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X2048, A High Strength, High Toughness Aluminum Alloy for Aircraft Applications

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X2048 is an aluminum alloy which retains all of the desirable properties of 2024 or 2124-T851, but exhibits fracture toughness equal to or greater than that of 2219-T851. Testing of 3-in. thick plant-produced plate has shown that the strength, corrosion resistance, fatigue resistance, and elevated temperature stability of 2024-T851 are maintained. Through control of chemistry and processing, the level of brittle second-phase particles is substantially reduced for the new alloy. The resulting fracture toughness is above 33, 30, and 24 KSI (in.)$^{1/2}$ for the L-T, T-L, and S-L directions, respectively. Short transverse elongations as high as 8% have been obtained for X2048.

I. Introduction

FRACTURE toughness and fatigue crack propagation rates may presently be regarded as the two principal design limiting parameters for aircraft materials. In the future these two parameters will play an even greater role as aircraft are designed on fail-safe principles which incorporate fracture toughness and fatigue crack propagation criteria. In spite of considerable fundamental and applied research, major improvements in the fatigue performance of the high-strength aluminum alloys have not occurred. Major fracture toughness improvements, without loss of strength, have recently been achieved. A second generation of aircraft alloys have recently emerged which are basically variations of the alloys 7075 and 2024, with carefully controlled chemistry and processing to optimize fracture toughness. The purpose of the present paper is to introduce a new Al-Cu-Mg alloy which retains the desirable properties of 2024-T851, but provides a 50% improvement in fracture toughness.

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Index categories: Aircraft Structural Materials; Materials, Properties of.

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The first major step in the direction of improving the toughness of 2024-T851 was the development of 2124-T851. The major difference between these two alloys is that the latter alloy is produced with reduced levels of the impurity elements iron and silicon, and with improved processing practices. The toughness and short transverse elongation of the 2124 is equal to or better than that which had been obtained with 2024 only when a costly preforging operation was employed.

X2048 is the next step in the attainment of high fracture toughness, without sacrificing the other important properties of either 2024 or 2124-T851. Thus, plane strain fracture toughness exceeding 33, 30, and 24 KSI (in.)$^{1/2}$ have been obtained for the L-T, T-L, and S-L directions (ASTM-E399 designations), while maintaining the strength, stress corrosion resistance, fatigue resistance, and thermal stability of 2024-T851 or 2124-T851. Short transverse elongations as high as 8% have been obtained for the new alloy, where 1.5% was difficult to achieve consistently with unpreforged 2024. Reynolds Metals Co. now has produced eight plant lots of the new alloy. The majority of the data has been gathered for 3-in.-thick plate, but other thicknesses are currently being evaluated. At present the product is available as plate with a finished weight of up to 8000 lb. Larger ingots have recently been cast and the ability to provide the properties described below, for larger finished plates, is currently being evaluated. The latest standard or recommended ASTM testing methods were employed to determine the properties of the alloy.

II. Composition

The following chemical composition was registered with the Aluminum Association as X2048:

Si 0.15 max.	Zn 0.25 max.
Fe 0.20 max.	Ti 0.10 max.
Cu 2.8–3.8	Others, each 0.05 max.
Mn 0.20–0.60	Others, total 0.15 max.
Mg 1.2–1.8	

III. Physical Properties

The specific heat, density, thermal conductivity, and thermal expansion coefficient are essentially the same as those for 2024 or 2124.

IV. Minimum Mechanical Properties

Using the current data for the available plant heats of X2048 and statistical data for similar alloys, the following represent our best projection of the minimum properties of the former alloy in the T851 temper, for 2 to 3-in.-thick plate with an 8000 lb maximum plate size (see Table 1).

Figures 1–3 present detailed tensile and compressive stress-strain curves for plant lot V, which represents a midpoint of the registered chemistry range. Data are being collected to establish *A* and *B* values for Mil-HDBK-5.

V. Fracture Toughness

Figure 4 presents comparison data concerning the strength and toughness of 2024, 2124, 2219, and X2048 (all in the T851 temper). Note that X2048 provides toughness equal to/or greater than that of 2219 but with 11 KSI greater yield strength. The advantage is even somewhat greater when one considers that the density of X2048 (0.0994 lb/in.^{3}) is about 3% less than that of 2219 (0.1025 lb/in.^{3}).

