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## ABSTRACT

Tensile properties were evaluated for four aluminum alloys that are candidates for airframe applications on high speed transport aircraft. These alloys included the Al-Cu-Mg-Ag alloys C415 and C416 and the Al-Cu-Li-Mg-Ag alloys RX818 and ML377. The Al-Cu-Mg alloys CM001, which was used on the Concorde SST, and 1143, which was modified from the alloy used on the TU144 Russian supersonic aircraft, were tested for comparison. The alloys were subjected to thermal exposure at 200˚F, 225˚F and 275˚F for times up to 30,000 hours. Tensile tests were performed on thermally-exposed and as-received material at -65˚F, room temperature, 200˚F, 225˚F and 275˚F.

All four candidate alloys showed significant tensile property improvements over CM001 and 1143. Room temperature yield strengths of the candidate alloys were at least 20% greater than for CM001 and 1143, for both the as-received and thermally-exposed conditions. The strength levels of alloy RX818 were the highest of all materials investigated, and were 5-10% higher than for ML377, C415 and C416 for the as-received condition and after 5,000 hours thermal exposure. RX818 was removed from this study after 5,000 hours exposure due to poor fracture toughness performance observed in a parallel study. After 30,000 hours exposure at 200˚F and 225˚F, the alloys C415, C416 and ML377 showed minor decreases in yield strength, tensile strength and elongation when compared to the as-received properties. Reductions in tensile strength from the as-received values were up to 25% for alloys C415, C416 and ML377 after 15,000 hours exposure at 275˚F.

## INTRODUCTION

Development of economically viable high speed aircraft requires materials that exhibit stable mechanical properties for extended operating time at elevated temperatures. Aircraft operating in the Mach 2 regime will experience airframe temperatures in excess of 200˚F with anticipated service lifetime greater than 60,000 hours. The objective of this study was to evaluate the long-term thermal stability of four aluminum alloys that are candidates for airframe applications on high speed transport aircraft. Two Al-Cu-Mg-Ag alloys developed by Alcoa, C415 and C416, and two Al-Cu-Li-Mg-Ag alloys developed by Reynolds Metals Company, RX818 and ML377, were evaluated in this study. Two Al-Cu-Mg alloys that were developed for supersonic airframe applications, CM001 and 1143, were evaluated for baseline comparison.

The alloy CM001 was developed for structural application on the Concorde Supersonic Transport (SST) aircraft. The alloy composition limits and thermomechanical processing were modified from the British alloy RR58, which had been developed to produce forgings for engine applications and which had demonstrated excellent thermal stability [1,2]. The manufacturing processes for CM001 were tailored to optimize creep properties and ensure adequate strength and fracture properties in the required product forms. The U.S. Aluminum Association equivalent alloy to RR58 and CM001 is 2618.

The Russian alloy 1143 was developed from the Russian alloy AK4-1, which was the material used on the TU144 Russian supersonic aircraft [3,4]. The composition of AK4-1 is similar to RR58 and 2618. The composition of 1143 was modified from AK4-1 to improve fracture toughness while retaining elevated temperature properties. The properties of CM001 and 1143 were considered as a baseline.

The four candidate alloys were produced during a government and industry research program [5,6] to develop materials with improved strength, toughness, and thermal stability for elevated temperature service. Alloys C415 and C416 were developed as high toughness alloys and were based on 2519, an Al-Cu-Mg-Mn alloy with good high temperature properties. The alloys RX818 and ML377 were developed as high strength alloys and were based on the Al-Cu-Li-Mg-Ag Weldalite™ system.

In this study, the tensile properties of C415, C416, RX818 and ML377 were evaluated before and after long term exposure at elevated temperature. The alloys were tested in the as-received condition at room temperature, at the elevated temperatures of 200˚F, 225˚F and 275˚F, and at the cryogenic temperature of -65˚F. The alloys were also tested after exposures of up to 30,000 hours at 200˚F, 225˚F and 275˚F. CM001 and 1143 were tested in the as-received condition and after selected thermal exposures for comparison. The data that was generated for each test included yield strength, ultimate tensile strength, total elongation at failure and modulus. Results are presented to illustrate tensile property variations with test temperature, thermal exposure and orientation. Companion studies have been performed that evaluate creep properties [7] and fracture toughness [8] of the alloys.

## MATERIALS

The candidate aluminum alloys investigated in this study were the Al-Cu-Mg-Ag alloys C415 and C416, and the Al-Cu-Li-Mg-Ag alloys RX818 and ML377. The baseline aluminum alloys investigated were the Al-Cu-Mg alloys CM001 and 1143. The nominal chemical compositions of the alloys are given in Table 1. The materials used for this study were received from the manufacturers in sheet form. Table 2 summarizes the sheet thicknesses, heat treatments, and suppliers of the materials.

Table 1. Nominal Chemical Composition of Materials
(wt. %; Balance is Aluminum)

| Material | Cu | Li | Mg | Ag | Zr | Mn | Fe | Si | Ti | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| C415 | 5.0 | -- | 0.8 | 0.5 | 0.13 | 0.6 | -- | -- | -- | -- |
| C416 | 5.4 | -- | 0.5 | 0.5 | 0.13 | 0.3 | -- | -- | -- | -- |
| RX818 | 3.7 | 1.0 | 0.5 | 0.3 | 0.14 | -- | -- | -- | -- | -- |
| ML377 | 3.5 | 1.0 | 0.4 | 0.4 | 0.12 | 0.3 | -- | -- | -- | -- |
| CM001 | 2.3 | -- | 1.5 | -- | -- | -- | 1.0 | 0.22 | 0.09 | 1.12 |
| 1143 | 2.3 | -- | 1.5 | -- | -- | -- | 0.5 | 0.2 | 0.07 | 0.6 |

Table 2. Description of Sheet Materials

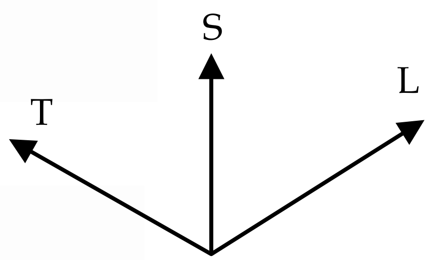
| Material | Thickness, in. | Condition | Material Supplier |
|---|---|---|---|
| C415 | 0.091 | T8 | Alcoa |
| C416 | 0.096 | T8 | Alcoa |
| RX818 | 0.086 | T8 | Reynolds |
| ML377 | 0.088 | T8 | Reynolds |
| CM001 | 0.158 | T6, clad | Pechiney |
| 1143 | 0.128 | T651 | Alcoa |

The alloys C415 and C416 were modifications of the Al-Cu-Mg alloy 2519, a material with relatively high strength and good thermal stability due to thermally stable Cu-containing phases [6]. Polmear demonstrated that small additions of Ag to Al-Cu-Mg alloys with high Cu/Mg ratios significantly increased strength and thermal stability [9,10]. Additions of Ag promoted formation of the Ω variant of $Al_2Cu$, which is a more effective strengthening precipitate and a more thermally stable precipitate than either Θ' ($Al_2Cu$) or S' ($Al_2CuMg$) [10,11]. The Cu and Mg contents and the Cu/Mg ratio of both alloys were selected to reduce the volume fraction of intermetallic phases in order to improve fracture toughness. The alloy C416 had lower Mg and Mn and higher Cu than the C415 alloy. The Cu/Mg ratio for C415 was 6, resulting in Ω being the dominant precipitate phase in the T8 condition. For C416, the Cu/Mg ratio was 10, resulting in the presence of both Ω and Θ' phases [6]. Both C415 and C416 were cast in 1200-pound ingots, processed to produce 0.090-inch thick sheet and aged to a T8 temper. These materials were received in sheets 22 inches wide by 48 inches long. The microstructures of C415 and C416 were homogeneous through the thickness of the sheets. Tri-planar sections from the mid-plane of the sheets, shown in Figure 1, exhibited recrystallized microstructures with nearly equiaxed grain structures, although the grain size was slightly smaller and less elongated in C416. The average grain diameters were 29 μm and 24 μm with aspect ratios of 2.6:1 and 1.3:1 for C415 and C416, respectively. Orientation distribution function (ODF) analysis indicated a weak recrystallization texture for both materials, which indicates that the grain structures fully recrystallized during post-deformation aging treatments but did not develop a preferred orientation.

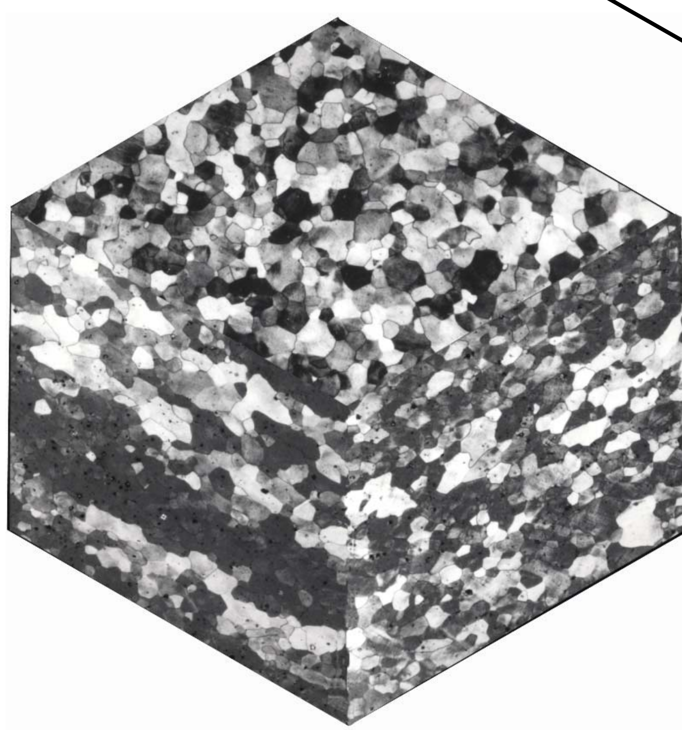
Al-Li alloys have been shown to have high strengths and toughness, and excellent specific properties due to the addition of Li and the associated reduction in density [12,13]. The alloys RX818 and ML377 were variants of the Weldalite™ (Al-Cu-Li-Mg-Ag) alloy system produced by Reynolds Metals, which are strengthened primarily by fine distributions of thermally stable $T_1$ ($Al_2CuLi$) and S' precipitates [6]. Cu and Mg levels were higher in the RX818 chemistry to increase the volume fraction of strengthening precipitates and thermomechanical processing was developed to produce an unrecrystallized microstructure. Mn was added to ML377 to encourage dispersoid formation and to promote recrystallization and thermomechanical processing was developed to produce a recrystallized microstructure [6]. Both RX818 and ML377 were cast in 10,000-pound ingots, processed to 0.090-inch thick sheet using commercial processes, and aged to a T8 temper. These materials were received in sheets 48 inches wide and between 8 feet and 10 feet long. The microstructures of RX818 and ML377 were uniform throughout the thickness of the sheets. Tri-planar sections from the mid-plane of the sheets, shown in Figure 2, illustrate the differences in grain morphology between RX818 and ML377. The microstructure of RX818 was unrecrystallized and characterized by thin lamellar grains, averaging 3.7 μm thick, that are elongated in the rolling direction. The average grain diameter was 11 μm with an aspect ratio of 13.4:1. ODF analysis indicated a strong deformation texture, similar to texture observed in other heavily deformed aluminum alloy products, which indicates that the grains have a preferred orientation associated with deformation during processing. The microstructure of ML377 appeared fully recrystallized with pancake shaped grains, averaging 17.2 μm thick, which were elongated in the rolling direction. Average grain diameter was 48 μm with an aspect ratio of 7.8:1. The grains had a preferred orientation that ODF analysis indicated as a strong recrystallization texture.

The alloy CM001 was developed by modifying the composition limits and thermomechanical processing schedule of RR58 to meet the creep, durability, fracture toughness and strength goals of the Concorde design and to produce the product forms necessary for structural application on the Concorde [1,2]. CM001 is strengthened by a fine dispersion of S' precipitates and the intermetallic phase $Al_9(Fe,Ni)$, which is virtually insoluble in aluminum and which imparts good thermal stability. A proprietary thermomechanical processing schedule was developed to produce material in the T6 condition for application on the Concorde because it was determined that stretching to achieve a T8 temper resulted in unacceptably low plastic elongation and had a deleterious effect on the alloy's creep properties. The CM001 material evaluated in this program was commercially produced as 0.158-inch thick Alclad sheet in the T6 condition and was supplied as a 36-inch wide by 72-inch long sheet. The clad layer, applied for corrosion resistance, was Al - 1% Zn and the thickness of the layer on each surface was 0.008 inch. The microstructure of CM001, shown in Figure 3, was recrystallized with nearly equiaxed grain structure. The average grain diameter was 20 μm with an aspect ratio of 1.2:1. The preferred orientation of the grains as determined by ODF analysis indicated a weak recrystallization texture.

The alloy 1143 is an Al-Cu-Mg alloy that was developed from the Russian alloy AK4-1, an alloy with composition similar to RR58 and 2618 [3,4]. The composition of 1143 reflects reduction in Fe and Ni levels and addition of Zr compared with AK4-1 to improve fracture toughness while retaining elevated temperature strength and creep properties. The 1143 material evaluated in this program was commercially produced as 0.128-inch thick sheet in the T651 condition and was supplied as 20-inch wide by 52-inch long sheet. The microstructure of 1143, shown in Figure 4, was recrystallized with nearly equiaxed grain structure. The average grain diameter was 26 μm with aspect ratio of 2.0:1. The preferred orientation of the grains as determined by ODF analysis indicated a weak recrystallization texture.

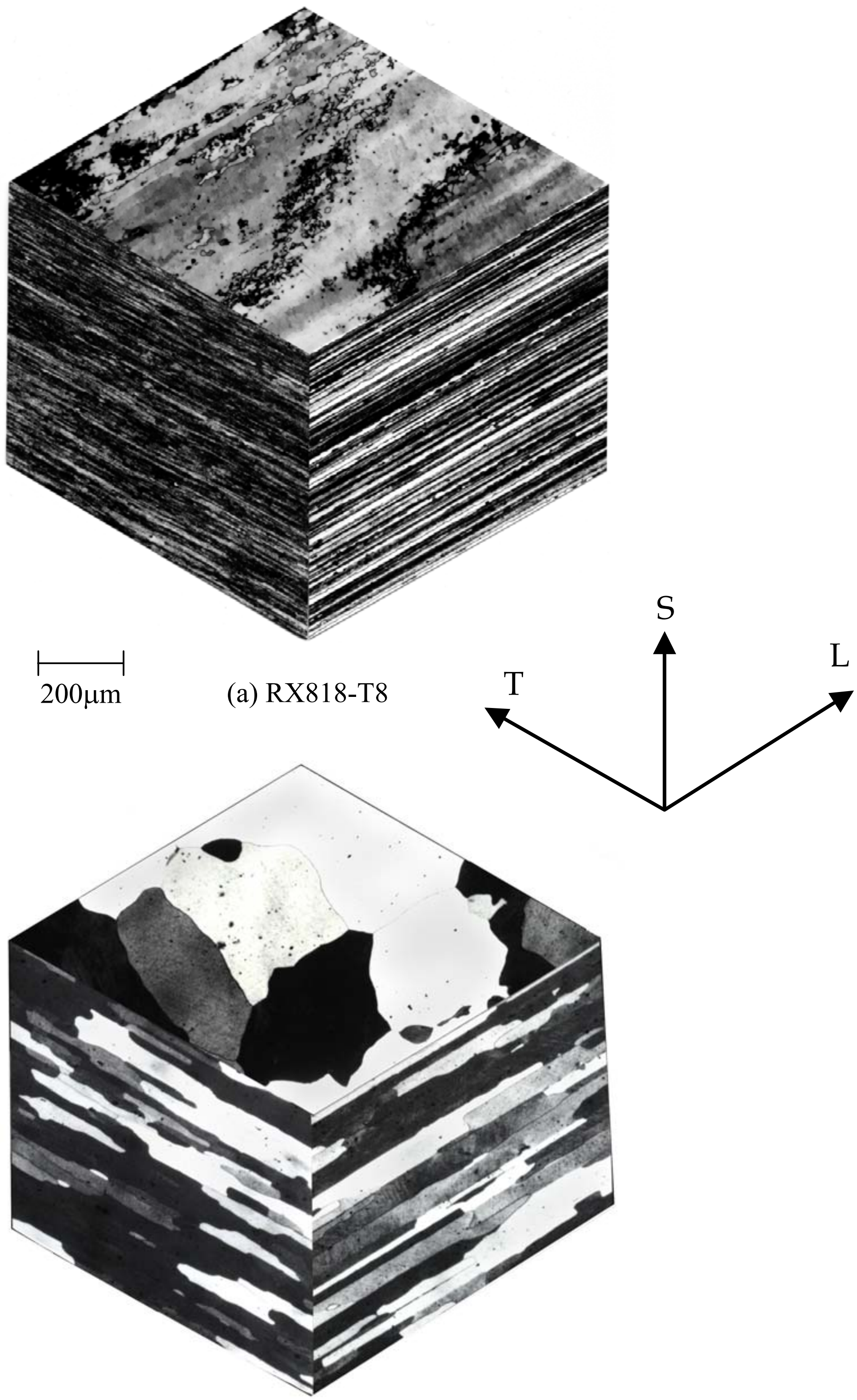




(a) C415-T8



(b) C416-T8

Figure 1. Microstructure of alloys C415 and C416 in the as-received condition.




