Structures Bulletin

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Subject: Material, Product Form, and Process Substitution Guidelines for Metallic Components

References:

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Background:

The need to replace metallic components on USAF aircraft is increasing as the force continues to age, components experience failures, and aircraft reach the end of their service lives. The use or proposed use of different materials, product forms, and processes that were used when many of the USAF's current weapon systems were designed and/or manufactured is being driven by a number of factors including, but not limited to, advances in metallurgy and alloy development, the unavailability of legacy alloys and product forms, environmental concerns, and alternative processes. Many of the new materials, product forms, and processes present unique challenges when applied to legacy aircraft, and to properly exploit them, their advantages and disadvantages must be understood. Of paramount importance is to ensure that the proposed materials are well characterized for the intended service environment, usage, and duration. In addition, careful consideration of all aspects of integrity and of requirements stated in the USAF integrity program specifications and guidelines related to selection of materials, product forms, and processes is required.

Purpose:

This Structures Bulletin provides guidance to assist USAF and industry engineers in ensuring that proper considerations are made when selecting substitutions for metallic components and in minimizing the potential for unintended negative consequences when making material, product form, and/or process changes. This guidance and the terminology used in this Structures Bulletin apply across the entire life cycle of USAF systems.

Overall Guidelines:

1. USAF and industry engineers should employ the tables and specific considerations in this Structures Bulletin when considering material, product form, and/or process substitutions.

2. Potential substitutions at any risk level should be reviewed using the appropriate documents, including those referenced in this Structures Bulletin.

3. Technology Readiness Levels and Manufacturing Readiness Levels (TRLs and MRLs) for materials, product forms, and/or processes being considered as substitutes should be at a level of 6 or greater.

4. Engineers should consult with AFRL/RX on potential substitutions characterized as “high” risk and are encouraged to do so for “low” and “moderate” risk substitutions.

5. Material, product form, and process substitution decisions should take nondestructive inspection/evaluation (NDI/E) requirements into account. The efficacy of these inspections must be validated either through the use of industry standard practices (e.g. SAE or ASTM) applicable to the material or product form or by demonstration. Demonstration must include empirical evidence that inspection processes can detect flaw types, sizes, and orientations germane to the material, product form, and/or manufacturing process being considered as a substitute. Inspection capabilities must be tied to requirements of the appropriate USAF integrity program.

6. Material, product form, and process substitution decisions should account for interface locations at which substitutes mate with existing components. Appropriate coatings and/or sealants must be considered for these locations to minimize potential risks of corrosion and wear. Engineers must also consider other interface-related issues such as thermal expansion coefficients, current and grounding paths (e.g., lightning strike protection), stiffness, etc.

7. Appropriate risk mitigation actions should be planned and executed for all substitutions. These actions include, but are not limited to, development testing, certification analyses, first article testing, reduced inspection intervals or improved inspection methods, higher margins for strength and/or life, etc.

8. The appropriate USAF integrity program Master Plan (or corresponding document) should be used to document the requirement, decision making process, and the risk mitigation actions taken for all substitutions.

Material Substitution Guidelines:

Table 1 illustrates, qualitatively, the relative complexity and technical/programmatic risk associated with potential material substitutions for a range of part types.

Table 1. Material Substitutions - Complexities and Risks

Substitution Type ▶ / ▼Part Type▼	**Same Alloy System, Same Heat Treatment** (e.g., 7XXX-TXYZ Al for 7ABC-TXYZ Al)	**Same Alloy System, Different Heat Treatment** (e.g., 7XXX-TXYZ Al for 7XXX-TABC Al)	**Different Alloy, Same Base** (e.g., 2XXX Al for 7XXX Al)	**Different Base** (e.g., Al for Ti)	**Different Class** (e.g., Composite for Metal)	**Hybrid Material** (e.g., Metal-Composite Laminate for Metal)
Safety-of-Flight*	M	H	H	H	NR	NR
Durability Critical	L	M	M	H	H	NR
All Others	L	L	L	M	H	H

KEY	*Complexity / Risk*
L	Low
M	Moderate
H	High
NR	NOT RECOMMENDED without extensive testing and AFRL/RX support

