

AEROSPACE INFORMATION REPORT

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Crack Initiation and Growth Considerations for
Landing Gear Steel with Emphasis on Aermet 100

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1. SCOPE:

Steel alloys, such as AF1410 (AMS 6527, UNS K92571) and AerMet 100 (AMS 6532), have been developed which have improved Fracture Toughness characteristics compared to the current landing gear steel alloy, 300M (AMS 6419 and AMS 6257, MIL-S-8844, UNS K44220). The 300M steel is the most widely used material in current landing gear designs. It has been successfully used in thousands of applications. The use of the 300M material necessitates a safe life design criterion where components are retired after one-fourth to one-sixth the laboratory test life. This criterion was established in part due to the relatively low fracture toughness of low-alloy steel in the 260 to 300 ksi strength range.

The high fracture tough alloys give comparable strength levels with an increase in fracture toughness and better resistance to stress corrosion cracking. These alloys may make possible the consideration of new procedures for operation, maintenance, and inspection. For the present, these materials in the 220 to 280 ksi strength range, cannot be certified to damage tolerant design criteria. They may not yield critical cracks readily detectable using normal in-service inspection methods. Even though they may not qualify as damage tolerant in single load path applications, the improved mechanical properties alone may justify the consideration of these materials, especially in corrosive environments. In the future, they may allow on-condition maintenance, crack growth monitoring, and increased potential for rework.

This document identifies several available materials. It compares properties of selected low-alloy steels to the higher alloyed steels. It also compares failure modes, maintenance, and inspection techniques. Although cost should be a factor when considering the material selection for landing gear application, this document will only focus on the technical aspects.

2. REFERENCES:

- (1) "Comparative Data of High Strength Aerospace Alloys" (Carpenter Technology Corporation).
- (2) "AerMet 100 - An Advanced Steel for the Aerospace Industry", James Dahl, Carpenter Technology Corporation, reprinted from Advanced Materials Technology International, 1991.
- (3) "Aerospace Materials Handbook", Vol. 1, Code 1217, 1987.
- (4) "Combined Strength and Toughness Characterize New Aircraft Alloy", Thomas J. McCaffrey, Carpenter Technology Corp., printed in Advanced Materials & Processes, Volume 142, Number 3, Sept 1992.
- (5) "AerMet 100 Alloy for Landing Gear Applications - A Summary of Forging Studies", SAE Aerotech '92: Presentation by Michael L. Schmidt, Senior Metallurgist, Tool and Alloy R&D, Carpenter Technology Corp., SAE Paper 922041.
- (6) Reports of Machinability Studies Conducted by Bendix Wheels and Brakes Division of Allied-Signal Aerospace, Westmoreland Mechanical Testing & Research Inc., Carpenter Technology Corp., and Waukesha Cutting Tools, Inc. in calendar year 1992.
- (7) "Fatigue Crack Growth in AerMet 100 Steel", Report Nos. AD-A249068 and NADC-91111-60, dated 18 Oct 1991 by Eun U. Lee, Air Vehicle and Crew Systems Technology Directorate (Code 6063), Sponsor N0000154 Naval Air Development Center.
- (8) MIL-HDBK-5F, Change Notice 2, 15 Dec 1992, Section 2.5.3.
- (9) "875 °F (5 h) Aged AerMet 100: Data for AMS and MIL-HDBK-5 Specifications", CarTech Research and Development, Paul M. Novotny, Metallurgist, Tool & Alloy R&D.
- (10) "Corrosion of Landing Gear Steels", E. U. Lee, J. Kozol, J. B. Boodey, J. Waldman, Naval Air Warfare Center, Aircraft Division Warminster, Warminster, PA 18974, USA.

3. MATERIALS:

The steel alloy 300M is a traditional quench and temper, low-alloy steel. This steel is usually used in the 280 to 300 ksi ultimate tensile strength range. The prime candidates for supplementing the low-alloy steels in current use, are AF1410 and AerMet 100. They are highly alloyed, martensitic precipitation/age hardening alloys (maraging steels).