In comparison to 2024-T851, X2048 provides about a 50% improvement in fracture toughness, with essentially equal strength. Note in Fig. 4 that the first plant lot did not achieve the toughness values quoted above as tentative minimum values. For all subsequent heats, an improved processing sequence was employed and the later lots exceeded the minimums.

Although the majority of data has concerned 3-in. plate in the -T851 temper, a limited amount of plane stress testing of thinner gages in this temper has been conduct-

Table 1 Proposed minimum properties (2 in.-3 in.-thick plate)

Direction	TUS (KSI)	TYS (KSI)	Elong. in 4D (%)
L	62	56	6
LT	62	56	5
ST	60	54	2.5

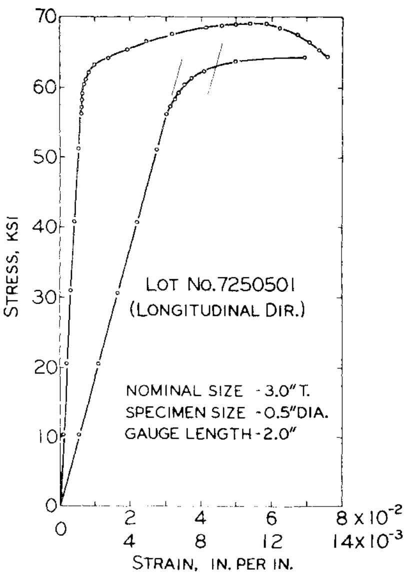

Fig. 1 Tensile stress-strain curves for X2048-T851 plate.

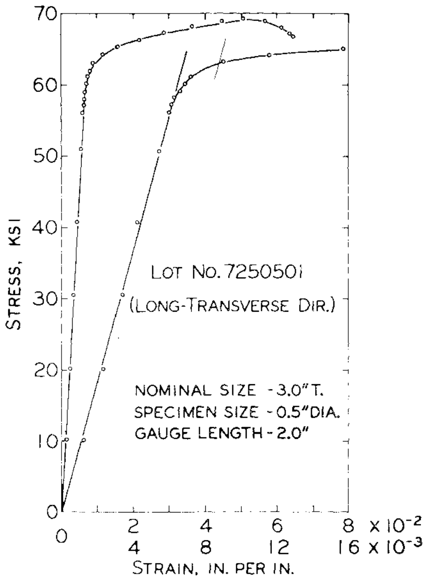

Fig. 2 Tensile stress-strain curves for X2048-T851 plate.

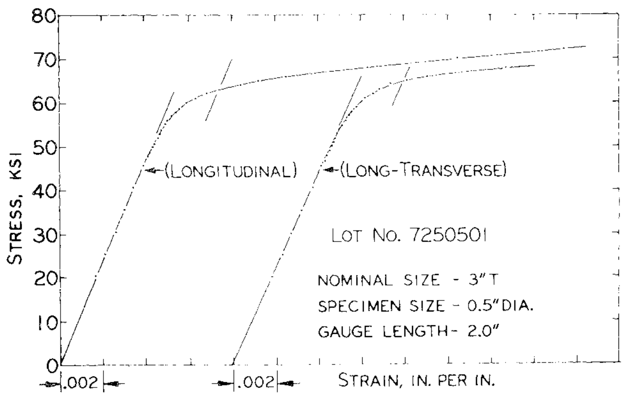

Fig. 3 Compressive stress-strain curves for X2048-T851 plate.

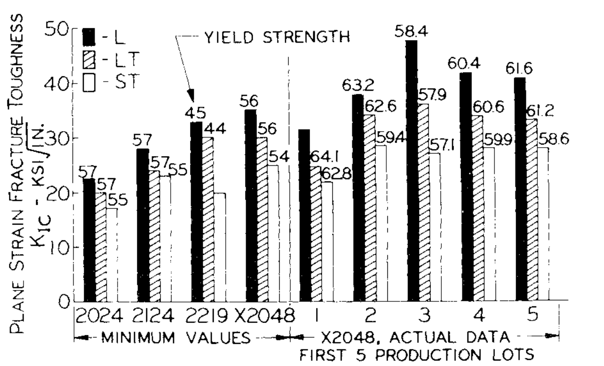

Fig. 4 Fracture toughness and yield strength of 2000 series alloys.-T851 Temper (2 to 3-in.-thick plate).

ed. Using 15-in. wide center-notched unstiffened panels with antibuckling guides surrounding the 4-in. slit, K_c was measured at the initial point of maximum load and critical crack length based upon a crack opening displacement calibration technique. K_c was determined to be about 125 KSI in.$^{1/2}$ with net section stress equivalent to the yield strength of about 62 KSI.[1] It is believed that this value would be conservative if compared to larger panels.