* Includes component types designated as Critical Safety Items (CSI), Safety Critical, and Mission Critical

Specific Considerations for Substituted Materials

Material Property Requirements – As a minimum, the material properties (e.g., F_{tu}, F_{ty}, da/dN, K_{IC}, K_{ISCC}) used in the original design and analysis of a component should be maintained or should be improved with knowledge of usage and field failures. Properties should be obtained from the minimum set of data necessary to ensure that correct values are used in the design (e.g. A- and B-basis allowables). Specifications should be available for the materials under consideration and the data should be qualified in accordance with the controlling specification. Standardized testing (e.g., ASTM) should be used, and additional testing should be conducted to evaluate any unique characteristics of the material under consideration.

Product Form Substitution Guidelines:

Table 2 illustrates, qualitatively, the relative complexity and technical/programmatic risk associated with potential product form substitutions. Although, welded and built-up structures are not product forms, they are included in this table to reflect recent manufacturing trends toward unitization and monolithic alternatives.

Table 2. Product Form Substitutions - Complexities and Risks

Replacing ► / ▼With▼	Forging	Extrusion	Machined Plate	Casting	Welded Structure	Built-Up Structure
Forging	L	L	L	L	L	M
Extrusion	M	L	L	M	L	M
Machined Plate	H	H	L	M	M	H
Casting	H	H	H	L	M	H
Welded Structure	H	H	H	H	L	H
Additive Mfg.*	NR	NR	NR	NR	NR	NR

KEY	*Complexity / Risk*
L	Low
M	Moderate
H	High
NR	NOT RECOMMENDED without extensive testing and AFRL/RX support

* Additive Manufacturing includes, but is not limited to, laser additive manufacturing, electron beam additive manufacturing, cold spray processes, etc.

<u>Specific Considerations for Substituted Product Forms</u>

Forgings, Extrusions, and Machined Plate – When monolithic product forms such as forgings, extrusions, and machined plate are considered as substitutes for other product forms, the following issues should be addressed:

1. Care must be taken to ensure that loads are not applied in directions that would adversely affect component integrity. Substituted materials may have some directions that are weaker or less damage tolerant than others. For plate, the risk of failure due to out-of-plane loading should be mitigated since the short transverse (S-T) direction in many alloys is usually less crack resistant than the long transverse (L-T) or longitudinal (S-L) directions.
2. Potential defects in these product forms such as strain-induced porosity, improper microstructure (e.g., grain growth, insufficient work, inclusions) and internal cracking should be accounted for.
3. The residual stress state of the substitute product form should be accounted for to avoid introducing failure initiation sites at unexpected locations.

Machined Plate – When machined plate is considered as a substitute for other product forms, the following issues should be addressed:

1. Grain Flow – The grain flow direction in machined components should be optimized for the specific application. However, this consideration may prevent "nesting" of components when laying out machining plans.
2. End Grain Exposure – Exposed end grains are inevitable in any machined component. The risk for these exposed end grains to serve as crack or exfoliation initiation sites should be mitigated (e.g., by shot peening).
3. Thickness – Residual stresses, mechanical/physical properties, and composition all vary through the thickness and as plate thickness increases. Any thickness effects should be thoroughly characterized and understood.
4. Surface Roughness – Improperly controlled machining techniques can result in surface roughness levels that increase the probability of fatigue crack initiation. Machined surface roughness levels should be limited to 125 micro-inches or the surface roughness of the original component, whichever is lower.
5. Fillets and radii – Curvatures of fillets and radii of machined components should be optimized for the specific application and approved by the cognizant engineering authority for the application.

Castings – When castings are considered as substitutes for other product forms, casting factors, and initial flaw assumptions (especially for durability and damage tolerance applications) should properly account for defects specific to castings such as shell defects, hard-alpha contamination, shrink, porosity, weld defects, grain size, hot tears, incomplete densifications, prior particle boundaries, etc. Reference 1 should be consulted when titanium castings are being considered as substitutes for other product forms.

