CRYOGENIC MATERIALS SELECTION, AVAILABILITY, AND COST CONSIDERATIONS

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Material selection for cryogenic models is similar to that for conventional models, with the added requirements of fracture toughness and alloy phase stability. The requirements for close tolerances and surface finish dictate the use of dimensionally stable material. To ensure required properties, materials should be ordered to tight specifications, with guaranteed properties if possible (fig. 1). Surface protection of finished models may be required for highly loaded models. Material cost, while high compared to common alloys, should not be a major selection factor for cryogenic wind tunnel models.

At Langley, all basic alloy groups have been considered for cryogenic models, but only the iron-base (steels) and aluminum alloys appear to be viable candidates (fig. 2). Because of the high loads expected in the National Transonic Facility (NTF), steels have received the most attention. The divergent requirements of high strength and high toughness are illustrated by the technology trend line for commercial alloys (fig. 3 and ref. 1). As loads are increased, the number of available alloys is severely constrained by toughness requirements. The material selection for the Pathfinder I model was further restrained by delivery schedules, which prompted a consideration of several alloy groups before NITRONIC 40 was selected (fig. 4 and ref. 2).

Figure 5 lists alloys currently under study at Langley, with particular emphasis on austenitic A-286 and martensitic Vascomax 200 and PH 13-8 Mo. The ferritic Fe-12 Ni alloy developed at NASA Lewis Research Center appears to be a promising future material. The Fe-12 Ni alloys have demonstrated yield strengths in excess of 200 ksi with fracture toughness K_{Ic} = 200 ksi-in.$^{1/2}$ at 77 K (fig. 6). In preliminary tests at Langley, the Fe-12 Ni alloys have demonstrated cryogenic stability superior to Vascomax 200 with relative ease of machinability. Langley is currently procuring two 7000-lb (14,000 lb total) melts of Fe-12 Ni in various-size plate and bar stock. If the same properties demonstrated in small experimental melts can be duplicated in these large melts, Fe-12 Ni should become the preferred material for cryogenic models.

Multistep heat treatment to refine the grain size appears to be a viable processing technique to improve the toughness of many existing high-strength materials (fig. 7). These techniques were developed at the University of California at Berkeley by J. W. Morris (ref. 3). Recent experiments at Langley using a modified version of this heat treatment have improved the CVN (Charpy V-notch) impact strength of HP 9-4-20 steel from 14 ft-lb to 39 ft-lb at 77 K. This is an improvement of 179 percent, with only a 25-percent loss in tensile strength. Langley is continuing this work to include other high-strength alloys such as Vascomax 200 and HP 9-4-30.

Langley experience to date has shown long lead times for all candidate cryogenic model materials (fig. 8). Lead times of 26 to 52 weeks are not unusual for quality material purchased to tight specifications (fig. 9). Material cost, although small compared to total model cost, will approach $10/lb for quality material (fig. 10). Langley experience with the Pathfinder I model has demonstrated the necessity for high-quality material even at premium prices.

All the preferred materials listed in figure 11 were selected for their combinations of cryogenic strength and toughness, except NITRONIC 60. Although it is not considered as a primary construction material, NITRONIC 60 is included for its nongalling characteristics, which make it suitable for balance mounts, sting nuts, and other close-tolerance fits where galling may be a problem.

Composite materials for cryogenic models have received low priority at Langley, with the work limited to "proof of concept" and conceptual designs only (fig. 12). An extensive data base was developed for epoxy/glass laminates during the NTF fan blade program, but no work has been done to date on advanced composites. The NTF fan blade experience has pointed out the necessity for an extensive testing and qualification program before any composite material can be considered for primary structural use.