4. MATERIAL PROPERTIES:

4.1 Mechanical Properties:

Comparisons of several mechanical properties for AF1410, AerMet 100, and 300M are shown in Figures 1 through 6 (1). For illustration, properties for H11 medium-alloy steel and Hy-Tuf steel are included. In general, AerMet 100 exceeds 300M for yield strength and fracture toughness at an equal or greater ultimate tensile strength. AF1410 falls slightly lower than 300M for yield and tensile strengths at a much greater fracture toughness. (2)

4.2 Fracture Toughness:

AF1410 and AerMet 100 alloys offer significant advantages over 300M in fracture toughness capabilities. Typical K_{Ic} fracture toughness values are 50 $\text{ksi}\sqrt{\text{in}}$ at 290 ksi UTS for 300M. This value is compared to 105 $\text{ksi}\sqrt{\text{in}}$ at 285 ksi UTS for AerMet 100 and 140 $\text{ksi}\sqrt{\text{in}}$ at 240 ksi UTS for AF1410. Similar improvements are noted for the Charpy V-Notch impact fracture test. Typical values are 15 ft lbf for 300M steel, 30 ft lbf for AerMet 100 and 45 ft lbf for AF1410. (2)

4.3 Fatigue Properties and Crack Growth:

Based on fatigue test data, AerMet 100 ranks highest followed by AF1410 and the other low-alloy steels (1) (2).

Test Conditions:

The fatigue behavior of AerMet 100 steel was investigated under constant amplitude loading in inert and corrosive environments. The AerMet used in this study was initially forged at 1850 °F and annealed at 1250 °F for 16 hours. It was subjected to the following heat treatment:

1. Solution treatment at 1625 °F for 1 hour and air cooling
2. Deep freezing at -100 °F for 1 hour and air warming
3. Aging at 900 °F for 5 hours and air cooling

Material Properties:

Test sample mechanical properties in the longitudinal orientation compared to standard AMS 6532 properties were:

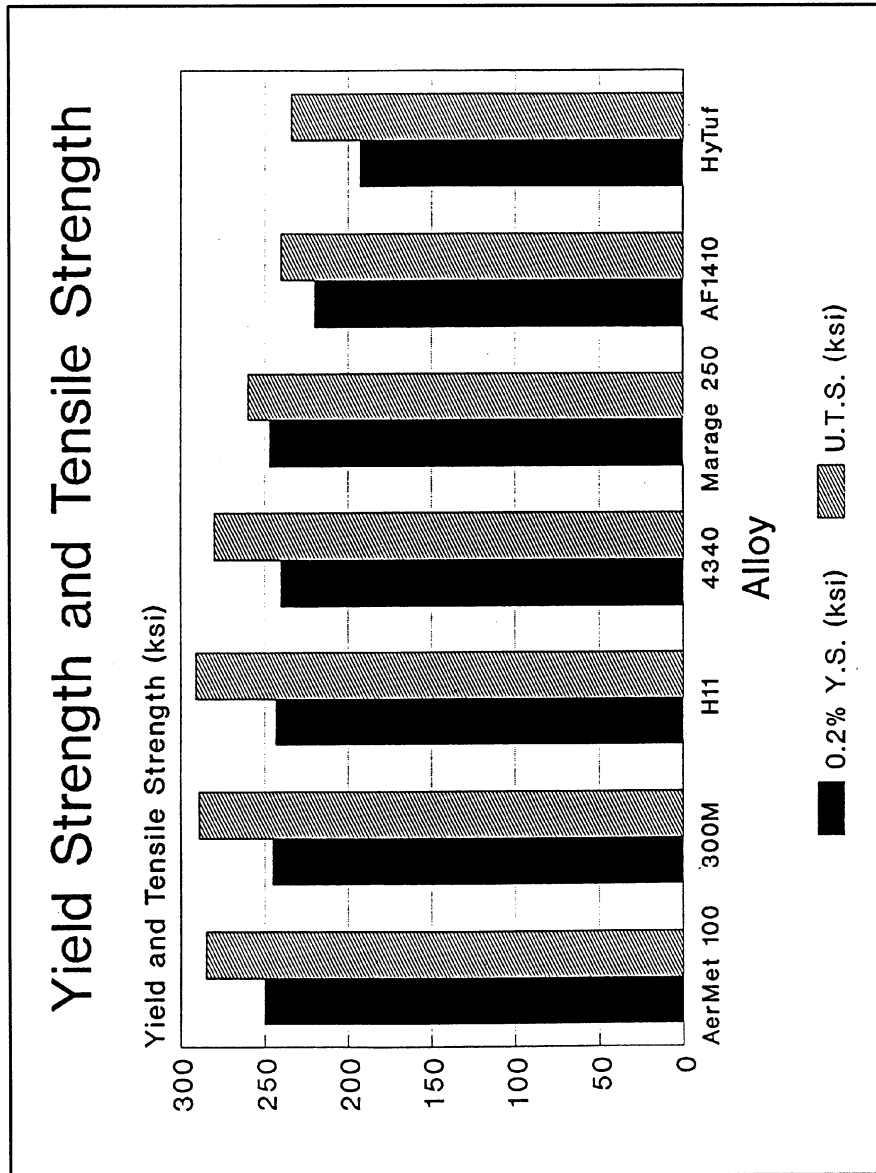


FIGURE 1 - Yield Strength and Tensile Strength

