.12-M, System Safety Engineering Manual
 - (e) NAVSEA T9074-AX-GIB-010/100, Material Selection Requirements
 - (f) T9070-AK-DPC-010/078-1, Composite Materials, Surface Ships, Topside Structural and Other Topside Applications - Fire Performance Requirements
 - (g) MIL-STD-31000, Technical Data Packages
 - (h) ISO 19005-3, Document Management Electronic Document File Format for Long-Term Preservation - Part 3: Use of ISO 32000-1 with Support for Embedded Files (PDF/A-3)
- Encl: (1) Additive Manufacturing Definitions
 - (2) Identifying Components for AM -Decision Process/Flowchart
 - (3) AM Processes and Post-Processing
 - (4) AM Materials
 - (5) Technical Data Package (TDP)

1. <u>Purpose</u>. To provide Naval Sea Systems Command (NAVSEA) policy, guidance, and direction on the use of Additive Manufacturing (AM).

2. Scope and Applicability

a. This document defines the requirements for utilization of metallic and non-metallic AM that shall be met in order to install an AM component in NAVSEA-cognizant applications.

b. This document does not apply to Naval Nuclear Propulsion plant systems, equipment, and facilities under the cognizance of the Deputy Commander, Nuclear Propulsion Directorate (SEA 08).

As outlined in 50 U.S.C. § 2406 and § 2511 (codifying Executive Order 12344, February 1, 1982) the Deputy Commander, Nuclear Propulsion Directorate (SEA 08) has responsibilities and authorities over all facilities and activities which comprise the Naval Nuclear Propulsion Program, a joint Department of Energy (DOE) and Navy organization. These responsibilities and authorities include all technical and logistical matters related to Naval Nuclear Propulsion. Accordingly, nothing in this document supersedes or changes those authorities, and SEA 08 shall be consulted concerning all matters related to Naval Nuclear Propulsion.

c. This document does not apply to Strategic Weapons Systems and Attack Weapons Systems and associated spares and repair parts under the cognizance of Strategic Systems Programs (SSP).

3. <u>Discussion</u>. AM is an emerging technology with potentially significant implications for the U.S. manufacturing and AM logistics base. AM can shorten the design-to-production cycle, and enable cost-effective, on-demand manufacturing of critical parts in support of accomplishing the Navy mission.

4. Policy

a. This letter applies to design activities, AM designers, operators, and maintainers involved in design, modification, maintenance, repair, and overhaul of ships and ship system applications under the cognizance of NAVSEA. For all other NAVSEA applications (e.g., research and development, noncalibrated tooling, fixturing, etc.), this letter shall be used for guidance only. Where other documents, such as the equipment or ship specifications, have provisions for the use of substitute materials, the direction and guidance in this manual are intended to supplement those requirements, and does not supersede them.

b. Enclosures (1) through (5) provide the necessary terminology, decision process, recording/approval form for AM components, AM processes and post-processing, AM materials, and Technical Data Package (TDP) information.

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5. Action.

a. The implementation of AM technologies for NAVSEA cognizant applications shall be in accordance with the guidance provided in enclosures (1) through (5).

b. Provide feedback on the content and process of this letter to the NAVSEA AM Team (NAVSEA AM@navy.mil).

c. SEA 05 shall update this letter annually to capture updates/advancements to the technology, address user feedback, and continue to develop standards and mature the technology.

6. <u>Point of Contact</u>. The NAVSEA point of contact for this matter is Dr. Justin Rettaliata, Technical Warrant Holder for Additive Manufacturing, SEA 05T, (202) 781-5312.

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By direction

Distribution:

NAVSEA affiliates, TYCOMs, and PEOs engaged in the practice of additive manufacturing can obtain a copy of this letter via iNAVSEA at

https://navsea.navy.deps.mil/hq/05/ta/Technical%20Authority%20Alignmen t/05P Ship Integrity and Performance Engineering/Additive%20Manufactur ing/Additive%20Manufacturing%20Guidance.

ADDITIVE MANUFACTURING DEFINITIONS

1. <u>Additive Manufacturing (AM)</u>. The process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies, as defined in ISO/ASTM 52900.

2. <u>Additive Repair</u>. The process of using an AM process, such as Direct Energy Deposition (DED), to repair damaged components. These components can be originally manufactured via either AM or conventional means.

3. <u>AM Designer</u>. The personnel responsible for developing the component and its build (construction, design, orientation, etc.) for AM.

4. <u>AM Processes</u>. The AM process categories are defined in ISO/ASTM 52900, with detailed process descriptions in enclosure (3) of this letter.

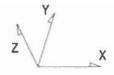
5. <u>Build Orientation</u>. The X- and Y-axes run in the plane of the build plate; the Z-axis is perpendicular to the build plate (see paragraph 9 of this section).

6. <u>Build Package</u>. Collective data and instructions for fabricating a component.

7. <u>Build Volume</u>. The volume encompassing a completed single build, including support structure.

8. <u>Computer-Aided Design (CAD)</u>. CAD is defined in ISO/ASTM 52900.

9. <u>Coordinate System</u>. In the right-handed coordinate system, X- and Y-coordinates are in the plane of the build platform and the Z-coordinates are in the direction perpendicular to the build platform.



10. <u>Design Activity</u>. The activity responsible for the final design. This may be NAVSEA or a ship design agent. Specific

Enclosure (1)

design activity responsibilities may be delegated by the design activity to its contractors.

11. <u>Design Activity AM Approval Authority</u>. The activity responsible for the compliant and knowledgeable implementation of this manual and the approval of the required documentation.

12. <u>Design Intent</u>. The process of determining that all design requirements are met in a component. Can be referred to as the "form/fit/function" of a component.