Welded Structure – When welded structure is considered as a substitute for other product forms, component design and initial flaw size assumptions (especially for durability and damage tolerance applications) should properly account for defects specific to weldments such as lack of fusion, inclusions, arc damage, burn through, warping, residual stresses, etc. Welds should be located in non-critical areas with both fabricability and inspectability considerations taken into account. Residual stress and property knockdowns should be considered for any weldments not fully heat treated after welding. Approved aerospace welding specifications (References 6 - 8) should be used, and mechanical and physical properties should be determined and documented in the Procedure Qualification Record using the component's production weld processes. Fastener holes should not be made through the welds.

Process Substitution Guidelines:

Table 3 illustrates, qualitatively, the relative complexity and technical/programmatic risk associated with potential process substitutions.

Table 3. Process Substitutions - Complexities and Risks

Replacing► ▼With▼	Metal Cutting Processes	Metal Removal Processes	Paint Removal	Plating & Coating	Heat Treating	Engineered Residual Stresses	Joining Methods	Proprietary Processes
Alternative Methods*	H	H	H	H	H	H	H	H

KEY	*Complexity / Risk*
L	Low
M	Moderate
H	High
NR	NOT RECOMMENDED without extensive testing and AFRL/RX support

* Alternative Methods include processes such as laser cutting, water jet cutting, mechanical paint removal (e.g., abrasive media blast), thermal paint removal (e.g., laser, flashlamp), cold/thermal/plasma spray, alternative plating processes, and other processes not fully evaluated by AFRL/RX.

General Considerations for Substituted Processes

The pace of technology development to reduce acquisition and sustainment costs as well as to comply with new environmental laws and policies, has resulted in many process substitution alternatives that do not have accepted standards and/or USAF guidance documents for qualification. Therefore, until specific USAF guidance documents and/or USAF-accepted industry standards are produced to cover new or novel processes, USAF and industry engineers should coordinate all process substitutions with AFRL/RX.

Specific Considerations for Substituted Processes

Laser Cutting – For aluminum materials, ensure the recast zone is mechanically removed and that material property reductions in the heat affected zone are accounted for. Proper execution of these requirements for aluminum materials is expected to show that laser cutting is not cost-competitive with traditional mechanical cutting methods, and therefore its proposed use should be carefully examined.

Water Jet Cutting – The cut edge will be cold worked and the work can be quite deep under some cutting conditions. The cold work combined with the surface condition and entrapment of particles can decrease the fatigue life of the part. In some cases, the parts may be re-heat treated after water jet cutting to relieve the residual stresses at the edges. This raises additional concern for re-crystallization and grain growth during heat treat in the cold worked areas, the loss of any mechanical stress relief in the original material (e.g. -T5X), and the opportunity to improperly heat treat. A tightly controlled process specification and an understanding of the effect on mechanical/physical properties should be accomplished before water jet cutting is used on aircraft parts.

Cold Spray – Cold Spray applications should be prohibited for use on safety-of-flight (incl. CSI, safety critical, mission critical) and FOD-critical components. Cold spray deposits are not considered to be “structural” in that they generally differ from the composition or processing of the base material. Specialized testing is required to fully assess the impact of cold spray processes.

Paint Removal Processes – If a mechanical process is proposed to replace a chemical process, then the effect of mechanical work on the materials should be characterized. If a thermal process is proposed to replace a chemical process, in addition to the tests required to qualify the chemical process, tests should be accomplished to evaluate the potential thermal effects. Multiple coating/strip cycles should be evaluated.

Alternative Plating/Coating – For proposed replacement plating/coatings, the characteristics of the proposed plating/coating should be compared to the current plating/coating. This comparison should include, but not be limited to, hardness, thickness, post-processing requirements (densification, sealing etc.), potential introduction of new failure mechanisms on the base metal (e.g., re-embrittlement of steels, de-alloying of aluminum alloys, cold work, etc.), removal requirements, etc.

Recommendations:

USAF and industry engineers are advised to use this Structures Bulletin to ensure that proper considerations are made when making material, product form, and/or process changes to original metallic components. USAF and industry engineers should consult with AFRL/RX on potential substitutions characterized as “high” risk and are encouraged to do so for “low” and “moderate” risk substitutions. AFRL/RX contact information is:

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