Langley's test program has identified several commercial solder alloys that are acceptable for cryogenic models. Bag-3, Eutectic 155, and Eutectic 157 have been the most successful; however, the trend is for lower temperature solders to be more difficult to use due to reduced wettability (fig. 13). A program has been initiated at Langley to identify additional low-temperature solders. Several epoxy-based adhesives have been found to be acceptable for cryogenic service, but they all require either long cure times (24 hours plus) or elevated-temperature cures. Currently there are no completely acceptable quick-cure filler materials. Experience to date in the Langley 0.3-Meter Transonic Cryogenic Tunnel has shown that polyester/plastic fillers can be used to fill gaps and screw heads if used in thin films. Langley currently has a program to identify additional fillers; however, requirements for quick cure (15 minutes or less) and cold model surfaces (40° to $60^{\circ}F$) may not be attainable (fig. 14). Of all the basic material requirements for cryogenic models, filler materials appear to pose the most difficult problem.

REFERENCES

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2. Hudson, C. Michael: Material Selection for the Pathfinder I Model. Cryogenic Technology, NASA CP-2122, Part II, 1980, pp. 423-441.

3. Jin, Sungho; Hwang, S. K.; and Morris, J. W., Jr.: Composite Fracture Toughness of an Ultra-Fine-Grained Fe-Ni Alloy at Liquid Helium Temperature. Metallurgical Transactions, vol. 6A, August 1975, pp. 1569-1575.

I MECHANICAL PROPERTIES
1. YIELD AND ULTIMATE STRENGTH
2. TOUGHNESS (25 FT. LBS. CVN, K_{1c} = 85 KSI $\sqrt{\text{IN.}}$ @ 77 K)
3. ELASTIC MODULUS

II THERMAL PROPERTIES
1. ALLOY PHASE STABILITY
2. EXPANSION COEFFICIENT
3. THERMAL CONDUCTIVITY

III FABRICATION
1. MACHINING (CLOSE TOLERANCES, SURFACE FINISH, MACHINING RATES)
2. DIMENSIONAL STABILITY (MACHINING INDUCED STRESSES, WORK HARDENING, HOT-WORK INDUCED STRESSES)
3. HOT-WORK FABRICATION (WELDING, BRAZING, CASTING, HEAT TREATMENT)

IV AVAILABILITY
1. AS SPEC. DELIVERY
2. DELIVERY DATE

V CORROSION RESISTANCE
1. STAINLESS ALLOYS AVAILABLE FOR LOW/MEDIUM STRENGTH REQUIREMENTS
2. SURFACE PROTECTION REQUIRED FOR HIGH STRENGTH ALLOYS

VI COST
1. \$5-\$10/LB; TIGHT SPECS AND QUALITY ASSURANCE CAN INCREASE COST 50-75%
2. MATERIAL COST SMALL COMPARED TO TOTAL MODEL COST (5% OR LESS)

Figure 1.- Metallic material selection for cryogenic models.

I IRON BASE (STEELS)
1. BEST MATCH FOR RESEARCH REQUIREMENTS
2. EXTENSIVE CRYO DATA BASE
3. LARC WORK CONCENTRATED ON (BUT NOT LIMITED TO) STEELS

II NICKEL BASED SUPERALLOYS
1. LIMITED CRYO DATA
2. FABRICATION DIFFICULTY
3. LIMITED AVAILABILITY AND HIGH COST

III ALUMINUM ALLOYS
1. 5000 & 6000 SERIES ACCEPTABLE FOR CRYO USE
2. LARC EXPERIENCE WITH 0.3-M TCT
3. LOW STRENGTH & MODULUS

IV COPPER BASED ALLOYS
1. SOME BECU ALLOYS ACCEPTABLE BUT DATA BASE LIMITED
2. COLD WORK MAY PRODUCE BRITTLE FRACTURE
3. LIMITED FABRICATION EXPERIENCE

V TITANIUM
1. FABRICATION DIFFICULTIES
2. LONG LEAD TIMES

Figure 2.- Basic alloy groups.