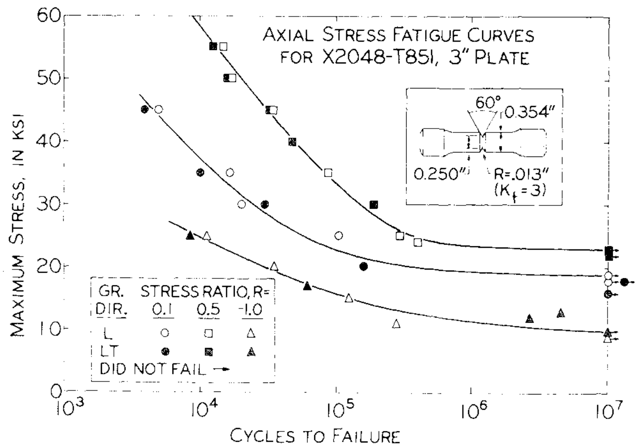

Fig. 5 Axial stress fatigue curves for X2048-T851, 3-in. plate (K_t = 3).

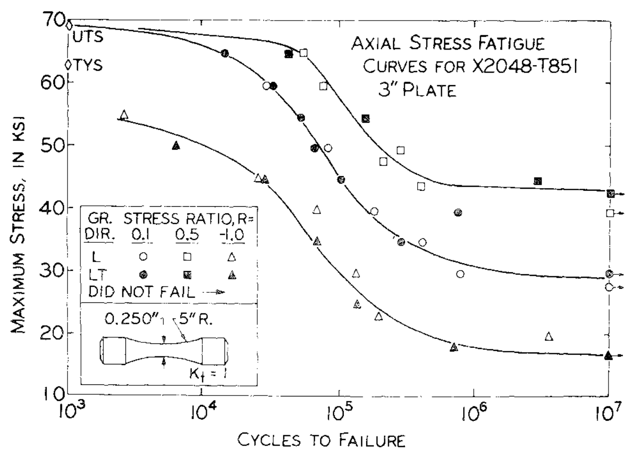

Fig. 6 Axial stress fatigue curves for X2048-T851 3-in. plate (K_t = 1).

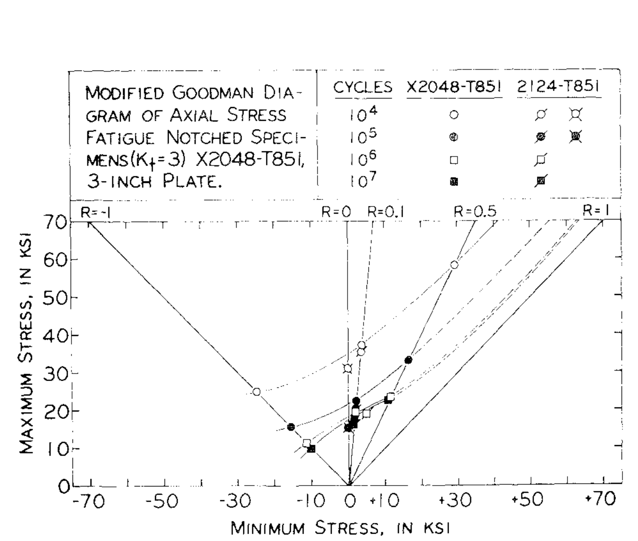

Fig. 7 Modified Goodman diagram of axial stress fatigue notched specimens (K_t = 3) X2048-T851, 3-in. plate.

VI. Stress Corrosion and Exfoliation Resistance

X2048 provides the same excellent stress corrosion and exfoliation resistance as 2024 or 2124-T851. The alloy routinely passes a 30-day alternate immersion test when stressed in the short transverse direction at 50% of the yield strength.

VII. Fatigue Properties

Both smooth (K_t = 1) and notched (K_t = 3) fatigue testing (axial-type test) and fatigue crack propagation tests indicate the X2048 is at least equivalent to 2024 or 2124-T851. Figures 5–12 provide test data obtained with lot II.