13. <u>Digital Security</u>. The security requirements for data management of Technical Data Packages (TDPs) related to AM.

14. <u>Digital Thread</u>. Data management infrastructure requirements for TDPs related to AM.

15. Essential Elements. Materials or processes that are important in fabricating the AM component. These elements are defined as part of an AM documentation package (see enclosure 4).

16. <u>Hybrid Technologies</u>. Any process that combines AM with secondary processing in the same piece of equipment.

17. Indirect AM. Any process that utilizes AM as one step in manufacturing, but does not directly use AM to produce the end use part.

18. <u>Part Combining</u>. Process whereby multiple discrete parts are designed and fabricated together into a single part, thereby reducing the number of individual parts required to make a single component.

19. <u>Procedural Post-Processing</u>. Any process performed on an additively manufactured component after completion of an AM process that must be performed to enable the AM component to meet requirements.

20. <u>Property Enhancing Post-Processing</u>. Any process performed on additively manufactured material with the purpose of improving, in any way, the material performance (e.g., Hot Isostatic Pressing [HIP], heat treatment).

21. <u>Service Conditions</u>. Component operational conditions, including loading and environmental considerations.

22. <u>Standard Triangle Tessellation (STL) File</u>. Translation of a native CAD file into a different CAD format that many AM systems and software can understand. STL consists of a triangle made of three X-, Y-, Z-coordinate points and a vector that points to the outside of the part. Most AM systems are designed to accept STL files for building parts.

23. <u>Technical Authority</u>. A NAVSEA command structure involving the NAVSEA Chief Engineer (CHENG), Deputy Warranting Officers (DWOs), TWHs, and TWH technical pyramids, as delineated in NAVSEA INST5400.111.

24. <u>Technical Data Package (TDP)</u>. The TDP includes all essential elements required to consistently fabricate an AM component. A typical TDP will include the following: fabrication information that includes the digital design file(s) (i.e., native CAD file, a neutral CAD file, STL file, etc.), component and sample build orientation(s), support structure parameters, process specific build parameters, and required post-processing.

25. <u>Topology Optimization</u>. An AM fabrication approach that optimizes material layout within a given design space, for a given set of loading requirements, such that the resulting material layout meets a prescribed set of performance standards.

IDENTIFYING COMPONENTS FOR AM -DECISION PROCESS/FLOWCHART

1. <u>PURPOSE</u>. This enclosure provides the considerations needed to evaluate if, when, and how to use AM for given applications and provides the approval requirements for differing risk severities. For NAVSEA ship and ship system applications, the requirements in paragraphs 2 through 11 in this section are depicted in the flowchart in Figure E-1.

NOTE

a. This enclosure shall be implemented for ship and ship system applications, with manufacturing being either shore-based or afloat. For research and development (R&D) applications, this enclosure can be utilized as a reference, but approvals, etc. are not required until the R&D is completed and moved toward shipboard installation.

b. NAVSEA HQ approval is required for additively manufactured components which will be used in shock hardened systems/equipment.

2. REQUIREMENTS.

a. <u>Applications for AM</u>. All ship and ship system AM applications shall be electronically submitted to the NAVSEA AM Team (<u>NAVSEA AM@navy.mil</u>) to be logged. In the event that the applications which can be approved locally cannot be submitted in a timely fashion (e.g., AM printers that are underway shipboard with limited connectivity), an electronic log shall be kept of applications to be submitted once connectivity is reestablished. Applications shall include, but not be limited to, the following information:

Ship class
Ship hull

Enclosure (2)

enclosure)

Component location/applicable system

Component requirements (per paragraph 3 of this

- Notes or other pertinent information that should accompany the submission

The AM Approval Form depicted in <u>Figure E-3</u> and <u>Figure E-4</u> of this enclosure can be utilized as a means to capturing this data and providing to the NAVSEA AM Team prior to gaining approval/disapproval/recommendation. A digital copy of these figures can be requested from the NAVSEA AM Team via NAVSEA AM@navy.mil.

b. <u>Approval of AM Components</u>. Approval of AM components shall follow the decision/approval process depicted in <u>Figure E-</u><u>1</u>. Design activity AM approval authorities shall report approval/disapproval decisions to the NAVSEA AM Team (<u>NAVSEA AM@navy.mil</u>), including application information (see paragraph 2a of this enclosure) and supporting rationale. Information and rationale can be captured in the AM Approval Form depicted in <u>Figure E-3</u> and <u>Figure E-4</u>. In the event that the local approval authority has concerns or determines approval exceeds their authority (e.g., risk determination to be higher than originally submitted), they may elevate to NAVSEA for consideration or disapprove. The NAVSEA AM Team will review disapproved applications to evaluate if/when future AM technology developments may support reevaluation.

c. <u>Approval Authority Designation</u>. Design activity AM Approval Authorities shall be identified and formally certified by the AM TWH, approved by the DWO for Ship Integrity and Performance Engineering, and receive their authority and responsibility through an Engineering Manager delegation letter. Requests for designation of a Design activity AM Approval Authority shall be submitted to <u>NAVSEA AM@navy.mil</u>. Waterfront CHENGs have approval authority per NAVSEAINST 5400.95F

3. <u>PART PERFORMANCE REQUIREMENTS</u>. The design activity shall determine the performance requirements for the specific AM component and identify the intended service conditions and service life to ensure adequate fit, form, and function. This shall include a determination of design intent and a review of key component structural and performance requirements, including certification testing and inspection requirements. Additionally, there shall be requirements for conformance

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testing to ensure the quality of individual builds and components. The design activity shall review those requirements and determine AM design suitability taking into account considerations including, but not limited to:

- a. Minimum wall thicknesses required
- b. Part thickness
- c. Features with very high aspect ratios
- d. Over-/under-hangs
- e. Support structure
- f. Internal geometry finish requirements
- g. Build volume
- h. Dimensional tolerances
- i. Potential effects of build orientation and anisotropy

4. DETERMINING APPLICATION SERVICE CONDITION LEVEL.

a. An application's service condition level of severity is determined by the consequences of AM part failure, as defined in NAVSEA 5100.12-M, the NAVSEA-Tailored Environment, Safety and Occupational Health (ESOH) Risk Matrix. The different levels are listed below, as defined in NAVSEA 5100.12-M, with required approval specified in paragraph 11 of this enclosure.