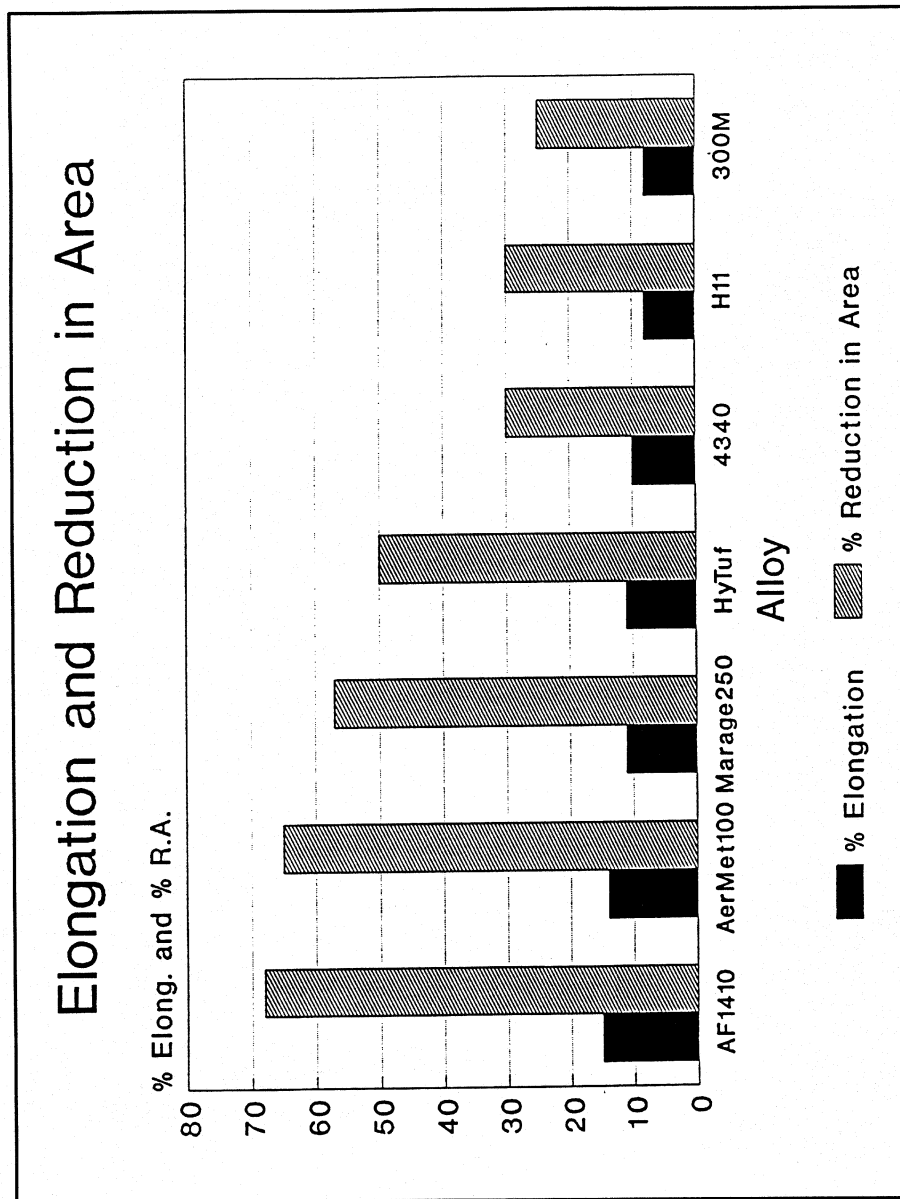


FIGURE 2 - Elongation and Reduction in Area