(a) RX818-T8

(b) ML377-T8

Figure 2. Microstructure of alloys RX818 and ML377 in the as-received condition.

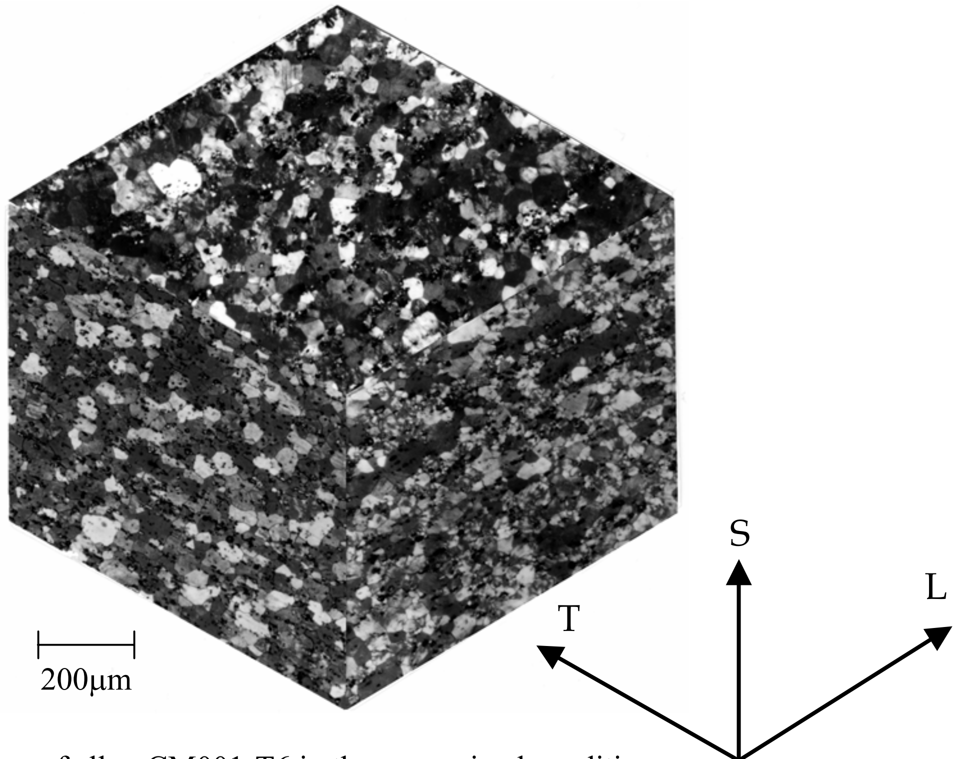



Figure 3. Microstructure of alloy CM001-T6 in the as-received condition.

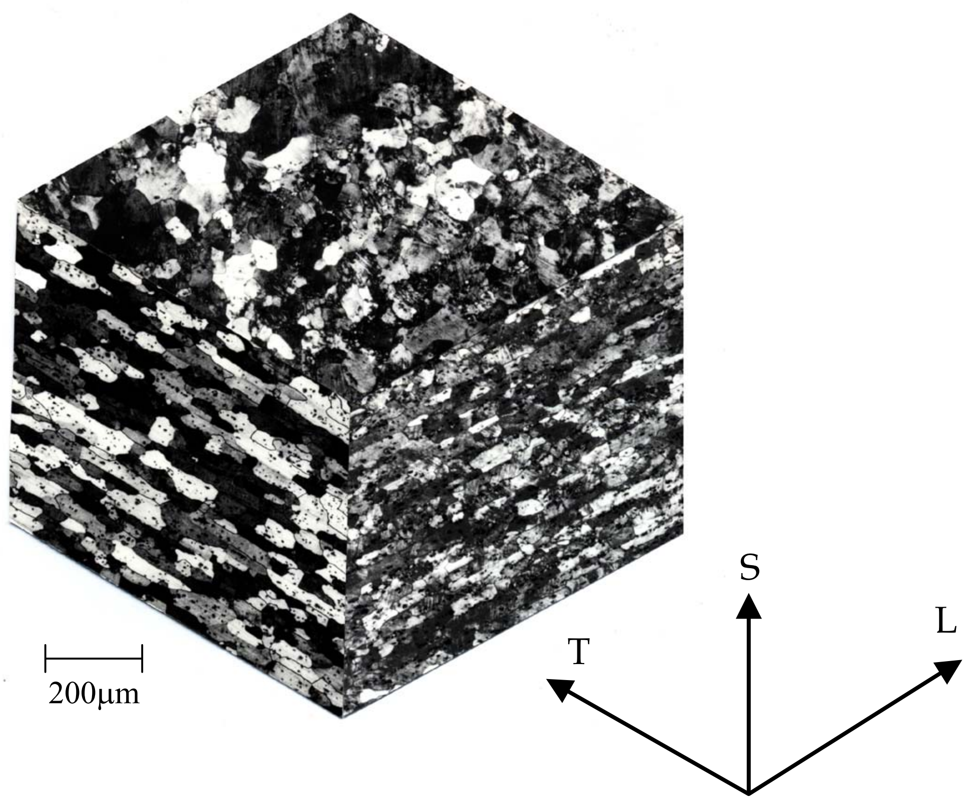



Figure 4. Microstructure of alloy 1143-T651 in the as-received condition.

## EXPERIMENTAL PROCEDURES

### Thermal Exposures

The candidate and baseline alloys were isothermally exposed for up to 30,000 hours at 200˚F, 225˚F and 275˚F. Table 3 shows the exposure temperatures and times for each alloy. Machined specimens were exposed for times up to 1,000 hours whereas sections of sheet measuring about 8 inches by 8 inches were exposed for times 3,000 to 30,000 hours. The oven temperature was controlled to ±2˚F over the duration of exposure. RX818 was removed from thermal exposure and subsequent testing after 5,000 hours due to poor fracture toughness properties [8].

### Test Specimens

Sub-size tensile specimens were machined from the sheet material in the longitudinal (L) and transverse (T) directions and at a 45˚ angle to the rolling direction. The specimen dimensions, shown in Figure 5, were in accordance with ASTM E8 [14]. The specimens were machined at the full sheet thickness for each alloy and the width of the reduced section was gradually tapered by 0.003 inch from the ends to the mid-point.

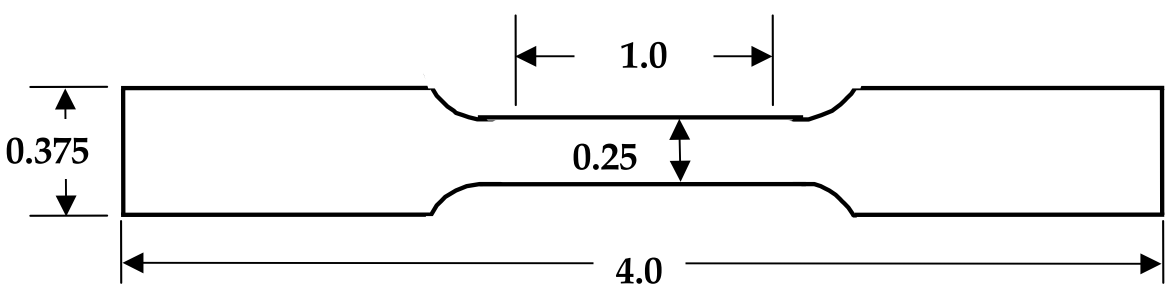



Figure 5. Sub-size tensile specimen dimensions in inches.

### Tensile Tests

The test temperatures and specimen orientations evaluated for each exposure condition are summarized in Table 3. For materials in the as-received (T8 or T6) condition, tensile tests were performed at room temperature, at the elevated temperatures of 200˚F, 225˚F and 275˚F and at the cryogenic temperature of -65˚F. After thermal exposure, tests were performed at room temperature and in some cases at the exposure temperature or at -65˚F. Generally, duplicate specimens were tested for each condition evaluated.

All testing was done in accordance with ASTM E8 [14]. All tensile tests were conducted in a servo-hydraulic testing machine with hydraulic grips. Specimens were loaded to failure at a constant stroke rate of 0.0625 in/min. An environmental chamber was used for cryogenic and elevated temperature tests. The tensile testing equipment is shown in Figure 6, with the chamber door open to show the specimen, extensometer and thermocouples. For the tests at elevated and cryogenic temperatures, the specimens and grips were enclosed within the chamber and allowed to reach thermal equilibrium at the desired temperature. Tests were initiated when a thermocouple attached to the specimen indicated that the desired temperature had been reached. The approximate time required to heat or cool the specimen to the desired test temperature was 30 minutes and the temperature during the test was held to within ±2˚F.

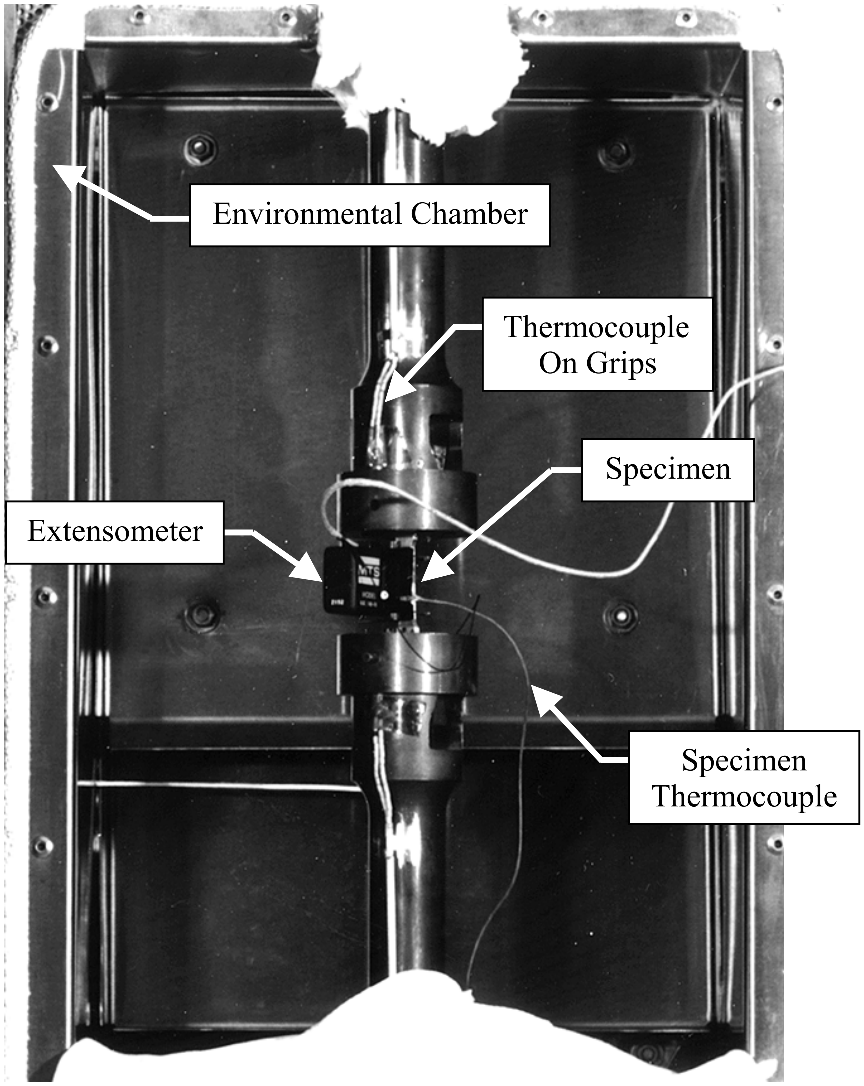



Figure 6. Tensile test equipment showing environmental chamber with door open, specimen, extensometer and thermocouples.

For specimens tested in the as-received condition and after exposures up to 3,000 hours, both strain gages and extensometers were used to acquire strain data. Yield strength was determined as the 0.2% offset yield strength and modulus was generally calculated over the strain range of 0.1 to 0.5%. Yield strength and modulus values calculated from strain gage and extensometer data agreed within 2%, consequently, strain gages were not used for exposures greater than 3,000 hours. For tests at room temperature, two 1-inch gage length extensometers were placed on the front and back faces about the specimen center. For elevated and cryogenic temperature tests, displacements were measured by a single 1-inch gage length extensometer placed about the center of the specimen.

Table 3. Specimen Orientations and Test Temperatures for each Alloy and Thermal Exposure Condition.

| Alloy | Exposure Conditions | | Test Temperature | | | | |
|---|---|---|---|---|---|---|---|
| | Temp, ˚F | Time, hrs | -65 ˚F | RT | 200 ˚F | 225 ˚F | 275 ˚F |
| C415 | -- | -- | L, T, 45 | L, T, 45 | L, T | L, T, 45 | L, T, 45 |
| | 200 | 300 | | L, T | | | |
| | | 1,000 | | L, T | | | |
| | | 3,000 | | L | L | | |
| | | 5,000 | | L, T | | | |
| | | 10,000 | L, T | L, T | L, T | | |
| | | 15,000 | L, T, 45 | L, T, 45 | L, T, 45 | | |
| | 225 | 300 | | L, T | | | |
| | | 1,000 | | L, T | | | |
| | | 3,000 | | L | | L | |
| | | 5,000 | | L, T | | | |
| | | 10,000 | L, T | L, T | | L, T | |
| | | 15,000 | L, T, 45 | L, T, 45 | | L, T, 45 | |
| | | 30,000 | | L, T | | L, T | |
| | 275 | 1,000 | | L | | | |
| | | 3,000 | | L | | | L |
| | | 10,000 | L, T | L, T | | | L, T |
| | | 15,000 | L, T, 45 | L, T, 45 | | | L, T, 45 |
| C416 | -- | -- | L, T, 45 | L, T, 45 | L, T | L, T, 45 | L, T, 45 |
| | 200 | 300 | | L, T | | | |
| | | 1,000 | | L, T | | | |
| | | 3,000 | | L | L | | |
| | | 5,000 | | L, T | | | |
| | | 10,000 | L, T | L, T | L, T | | |
| | | 15,000 | L, T, 45 | L, T, 45 | L, T, 45 | | |
| | 225 | 300 | | L, T | | | |
| | | 1,000 | | L, T | | | |
| | | 3,000 | | L | | L | |
| | | 5,000 | | L, T | | | |
| | | 10,000 | L, T | L, T | | L, T | |
| | | 15,000 | L, T, 45 | L, T, 45 | | L, T, 45 | |
| | | 30,000 | | L, T | | L, T | |
| | 275 | 1,000 | | L | | | |
| | | 3,000 | | L | | | L |
| | | 10,000 | L, T | L, T | | | L, T |
| | | 15,000 | L, T, 45 | L, T, 45 | | | L, T, 45 |

Table 3. Specimen Orientations and Test Temperatures for each Alloy and Thermal Exposure Condition. (concluded)

| Alloy | Exposure Conditions | | Test Temperature | | | | |
|---|---|---|---|---|---|---|---|
| | Temp, ˚F | Time, hrs | -65 ˚F | RT | 200 ˚F | 225 ˚F | 275 ˚F |
| RX818 | -- | -- | | L, T, 45 | L, T | L, T | L, T |
| | 200 | 300 | | L | | | |
| | | 1,000 | | L | | | |
| | | 3,000 | | L | | | |
| | | 5,000 | | L, T | | | |
| | 225 | 300 | | L | | | |
| | | 1,000 | | L | | | |
| | | 3,000 | | L | | | |
| | | 5,000 | | L, T | | | |
| | 275 | 1,000 | | L | | | |
| ML377 | -- | -- | L, T, 45 | L, T, 45 | L, T | L, T, 45 | L, T, 45 |
| | 200 | 300 | | L, T | | | |
| | | 1,000 | | L, T | | | |
| | | 3,000 | | L | L | | |
| | | 5,000 | | L, T | | | |
| | | 10,000 | L, T | L, T | L, T | | |
| | | 15,000 | L, T, 45 | L, T, 45 | L, T, 45 | | |
| | 225 | 300 | | L, T | | | |
| | | 1,000 | | L, T | | | |
| | | 3,000 | | L | L | | |
| | | 5,000 | | L, T | | | |
| | | 10,000 | L, T | L, T | | L, T | |
| | | 15,000 | L, T, 45 | L, T, 45 | | L, T, 45 | |
| | | 30,000 | | L, T | | L, T | |
| | 275 | 1,000 | | L | | | |
| | | 3,000 | | L | | | L |
| | | 10,000 | L, T | L, T | | | L, T |
| | | 15,000 | L, T, 45 | L, T, 45 | | | L, T, 45 |
| CM001 | -- | -- | L, T | L, T | L, T | L, T | |
| | 200 | 3,300 | | L, T | | | |
| | | 10,000 | L, T | L, T | L, T | | |
| | 225 | 3,300 | | L, T | | | |
| | | 10,000 | L, T | L, T | | L, T | |
| 1143 | -- | -- | L, T | L, T | L, T | L, T | |
| | 200 | 3,300 | | L, T | | | |
| | | 10,000 | L, T | L, T | L, T | | |
| | 225 | 3,300 | | L, T | | | |
| | | 10,000 | L, T | L, T | | L, T | |

## RESULTS

Results of the tensile tests for the candidate materials C415, C416, RX818 and ML377 and the baseline materials CM001 and 1143 are presented in Figures 7-19 and in Appendixes A, B and C. Individual test results as well as average values for each material and condition are tabulated in Appendix A. Plots of results for each material tested in the as-received condition are presented in Appendix B and plots of the results of testing after thermal exposure are presented in Appendix C. Selected results are presented in Figures 7-19 to illustrate overall material comparisons and highlight trends with temperature and thermal exposure. All graphs are based on the average values of duplicate tests.