 Level 1, 2, and 3 severities are CVN Loss, Ship Loss, and Catastrophic.

Level 4 severity is Critical.

 Level 5 and 6 severities are Significant and Marginal, respectively. Applications may include temporary installation of an AM component with additional inspections/monitoring required.

- Level 7 and N/A severities are Negligible and N/A, respectively. Applications may include temporary installation of an AM component with additional inspections/monitoring required.

b. The design activity shall determine the service condition level for an application. If the service condition level is Level 1-5, the design activity shall invoke T9074-AX-GIB-010/100 for metallic applications. These service condition levels will also require process/material qualification for polymer or metal based on specifications provided in enclosure

(3) paragraph 2. In all cases, the design activity shall continue with the following steps. Approval of this determination shall be by the design activity AM Approval Authority, unless otherwise specified in the ship specification or Program Plan.

5. PROJECT TECHNICAL AUTHORITY CONSIDERATION. For Severity Levels 1-6, the component owner/sponsor shall coordinate with the AM TWH or the design activity AM Approval Authority to determine the feasibility of utilizing AM for manufacturing the component. For Severity Levels 7 and N/A, the component owner/sponsor shall coordinate with the appropriate Waterfront CHENG (pier-side) or Ship's Commanding Officer/CHENG (underway) to determine the feasibility of utilizing AM for manufacturing the component. CHENGs or Ship's Commanding Officers/CHENGs are responsible for reporting 7 and N/A applications to NAVSEA AM@navy.mil in addition to following the appropriate approval steps outlined. Information to be provided shall be in accordance with paragraph 2a of this enclosure.

6. <u>COMPONENT CAPABILITY IMPROVEMENTS USING AM</u>. The design activity may identify potential component capability improvements possible through redesign using AM (i.e., part consolidation, topology optimization, and complex geometry to improve performance).

7. <u>RISK ASSESSMENT</u>. For Severity Levels 1-6, using NAVSEA 5100.12-M, the design activity shall work with the AM TWH and associated Ship Design Manager (SDM) and component TWH(s) to generate the appropriate risk matrix/cube for the component being manufactured utilizing AM. These risks shall be identified based on the service condition level denoted in paragraph 4a of this enclosure and the likelihood of those consequences. The Level of Risk (High, Serious, Medium, Low, N/A) identified during this step will drive the approval authority required in paragraph 11 of this enclosure.

8. <u>AM PROCESS AND MATERIAL SELECTION</u>. The design activity shall select an AM process and AM material for the candidate component, utilizing enclosures (3) and (4). A flowchart for this selection is provided in Figure E-2.

a. <u>Direct Replacement</u>. The design activity shall identify whether the candidate AM component is a direct replacement utilizing the original component design.

- <u>AM Repair</u>. AM repair technologies shall be identified by the design activity and approved by the appropriate approval authority per enclosure (3), paragraph 4.

- <u>Design (or Redesign) of a Component for AM</u>. Components designed (or redesigned) for AM shall be identified by the design activity, in conjunction with the AM Designer, and approved by the approval authority (component owner, etc.).

b. Determining Legacy Design Availability. The design activity shall verify that the component design drawings are available. If the component design drawings are not available, reverse-engineering may be used to determine component design. This process shall be reviewed by the design activity AM Approval Authority and, if Severity Level is 1-6, NAVSEA.

c. <u>AM Process/Material Availability</u>. The design activity AM Approval Authority shall review component design requirements to determine process/material selection and determine the appropriateness of an AM process and an AM material per enclosures (3) and (4). Materials and processes for AM are intrinsically linked and material selection must occur in conjunction with selection of a specific AM process. For Severity Levels 1-5, the processes of T9074-AX-GIB-010/100 shall be used where required by this document, and the subparagraphs below shall serve to amplify T9074-AX-GIB-010/100, if invoked per the guidance herein.

- <u>Determining AM Process Suitability</u>. The design activity AM Approval Authority shall determine AM process suitability, taking into account considerations including, but not limited to:

- Geometric constraints
- Build volume
- Part size
- Surface finish
- Mating surfaces/interfaces
- Internal geometries
- Post-processing requirements

Determining Key Material Characteristics of an AM

Part. The design activity AM Approval Authority shall determine AM material suitability, including effects from post-processing. Key AM material characteristics for the selected AM process

shall take into account considerations including, but not limited to, those listed below (as applicable to the given application).

NOTE

Considerations listed below cover both metallic and non-metallic materials, where applicable. Additionally, material behavior of AM parts may vary from similar materials used in legacy parts (e.g., large mechanical property anisotropy). Depending on part orientation and loads on the component, an AM part will perform differently due to the anisotropic nature of the process, based on continuous X-Y adhesion with continuous chains/grains and non-continuous layer-by-layer adhesion in direction of the Z-axis with fewer linked chains/grain mixture.

 Strength - tension, compression and shear properties, stress/strain curves, elastic moduli, Poisson's ratio, and strain rate (dynamic effects, notch effects, and sensitivity)

Toughness - fracture toughness (static and dynamic), impact toughness, temperature effects (including transition temperature behavior for metallics and heat deflection temperature and glass transition temperature for non-metallics), sustained load, crack arrest, loading types, etc.
 Physical properties - density, coefficient

of thermal expansion, thermal conductivity, electrical resistivity, magnetic properties, damping coefficient, etc. • Frictional properties (i.e. wear properties,

etc.)