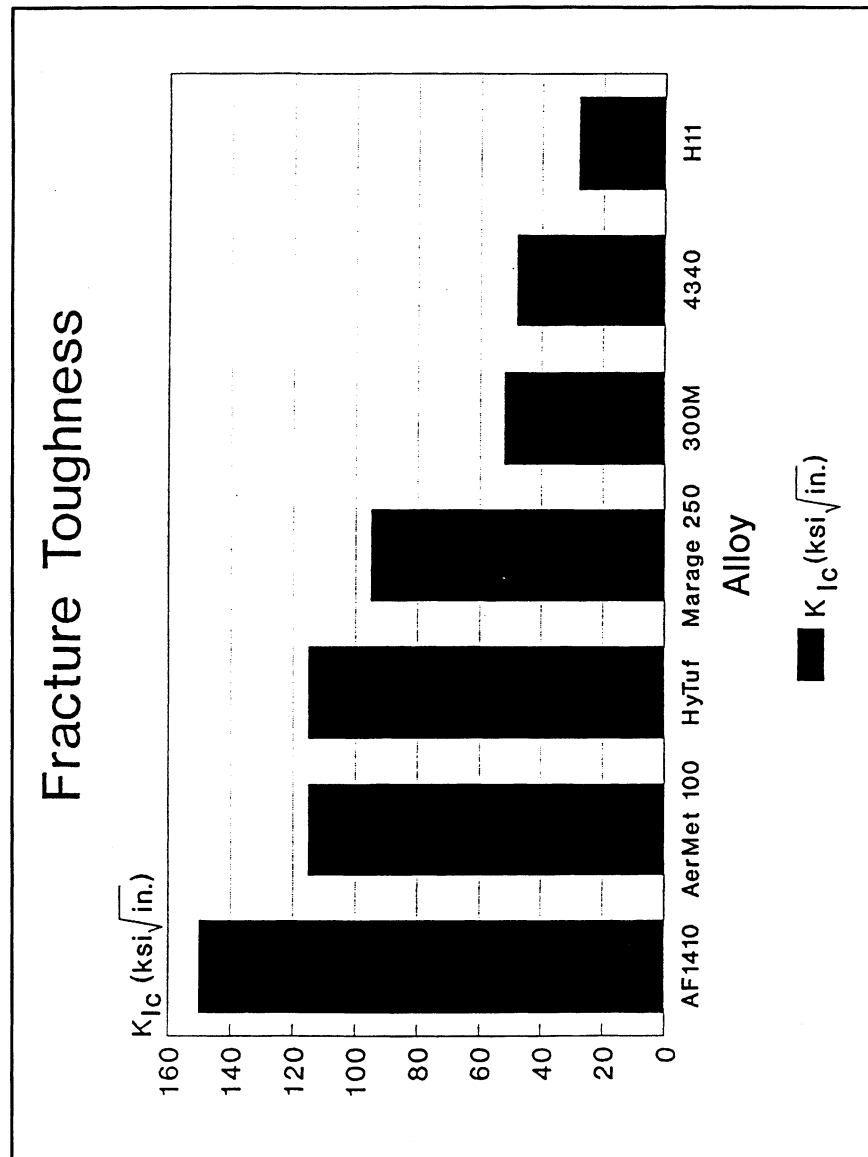
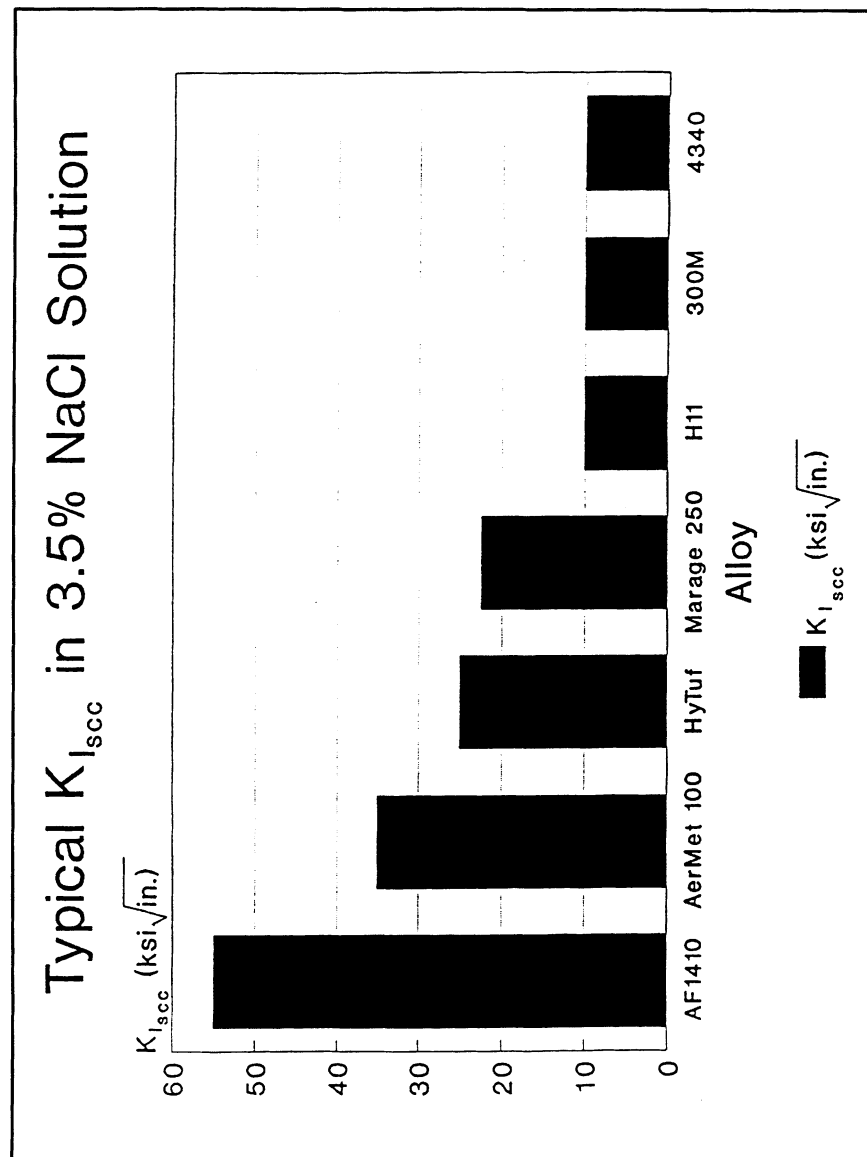