### Room Temperature Properties of Material in the As-Received Condition

Figure 7 presents room temperature tensile properties for each alloy in the as-received condition. Results are presented for longitudinal, transverse and 45˚ orientations for the four candidate alloys and longitudinal and transverse orientations only for the baseline alloys. Test results presented include ultimate tensile strength, yield strength and total elongation at failure. The yield and tensile strengths of the candidate alloys were more than 20% higher than those of the CM001 and 1143 baseline alloys. The yield and tensile strengths of the Al-Li alloys were higher than for the non-Li containing alloys, with RX818 exhibiting the highest strength. Average strength levels of RX818 were about 8% higher than those of ML377 and nearly 13% higher than those of C415 and C416. Also noted for ML377 was the small difference between yield and ultimate strength in the longitudinal orientation.

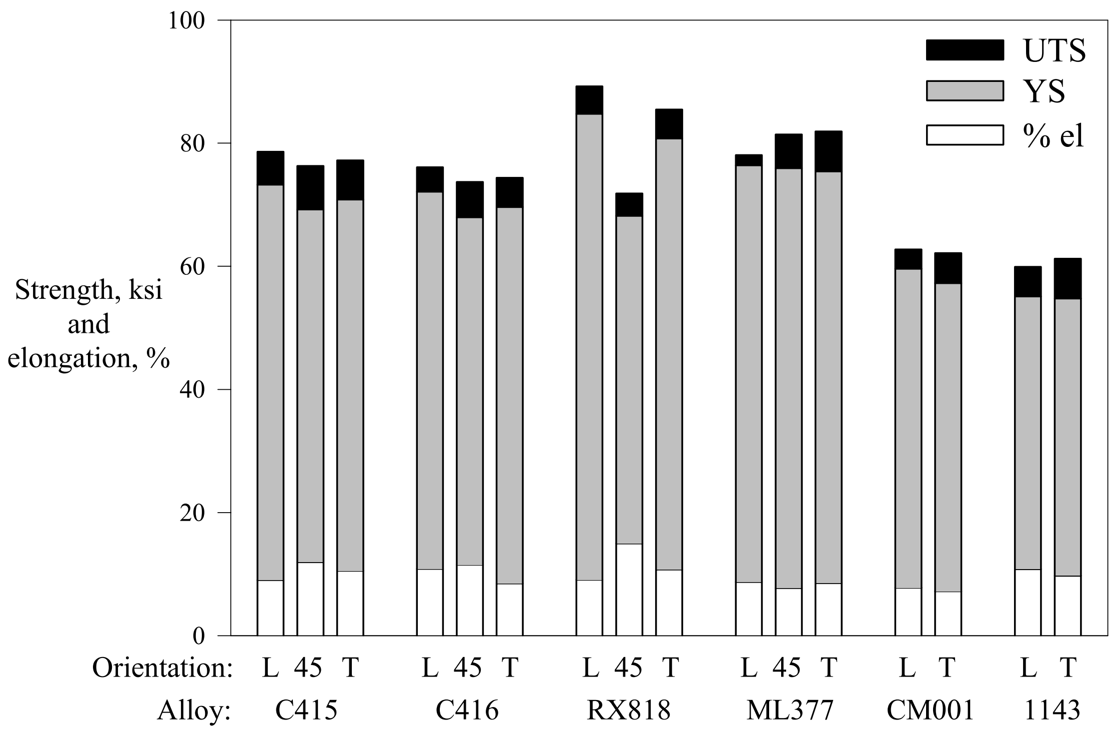



Figure 7. Tensile properties at room temperature for alloys C415, C416, RX818, ML377, CM001 and 1143.

RX818 exhibited more significant anisotropy in both strength and elongation than the other alloys tested. The variation in yield strength for RX818 was approximately 20% between the 45˚ and longitudinal orientations whereas strengths in the L, T and 45˚ orientations were within 5% for all of the other alloys tested. The variation in elongation for RX818 was approximately 65% between the 45˚ and longitudinal orientations but no more than 35% for any of the other alloys tested. Alloys CM001 and 1143 were not tested in the 45˚ orientation. The higher degree of anisotropy observed in RX818 is similar to that observed in heavily worked Al-Li alloys that exhibit thin lamellar microstructures [15, 16]. Alloys C415, C416 and RX818 exhibited the trend in anisotropy typical for aluminum alloys, with strengths highest in the longitudinal orientation and lowest in the 45˚ orientation. For ML377, however, the ultimate strength was lowest in the longitudinal orientation while yield strength was nearly constant for L, T and 45$^{o}$ orientations.

**Effect of Test Temperature on Properties of Material in the As-Received Condition**

In general, the effect of test temperature was similar for all of the materials evaluated, and is illustrated for the longitudinal yield strength and elongation at failure in Figures 8 and 9, respectively. Yield strength decreased and elongation increased with increasing test temperature over the range from room temperature to 275˚F. Both strength and elongation increased when the temperature was reduced from room temperature to -65˚F. As shown in Figure 8, the yield strengths of the candidate alloys remained higher than the baseline materials, with RX818 maintaining the highest strength level. The effect of temperature on yield strength was

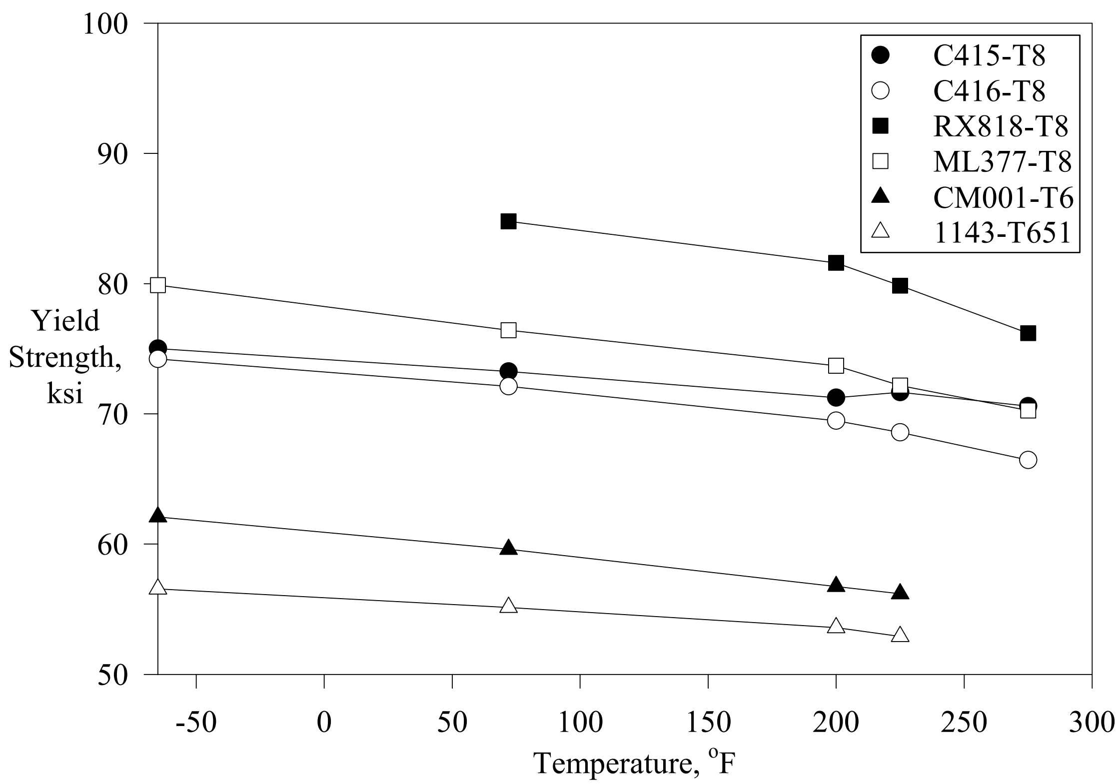



Figure 8. Variation in longitudinal yield strength with test temperature for material in the as-received condition.

somewhat less significant for alloy C415 than the other alloys tested. Yield strength varied by less than 5% for C415 over the entire temperature range compared with variations of 8-10% for the other candidate alloys and the baseline alloys.

As shown in Figure 9, trends in elongation values from room to elevated temperatures were less systematic than those observed for yield strength. Alloys C415 and C416 exhibited an increase in elongation at 200˚F, but elongation values remained relatively constant with further increases in temperature. Alloys RX818 and ML377 exhibited continually increasing values up to 275˚F. The baseline alloys CM001 and 1143 exhibited fairly constant values to 200˚F and an increase in elongation at 225˚F.

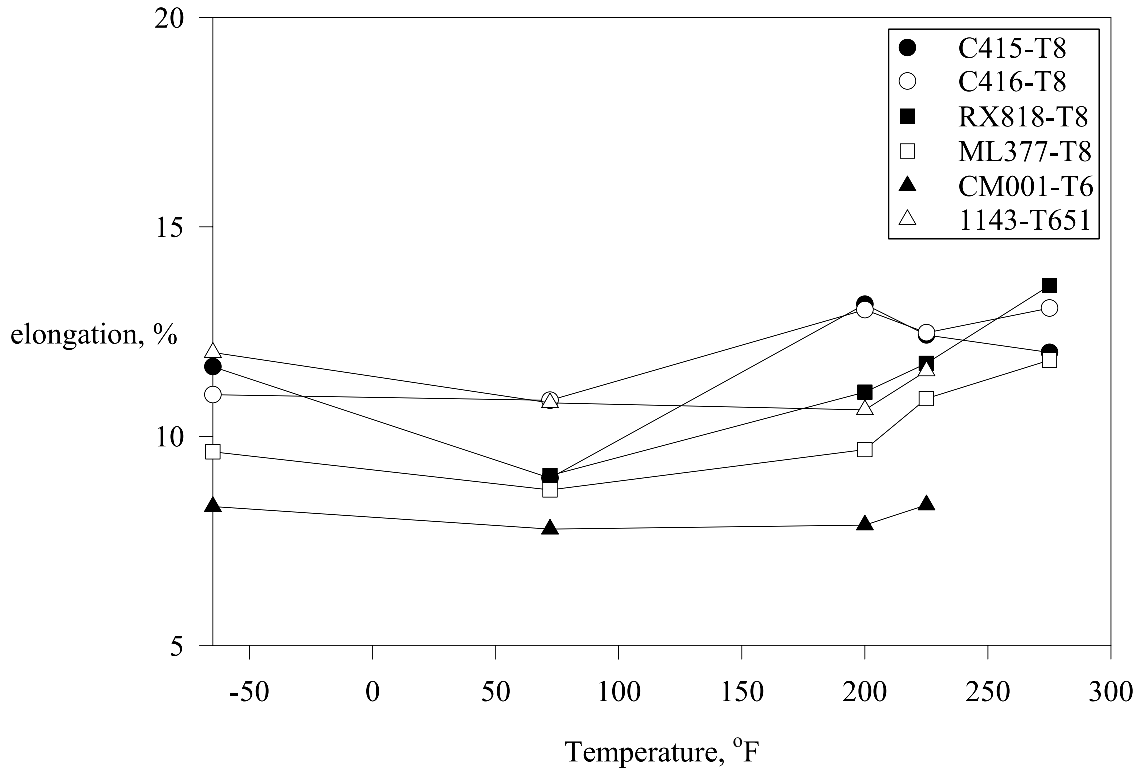



Figure 9. Variation in longitudinal elongation with test temperature for material in the as-received condition.

An additional thermal effect observed for all of the candidate alloys was a decrease in the difference between the ultimate and yield strength with increasing temperature. This effect, illustrated for C416 in Figure 10, was observed for all of the candidate alloys and was most pronounced for the longitudinal orientation. In ML377, the ultimate and yield strengths converged completely for the longitudinal orientation but only slightly for the transverse orientation. The convergence occurred at a lower temperature for ML377 than for the other candidate alloys (Appendix B, Figures B1-B4). For both CM001 and 1143, convergence of the ultimate and yield strengths was very slight (Appendix B, Figures B5 and B6). The convergence of yield and ultimate strengths was related to variations in overall stress-strain behavior with test temperature. In general, the stress-strain curves reflected the decreases in strength and increases

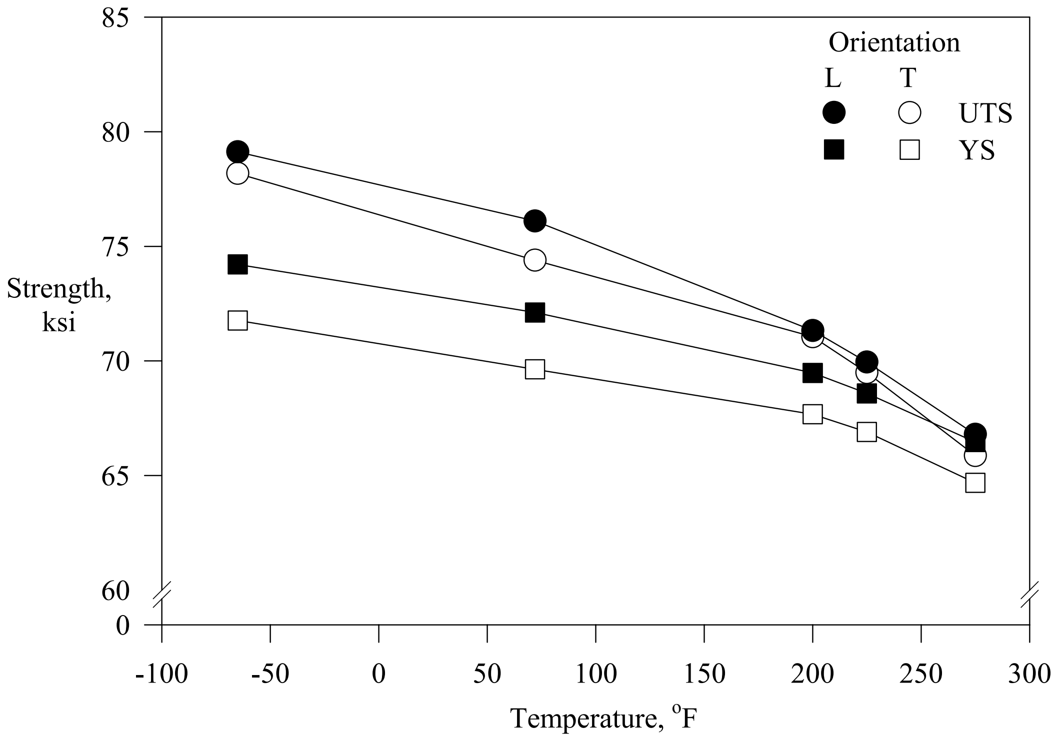



Figure 10. Variation in tensile properties with test temperature for C416-T8.

in elongation that occurred with increased test temperature. For the candidate alloys, however, the curves also reflected that the regions of uniform elongation and the extent of strain hardening decreased at higher temperatures. Variations in the shape of the stress-strain curves with test temperature were similar for the candidate alloys and are illustrated for the longitudinal orientation for C416 in Figure 11. As the test temperature was increased the ultimate strength (arrows) and onset of localized deformation occurred progressively closer to the offset yield strength, reflecting progressive reduction in strain hardening capability. There was no evidence of work hardening in the stress-strain curve for C416 at 275˚F. The temperature associated with loss of work hardening capability varied between the alloys tested (Appendix B, Figures B11-16). For alloys CM001 and 1143, the stress-strain curves exhibited fairly constant levels of strain hardening at all test temperatures.