Fatigue strength, crack initiation, and

growth

Creep and stress relaxation

Corrosion resistance

 Joining, including weldability and ability to be brazed, if required

Fire/smoke/toxicity requirements

 Environmental requirements - light, temperature, and humidity

- Inspectability
- Sealing requirements

Chemical compatibility

d. <u>Property Enhancing Post-Processing</u>. The design activity shall determine if property enhancing post-processing exists or is required for the material to meet design requirements.

9. <u>TESTING AND QUALIFICATION REQUIREMENTS</u>. The design activity shall develop testing and qualification requirements (shock, NDE, etc.) for the AM part for approval by the appropriate authority. This may include testing beyond those required for the legacy part. The design activity shall determine whether testing must be tailored to the AM material and process. Applicable tests should be considered to identify potential new failure mechanisms that might be experienced by AM versions.

10. <u>GENERATING TDP</u>. The design activity/vendor shall generate TDP fabrication requirements per enclosure (5), and provide these to NAVSEA for approval. For Level 7 and N/A applications, a TDP is not required. The essential fabrication elements shall be recorded and provided in a document along with the pertinent files, etc. as outlined in enclosure (5), and provided to <u>NAVSEA AM@navy.mil</u>. The NAVSEA AM Team will provide assistance in developing a TDP, where required.

11. <u>GENERATING VERIFICATION PACKAGE FOR COMPONENT APPROVAL</u>. This section provides the Technical Authority Acceptance Roles for additively manufactured components. The proper programmatic and user/Fleet acceptance of application shall be in accordance with NAVSEA 5100.12-M.

The design activity shall obtain approval of the component/application from the required technical authority per paragraph 5 of this enclosure. Components under cognizance other than NAVSEA also require concurrence from the applicable SYSCOM Technical Authority. Per NAVSEA 5100.12-M, the signature authorities for the levels of risk analysis (High, Serious, Medium, Low) are listed below:

a. <u>High Level of Risk</u>. Analysis of Residual Risk is approved by Commander, NAVSEA and the NAVSEA CHENG.

b. <u>Serious Level of Risk</u>. Analysis of Residual Risk is approved by the NAVSEA CHENG and the DWO (Technical Domain Manager and Chief Systems Engineer, as required).

c. <u>Medium Level of Risk</u>. Analysis of Residual Risk is approved by the AM TWH, the component TWH, and the applicable SDM TWH.

d. Low Level of Risk. The Waterfront CHENG can approve. In the event that the Waterfront CHENG does not approve locally, the AM TWH, the component TWH, and the applicable SDM TWH shall review and approve. If a Severity Level 7, the Waterfront CHENG or Ship's Commanding Officer/CHENG may approve low risk applications.

e. <u>N/A Level of Risk</u>. Approved by the Waterfront CHENG or Ship's Commanding Officer/CHENG.

Enclosure (2)