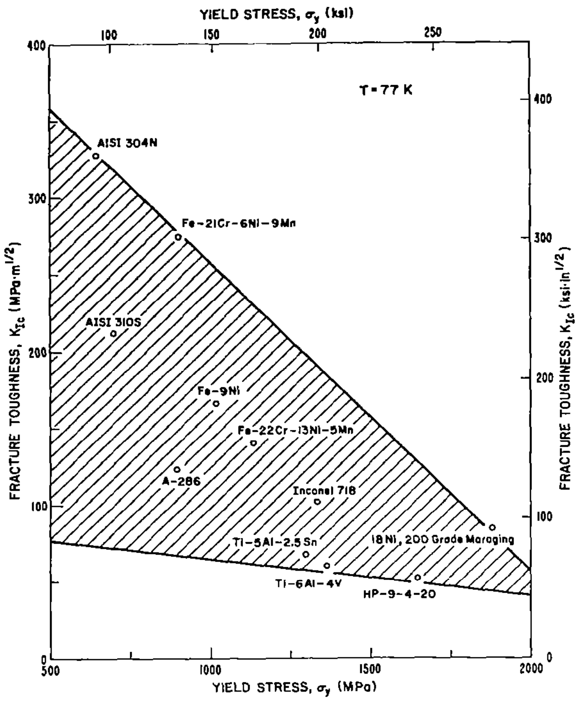

Figure 3.- Toughness versus strength trend for structural metals at 77 K. (From ref. 1.)

MATERIAL	CONDITION	σ_{yp}, ksi		σ_u, ksi		C_{VN}, ft-lb		K_{Ic}, ksi-in$^{1/2}$	
		RT	140° R	RT	140° R	RT	140° R	RT	140° R
18 Ni STEEL	250	250	320	260	330	20	10	100	40
18 Ni STEEL	200	205	270	210	280	35	25	170	80
AF 1410 STEEL	DOUBLE AUSTENITIZED AND AGED	230	250	250	260	40	30	125	--
SPECIAL 9% Ni STEEL	NORMALIZED & TEMPERED QUENCHED & TEMPERED STRESS RELIEVED	105	145	115	175	--	80	--	160
A286 STAINLESS STEEL	SOLUTION TREATED AND AGED	100	120	160	215	55	50	120	110
NITRONIC 40 STAINLESS STEEL	ANNEALED	70	150	110	200	200	65	--	165
PH 13-8 Mo STAINLESS STEEL	H1150M	85	145	130	175	80	60	--	--
INVAR	ANNEALED	40	90	80	125	220	50	--	--
INCONEL 718	SOLUTION TREATED AND AGED	150	175	185	235	20	20	90	100
INCONEL X750	SOLUTION TREATED AND AGED	110	125	180	215	35	35	--	100
Ti-6Al-4V ELI	ANNEALED	130	190	135	205	20	10	90	55
Ti-5Al-2.5Sn ELI	ANNEALED	105	175	120	180	25	10	90	65

Figure 4.- Nominal tensile and toughness properties of materials considered for the Pathfinder I model. (From ref. 2.)

I AUSTENITIC

1. 300 SERIES STAINLESS STEELS
2. NITRONIC STAINLESS STEELS
3. A-286

II MARTENSITIC

1. VASCOMAX 200
2. PH 13-8 Mo STAINLESS STEEL
3. HP 9-4-20

III FERRITIC

1. 9 Ni (ASTM A353)
2. Fe-12 Ni (LEWIS RESEARCH CENTER)

Figure 5.- Alloys under current study at Langley.

1. HIGH STRENGTH/TOUGHNESS CRYOGENIC ALLOYS DEVELOPED AT LeRC
2. 200 KSI YIELD AND K_{Ic} = 200 KSI $\sqrt{\text{IN.}}$ AT 77 K
3. STABLE PHASE ALLOY
4. SIMPLE ALLOY SYSTEM (NO SCARCE, STRATEGICALLY CRITICAL INGREDIENTS)
5. LaRC CURRENTLY PROCURING LARGE MELT (14,000 LBS.)

Figure 6.- Fe-12 Ni alloys.