**Effect of Thermal Exposure**

The effect of thermal exposure on tensile properties was examined for all of the candidate and baseline alloys. The candidate alloys were exposed at temperatures of 200˚F, 225˚F and 275˚F, for times of up to 30,000 hours. RX818 was dropped from the study after 5,000 hours due to poor fracture toughness properties. The baseline alloys were only exposed at temperatures of 200˚F and 225˚F for times of 1,000 and 10,000 hours due to material availability. Properties were evaluated at room temperature for each alloy and exposure condition and were also evaluated at elevated and cryogenic temperatures after selected thermal exposures.

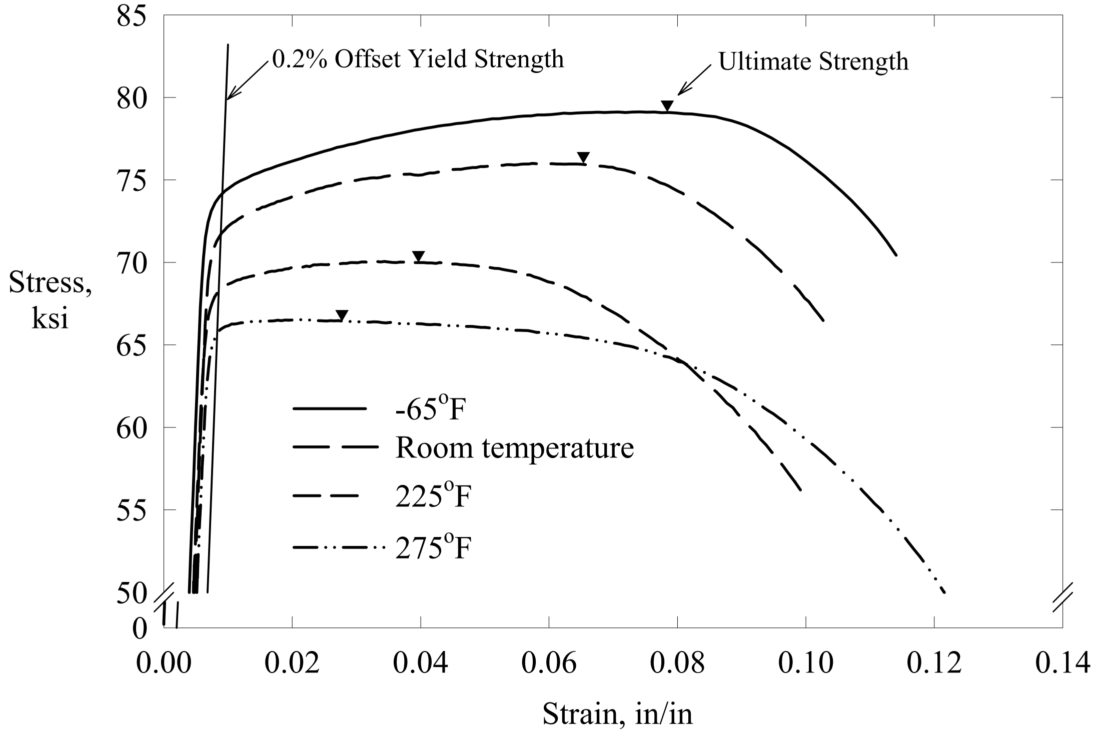



Figure 11. Longitudinal stress-strain curves for C416-T8 tested at -65˚F, room temperature, 225˚F and 275˚F.

**Room Temperature Properties after Thermal Exposure**

The trends in room temperature tensile properties after thermal exposure were similar for both longitudinal and transverse orientations. The effect of thermal exposure at 200˚F and 225˚F on yield and tensile strengths was negligible but was more pronounced at 275˚F. Notable variations in elongation were measured at all exposure temperatures. Selected results illustrating the effect of thermal exposure at 225˚F and 275˚F are shown in Figures 12-17. Complete results for each alloy and exposure condition are provided in Appendix C.

For the candidate and baseline alloys, longitudinal yield strengths measured at room temperature after exposure for 10,000 hours at 225˚F were equal to or slightly higher than those for the as-received condition [Figure 12]. Figure 12 illustrates that after 10,000 hours exposure at 225˚F, the candidate alloys exhibited yield strength values at least 18% higher than the baseline alloys. The Al-Li alloy RX818 exhibited the highest strength level with yield strength 10-15 ksi greater than C415, C416 and ML377. The results shown in Figure 12 also illustrate that while the yield strengths of C415, C416 and ML377 were relatively stable from 1,000 to 30,000 hours exposure at 225˚F, variations occurred between 0 and 1,000 hours exposure. Similar results were observed for exposures at 200˚F (See Figures C1-C6) and suggest that microstructural evolution occurred in these alloys during the early portion of the exposures.

For exposures at 275˚F the yield strengths of the candidate alloys remained stable or increased slightly up to 1,000 hours then decreased with subsequent exposures [Figure 13]. After 15,000 hours exposure at 275˚F, the longitudinal yield strengths of C415, C416 and ML377 measured at room temperature were lower than those for the as-received condition by approximately 26%, 21% and 9%, respectively.

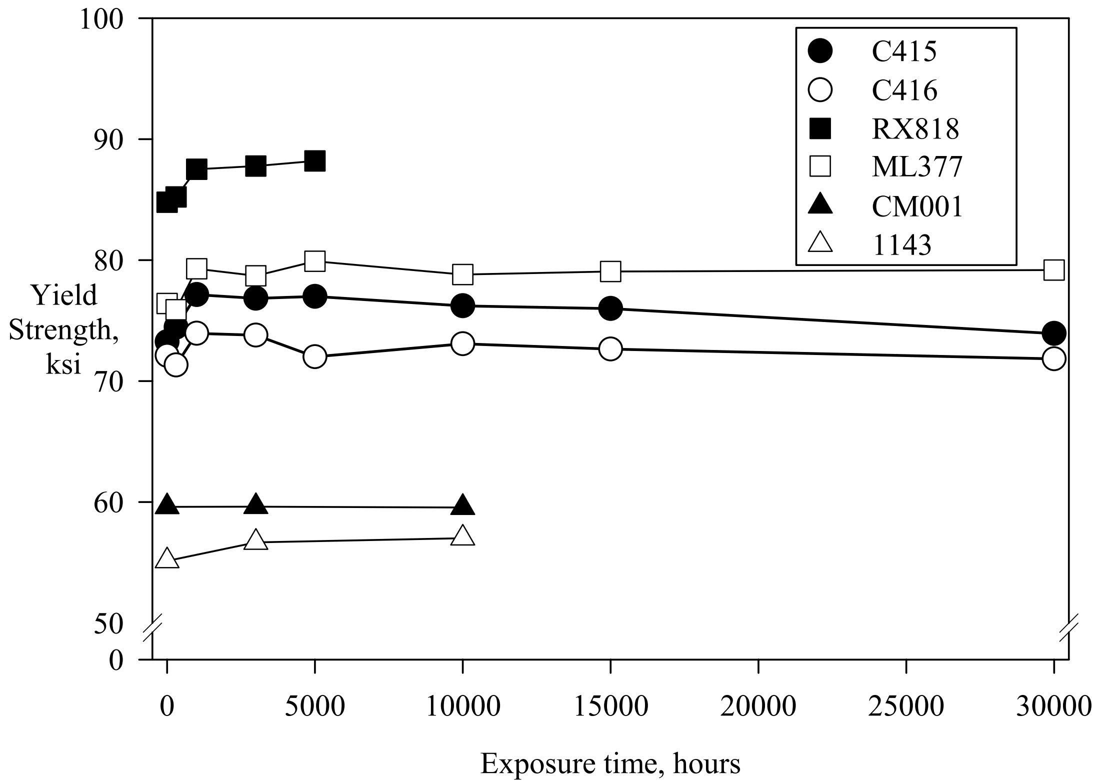


Figure 12. Variation in room temperature longitudinal yield strength with exposure at 225˚F.

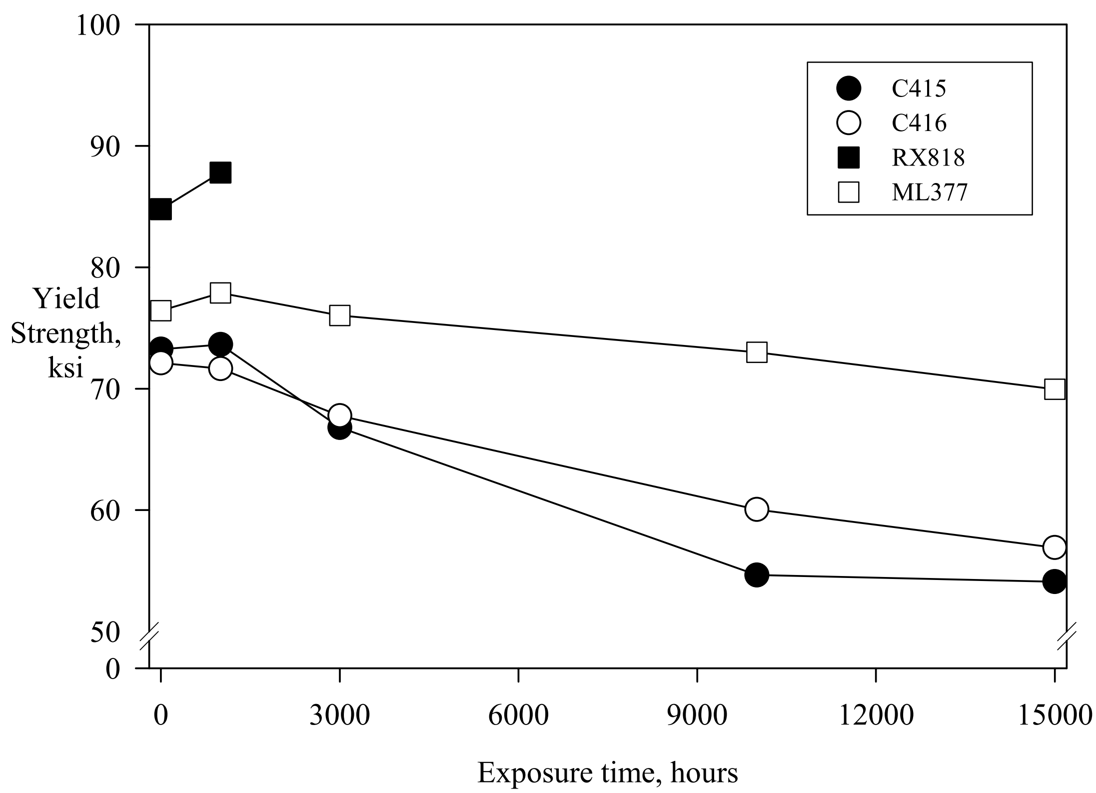


Figure 13. Variation in room temperature longitudinal yield strength with exposure at 275˚F.

The effect of thermal exposure on the elongation of the candidate alloys [Figures 14 and 15] was less systematic than was observed for yield strengths, with significant variations occurring as a result of progressive thermal exposure. Longitudinal elongation values measured at room temperature after 30,000 hours exposure at 225˚F [Figure 14] were lower than those for the as-received condition by about 15%, 25% and 9% for C415, C416 and ML377, respectively. Large variations in elongation were observed for exposure times up to 1,000 hours, particularly for alloys C415 and C416, further suggesting that microstructural evolution occurred during the early part of the exposures. Elongation values for CM001 and 1143 measured at room temperature after 10,000 hours exposure at 225˚F were within 1.5% of the as-received values. Stability with thermal exposure at anticipated service temperature was a major criteria in the selection of CM001 and 1143 for SST applications [2, 3]. After 15,000 hours exposure at 275˚F [Figure 15], elongation had increased by 15% for the longitudinal orientation for C415, but was reduced by about 15% for ML377.

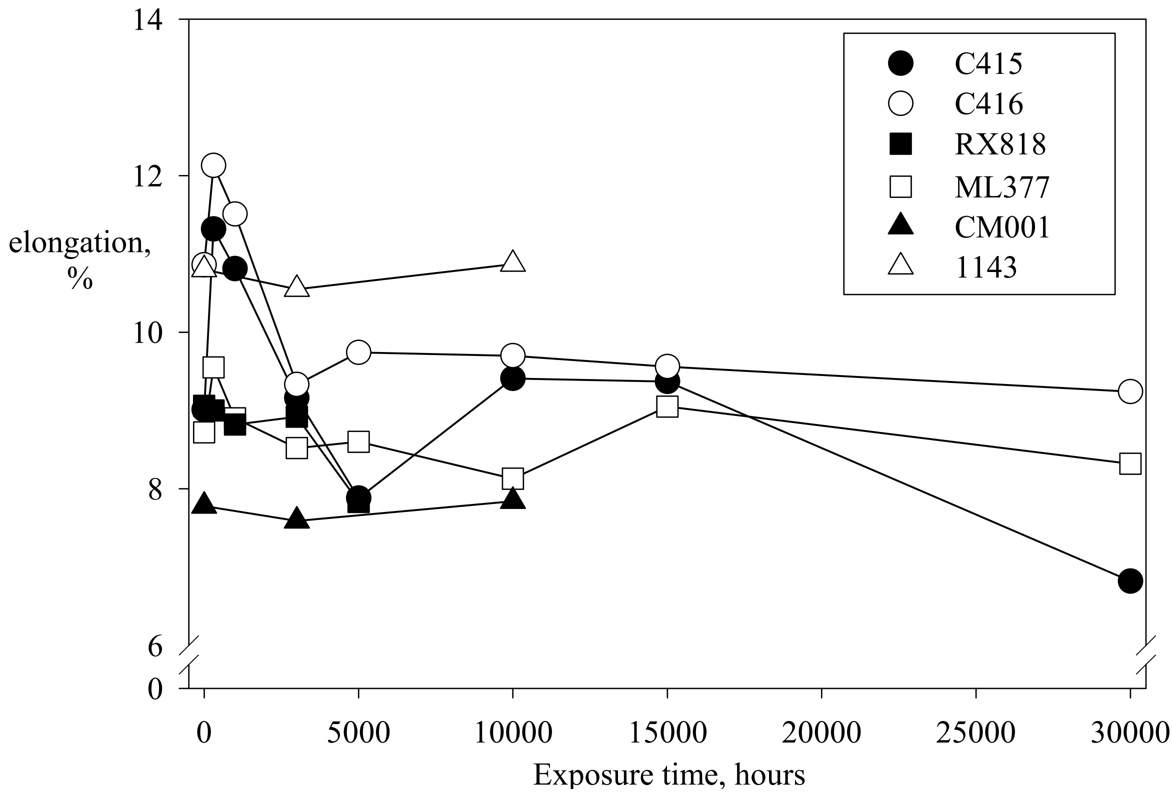


Figure 14. Variation in room temperature longitudinal elongation with exposure at 225˚F.

A comparison of the tensile properties of alloys C415, C416 and ML377 after 30,000 hours at 225˚F and 15,000 hours at 275˚F is shown in Figure 16. The strength levels of ML377 were approximately 10% and 20% higher than for C415 and C416 after 30,000 hours at 225˚F and 15,000 hours at 275˚F, respectively. For alloys C415 and C416, the difference between yield and ultimate tensile strength values was much greater after 15,000 hours exposure at 275˚F than was observed for the unexposed condition [Figure 7] but was not significantly different after 30,000 hours exposure at 225˚F. This effect was observed for ML377 in the longitudinal orientation but the increase in separation of values was much less significant. The increased separation of yield and ultimate strengths was related to recovery of strain hardening after thermal exposure. Stress-strain curves for the unexposed condition and after thermal exposure, shown for C416 in Figure 17, illustrate that while the strain range for uniform elongation was not significantly different, the extent of strain hardening from the offset yield strength to the ultimate strength (arrows) was higher after 15,000 hours exposure at 275˚F.