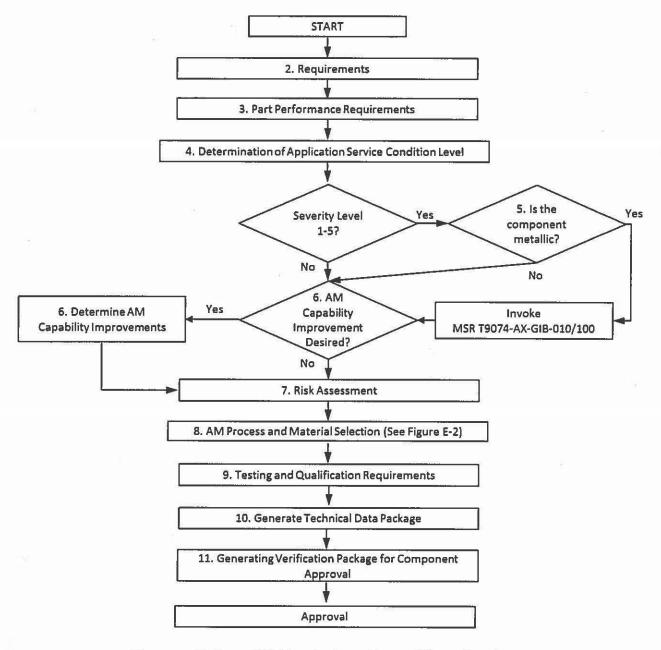


Figure E-1. AM Decision Tree Flowchart

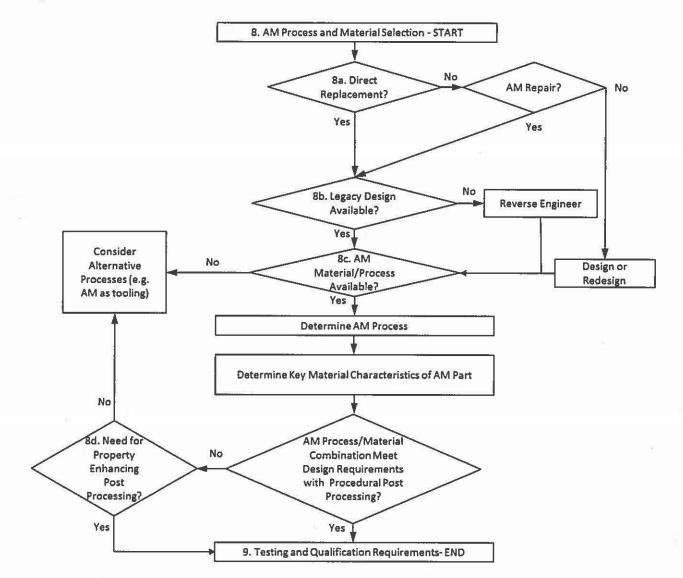
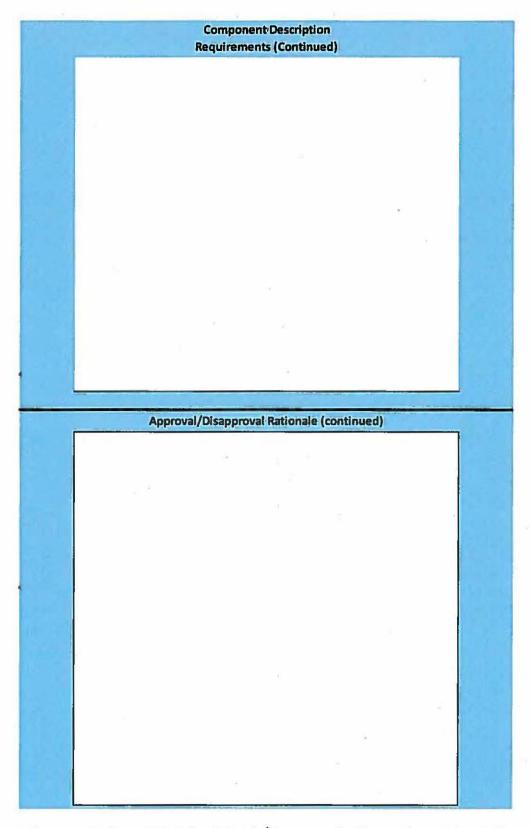


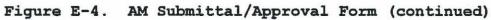
Figure E-2. AM Material and Process Selection Flowchart

Enclosure (2)

	Component Desar	iption
Component/Item		
Existing Component	1 million and 1	New Component
Part No. (NSN)		Mfr. Part No.
Ship Class		Ship Hull
Component Location (Roon	n/Compartment, etc.)	
Applicable System		
Controlling Drawing # {if a	available)	
Controlling MIL-SPC/STD (in	favailable)	
Requirements		
(see Encl 2, para 3):		
Present and the		
Additional	and the second	
Remarks/Notes/Info		
	and the second se	
	Additive Manufactur	ing Data
Drawing (CAD)/STL File		
Printer Type/Process		
Printer Model #		
Slicing Software/Version		
Material	·	
Component Weight		
TDP File Name (if		
Additional		
Remarks/Notes/Info	Network Concerning Street	1000 Contraction of the local sector of the lo
-	Approval/Disappr	and the second
Approve		Disapprove
Approval Authority		
(Print)		
Approval Authority Signature:		Date:
Approval/Disapproval		Uate.
Rationale		

Figure E-3. AM Submittal/Approval Form





AM PROCESSES AND POST-PROCESSING

1. <u>PURPOSE</u>. This enclosure provides guidance on utilizing the seven AM processes that are accepted and identified by industry, as of the publication date of this document. Additionally, it discusses the methods in which the components manufactured via AM can be post-processed, including removal from build plates and material enhancement.

2. <u>AM PROCESSES</u>. The seven accepted AM processes shall be used in accordance with the instructions applicable to the AM machine. In the absence of additional needed specifications or standards, NAVSEA shall be the technical authority for evaluation of proposed processes and applications. The seven processes are:

- a. Binder Jetting.
- b. Directed Energy Deposition (DED).
- c. Material Extrusion.
- d. Material Jetting.
- e. Powder Bed Fusion (PBF).
- f. Sheet Lamination.
- g. Vat Polymerization.

3. <u>CALIBRATION</u>. There are no defined calibration requirements identified for AM machines. To verify calibration for AM processes, machine calibration shall be indirectly determined through comparing the drawing requirements (including Major, Minor, and Critical dimensions) to the actual dimensions of printed components per DOD-STD-2101. For Severity Level 7 and N/A applications as defined in enclosure (2), the requirement for calibration plans shall be determined by the design activity AM Approval Authority. For all other severity levels, calibration plans shall be approved by NAVSEA

4. <u>HYBRID TECHNOLOGIES</u>. Hybrid technologies describe any process that combines multiple forms of AM or combines AM with other manufacturing processes in a single machine.

a. Additive and Subtractive. This hybrid technology combines additive technology with Computer Numerical Control (CNC) machining and is typically used for metal components. This process uses DED (powder or wire) or sheet lamination AM processes to build the component and CNC machining to achieve the final geometry. The laser utilized for the DED AM process can also be used to perform local heat treatment on the part.

This process shall be used in accordance with the standards that govern the applicable hybrid manufacturing technology. In the absence of standards for a hybrid technology, standards that govern each individual process within the hybrid technology shall be used (i.e., wire DED and CNC milling). In the absence of any relevant specifications or standards, NAVSEA shall be the final approval authority for use of this technology.

5. <u>ADDITIVE REPAIR</u>. Additive repair includes several processes that are guided by different fabrication documents and specifications. In the absence of appropriate specifications and standards, NAVSEA shall be the decision authority for evaluation of proposed processes and applications.

a. <u>Cold Spray</u>. The cold spray deposition process is capable of depositing metal, ceramic, or polymer material onto a substrate by utilizing kinetic energy to bond the coating material to the substrate. Neither feedstock nor substrate material are melted during this process; instead, the feedstock material is accelerated to supersonic speeds, which results in the plastic deformation of the feedstock powder particles upon impact with the substrate. This impact is capable of forming metallurgical bonds between the feedstock and the substrate, as well as between multiple layers of deposited feedstock material. As of the publication of this document, requirements for cold spray are not part of this letter.

b. <u>DED</u>. DED can also be used for repair of AM components. DED is capable of repair procedures due to the nature of the deposition process. Feedstock material is fused/melted to the substrate material during this process; the feedstock material can be deposited over existing material on a part or component that is in need of repair.

