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Comparative Analysis of Materials for Aerospace Tooling

Steel | Aluminum | Invar | Tooling Board | CFOAM

Executive Summary

Aerospace tooling demands a careful balance of thermal stability, machinability, structural integrity, and cost. This paper compares four commonly used materials — Steel, Aluminum, Invar, Tooling Board, and CFOAM.

Material Comparison Summary

Tooling Material	~CTE	Max use temp F	Tooling Life	Machinability	Density, lbs/ft3	$Cost/ft3	Easily modifiable
Aluminum	13	300-400	Moderate	Excellent	169	$300-$1,000	No
Invar 36	2.1	550-600	High	Fair	506	$5,000-$10,000	No
Epoxy Tooling Board	20	250	Low	Excellent	45	~$315	Yes
CFOAM	2.8	600 +	Moderate	Excellent	30	$350-$500	Yes
Steel	7.2	300-400	High	Fair	490	$800-1200	No

Key Considerations by Material

Steel

Best For: Durable applications with extended service life where CTE is not a concern.
Limitations: Heavier than alternatives and requires robust machining equipment. Thermal expansion and moderate thermal tolerance limit use in precision layup tooling compared to Invar or CFOAM.
Cost: Moderate per volume; excellent for mid-temp tools when CTE is not a concern.

Aluminum

Best For: General-purpose tooling with good machinability geometries where CTE is not a concern.
Limitations: Thermal expansion and moderate thermal tolerance limit use in precision

layup tooling.
Cost: Moderate per volume; excellent for mid-temp tools when CTE is not a concern.

Invar

Best For: Precision composite layup tooling where dimensional stability is critical across temperature changes and production needs are in the thousands of units.
Limitations: High cost, heavy weight, and additional machining difficulties. Very difficult to modify. Long lead times to source and fabricate tooling from Invar.
Cost: Highest of all options; justified only when production needs are very high, and thermal expansion control is vital.

Epoxy Tooling Board

Best For: Mockups, prototypes, short-run molds, and complex geometries requiring fast modifications when minimal cure cycles are needed.
Limitations: Not suitable for repeated thermal cycling or high loads. Tool cracking is common during curing. Difficult to modify after use due to susceptibility to cracking.
Cost: Economical when only 1 part is needed; especially attractive for large, temporary tooling.

CFOAM

Best For: Lightweight, thermally stable tooling with good machinability and elevated temperature capability. Greatly reduces the risk of tool cracking during cure due to the low CTE properties of the material. Good for developmental to Production programs as tooling is easily modifiable and able to be converted to production tooling.
Limitations: Still under broader industry adoption; surface finish requires post-processing.
Cost: Lower than Invar but higher than tooling board (if only 1 cure cycle is needed) — cost-effective for high-temp, low CTE requirements or when more than one cure cycle is needed. Lead times are similar to epoxy tooling board tooling. Easily converted to production tooling or modified for development programs.

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Recommendations

Application Need	Recommended Material
Dimensional stability in heat cycles	Invar or CFOAM
Cost-effective general tooling	Aluminum or Steel
Large, lightweight, 1 cure cycle tooling	Tooling Board
Easily machinable high-temp tools	CFOAM
Developmental programs	CFOAM
Conversion of prototype programs to production	CFOAM

CFOAM Advantages

CFOAM stands out as superior tooling material in several critical aspects:

- Ultra-low Coefficient of Thermal Expansion (CTE ~2.8 µin/in°F), comparable to Invar, ensuring dimensional stability under temperature changes. This removes the requirement for CTE compensation, streamlining the tool design process and lowering engineering expenses.
- Excellent machinability and ease of modification, unlike Invar, steel or aluminum.
- Capable of withstanding temperatures exceeding 600°F, making it suitable for high-temp composite cure cycles.
- Significantly lower cost than Invar on a volumetric basis with much shorter lead times.
- Reduced risk of thermal cracking during cure, outperforming tooling board for repeated use.
- Seamless transition from development tooling to production without replacing the tool base.