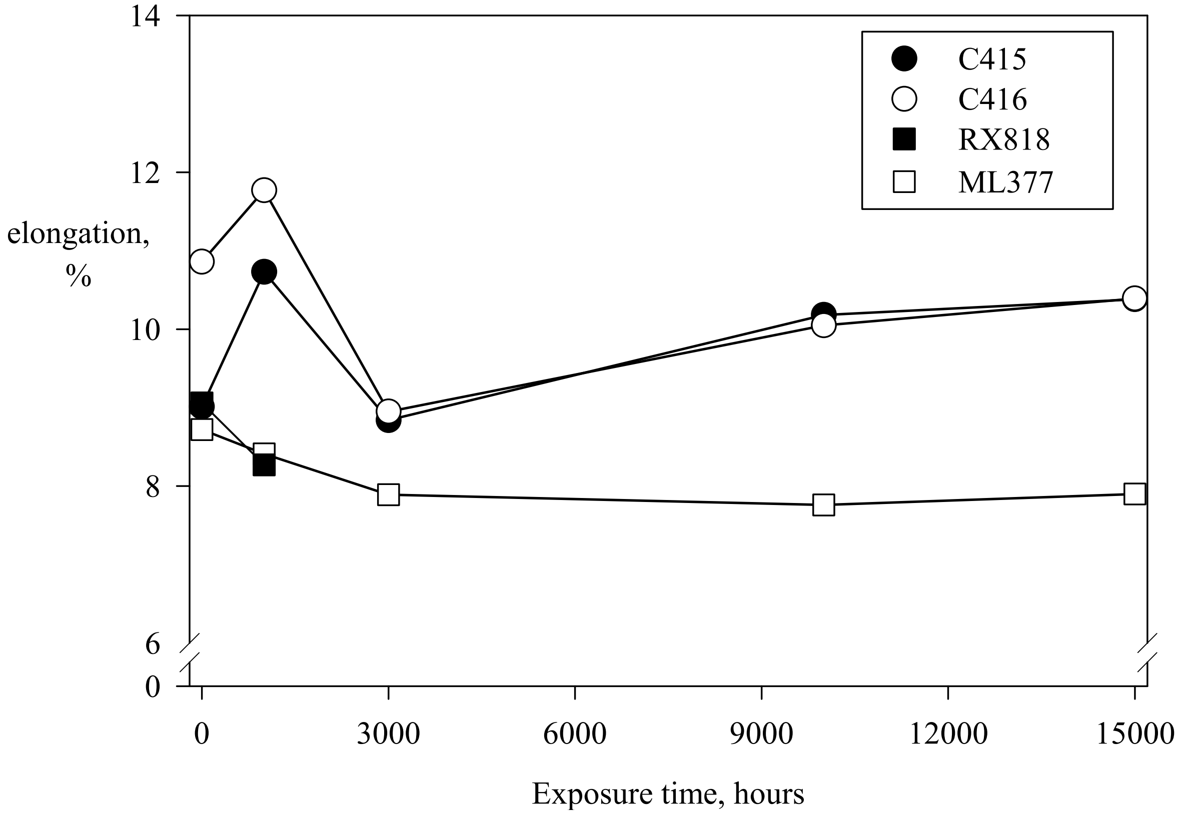



Figure 15. Variation in room temperature longitudinal elongation with exposure at 275˚F.

Microstructural analysis of the candidate alloys was conducted to explain the variations in yield strength and elongation noted during thermal exposure. Analysis of alloys C415 and C416 after 1,000 hours exposure at 200˚F determined that additional precipitation of the Ω phase had occurred, and was attributed to the availability of excess solute present in the T8 condition [17]. Precipitate coarsening occurred during further exposure at 200˚F to 10,000 hours. Alloys RX818 and ML377 exhibited coarsening of existing $T_1$ precipitates after 1,000 hours exposure at 200˚F, which continued with further exposure at 200˚F to 10,000 hours [18]. Microstructural analysis of the candidate alloys after exposure at 275˚F indicated similar microstructural changes after 1,000 hours to those noted for exposures at 200˚F. However, with further exposure to 10,000 hours at 275˚F, C415 and C416 exhibited more significant precipitate coarsening with some dissolution of the Ω phase. Alloys RX818 and ML377 exhibited both coarsening of existing $T_1$ precipitates and significant additional $T_1$ precipitation after 10,000 hours at 275˚F. The additional precipitation and coarsening of strengthening phases noted in the candidate alloys were consistent with the observed variations in yield strength and elongation. The extent of precipitate coarsening that occurred after 10,000 hours exposure at 275˚F, and the resulting reduction in yield strength, indicated that 200˚F-225˚F is the upper service temperature range for the candidate alloys.

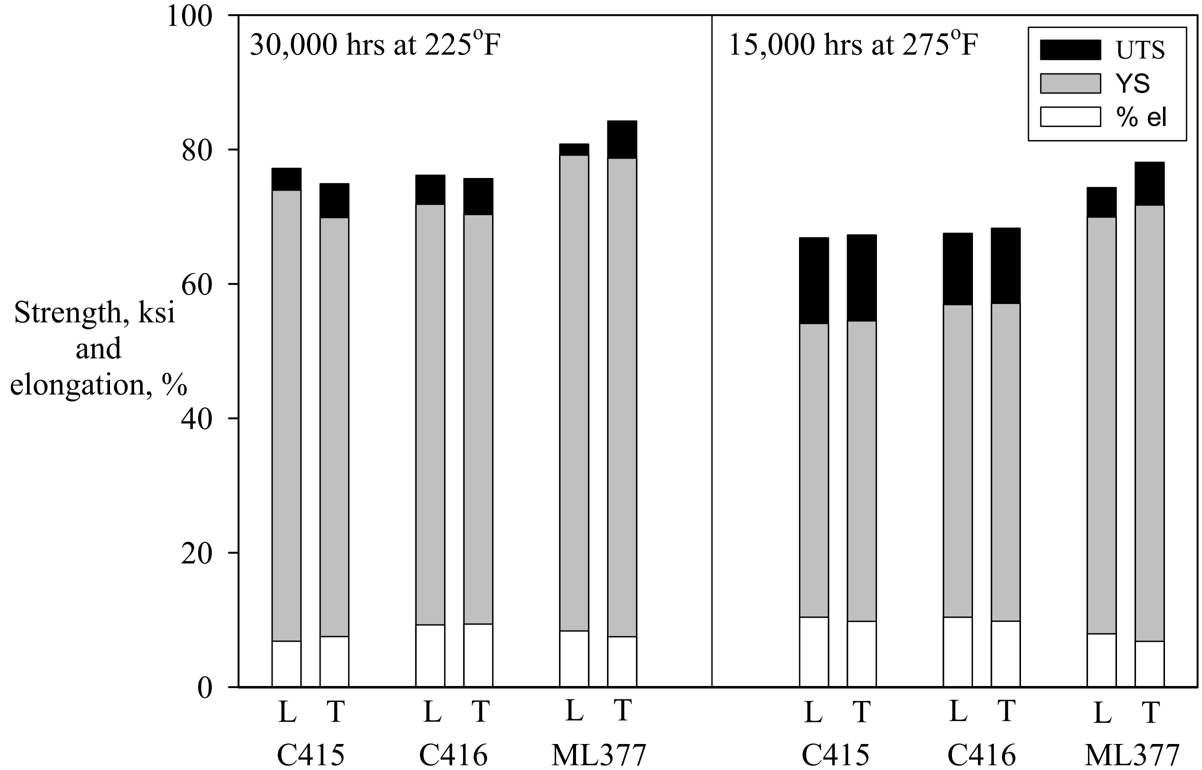



Figure 16. Room temperature tensile properties of C415, C416 and ML377 after 30,000 hours exposure at 225˚F and after 15,000 hours exposure at 275˚F.

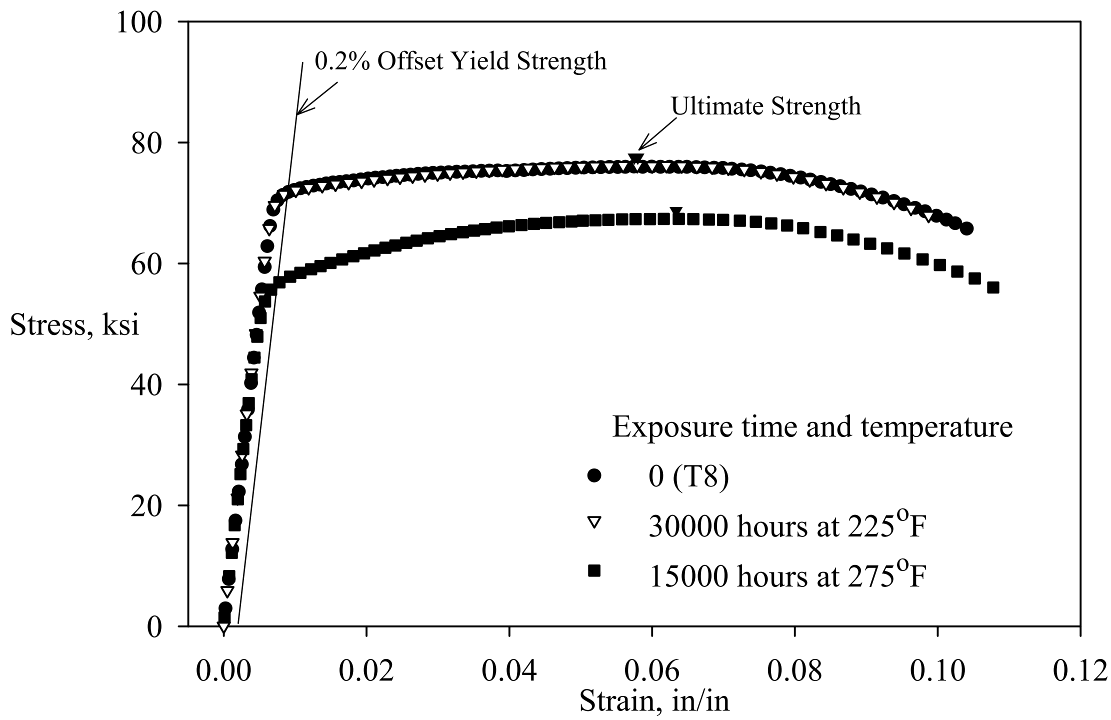



Figure 17. Room temperature longitudinal stress-strain curves for C416 in the T8 condition, after 30,000 hours exposure at 225˚F, and after 15,000 hours exposure at 275˚F.

## Elevated Temperature Properties after Thermal Exposure

Tensile properties were evaluated at elevated temperature after selected thermal exposure times with specimens tested at the temperature to which they were exposed. In general, the trends in elevated temperature tensile properties after thermal exposure were similar to those observed at room temperature after thermal exposure. At exposure temperatures of 200˚F and 225˚F, elevated temperature tensile properties for all of the alloys were fairly stable with strength levels equal to or slightly greater than levels from that of as-received material. Yield and ultimate strengths of the candidate alloys measured at 225˚F after 10,000 hours exposure at 225˚F were more than 20% greater than for CM001 and 1143, as shown in Figure 18. The candidate alloys, however, exhibited reductions in elevated temperature yield and ultimate strengths after 15,000 hours exposure at 275˚F of up to 20% for C415 and C416 and about 10% for ML377.

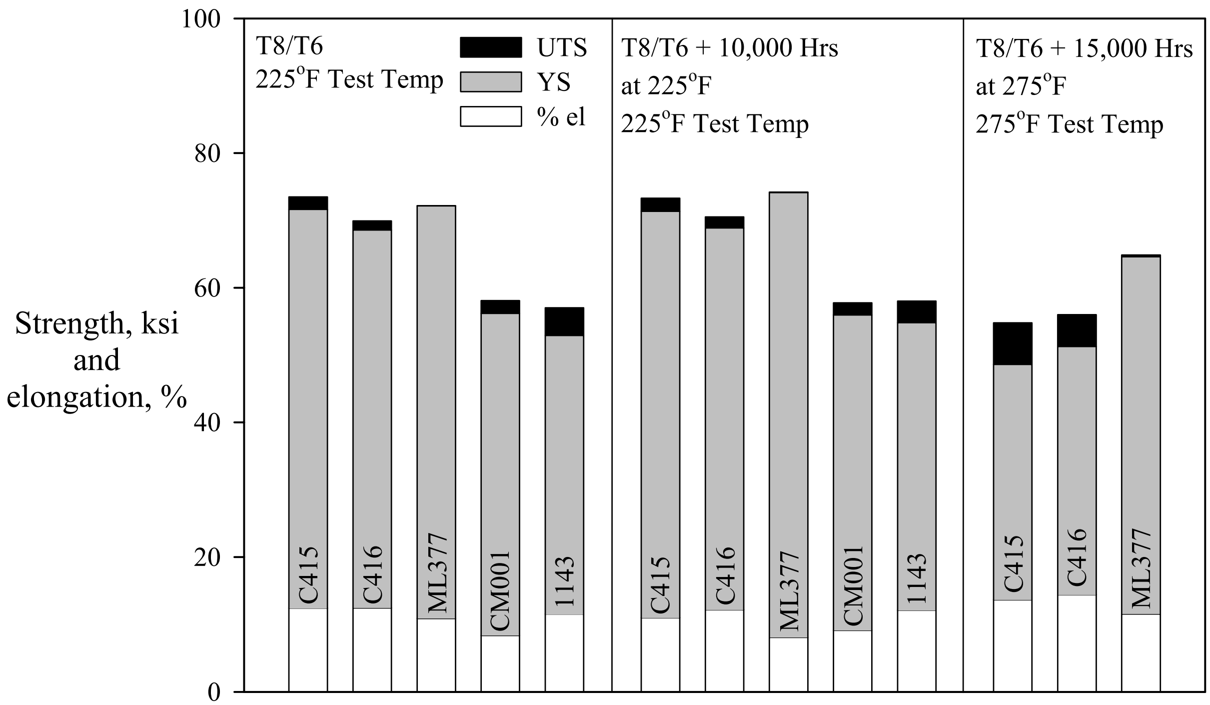



Figure 18. Effect of 10,000 hours exposure at 225˚F and 15,000 hours exposure at 275˚F on longitudinal tensile properties of candidate and baseline alloys measured at elevated temperature.

## Cryogenic Temperature Properties after Thermal Exposure

Tensile properties were also evaluated at -65˚F after selected thermal exposures. In general, the trends with thermal exposure were the same for testing at room temperature, elevated temperature, and at the cryogenic temperature of -65˚F. Changes in cryogenic strength with thermal exposure were similar in magnitude for each material and exposure condition to those observed at room and elevated temperatures. For material exposed at 200˚F and 225˚F the ultimate and yield strengths measured at -65˚F varied by no more than 5% for any of the alloys over values for unexposed material. The rankings based on yield strength were the same both before and after thermal exposure. As shown in Figure 19, both yield and ultimate strength levels of C415, C416 and ML377 were more than 20% greater than those of CM001 and 1143. For material exposed at 275˚F, yield strengths measured at -65˚F decreased more than 20% for C415 and C416 and up to 8% for ML377, and ultimate strength decreased by about 10% for C415 and C416 and less than 5% for ML377 when compared with cryogenic testing of as-received material.

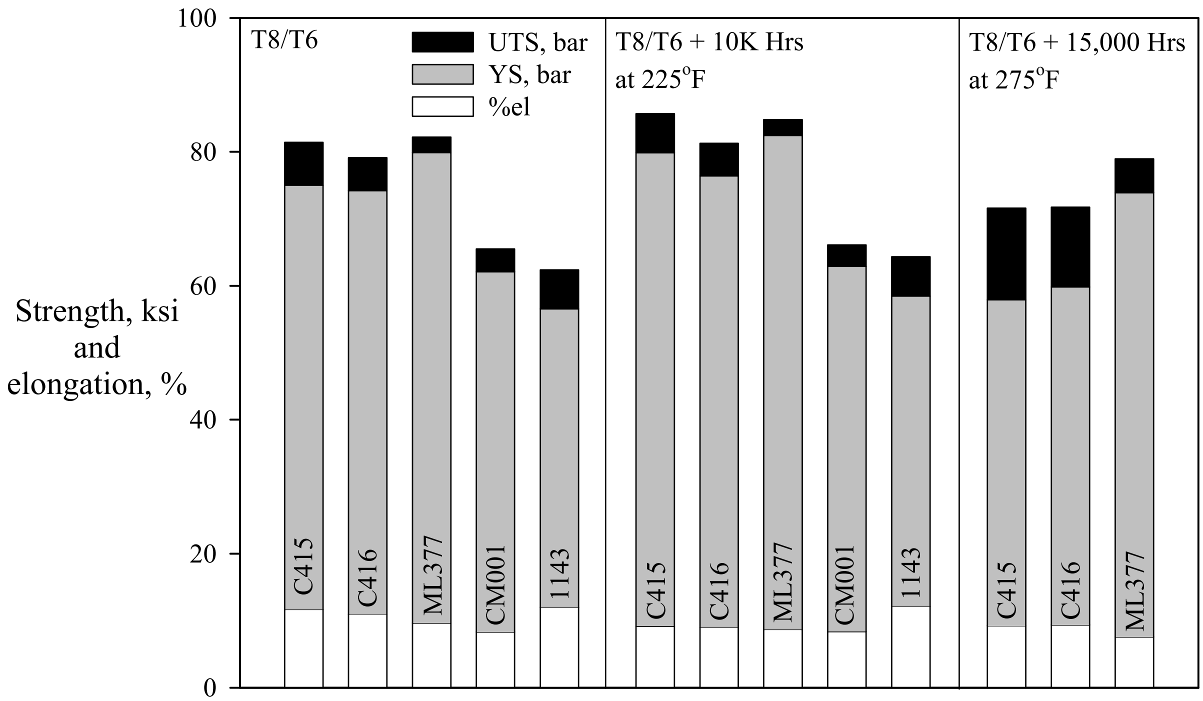



Figure 19. Effect of 10,000 hours exposure at 225˚F and 15,000 hours at 275˚F on longitudinal tensile properties of candidate and baseline alloys measured at -65˚F.