6. <u>INDIRECT AM</u>. Indirect AM refers to processes in which AM is used to facilitate other conventional manufacturing processes (e.g., AM production of a form, a pattern, a mold, or mandrel used in the conventional process). Manufacture of molds for hydroforming, sand casting, investment casting, composite layups, resin molding, and injection molding are a few of the applications demonstrated to date.

a. Additive Manufacturing of Casting Molds (AMCAST). AMCAST refers to the use of AM processes to produce the molds used during a casting process. One such AMCAST method is the

use of binder jetting to directly print sand molds for sand casting. As of the publication date of this document, there is no established guidance on utilizing AMCAST. In absence of established guidance, NAVSEA shall be the final approval authority for the use of this technology.

b. <u>DED</u>. DED can also be used to develop special purpose fixturing and tooling, as well as limited use forming dies for sheet metal, etc.

7. <u>POST-PROCESSING FOR AM</u>. Post-processing may be required for AM builds, both polymeric and metallic. The post-processing may be minimal or extensive. Post-processing for AM is used in two ways:

- The removal of material not needed for the final component (e.g., build plate, support structures).
- To provide a method of improving the properties of the component produced through heat treatment, etc.

a. <u>Part Removal</u>. The method used to separate the part(s) from a build plate will depend on several factors. These factors include the necessary precision, the amount of support structure used, the type of support structure used, and the geometry of the part(s). The method and type of part removal used after manufacturing shall be included in the TDP.

- Polymeric Materials. For polymeric materials, part removal from the build plate can typically be achieved through the use of hand tools. However, it is often necessary to remove support structure through the use of a chemical bath that preferentially dissolves only the support structure. Use of a chemical bath depends on the process used and the type of support structure. Removal using advanced machining is generally not required for polymeric materials.

- <u>Metallic Materials</u>. For metallic materials, part removal is achieved through the use of machining tools. The most common removal processes are wire electrical discharge machining or the use of a band saw. The selection of a removal process is dictated by the necessary precision, which is dependent upon the amount of support structure used, the geometry of the part, and the material compatibility between the cutting tooling and component base material. Considerations must be made regarding the interface of heat affected zones and

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final material properties of the component as to whether further machining will be required after removal from the build plate. Chemical cleaning may be acceptable, dependent upon the specific requirements for a given part.

b. <u>Material Enhancing Post-Processing</u>. Post processing shall be performed in accordance with applicable standards. In the absence of such standards, NAVSEA shall be the technical authority for adequacy of a post processing plan. This information shall be documented in the TDP.

AM MATERIALS

1. <u>PURPOSE</u>. This enclosure provides an overview of the requirements for use of AM materials. Not all materials available for use in AM equipment are represented in this document. The materials available for use in the varying AM processes is an ever-evolving list as custom materials are developed and tested or as existing materials are adapted into product forms that make them amenable for use in AM systems.

NOTE

The majority of AM equipment requires use of manufacturer specific materials/feedstock. Material and mechanical properties are greatly affected by the choice of manufacturing process, process parameters, and orientation of the build. Selecting the appropriate material/feedstock and process combination and component orientation in build area is critical to achieving the acceptable material properties for design.

2. POLYMERIC MATERIALS

The majority of the commercially available polymer AM a. materials that are used in the more common printers today are what is typically known as a neat resin system. This means that there are not typically any reinforcing particles or fibers to add additional strength and stiffness to the polymer. As the industry is evolving, there are more machines adding the capability of reinforcement, since this is where one would get the most capability with stronger and stiffer components. Additionally, these reinforcement fibers/additives can assist with mitigating flaming droplets if the polymer is exposed to fire. All the resins that are currently being used are classified as thermoplastic polymers. These are polymers that will melt after exposure to a certain melting temperature and then re-solidify once the temperature falls below the melting temperature.

NOTE

Materials listed in this section are applicable for surface shipboard use only. As of the publication date of this document, for any submarine applications, NAVSEA shall be the technical authority for approving material use.

b. A safety risk assessment shall be performed for all surface shipboard AM applications to ensure that all safety risks are appropriately captured, characterized, and accepted prior to approval for use in accordance with enclosure (3). Fire, Smoke, and Toxicity (FST) design requirements for topside composite materials are outlined in T9070-AK-DPC-010/078-1 (formerly DDS 078-1). The current FST testing and criteria for AM materials, as of the publication date of this document, are outlined in <u>Table E-1</u>. Depending on the application and selection of materials, additional requirements may be applicable. If material is not listed in <u>Table E-2</u>, NAVSEA shall be the approval authority.

Test	Passing Criteria				
Flame spread: ASTM E162	 Flame Spread Index ≤ 25 No melting, dripping, flaming droplets, or flaming debris 				
Smoke: ASTM E662	 Smoke Density (D_m) ≤ 200 No melting, dripping, flaming droplets, or flaming debris 				
Toxicity: ASTM E662 and ASTM E800	 CO: 600 ppm (max) HCL: 30 ppm (max) HCN: 30 ppm (max) IDLH Index: < 1 See section 4.4 of T9070-AK-DFC-010/078-1 				
ASTM E1354 (50 & 75 KW)	 Time to Ignition ≥ TBD: Provide data Peak Heat Release Rate ≤ TBD: Provide data 				
Additional Test(s)	Additional fire test(s) may be required depending upon the application, size, and location of the item.				

Table E	-1. FST	Testing	and	Requirements.
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c. <u>FST Limitations</u>. This section provides AM material limitations for shipboard use, as well as necessary design

considerations. The materials listed in <u>Table E-2</u> have been tested against NAVSEA FST requirements and are candidates for use on surface ships in accordance with the limitations stated therein. These limitations are not applicable when replacing a polymer part with a similar additively manufactured part. The AM TWH shall approve applications not complying with Table E-2.