FIGURE 3 - Fracture Toughness

FIGURE 4 - Typical $K_{I_{SCC}}$ in 3.5% NaCl Solution

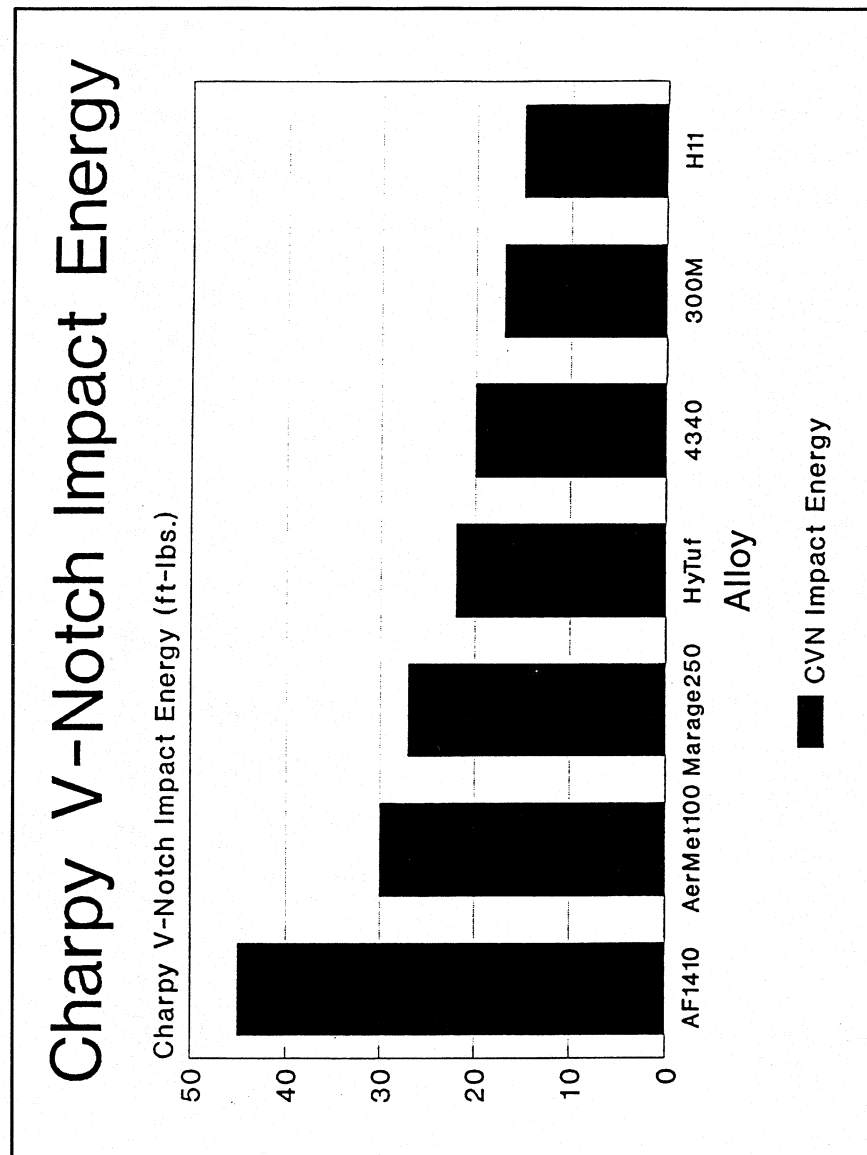


FIGURE 5 - Charpy V-Notch Impact Energy

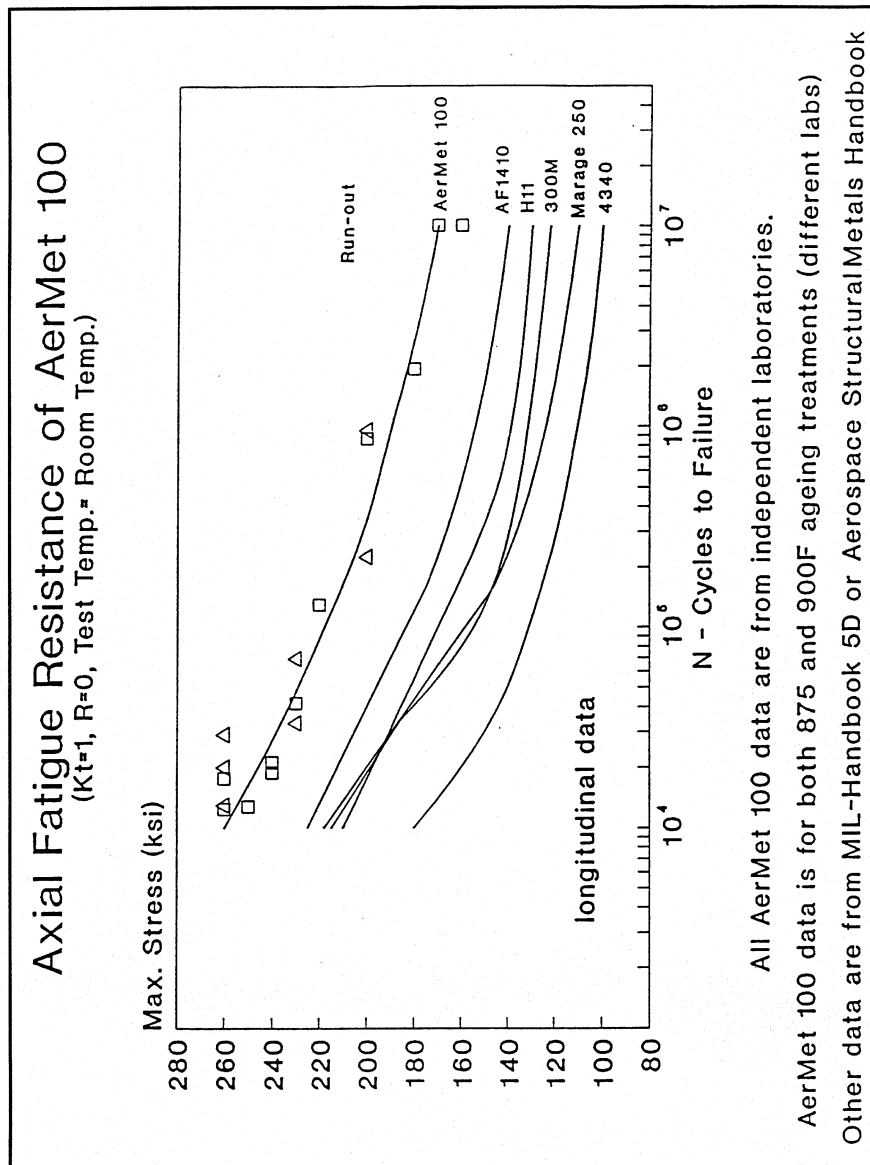


FIGURE 6 - Axial Fatigue Resistance of AerMet 100

TABLE 1

	Test Sample	AMS 6532 Per MIL-HDBK-5F
Yield Strength (ksi)	250	235
Tensile Strength (ksi)	285	280
Elongation (%)	14	10
Reduction of Area (%)	65	55
KIc (ksi√in)	115	
Modules (1000 ksi)	28.2	28.2
Density (lb/in ³)	.285	.285

4.3 (Continued):

Conclusions:

Based on a study of fatigue crack growth in AerMet 100 steel, tested in dry nitrogen gas and a 3.5% NaCl solution, the following conclusions can be drawn:

1. The fatigue crack growth resistance of the AerMet 100 Steel is superior to that of the 300M steel in inert and corrosive environments.
2. The significant features of fatigue crack growth in the AerMet 100 steel are:
 - (a) Near threshold fatigue crack growth rates, below 10E-6 in/cycle, are faster in dry nitrogen gas than in a 3.5% NaCl solution due to corrosion product induced crack closure.
 - (b) For each of the employed stress ratios, $R = 0.1, 0.5$ and 0.8 , the delta K threshold value is less in dry nitrogen gas than in a 3.5% NaCl solution.
 - (c) The larger the stress ratio, the greater is the near-threshold fatigue crack growth rate and the smaller is the delta K threshold value in both environments.
 - (d) At high fatigue crack growth rates, above 10E-6 in/cycle, the effects of environment and stress ratio are substantially reduced.
 - (e) The near-threshold fatigue crack growth behavior in a 3.5% NaCl solution is attributed to a mechanism involving corrosion-product-induced crack closure.