## CONCLUDING REMARKS

Tensile properties were evaluated for four aluminum alloys that are candidates for airframe structural applications at elevated temperature. The alloys included the Al-Cu-Mg-Ag alloys C415 and C416 and the Al-Cu-Li-Mg-Ag alloys RX818 and ML377. Measured properties were compared with the Concorde material CM001 and the Russian alloy 1143. Tensile properties were evaluated for material in the as-received (T8 or T6) condition at -65˚F, room temperature, 200˚F, 225˚F and 275˚F and after thermal exposure at 200˚F, 225˚F and 275˚F for times up to 30,000 hours.

All four candidate alloys showed significant tensile property improvements over CM001 and 1143. Room temperature yield strengths of the candidate alloys were at least 20% greater than for CM001 and 1143, for both the as-received and thermally-exposed conditions. The strength levels of alloy RX818 were the highest of all materials investigated, and were 5-10% higher than for ML377, C415 and C416 for the as-received condition and after 5,000 hours thermal exposure. RX818 was removed from this study after 5,000 hours exposure due to poor fracture toughness performance observed in a parallel study.

Tensile strengths of the candidate and baseline alloys varied by less than 10% over the temperature range from -65˚F to 225˚F. For the candidate alloys, the stress-strain behavior at elevated temperatures exhibited reduced levels of strain hardening and uniform elongation, which resulted in convergence of yield and ultimate tensile strengths.

Tensile strengths of the candidate and baseline alloys were stable within 5% after 10,000 hours exposure at 200˚F and 225˚F, and remained stable for alloys ML377, C415, and C416 with continued exposure for up to 30,000 hours. This is the temperature range that the fuselage and wing would experience on a high-speed aircraft operating in the Mach 2 flight regime. After exposure at 275˚F, however, reductions in tensile strength were from 5% to 25% for the four candidate alloys when compared with results for as-received material. The change in microstructure due to precipitate coarsening that occurred after 10,000 hours exposure at 275˚F, and the resulting reduction in yield strength, indicated that 200˚F-225˚F is the upper service temperature range for the candidate alloys. Trends with thermal exposure were similar for properties measured at cryogenic, room, and elevated temperatures after thermal exposure.

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Appendix A. Tabulated tensile test results for alloys C415, C416, RX818, ML377, CM001 and 1143

Table A1. Tensile Results for C415.

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 5L-1 | L | - | - | 72 | 79.2 | 73.9 | 10.0 | 10.3 |
| 5L-2 | L | - | - | 72 | 78.0 | 72.6 | 8.0 | 10.3 |
| Avg. | | | | | 78.6 | 73.3 | 9.0 | 10.3 |
| 5T-11 | T | - | - | 72 | 77.1 | 70.9 | 8.8 | 10.3 |
| 5T-12 | T | - | - | 72 | 77.4 | 70.8 | 12.2 | 10.3 |
| Avg. | | | | | 77.3 | 70.9 | 10.5 | 10.3 |
| 5A-4 | 45 | - | - | 72 | 76.4 | 69.3 | 12.6 | 10.2 |
| 5A-5 | 45 | - | - | 72 | 76.2 | 69.2 | 11.2 | 10.2 |
| Avg. | | | | | 76.3 | 69.3 | 11.9 | 10.2 |
| 5L-3 | L | - | - | 200 | 74.3 | 71.2 | 13.5 | 10.3 |
| 5L-4 | L | - | - | 200 | 74.2 | 71.3 | 12.8 | 10.3 |
| Avg. | | | | | 74.3 | 71.3 | 13.2 | 10.3 |
| 5T-13 | T | - | - | 200 | 73.1 | 69.0 | 12.7 | 10.3 |
| 5T-14 | T | - | - | 200 | 73.2 | 68.9 | 13.9 | 10.3 |
| Avg. | | | | | 73.2 | 69.0 | 13.3 | 10.3 |
| 5L-5 | L | - | - | 225 | 73.4 | 71.3 | 11.7 | 10.3 |
| 5L-6 | L | - | - | 225 | 73.7 | 72.1 | 13.1 | 10.3 |
| Avg. | | | | | 73.6 | 71.7 | 12.4 | 10.3 |
| 5T-15 | T | - | - | 225 | 71.7 | 68.3 | 12.2 | 10.3 |
| 5T-16 | T | - | - | 225 | 71.7 | 67.9 | 14.9 | 10.3 |
| Avg. | | | | | 71.7 | 68.1 | 13.6 | 10.3 |
| 5A-1 | 45 | | | 225 | 70.7 | 66.3 | >15 | 9.7 |
| 5L-7 | L | - | - | 275 | 70.8 | | >15 | |
| 5L-8 | L | - | - | 275 | 70.8 | 70.6 | 9.0 | 10.1 |
| Avg. | | | | | 70.8 | 70.6 | >12.0 | 10.1 |
| 5T-18 | T | - | - | 275 | 68.3 | 66.3 | 15.0 | 10.2 |
| 5T-20 | T | - | - | 275 | 68.1 | 66.2 | 14.8 | 10.1 |
| Avg. | | | | | 68.2 | 66.3 | 14.9 | 10.2 |
| 5A-2 | 45 | - | - | 275 | 67.2 | 64.5 | 18.2 | 9.9 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 5L-9 | L | - | - | -65 | 81.5 | 74.9 | 12.1 | 10.8 |
| 5L-10 | L | - | - | -65 | 81.4 | 75.2 | 11.2 | 10.7 |
| Avg. | | | | | 81.5 | 75.1 | 11.7 | 10.8 |
| 5T-9 | T | - | - | -65 | 79.4 | 71.5 | 12.6 | 10.6 |
| 5T-10 | T | - | - | -65 | 79.1 | 71.4 | 11.0 | 10.8 |
| Avg. | | | | | 79.3 | 71.5 | 11.8 | 10.7 |
| 5A-3 | 45 | - | - | -65 | 78.6 | 70.6 | 13.2 | 10.3 |
| 5L-14 | L | 301 | 200 | 72 | 78.4 | 73.7 | 11.1 | 10.3 |
| 5L-15 | L | 301 | 200 | 72 | 78.5 | 73.5 | 10.7 | 10.2 |
| Avg. | | | | | 78.5 | 73.6 | 10.9 | 10.3 |
| 5T-1 | T | 301 | 200 | 72 | 76.5 | 69.7 | 12.3 | 10.3 |
| 5T-2 | T | 301 | 200 | 72 | 76.6 | 70.3 | 10.3 | 10.3 |
| Avg. | | | | | 76.6 | 70.0 | 11.3 | 10.3 |
| 5L-18 | L | 301 | 225 | 72 | 79.5 | 74.7 | 10.1 | 10.3 |
| 5L-19 | L | 301 | 225 | 72 | 79.2 | 74.2 | 12.6 | 10.2 |
| Avg. | | | | | 79.4 | 74.5 | 11.4 | 10.3 |
| 5T-5 | T | 301 | 225 | 72 | 77.4 | 71.2 | 10.9 | 10.1 |
| 5T-6 | T | 301 | 225 | 72 | 77.4 | 71.4 | 11.4 | 10.3 |
| Avg. | | | | | 77.4 | 71.3 | 11.2 | 10.2 |
| 5L-16 | L | 1006 | 200 | 72 | 81.3 | 76.1 | 12.9 | 10.4 |
| 5L-17 | L | 1006 | 200 | 72 | 81.0 | 76.0 | 11.3 | 10.5 |
| Avg. | | | | | 81.2 | 76.1 | 12.1 | 10.5 |
| 5T-3 | T | 1006 | 200 | 72 | 79.3 | 73.1 | 11.0 | 10.5 |
| 5T-4 | T | 1006 | 200 | 72 | 78.8 | 72.8 | 10.6 | 10.4 |
| Avg. | | | | | 79.1 | 73.0 | 10.8 | 10.5 |
| 5L-20 | L | 1006 | 225 | 72 | 82.0 | 77.2 | 11.0 | 10.5 |
| 5L-21 | L | 1006 | 225 | 72 | 81.9 | 77.1 | 10.6 | 10.5 |
| Avg. | | | | | 82.0 | 77.2 | 10.8 | 10.5 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 5T-7 | T | 1006 | 225 | 72 | 79.8 | 73.9 | 11.5 | 10.4 |
| 5T-8 | T | 1006 | 225 | 72 | 79.4 | 73.6 | 10.5 | 10.4 |
| Avg. | | | | | 79.6 | 73.8 | 11.0 | 10.4 |
| 5L-22 | L | 1006 | 275 | 72 | 78.5 | 72.7 | 11.1 | 10.5 |
| 5L-23 | L | 1006 | 275 | 72 | 79.2 | 74.5 | 10.3 | 10.5 |
| Avg. | | | | | 78.9 | 73.6 | 10.7 | 10.5 |
| 5L-30 | L | 3000 | 200 | 72 | 81.5 | 76.7 | 9.5 | 10.3 |
| 5L-31 | L | 3000 | 200 | 72 | 82.1 | 77.5 | 9.2 | 10.3 |
| Avg. | | | | | 81.8 | 77.1 | 9.4 | 10.3 |
| 5L-32 | L | 3000 | 200 | 200 | 77.4 | 74.5 | 11.4 | 10.4 |
| 5L-33 | L | 3000 | 200 | 200 | 77.2 | 74.5 | 10.3 | 10.3 |
| Avg. | | | | | 77.3 | 74.5 | 10.9 | 10.4 |
| 5L-34 | L | 3000 | 225 | 72 | 81.1 | 75.9 | 9.3 | 10.4 |
| 5L-35 | L | 3000 | 225 | 72 | 82.3 | 77.8 | 9.0 | 10.5 |
| Avg. | | | | | 81.7 | 76.9 | 9.2 | 10.5 |
| 5L-36 | L | 3000 | 225 | 225 | 75.5 | 72.6 | 11.5 | 10.3 |
| 5L-37 | L | 3000 | 225 | 225 | 74.9 | 72.7 | 10.7 | 10.3 |
| Avg. | | | | | 75.2 | 72.7 | 11.1 | 10.3 |
| 5L-38 | L | 3000 | 275 | 72 | 74.2 | 67.0 | 8.8 | 10.4 |
| 5L-39 | L | 3000 | 275 | 72 | 73.6 | 66.6 | 8.9 | 10.2 |
| Avg. | | | | | 73.9 | 66.8 | 8.9 | 10.3 |
| 5L-40 | L | 3000 | 275 | 275 | 62.6 | 59.8 | 12.0 | 10.2 |
| 5L-41 | L | 3000 | 275 | 275 | 62.9 | 60.2 | 12.4 | 10.5 |
| Avg. | | | | | 62.8 | 60.0 | 12.2 | 10.4 |
| 2211L1 | L | 5,000 | 200 | 72 | 75.6 | 82.6 | 9.79 | 9.12 |
| 2211L2 | L | 5,000 | 200 | 72 | 77.7 | 82.8 | 9.80 | 9.12 |
| Avg. | | | | | 76.7 | 82.7 | 9.80 | 9.12 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 2211T1 | T | 5,000 | 200 | 72 | 72.6 | 80.2 | 10.02 | 9.40 |
| 2211T2 | T | 5,000 | 200 | 72 | 72.8 | 80.4 | 9.79 | 9.12 |
| Avg. | | | | | 72.7 | 80.3 | 9.91 | 9.26 |
| 225L1 | L | 5,000 | 225 | 72 | 77.0 | 81.1 | 7.41 | 6.66 |
| 225L2 | L | 5,000 | 225 | 72 | 77.0 | 81.1 | 8.35 | 7.65 |
| Avg. | | | | | 77.0 | 81.1 | 7.88 | 7.16 |
| 225T1 | T | 5,000 | 225 | 72 | 73.8 | 80.1 | 10.53 | 9.86 |
| 225T2 | T | 5,000 | 225 | 72 | 73.8 | 80.1 | 10.78 | 10.13 |
| Avg. | | | | | 73.8 | 80.1 | 10.66 | 10.00 |
| 5L-50 | L | 10,000 | 200 | 72 | 81.6 | 76.9 | 9.9 | 10.4 |
| 5L-51 | L | 10,000 | 200 | 72 | 81.7 | 76.8 | 10.2 | 10.3 |
| Avg. | | | | | 81.7 | 76.9 | 10.1 | 10.4 |
| 5T-29 | T | 10,000 | 200 | 72 | 80.0 | 74.7 | 9.6 | 10.3 |
| 5T-30 | T | 10,000 | 200 | 72 | 80.2 | 74.6 | 9.9 | 10.4 |
| Avg. | | | | | 80.1 | 74.7 | 9.8 | 10.4 |
| 5L-52 | L | 10,000 | 200 | 200 | 76.6 | 73.8 | 11.0 | 10.2 |
| 5L-53 | L | 10,000 | 200 | 200 | 76.5 | 73.5 | 11.0 | 10.2 |
| Avg. | | | | | 76.6 | 73.7 | 11.0 | 10.2 |
| 5T-31 | T | 10,000 | 200 | 200 | 75.2 | 71.8 | 10.7 | 10.2 |
| 5T-32 | T | 10,000 | 200 | 200 | 75.3 | 71.6 | 11.2 | 9.9 |
| Avg. | | | | | 75.3 | 71.7 | 11.0 | 10.1 |
| 5L-54 | L | 10,000 | 200 | -65 | 85.8 | 80.4 | 9.2 | 10.8 |
| 5L-55 | L | 10,000 | 200 | -65 | 85.6 | 79.3 | 9.1 | 10.8 |
| Avg. | | | | | 85.7 | 79.9 | 9.2 | 10.8 |
| 5T-33 | T | 10,000 | 200 | -65 | 83.3 | 76.1 | 9.7 | 11.0 |
| 5T-34 | T | 10,000 | 200 | -65 | 83.5 | 77.0 | 9.0 | 10.9 |
| Avg. | | | | | 83.4 | 76.6 | 9.4 | 11.0 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 5L-42 | L | 10,000 | 225 | 72 | 80.8 | 76.4 | 9.4 | 10.4 |
| 5L-43 | L | 10,000 | 225 | 72 | 80.6 | 76.1 | 9.5 | 10.3 |
| Avg. | | | | | 80.7 | 76.3 | 9.5 | 10.4 |
| 5T-21 | T | 10,000 | 225 | 72 | 79.1 | 74.0 | 9.3 | 10.4 |
| 5T-22 | T | 10,000 | 225 | 72 | 78.8 | 73.8 | 9.4 | 10.4 |
| Avg. | | | | | 79.0 | 73.9 | 9.4 | 10.4 |
| 5L-44 | L | 10,000 | 225 | 225 | 73.3 | 71.2 | 10.8 | 9.9 |
| 5L-45 | L | 10,000 | 225 | 225 | 73.4 | 71.5 | 11.2 | 10.2 |
| Avg. | | | | | 73.4 | 71.4 | 11.0 | 10.1 |
| 5T-23 | T | 10,000 | 225 | 225 | 72.1 | 69.7 | 11.1 | 9.9 |
| 5T-24 | T | 10,000 | 225 | 225 | 72.2 | 69.7 | 11.0 | 10.0 |
| Avg. | | | | | 72.2 | 69.7 | 11.1 | 10.0 |
| 5L-46 | L | 10,000 | 225 | -65 | 84.2 | 78.9 | 8.4 | 10.9 |
| 5L-47 | L | 10,000 | 225 | -65 | 84.2 | 79.0 | 9.0 | 10.8 |
| Avg. | | | | | 84.2 | 79.0 | 8.7 | 10.9 |
| 5T-25 | T | 10,000 | 225 | -65 | 82.5 | 76.2 | 9.0 | 10.8 |
| 5T-26 | T | 10,000 | 225 | -65 | 82.6 | 76.7 | 8.9 | 11.0 |
| Avg. | | | | | 82.6 | 76.5 | 9.0 | 10.9 |
| 5L-58 | L | 10,000 | 275 | 72 | 66.1 | 54.7 | 10.0 | 10.6 |
| 5L-59 | L | 10,000 | 275 | 72 | 66.0 | 54.6 | 10.1 | 10.4 |
| Avg. | | | | | 66.0 | 54.7 | 10.1 | 10.5 |
| 5T-37 | T | 10,000 | 275 | 72 | 67.5 | 55.6 | 9.8 | 10.4 |
| 5T-38 | T | 10,000 | 275 | 72 | 67.5 | 55.6 | 9.8 | 10.4 |
| Avg. | | | | | 67.5 | 55.6 | 9.8 | 10.4 |
| 5L-60 | L | 10,000 | 275 | 275 | 53.9 | 48.2 | 14.2 | 10.1 |
| 5L-61 | L | 10,000 | 275 | 275 | 53.9 | 48.4 | 14.6 | 10.7 |
| Avg. | | | | | 53.9 | 48.3 | 14.4 | 10.4 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 5T-39 | T | 10,000 | 275 | 275 | 54.8 | 48.8 | 14.1 | 10.4 |
| 5T-40 | T | 10,000 | 275 | 275 | 54.7 | 48.9 | 16.3 | 10.6 |
| Avg. | | | | | 54.8 | 48.9 | 15.2 | 10.5 |
| 5L-62 | L | 10,000 | 275 | -65 | 70.1 | 58.0 | 9.6 | 10.9 |
| 5L-63 | L | 10,000 | 275 | -65 | 70.2 | 58.0 | 9.3 | 10.8 |
| Avg. | | | | | 70.2 | 58.0 | 9.5 | 10.9 |
| 5T-41 | T | 10,000 | 275 | -65 | 70.7 | 57.4 | 9.3 | 10.6 |
| 5T-42 | T | 10,000 | 275 | -65 | 70.5 | 57.9 | 8.9 | 11.0 |
| Avg. | | | | | 70.6 | 57.7 | 9.1 | 10.8 |
| 155L-1 | L | 15,000 | 200 | 72 | 82.72 | 78.32 | 9.65 | 10.53 |
| 155L-2 | L | 15,000 | 200 | 72 | 82.64 | 78.12 | 9.63 | 10.51 |
| Avg. | | | | | 82.68 | 78.22 | 9.64 | 10.52 |
| 155T-1 | T | 15,000 | 200 | 72 | 80.50 | 74.77 | 9.60 | 10.49 |
| 155T-2 | T | 15,000 | 200 | 72 | 80.27 | 74.71 | 9.71 | 10.32 |
| Avg. | | | | | 80.39 | 74.74 | 9.66 | 10.41 |
| 155X-1 | 45 | 15,000 | 200 | 72 | 79.63 | 73.73 | 11.35 | 10.29 |
| 155X-2 | 45 | 15,000 | 200 | 72 | 79.60 | 73.48 | 10.14 | 10.29 |
| Avg. | | | | | 79.62 | 73.61 | 10.75 | 10.29 |
| 155L-3 | L | 15,000 | 200 | 200 | 77.43 | 74.93 | 10.53 | 10.26 |
| 155L-4 | L | 15,000 | 200 | 200 | 77.27 | 74.68 | 10.69 | 10.15 |
| Avg. | | | | | 77.35 | 74.81 | 10.61 | 10.21 |
| 155T-3 | T | 15,000 | 200 | 200 | 75.51 | 72.43 | 11.17 | 10.24 |
| 155T-4 | T | 15,000 | 200 | 200 | 75.44 | 71.77 | 10.96 | 10.15 |
| Avg. | | | | | 75.48 | 72.10 | 11.07 | 10.20 |
| 155X-3 | 45 | 15,000 | 200 | 200 | 74.84 | 71.04 | 12.65 | 10.04 |
| 155X-4 | 45 | 15,000 | 200 | 200 | 74.71 | 70.81 | 11.83 | 10.10 |
| Avg. | | | | | 74.78 | 70.93 | 12.24 | 10.07 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 155L-5 | L | 15,000 | 200 | -65 | 86.42 | 81.67 | 8.72 | 10.71 |
| 155L-6 | L | 15,000 | 200 | -65 | 86.50 | 81.43 | 9.24 | 10.57 |
| Avg. | | | | | 86.46 | 81.55 | 8.98 | 10.64 |
| 155T-5 | T | 15,000 | 200 | -65 | 84.28 | 78.17 | 9.03 | 10.94 |
| 155T-6 | T | 15,000 | 200 | -65 | 84.29 | 78.03 | 9.51 | 10.74 |
| Avg. | | | | | 84.29 | 78.10 | 9.27 | 10.84 |
| 155X-5 | 45 | 15,000 | 200 | -65 | 83.20 | 76.16 | 10.65 | 10.53 |
| 155X-6 | 45 | 15,000 | 200 | -65 | 83.21 | 76.71 | 11.11 | 10.62 |
| Avg. | | | | | 83.21 | 76.44 | 10.88 | 10.58 |
| 155L-11 | L | 15,000 | 225 | 72 | 80.42 | 75.81 | 9.54 | 10.63 |
| 155L-12 | L | 15,000 | 225 | 72 | 80.80 | 76.17 | 9.19 | 10.58 |
| Avg. | | | | | 80.61 | 75.99 | 9.37 | 10.61 |
| 155T-11 | T | 15,000 | 225 | 72 | 79.31 | 73.50 | 9.39 | 10.58 |
| 155T-12 | T | 15,000 | 225 | 72 | 78.85 | 73.62 | 9.28 | 10.57 |
| Avg. | | | | | 79.08 | 73.56 | 9.34 | 10.58 |
| 155X-11 | 45 | 15,000 | 225 | 72 | 78.17 | 71.75 | 10.57 | 10.41 |
| 155X-12 | 45 | 15,000 | 225 | 72 | 78.17 | 71.55 | 10.16 | 10.46 |
| Avg. | | | | | 78.17 | 71.65 | 10.37 | 10.44 |
| 155L-13 | L | 15,000 | 225 | 225 | 72.91 | 71.13 | 10.67 | 10.10 |
| 155L-14 | L | 15,000 | 225 | 225 | 73.02 | 71.06 | 11.06 | 10.13 |
| Avg. | | | | | 72.97 | 71.10 | 10.87 | 10.12 |
| 155T-13 | T | 15,000 | 225 | 225 | 71.96 | 69.32 | 12.70 | 10.21 |
| 155T-14 | T | 15,000 | 225 | 225 | 71.68 | 68.93 | 12.44 | 9.58 |
| Avg. | | | | | 71.82 | 69.13 | 12.57 | 9.89 |
| 155X-13 | 45 | 15,000 | 225 | 225 | 71.09 | 68.38 | 12.12 | 10.13 |
| 155X-14 | 45 | 15,000 | 225 | 225 | 71.25 | 68.20 | 12.36 | 9.99 |
| Avg. | | | | | 71.17 | 68.29 | 12.24 | 10.06 |