Material Bul At	Location on Bulkhead		Polymer Weight Allowance (pounds [lb] or kilogram [kg]) per Compartment Square Footage (ft ²) 1/				Marking
	Above Deck	Less than50 0 ft ²	500-1000 ft ²	1000-3000 ft ²	3000-6000 ft ²	Over 6000 ft ²	2/
Polyethylene Terephthalate Glycol (PETG)	Less than or equal to 6 ft <u>3</u> /	3 lb (1.4 kg)	4 lb (1.8 kg)	7 lb (3.2 kg)	12 lb (5.44 kg)	15 lb (6.8 kg)	1
ABS M30	Less than or equal to 6 ft <u>3</u> /	2 lb (0.91 kg)	2 1b (0.91 kg)	4 lb (1.8 kg)	6 lb (2.72 kg)	8 lb (3.63 kg)	2
Nylon 12	Less than or equal to 6 ft <u>3</u> /	6 lb (2.72 kg)	7 lb (3.2 kg)	14 lb (6.35 kg)	26 lb (11.8 kg)	34 lb (15.42 kg)	3
DuraForm® HST Composite	Less than or equal to 6 ft <u>3</u> /	6 lb (2.72 kg)	7 lb (3.2 kg)	15 lb (6.8 kg)	30 lb (13.6 kg)	39 lb (17.7 kg)	4
DuraForm® GF Composite	Less than or equal to 6 ft <u>3</u> /	8 lb (3.63 kg)	11 lb (5 kg)	23 lb (10.4 kg)	48 lb (21.8 kg)	63 lb (28.6 kg)	3
Polycarbonate (PC) White	Less than or equal to 6 ft <u>3</u> /	6 lb (2.72 kg)	6 lb (2.72 kg)	7 lb (3.2 kg)	8 lb (3.63 kg)	10 lb (4.54 kg)	6
ULTEM 1010™	None 4/	42 lb (19 kg)	43 lb (19.5 kg)	45 lb (20.4 kg)	49 lb (22.23 kg)	51 lb (23.13 kg)	0
ULTEM 9085™	None 4/	57 lb (25.9 kg)	59 1b (26.8 kg)	73 lb (33.1 kg)	99 lb (44.9 kg)	115 lb (52.2 kg)	3

Table E-2. Materials for Surface Shipboard Use

When two or more different polymer AM materials are used in the same space, notification of and approval from the AM TWH is required if the total amount of combined material exceeds the lesser of the individual polymer weight allowances for each material present.

- 2/ All AM components shall be marked using indelible ink (black, silver, etc.) or another permanent marking method. Numbers shall coincide with material as depicted in table and circled.
- For parts/components that weigh less than ½ lb (0.23 kg), there is no height restriction on bulkheads if they are not weight bearing or supporting components.
- ULTEM (1010/9085) experienced no flaming droplets when subjected to flame testing; therefore, for parts and components that are not weight bearing or supporting, and weigh less than 2 lb (0.91 kg), there is no height restriction on bulkheads and no prohibition on ceiling mounting. For weights greater than 2 lb (0.91kg), the AM TWH shall approve applications.

d. <u>Mechanical Design Considerations</u>. A part is assigned a Service Condition Level per enclosure (2), paragraph 4. For structural applications and Service Condition Levels 1-5, NAVSEA shall be the technical authority for polymer material qualification. For Service Condition Levels 6, 7, and N/A nonstructural/limited load bearing (per paragraph 2e of this section) applications, materials identified in <u>Table E-2</u> and <u>Table E-3</u> shall be utilized.

In addition to temperature and humidity, the liquids or gases that the part will encounter during service should also be considered to ensure that the base polymer material will not interact with these materials. Typical chemical compatibility charts are available via the internet for general classes of polymer. It should be noted that polymer AM material suppliers have not provided generic chemical compatibility charts for their specific material make up and, therefore, if specific cleaning solutions, solvents, gases, etc. will be known to interact with the component, a small scale test should be performed to ensure that the component will not be adversely affected by the liquid or gas exposure. Some thermoplastics have been known to be adversely affected when submerged in fuel and undergo swelling, for example, and others, like PETG, are stated to be adversely affected by strong oxidizers. Due to the porous nature of polymer AM components, this might accelerate diffusion of liquids and gases into components and change their behavior as compared to parts manufactured via other manufacturing methods, such as injection molding

- For mechanical properties, the designer shall utilize material data sheets at a minimum to identify initial mechanical properties and characteristics. The data on the material data sheets can be correlated to printing a component

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with 100-percent infill. If printing with less than 100-percent infill, the mechanical property/characteristic values will not be as high. Additionally, these values are not design values, and should only be used for informational purposes when designing components. Depending on part orientation and loads on the component, an AM part will perform differently due to the anisotropic nature of the process, based on continuous X-Y adhesion with continuous chains/grains and non-continuous layerby-layer adhesion in the Z-axis with fewer linked chains/grain mixture. If necessary, small scale load testing can be performed to confirm that the part will be able to withstand any installed loading requirements prior to installation.