See Figures 7 through 14. (7)

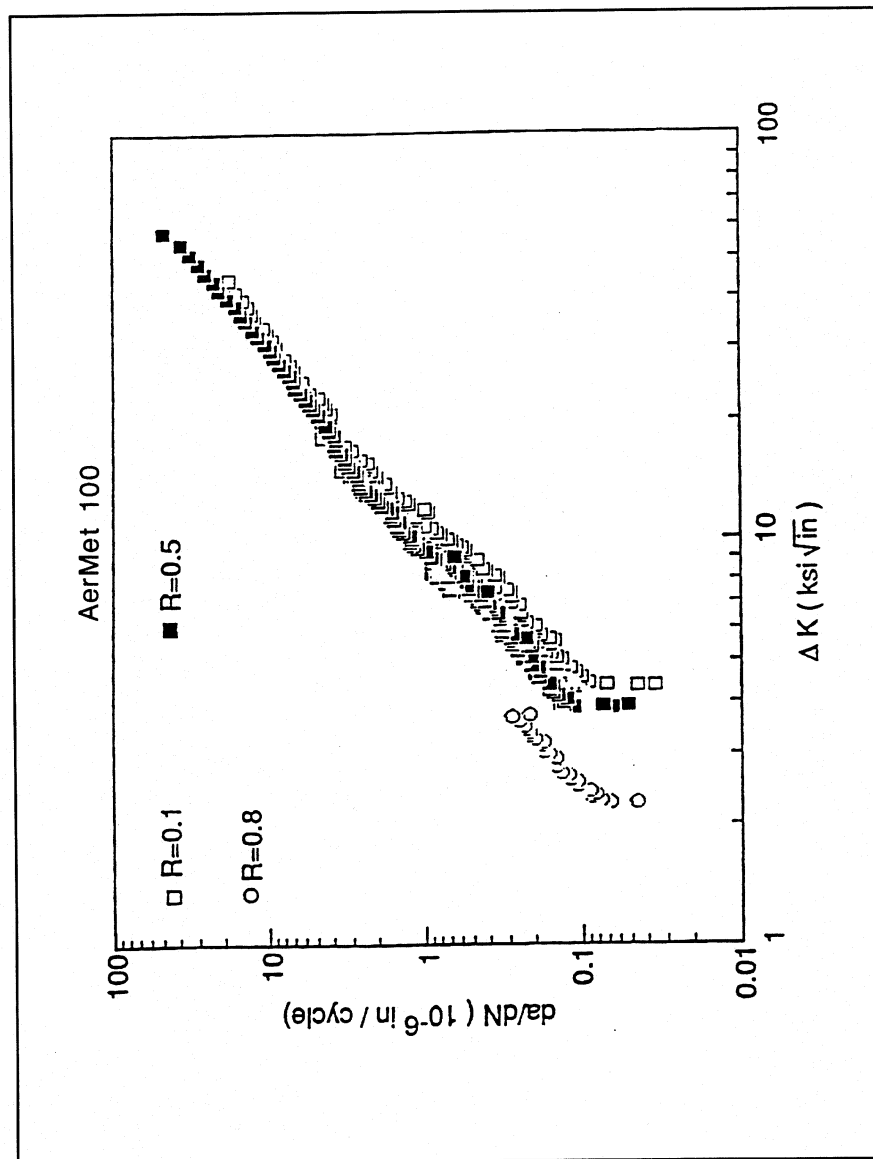


FIGURE 7 - Variation of Fatigue Crack Growth Rate, da/dN , with Stress Intensity Range, ΔK , for Stress Ratio $R = 0.1, 0.5$ and 0.8 in Dry Nitrogen Gas