Table A1. Tensile Results for C415. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 155L-15 | L | 15,000 | 225 | -65 | 85.22 | 79.94 | 8.69 | 10.70 |
| 155L-16 | L | 15,000 | 225 | -65 | 84.27 | 79.35 | 8.06 | 10.62 |
| Avg. | | | | | 84.75 | 79.65 | 8.38 | 10.66 |
| 155T-15 | T | 15,000 | 225 | -65 | 82.81 | 76.80 | 8.94 | 10.40 |
| 155T-16 | T | 15,000 | 225 | -65 | 82.82 | 76.99 | 9.08 | 10.61 |
| Avg. | | | | | 82.82 | 76.90 | 9.01 | 10.51 |
| 155X-15 | 45 | 15,000 | 225 | -65 | 81.72 | 75.53 | 8.84 | 10.86 |
| 155X-16 | 45 | 15,000 | 225 | -65 | 82.01 | 75.74 | 10.08 | 10.66 |
| Avg. | | | | | 81.87 | 75.64 | 9.46 | 10.76 |
| 155L-21 | L | 15,000 | 275 | 72 | 67.17 | 54.69 | 10.43 | 10.68 |
| 155L-22 | L | 15,000 | 275 | 72 | 66.51 | 53.51 | 10.33 | 10.41 |
| Avg. | | | | | 66.84 | 54.10 | 10.38 | 10.55 |
| 155T-21 | T | 15,000 | 275 | 72 | 67.31 | 54.46 | 9.60 | 10.37 |
| 155T-22 | T | 15,000 | 275 | 72 | 67.23 | 54.49 | 9.93 | 10.45 |
| Avg. | | | | | 67.27 | 54.48 | 9.77 | 10.41 |
| 155X-21 | 45 | 15,000 | 275 | 72 | 65.86 | 53.54 | 10.45 | 10.56 |
| 155X-22 | 45 | 15,000 | 275 | 72 | 66.71 | 54.32 | 10.19 | 10.47 |
| Avg. | | | | | 66.29 | 53.93 | 10.32 | 10.52 |
| 155L-23 | L | 15,000 | 275 | 275 | 54.85 | 48.58 | 13.93 | 10.14 |
| 155L-24 | L | 15,000 | 275 | 275 | 54.73 | 48.64 | 13.41 | 10.27 |
| Avg. | | | | | 54.79 | 48.61 | 13.67 | 10.21 |
| 155T-23 | T | 15,000 | 275 | 275 | 55.32 | 49.32 | 12.29 | 9.85 |
| 155T-24 | T | 15,000 | 275 | 275 | 54.99 | 49.04 | 13.39 | 10.08 |
| Avg. | | | | | 55.16 | 49.18 | 12.84 | 9.97 |
| 155X-23 | 45 | 15,000 | 275 | 275 | 54.15 | 48.26 | 12.88 | 10.60 |
| 155X-24 | 45 | 15,000 | 275 | 275 | 54.80 | 48.95 | 14.19 | 10.10 |
| Avg. | | | | | 54.48 | 48.61 | 13.54 | 10.35 |

Table A1. Tensile Results for C415. (concluded)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 155L-25 | L | 15,000 | 275 | -65 | 72.11 | 58.34 | 9.02 | 11.02 |
| 155L-26 | L | 15,000 | 275 | -65 | 71.04 | 57.44 | 9.46 | 11.10 |
| Avg. | | | | | 71.58 | 57.89 | 9.24 | 11.06 |
| 155T-25 | T | 15,000 | 275 | -65 | 71.95 | 58.04 | 8.64 | 10.75 |
| 155T-26 | T | 15,000 | 275 | -65 | 71.98 | 58.87 | 8.23 | 11.00 |
| Avg. | | | | | 71.97 | 58.46 | 8.44 | 10.88 |
| 155X-25 | 45 | 15,000 | 275 | -65 | 71.22 | 57.59 | 9.42 | 10.92 |
| 155X-26 | 45 | 15,000 | 275 | -65 | 70.84 | 57.32 | 9.71 | 10.84 |
| Avg. | | | | | 71.03 | 57.46 | 9.57 | 10.88 |
| 306L-1 | L | 30,000 | 225 | 72 | 77.26 | 73.82 | 6.89 | 10.32 |
| 305L-2 | L | 30,000 | 225 | 72 | 77.13 | 74.03 | 6.65 | 10.28 |
| Avg. | | | | | 77.20 | 73.93 | 6.82 | 10.30 |
| 305T-1 | T | 30,000 | 225 | 72 | 74.94 | 70.02 | 7.85 | 10.09 |
| 305T-2 | T | 30,000 | 225 | 72 | 74.88 | 69.71 | 7.15 | 10.19 |
| Avg. | | | | | 74.91 | 69.87 | 7.50 | 10.14 |

Table A2. Tensile Results for C416.