Material ID	Base Polymer	Manufacturing Type	Maximum Operating Temperature			
PETG	Polyethylene Terephthalate	ME/FFF	69 °C (156 °F)			
ABS M30	Acrylonitrile butadiene styrene (ABS)	ME/FFF	101 °C (214 °F)			
Nylon-12	Nylon-12 (polyamide)	ME/FFF	102 °C (216 °F)			
Duraform® HST	Mineral Fiber Filled Polyamide (Nylon)	PBF/SLS	21 °C (70 °F)			
Duraform® GF	Glass Filled Polyamide (Nylon)	PBF/SLS	23 °C (73 °F)			
PC White	Polycarbonate (PC)	ME/FFF	141 °C (286 °F)			
ULTEM 9085™	Polyetherimide (PEI)	ME/FFF	169 °C (336 °F)			
ULTEM 1010 TM	Polyetherimide (PEI)	ME/FFF	209 °C (408 °F)			
NOTES: 1. PBF - Powde 2. SLS - Selec 3. ME - Materi	tive Laser Sinterin	g				

Table E-3. Material Surround Temperature

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4. FFF - Fused Filament Fabrication

e. <u>Polymer Design Requirements and Material Selection</u>. <u>Table E-2</u> and <u>Table E-3</u> provide the materials to be considered when utilizing an AM component shipboard. If an AM component is to be weight bearing, and complies with paragraph 2c of this section, the supported weight (in tension) shall not exceed 5 pounds. If an AM component must support a weight greater than 5 pounds, NAVSEA shall be contacted for approval. If component is to support a compressive load, there is no weight limitation, but the design of the component shall be adequate to support the weight requirement.

- <u>New Designs and Components</u>. The polymer materials shall be utilized to meet the necessary design requirements of the component.

- Existing Components. For existing polymer components that are to be replaced with additively manufactured components, the material selected shall meet or exceed the performance requirements of the original component. The designer shall consider build direction and part orientation to ensure that the inherent anisotropic properties of the printed components do not negatively impact performance.

f. <u>Feedstock Material Storage Considerations</u>. For shipboard installed printers, any AM feedstock material (e.g., spools of filament) not directly loaded in or installed on an AM printer shall be stored in an enclosed non-combustible container. The container shall be kept closed and latched, except when materials are being stowed or removed for use.

3. <u>METALLIC MATERIALS</u>. Metallic materials are used in several forms during AM processes. As of the publication date of this document, there are no standards relevant to NAVSEA applications that exist for AM powders or processes, though metallic powder specifications exist. In the absence of specifications and standards for AM powder materials and processes, each application shall be approved by NAVSEA and the material requirements shall be determined based on application specific properties and requirements. Test plans for first article inspection of an AM part shall be developed by the part manufacturer to provide process and data demonstrating feasibility for additively manufacturing a component. These plans shall be approved by NAVSEA and shall require the use of qualified equipment and qualified feedstock material.

a. <u>Material Selection</u>. When required by NAVSEA, the Material Selection Requirements document shall be used per enclosure (2) of this document. For all other applications, the MSR may be utilized as a guidance document for selection of materials. Material selection of metals is greatly dependent upon the material property requirements for a given application. This includes strength, ductility, fatigue, wear, and corrosion resistance. It is important to have a full understanding of the operational environment of a part to ensure the material selected for manufacturing will meet all the material requirements. This document does not supersede existing documentation with regards to materials selection or substitution.

- <u>Powder</u>. Powdered metal must be compatible with the parameters and tolerances specified by the selected AM machine and process for which it will be used. Powder may be re-used with a NAVSEA-approved process control procedure. In the absence of approved published fabrication requirements, material packaging, storage and handling, and powder requirements (chemistry, size distribution, morphology, and rheology) shall be included in the TDP. NAVSEA shall approve and may provide the necessary standards for these powder requirements. As of the publication of this document, powdered metal printers are not approved for shipboard use at this time.

- <u>Wire</u>. Wire material must be compatible with the parameters and tolerances specified by the selected AM machine and processes for which it will be used. Wire materials shall be procured utilizing military specifications that are accompanied by OEM lot conformance certifications. Wire material procured utilizing commercial specifications that are accompanied by OEM lot conformance certifications shall be approved for use by NAVSEA. Specifications and certifications that were utilized shall be included in the TDP.

- <u>Shielding Gas</u>. Shielding gas selection must account for manufacturability, as well as final part chemistry and material properties.

- <u>Build Plate</u>. Build plate material selection shall be determined and recorded based on material selection for fabrication. If the build plate's chemical composition is not the same as the component being built, a minimum of ½ inch of sacrificial material shall be added to the bottom of the

component to minimize potential contamination and dissimilar metals at interface.

b. <u>Material Properties</u>. Material properties of additively manufactured materials shall be sufficient to meet or exceed the requirements for a given design. In the absence of NAVSEA documentation defining how to identify material properties, the vendor/submitter shall provide a test plan for NAVSEA review and approval that proposes testing and evaluation for defining material properties.

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TECHNICAL DATA PACKAGE (TDP)

1. <u>PURPOSE</u>. This enclosure provides requirements for an AMspecific TDP to ensure that the part as-designed is the part asprinted. The requirements for an AM TDP, defined herein, shall be supplemental to the applicable requirements that are defined in MIL-STD-31000. The following section identifies the elements that shall be addressed in an AM TDP. The requirement for a TDP is defined in enclosure (2), paragraph 10.

2. <u>TDP ELEMENTS</u>. The TDP shall be provided in accordance with ISO 19005-3, which specifies the use of the Portable Document Format (PDF), and shall contain at least one 3D view for the purpose of visualization of the part, assembly, or mold to be manufactured. All information in addition to that specified in MIL-STD-31000 shall be included as an attachment to the PDF. The TDP content may vary based on the application, but shall contain sufficient detail to produce the part using additive manufacturing such that the following requirements are met for each part:

- a. 3D geometry
- b. Dimensions
- c. Tolerances
- d. Material(s)/Feedstock
- e. Finish
- f. Process data
- g. Specifications
- h. Standards
- i. Performance requirements
- j. Quality Assurance Provisions (QAP)
- k. Software documentation
- 1. Packaging details
- m. Weight (final)