1. TECHNIQUE DEVELOPED AT UNIVERSITY OF CALIFORNIA AT BERKELEY

2. LARC CURRENTLY STUDYING GRAIN REFINEMENT OF 9NI AND HP 9-4-20

3. STEEL INDUSTRY CURRENTLY DEVELOPING GRAIN REFINEMENT HEAT TREATS FOR VASCOMAX 200 AND AF-1410

Figure 7.- Grain refinement heat treating.

VASCOMAX 200	6/81 - 12/81	26 WEEKS
PH 13-8 Mo	7/80 - 10/81	65 WEEKS
A-286	10/81 - 2/82	17 WEEKS
A-286	CURRENT QUOTE (JAPAN)	26 WEEKS?

Figure 8.- Recent lead times at Langley for procurement of cryogenic model material.

13-26 WEEKS IF IN CURRENT PRODUCTION

26-52 WEEKS IF NOT IN PRODUCTION

50-75% INCREASE IN DELIVERY DATE FOR TIGHT SPECS AND INSPECTION

Figure 9.- Lead time minimums for procuring material for cryogenic models.

NITRONIC 40	\$3.00/LB.
VASCOMAX 200	\$8.71/LB.
A-286	\$7.75/LB.
PH 13-8 Mo	\$9.54/LB.

Figure 10.- Langley material cost (three 10K-lb lots).

AUSTENITIC	MARTENSITIC	FERRITIC
A-286	VASCOMAX 200	9Ni
NITRONIC 60	PH-13-8 Mo	
	HP 9-4-20	

PROMISING FUTURE MATERIALS

1. Fe - 12 Ni STEELS
2. GRAIN REFINED HIGH STRENGTH ALLOYS
3. POWDERED METAL ALLOYS

AVAILABILITY/LEAD TIME

1. ALL PREFERRED MATERIALS CURRENTLY AVAILABLE
2. TIGHT SPECS AND INSPECTION A MUST TO INSURE MATERIAL PROPERTIES
3. LONG LEAD TIME FOR ALL ALLOY GROUPS
4. MATERIAL SELECTION SHOULD BE MADE EARLY IN PROGRAM

Figure 11.- Preferred model materials as of May 1982.

I COMPOSITE CRYO MODELS CURRENTLY LOW PRIORITY AT LaRC

II EXTENSIVE CRYO DATA BASE FOR EPOXY/GLASS LAMINATES (NTF FAN BLADES)

III COMPOSITE MODEL DESIGN/FAB
1. 2D-AIRFOIL "PROOF OF CONCEPT" MODEL CONSTRUCTED FOR 0.3-M TCT
2. 3D-WING FOR NTF (CONCEPTUAL DESIGN)

IV COMPOSITE EFFORT TO INCREASE AS TIME AND RESOURCES BECOME AVAILABLE

Figure 12.- Composite materials.

I. CRYO SUITABILITY PROGRAM

	TYPE	TEMP(°F)	WETTABILITY
1.	BAG-3	1270	GOOD
2.	EUTECTIC-155	725	FAIR
3.	EUTECTIC-157	425	POOR

II. CURRENT PROGRAM TO IDENTIFY LOW TEMP SOLDERS WITH HIGH WETTABILITY
1. INDIUM ALLOYS
2. LEAD/SILVER ALLOYS

Figure 13.- Solders.

I. STRUCTURAL ADHESIVES

1. HYSOL EA-934 (FILLED EPOXY)
2. CYANAMID FM-1000 (NYLON/EPOXY FILM)
3. EPON 828 30%/VERSIMID 70%(EPOXY/POLYAMIDE)

II. FILLER MATERIALS

1. 0.3-M TCT (<1/8" THICK)
   - A. WHITE LIGHTNING, 15-20 MIN. (POLYESTER/PLASTIC)
   - B. PLASTIC PADDING, 5-10 MIN. (POLYESTER/PLASTIC)
   - C. DEVCON F, 2 HR. + (ALUMINUM/EPOXY)
2. CURRENT PROGRAM TO IDENTIFY ADDITIONAL FILLERS, IF NECESSARY DEVELOP NEW ONES

Figure 14.- Adhesives and fillers.