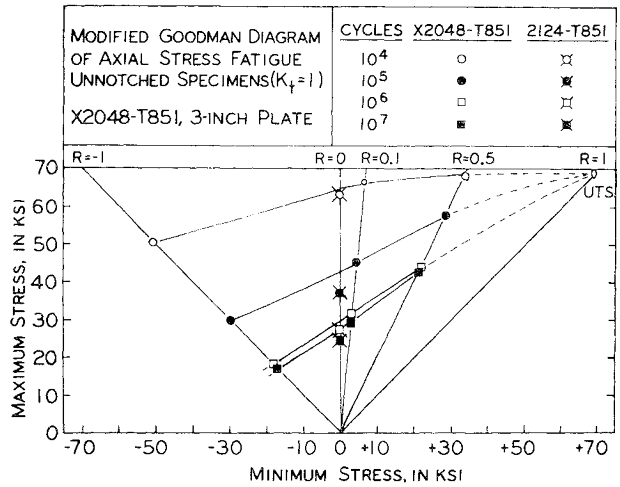

Fig. 8 Modified Goodman diagram of axial stress fatigue unnotched specimens (K_t = 1) X2048-T851, 3-in. plate.

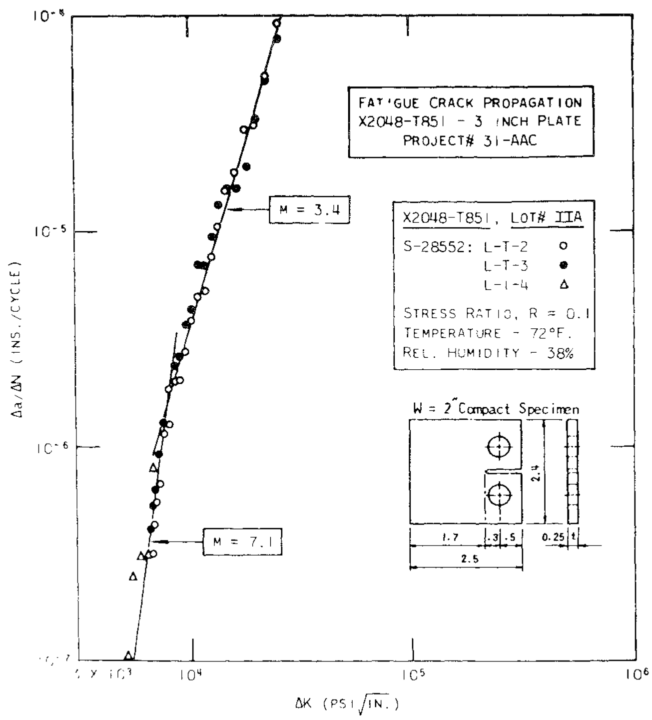

Fig. 9 Fatigue crack propagation of X2048-T851 (L-T direction).

VIII. Thermal Stability

Figure 13 presents data concerning this important property. For many aerospace applications a 2000 series, rather than a 7000 series alloy, must be employed due to the more rapid overaging found with the latter alloys above 200°F. As shown by these data, the superiority of 2024 or 2124-T851 over 7075-T7351 is maintained with X2048.

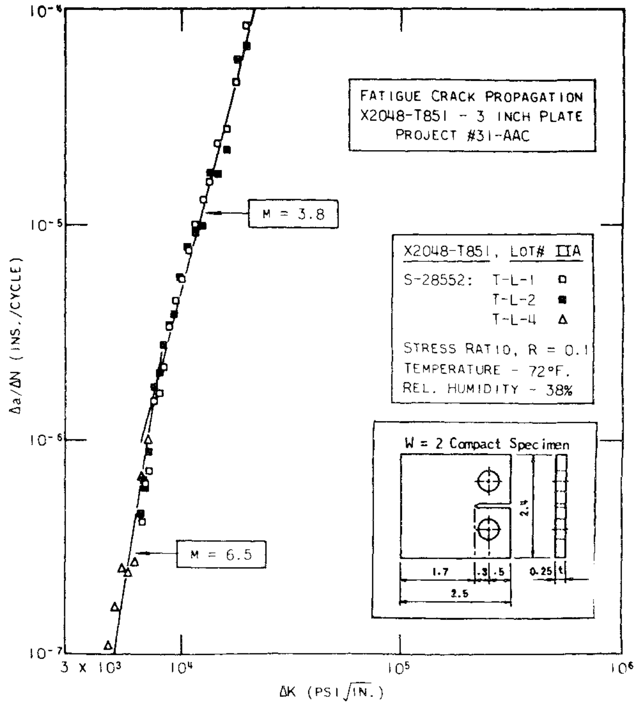

Fig. 10 Fatigue crack propagation of X2048-T851 (T-L direction).

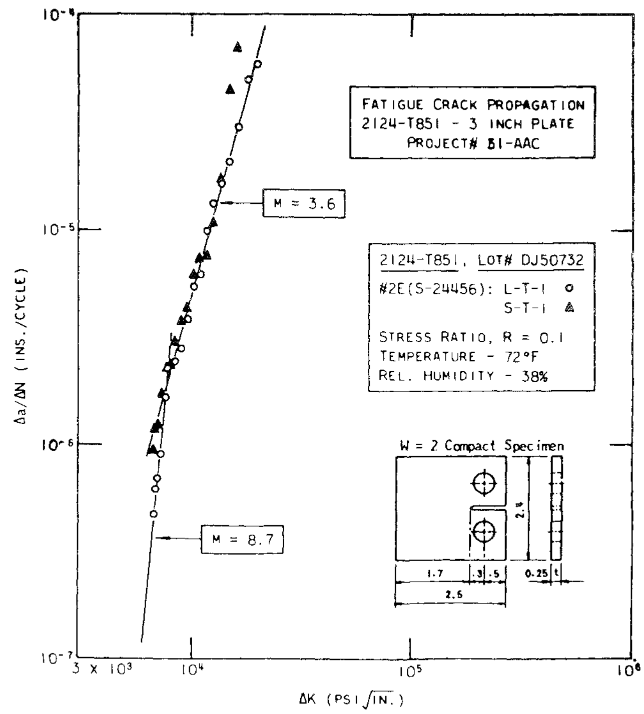

Fig. 11 Fatigue crack propagation of 2124-T851 (L-T vs S-T directions).

IX. Summary

A wide range of testing of X2048 has been conducted by the Metallurgical Research Div. of Reynolds Metals Co. The plate tested was plant-produced and the toughness improvements are commercially feasible. The testing has shown that all of the desirable properties of 2024 or 2124 can be maintained, but that the fracture toughness of the new alloy is substantially higher.

In addition to the in-house testing, samples have been circulated for independent evaluation. Battelle Memorial Inst. has recently completed testing of X2048, under Air Force sponsorship. Figures 14–18 present additional test data generated in the Battelle test program.[2]

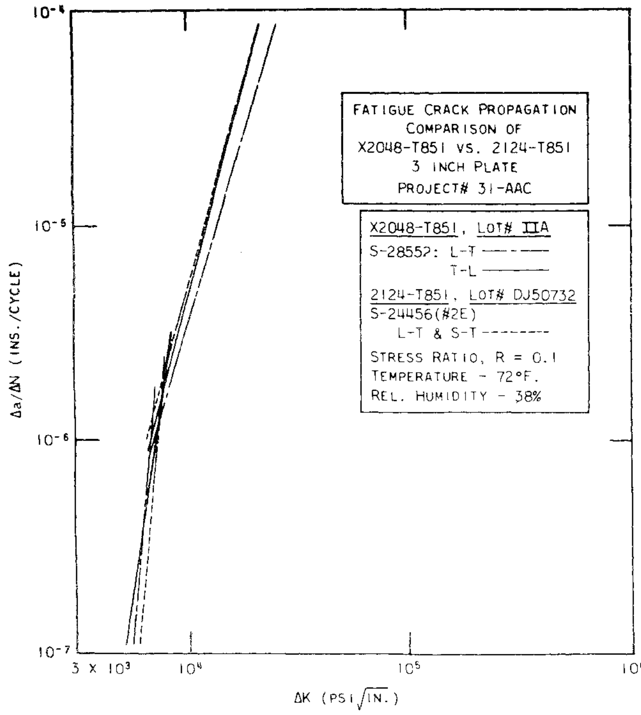

Fig. 12 Fatigue crack propagation of X2048-T851 vs 2124-0851.

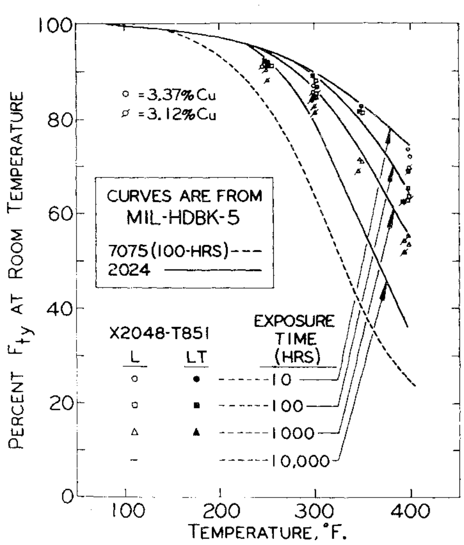

Fig. 13 Yield strength of X2048, in comparison to 2124 and 7075 at elevated temperatures (testing conducted at the exposure temperature).

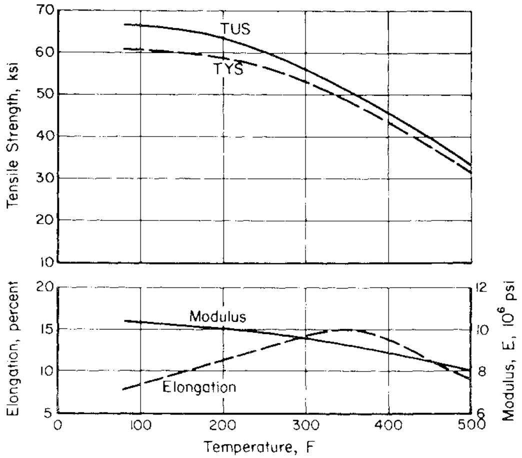

Fig. 14 Effect of temperature on the tensile properties of X2048-T851 plate.

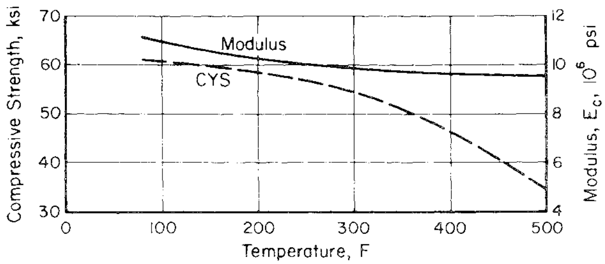

Fig. 15 Effect of temperature on the compressive properties of X2048-T851 plate.

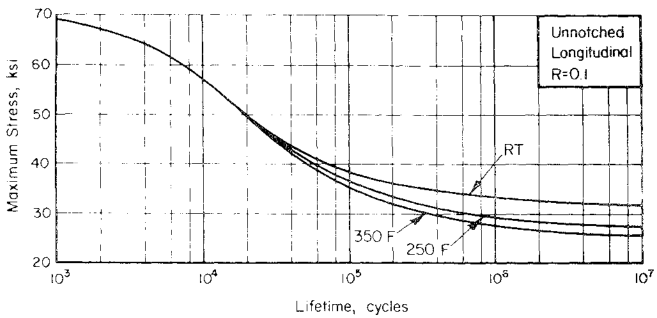

Fig. 16 Axial load fatigue behavior of unnotched X2048-T851 plate.

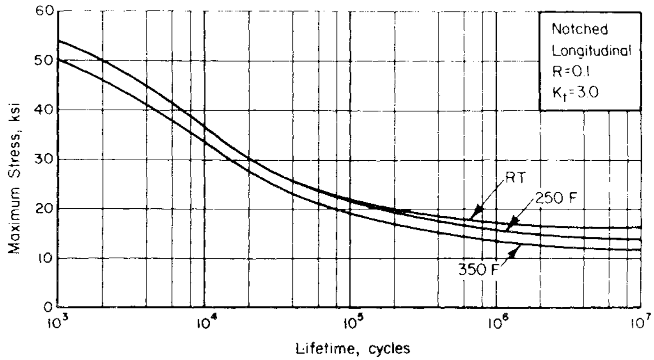

Fig. 17 Axial load fatigue behavior of notched (K_t = 3.0) X2048-T851 plate.

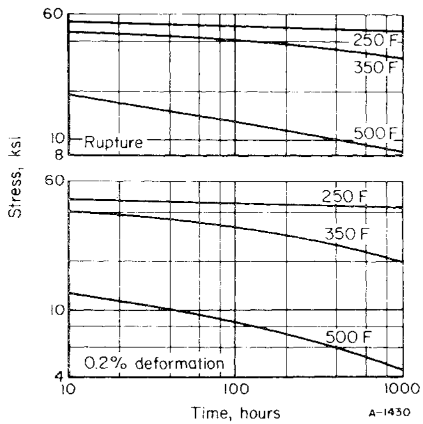

Fig. 18 Stress-rupture and plastic deformation curves for X2048-T851 plate (longitudinal).

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