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 6L-4 | L | - | - | 72 | 76.2 | 72.3 | 11.3 | 10.3 |
| 6L-5 | L | - | - | 72 | 76.0 | 72.0 | 10.4 | 10.3 |
| Avg. | | | | | 76.1 | 72.2 | 10.9 | 10.3 |
| 6T-1 | T | - | - | 72 | 75.4 | 69.9 | 8.3 | 10.3 |
| 6T-3 | T | - | - | 72 | 73.4 | 69.4 | 8.6 | 10.2 |
| Avg. | | | | | 74.4 | 69.7 | 8.5 | 10.3 |
| 6A-1 | 45 | - | - | 72 | 73.7 | 68.0 | 10.2 | 10.1 |
| 6A-2 | 45 | - | - | 72 | 73.7 | 67.9 | 12.8 | 10.0 |
| Avg. | | | | | 73.7 | 68.0 | 11.5 | 10.1 |
| 6L-6 | L | - | - | 200 | 71.4 | 69.6 | 12.3 | 10.3 |
| 6L-7 | L | - | - | 200 | 71.2 | 69.4 | 13.8 | 10.2 |
| Avg. | | | | | 71.3 | 69.5 | 13.1 | 10.3 |
| 6T-4 | T | - | - | 200 | 71.0 | 67.6 | 11.3 | 10.2 |
| 6T-6 | T | - | - | 200 | 71.1 | 67.7 | 10.1 | 10.2 |
| Avg. | | | | | 71.1 | 67.7 | 10.7 | 10.2 |
| 6L-8 | L | - | - | 225 | 69.8 | 68.4 | 14.9 | 10.3 |
| 6L-9 | L | - | - | 225 | 70.1 | 68.7 | 10.0 | 10.3 |
| Avg. | | | | | 70.0 | 68.6 | 12.5 | 10.3 |
| 6T-7 | T | - | - | 225 | 69.6 | 67.0 | 11.0 | 10.3 |
| 6T-8 | T | - | - | 225 | 69.4 | 66.8 | 10.7 | 10.2 |
| Avg. | | | | | 69.5 | 66.9 | 10.9 | 10.3 |
| 6A-3 | 45 | - | - | 225 | 68.0 | 64.7 | 14.9 | 9.8 |
| 6L-10 | L | - | - | 275 | 66.5 | 66.3 | 12.3 | 10.1 |
| 6L-11 | L | - | - | 275 | 67.1 | 66.7 | 13.9 | 10.2 |
| Avg. | | | | | 66.8 | 66.5 | 13.1 | 10.2 |
| 6T-9 | T | - | - | 275 | 66.0 | 64.8 | 13.0 | 10.1 |
| 6T-10 | T | - | - | 275 | 65.8 | 64.5 | 13.5 | 10.1 |
| Avg. | | | | | 65.9 | 64.7 | 13.3 | 10.1 |
| 6A-4 | 45 | - | - | 275 | 64.7 | 62.9 | 18.3 | 9.6 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 6L-12 | L | - | - | -65 | 79.1 | 74.1 | 10.6 | 10.9 |
| 6L-13 | L | - | - | -65 | 79.1 | 74.3 | 11.4 | 10.8 |
| Avg. | | | | | 79.1 | 74.2 | 11.0 | 10.9 |
| 6T-2 | T | - | - | -65 | 78.3 | 71.9 | 10.6 | 10.9 |
| 6T-5 | T | - | - | -65 | 78.1 | 71.6 | 10.6 | 10.6 |
| Avg. | | | | | 78.2 | 71.8 | 10.6 | 10.8 |
| 6A-5 | 45 | - | - | -65 | 77.3 | 70.5 | 11.4 | 10.2 |
| 6L-15 | L | 301 | 200 | 72 | 75.2 | 71.1 | 10.9 | 10.1 |
| 6L-16 | L | 301 | 200 | 72 | 75.3 | 71.6 | 9.8 | 10.1 |
| Avg. | | | | | 75.3 | 71.4 | 10.4 | 10.1 |
| 6T-11 | T | 301 | 200 | 72 | 74.9 | 70.5 | 9.2 | 10.1 |
| 6T-12 | T | 301 | 200 | 72 | 74.4 | 69.8 | 9.5 | 10.0 |
| Avg. | | | | | 74.7 | 70.2 | 9.4 | 10.1 |
| 6L-19 | L | 301 | 225 | 72 | 76.2 | 72.2 | 11.5 | 10.2 |
| 6L-20 | L | 301 | 225 | 72 | 74.4 | 70.5 | 12.8 | 9.9 |
| Avg. | | | | | 75.3 | 71.4 | 12.2 | 10.1 |
| 6T-15 | T | 301 | 225 | 72 | 74.4 | 69.6 | 10.7 | 10.1 |
| 6T-16 | T | 301 | 225 | 72 | 76.3 | 71.1 | 10.7 | 10.3 |
| Avg. | | | | | 75.4 | 70.4 | 10.7 | 10.2 |
| 6L-17 | L | 1006 | 200 | 72 | 76.6 | 72.3 | 10.8 | 10.3 |
| 6L-18 | L | 1006 | 200 | 72 | 76.2 | 72.0 | 10.9 | 10.2 |
| Avg. | | | | | 76.4 | 72.2 | 10.9 | 10.3 |
| 6T-13 | T | 1006 | 200 | 72 | 74.1 | 69.5 | 9.4 | 10.1 |
| 6T-14 | T | 1006 | 200 | 72 | 75.9 | 71.1 | 11.6 | 10.4 |
| Avg. | | | | | 75.0 | 70.3 | 10.5 | 10.3 |
| 6L-14 | L | 1006 | 225 | 72 | 77.8 | 73.9 | 11.1 | 10.4 |
| 6L-21 | L | 1006 | 225 | 72 | 77.9 | 73.9 | 11.9 | 10.4 |
| Avg. | | | | | 77.9 | 73.9 | 11.5 | 10.4 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 6T-17 | T | 1006 | 225 | 72 | 75.8 | 71.1 | 10.2 | 10.3 |
| 6T-18 | T | 1006 | 225 | 72 | 74.2 | 69.4 | 9.6 | 10.1 |
| Avg. | | | | | 75.0 | 70.3 | 9.9 | 10.2 |
| 6L-22 | L | 1006 | 275 | 72 | 76.5 | 72.0 | 12.4 | 10.4 |
| 6L-23 | L | 1006 | 275 | 72 | 75.9 | 71.3 | 11.1 | 10.3 |
| Avg. | | | | | 76.2 | 71.7 | 11.8 | 10.4 |
| 6L-30 | L | 3000 | 200 | 72 | 76.8 | 72.7 | 10.1 | 10.2 |
| 6L-31 | L | 3000 | 200 | 72 | 76.7 | 73.0 | 9.6 | 10.2 |
| Avg. | | | | | 76.8 | 72.9 | 9.9 | 10.2 |
| 6L-32 | L | 3000 | 200 | 200 | 72.1 | 70.1 | 10.7 | 10.2 |
| 6L-33 | L | 3000 | 200 | 200 | 72.5 | 70.4 | 12.0 | 10.2 |
| Avg. | | | | | 72.3 | 70.3 | 11.4 | 10.2 |
| 6L-34 | L | 3000 | 225 | 72 | 77.3 | 73.2 | 9.5 | 10.2 |
| 6L-35 | L | 3000 | 225 | 72 | 77.5 | 73.8 | 9.3 | 10.2 |
| Avg. | | | | | 77.4 | 73.5 | 9.4 | 10.2 |
| 6L-36 | L | 3000 | 225 | 225 | 71.5 | 70.1 | 11.0 | 10.2 |
| 6L-37 | L | 3000 | 225 | 225 | 71.7 | 70.1 | 11.3 | 10.2 |
| Avg. | | | | | 71.6 | 70.1 | 11.2 | 10.2 |
| 6L-38 | L | 3000 | 275 | 72 | 73.0 | 67.9 | 9.3 | 10.2 |
| 6L-39 | L | 3000 | 275 | 72 | 72.8 | 67.6 | 8.6 | 10.1 |
| Avg. | | | | | 72.9 | 67.8 | 9.0 | 10.2 |
| 6L-40 | L | 3000 | 275 | 275 | 64.2 | 62.5 | 11.3 | 10.2 |
| 6L-41 | L | 3000 | 275 | 275 | 64.1 | 62.2 | 11.4 | 10.2 |
| Avg. | | | | | 64.2 | 62.4 | 11.4 | 10.2 |
| 2210L1 | L | 5,000 | 200 | 72 | 77.4 | 72.8 | 9.7 | 10.2 |
| 2210L2 | L | 5,000 | 200 | 72 | 77.8 | 72.1 | 9.78 | 10.8 |
| Avg. | | | | | 77.6 | 72.5 | 9.74 | 10.5 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 2210T1 | T | 5,000 | 200 | 72 | 77.0 | 69.6 | 8.04 | 10.6 |
| 2210T2 | T | 5,000 | 200 | 72 | 77.3 | 70.4 | 8.014 | 10.5 |
| Avg. | | | | | 77.2 | 70.2 | 8.09 | 10.6 |
| 2206L1 | L | 5,000 | 225 | 72 | 77.6 | 72.7 | 9.68 | 11.32 |
| 2206L2 | L | 5,000 | 225 | 72 | 77.7 | 71.2 | 9.8 | 11.2 |
| Avg. | | | | | 77.7 | 72.0 | 9.74 | 11.3 |
| 2206T1 | T | 5,000 | 225 | 72 | 77.1 | 70.1 | 9.9 | 11.3 |
| 2206T2 | T | 5,000 | 225 | 72 | 77.4 | 70.5 | 10.0 | 11.6 |
| Avg. | | | | | 77.3 | 70.3 | 10.0 | 11.4 |
| 6L-51 | L | 10,000 | 200 | 72 | 77.4 | 74.0 | 9.5 | 10.3 |
| 6L-52 | L | 10,000 | 200 | 72 | 77.8 | 74.0 | 10.7 | 10.3 |
| Avg. | | | | | 77.6 | 74.0 | 10.1 | 10.3 |
| 6T-30 | T | 10,000 | 200 | 72 | 77.6 | 71.8 | 9.5 | 10.4 |
| 6T-31 | T | 10,000 | 200 | 72 | 76.9 | 71.9 | 9.7 | 10.4 |
| Avg. | | | | | 77.3 | 71.9 | 9.6 | 10.4 |
| 6L-53 | L | 10,000 | 200 | 200 | 72.3 | 70.4 | 11.2 | 10.1 |
| 6L-54 | L | 10,000 | 200 | 200 | 72.0 | 69.8 | 10.8 | 10.1 |
| Avg. | | | | | 72.2 | 70.1 | 11.0 | 10.1 |
| 6T-32 | T | 10,000 | 200 | 200 | 72.0 | 68.9 | 11.6 | 10.2 |
| 6T-33 | T | 10,000 | 200 | 200 | 71.9 | 68.8 | 11.1 | 10.4 |
| Avg. | | | | | 72.0 | 68.9 | 11.4 | 11.3 |
| 6L-55 | L | 10,000 | 200 | -65 | 81.1 | 76.1 | 8.8 | 10.6 |
| 6L-56 | L | 10,000 | 200 | -65 | 81.4 | 76.7 | 9.2 | 10.8 |
| Avg. | | | | | 81.3 | 76.4 | 9.0 | 10.7 |
| 6T-34 | T | 10,000 | 200 | -65 | 80.2 | 73.9 | 9.8 | 10.7 |
| 6T-35 | T | 10,000 | 200 | -65 | 80.4 | 73.5 | 9.7 | 10.8 |
| Avg. | | | | | 80.3 | 73.7 | 9.8 | 10.8 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 6L-42 | L | 10,000 | 225 | 72 | 77.1 | 73.0 | 9.8 | 10.3 |
| 6L-43 | L | 10,000 | 225 | 72 | 77.2 | 73.2 | 9.6 | 10.4 |
| Avg. | | | | | 77.2 | 73.1 | 9.7 | 10.4 |
| 6T-21 | T | 10,000 | 225 | 72 | 76.9 | 71.3 | 9.0 | 10.2 |
| 6T-22 | T | 10,000 | 225 | 72 | 77.4 | 71.8 | 9.7 | 10.2 |
| Avg. | | | | | 77.2 | 71.6 | 9.4 | 10.2 |
| 6L-44 | L | 10,000 | 225 | 225 | 70.4 | 68.8 | 12.3 | 10.2 |
| 6L-45 | L | 10,000 | 225 | 225 | 70.6 | 69.0 | 12.1 | 10.0 |
| Avg. | | | | | 70.5 | 68.9 | 12.2 | 10.1 |
| 6T-23 | T | 10,000 | 225 | 225 | 70.1 | 67.5 | 10.1 | 10.2 |
| 6T-24 | T | 10,000 | 225 | 225 | 69.7 | 67.2 | 10.7 | 10.3 |
| Avg. | | | | | 69.9 | 67.4 | 10.4 | 10.3 |
| 6L-46 | L | 10,000 | 225 | -65 | 79.6 | 74.5 | 10.0 | 10.8 |
| 6L-47 | L | 10,000 | 225 | -65 | 80.2 | 73.9 | 8.9 | 10.8 |
| Avg. | | | | | 79.9 | 74.2 | 9.5 | 10.8 |
| 6T-25 | T | 10,000 | 225 | -65 | 80.3 | 74.6 | 9.9 | 10.8 |
| 6T-26 | T | 10,000 | 225 | -65 | 80.0 | 74.3 | 8.3 | 11.1 |
| Avg. | | | | | 80.2 | 74.5 | 9.1 | 11.0 |
| 6L-59 | L | 10,000 | 275 | 72 | 68.7 | 59.7 | 10.0 | 10.4 |
| 6L-60 | L | 10,000 | 275 | 72 | 69.1 | 60.3 | 10.1 | 10.3 |
| Avg. | | | | | 68.9 | 60.0 | 10.1 | 10.4 |
| 6T-36 | T | 10,000 | 275 | 72 | 69.4 | 59.6 | 9.4 | 10.5 |
| 6T-37 | T | 10,000 | 275 | 72 | 69.5 | 59.3 | 10.1 | 10.5 |
| Avg. | | | | | 69.5 | 59.5 | 9.8 | 10.5 |
| 6L-61 | L | 10,000 | 275 | 275 | 58.1 | 54.6 | 11.8 | 10.7 |
| 6L-62 | L | 10,000 | 275 | 275 | 57.5 | 53.7 | 12.5 | 10.3 |
| Avg. | | | | | 57.8 | 54.2 | 12.2 | 10.5 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 6T-38 | T | 10,000 | 275 | 275 | 58.4 | 53.9 | 12.3 | 10.5 |
| 6T-39 | T | 10,000 | 275 | 275 | 58.2 | 53.7 | 14.8 | 9.9 |
| Avg. | | | | | 58.3 | 53.8 | 13.6 | 10.2 |
| 6L-63 | L | 10,000 | 275 | -65 | 73.4 | 63.3 | 9.0 | 10.7 |
| 6L-64 | L | 10,000 | 275 | -65 | 73.5 | 64.1 | 9.0 | 10.7 |
| Avg. | | | | | 73.5 | 63.7 | 9.0 | 10.7 |
| 6T-40 | T | 10,000 | 275 | -65 | 73.8 | 63.0 | 9.6 | 10.8 |
| 6T-41 | T | 10,000 | 275 | -65 | 73.1 | 62.6 | 8.3 | 10.7 |
| Avg. | | | | | 73.5 | 62.8 | 9.0 | 10.8 |
| 156L-1 | L | 15,000 | 200 | 72 | 77.58 | 73.81 | 9.52 | 10.43 |
| 156L-2 | L | 15,000 | 200 | 72 | 77.42 | 73.60 | 9.67 | 10.38 |
| Avg. | | | | | 77.50 | 73.71 | 9.60 | 10.41 |
| 156T-1 | T | 15,000 | 200 | 72 | 76.96 | 71.68 | 9.56 | 10.36 |
| 156T-2 | T | 15,000 | 200 | 72 | 77.48 | 72.31 | 9.16 | 10.43 |
| Avg. | | | | | 77.22 | 72.00 | 9.36 | 10.40 |
| 156X-1 | 45 | 15,000 | 200 | 72 | 76.51 | 70.82 | 10.12 | 10.26 |
| 156X-2 | 45 | 15,000 | 200 | 72 | 76.57 | 71.20 | 10.62 | 10.16 |
| Avg. | | | | | 76.54 | 71.01 | 10.37 | 10.21 |
| 156L-3 | L | 15,000 | 200 | 200 | 72.29 | 70.09 | 10.90 | 10.08 |
| 156L-4 | L | 15,000 | 200 | 200 | 71.90 | 69.79 | 11.18 | 10.05 |
| Avg. | | | | | 72.10 | 69.94 | 11.04 | 10.07 |
| 156T-3 | T | 15,000 | 200 | 200 | 72.02 | 68.50 | 10.87 | 10.25 |
| 156T-4 | T | 15,000 | 200 | 200 | 72.31 | 68.61 | 10.89 | 10.02 |
| Avg. | | | | | 72.17 | 68.56 | 10.88 | 10.14 |
| 156X-3 | 45 | 15,000 | 200 | 200 | 71.66 | 67.95 | 12.24 | 10.07 |
| 156X-4 | 45 | 15,000 | 200 | 200 | 71.41 | 67.29 | 11.73 | 9.93 |
| Avg. | | | | | 71.54 | 67.62 | 11.99 | 10.00 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 156L-5 | L | 15,000 | 200 | -65 | 81.86 | 77.07 | 9.73 | 10.63 |
| 156L-6 | L | 15,000 | 200 | -65 | 80.58 | 76.06 | 9.50 | 10.64 |
| Avg. | | | | | 81.22 | 76.57 | 9.62 | 10.64 |
| 156T-5 | T | 15,000 | 200 | -65 | 81.38 | 75.24 | 9.89 | 10.66 |
| 156T-6 | T | 15,000 | 200 | -65 | 81.30 | 75.72 | 9.33 | 11.14 |
| Avg. | | | | | 81.34 | 75.48 | 9.61 | 10.90 |
| 156X-5 | 45 | 15,000 | 200 | -65 | 81.00 | 74.56 | 10.54 | 10.58 |
| 156X-6 | 45 | 15,000 | 200 | -65 | 80.52 | 74.15 | 10.58 | 10.59 |
| Avg. | | | | | 80.76 | 74.36 | 10.56 | 10.59 |
| 166L-11 | L | 15,000 | 225 | 72 | 77.14 | 72.62 | 9.20 | 10.23 |
| 166L-12 | L | 15,000 | 225 | 72 | 77.12 | 72.66 | 9.92 | 10.48 |
| Avg. | | | | | 77.13 | 72.64 | 9.56 | 10.36 |
| 166T-11 | T | 15,000 | 225 | 72 | 76.74 | 71.16 | 9.15 | 10.52 |
| 166T-12 | T | 15,000 | 225 | 72 | 76.60 | 70.67 | 9.01 | 10.43 |
| Avg. | | | | | 76.67 | 70.92 | 9.08 | 10.48 |
| 166X-11 | 45 | 15,000 | 225 | 72 | 76.43 | 70.21 | 10.03 | 10.33 |
| 166X-12 | 45 | 15,000 | 225 | 72 | 76.18 | 70.06 | 9.98 | 10.31 |
| Avg. | | | | | 76.31 | 70.14 | 10.01 | 10.32 |
| 166L-13 | L | 15,000 | 225 | 225 | 70.57 | 68.52 | 11.06 | 9.96 |
| 166L-14 | L | 15,000 | 225 | 225 | 70.08 | 68.14 | 10.34 | 10.07 |
| Avg. | | | | | 70.33 | 68.33 | 10.70 | 10.01 |
| 166T-13 | T | 15,000 | 225 | 225 | 70.14 | 67.10 | 10.32 | 10.19 |
| 166T-14 | T | 15,000 | 225 | 225 | 70.00 | 66.70 | 9.85 | 10.16 |
| Avg. | | | | | 70.07 | 66.90 | 10.09 | 10.18 |
| 166X-13 | 45 | 15,000 | 225 | 225 | 69.90 | 66.24 | 11.59 | 9.92 |

Table A2. Tensile Results for C416. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 166L-15 | L | 15,000 | 225 | -65 | 81.24 | 76.20 | 8.63 | 10.66 |
| 166L-16 | L | 15,000 | 225 | -65 | 81.11 | 76.03 | 9.17 | 10.67 |
| Avg. | | | | | 81.18 | 76.12 | 8.90 | 10.67 |
| 166T-15 | T | 15,000 | 225 | -65 | 80.72 | 74.54 | 8.09 | 10.70 |
| 166T-16 | T | 15,000 | 225 | -65 | 80.68 | 74.37 | 8.25 | 10.63 |
| Avg. | | | | | 80.70 | 74.46 | 8.17 | 10.67 |
| 166X-15 | 45 | 15,000 | 225 | -65 | 80.12 | 73.38 | 9.55 | 10.42 |
| 166X-16 | 45 | 15,000 | 225 | -65 | 79.68 | 72.97 | 9.40 | 10.66 |
| Avg. | | | | | 79.90 | 73.18 | 9.48 | 10.54 |
| 166L-21 | L | 15,000 | 275 | 72 | 67.36 | 56.88 | 10.78 | 10.52 |
| 166L-22 | L | 15,000 | 275 | 72 | 67.76 | 56.91 | 9.99 | 10.48 |
| Avg. | | | | | 67.50 | 56.90 | 10.39 | 10.50 |
| 166T-21 | T | 15,000 | 275 | 72 | 67.98 | 56.67 | 10.16 | 10.53 |
| 166T-22 | T | 15,000 | 275 | 72 | 68.55 | 57.50 | 9.40 | 10.58 |
| Avg. | | | | | 68.27 | 57.09 | 9.78 | 10.56 |
| 166X-21 | 45 | 15,000 | 275 | 72 | 67.98 | 56.67 | 10.16 | 10.53 |
| 166X-22 | 45 | 15,000 | 275 | 72 | 67.69 | 56.17 | 10.34 | 10.37 |
| Avg. | | | | | 67.84 | 56042 | 10.25 | 10.45 |
| 166L-23 | L | 15,000 | 275 | 275 | 55.93 | 51.25 | 13.67 | 10.26 |
| 166L-24 | L | 15,000 | 275 | 275 | 56.08 | 51.31 | 15.21 | 10.47 |
| Avg. | | | | | 56.01 | 51.28 | 14.44 | 10.37 |
| 166T-23 | T | 15,000 | 275 | 275 | 56.95 | 51.29 | 12.89 | 10.14 |
| 166T-24 | T | 15,000 | 275 | 275 | 56.49 | 51.45 | 13.13 | 9.87 |
| Avg. | | | | | 56.72 | 51.69 | 13.01 | 10.01 |
| 166X-23 | 45 | 15,000 | 275 | 275 | 55.71 | 50.70 | 14.13 | 10.31 |

Table A2. Tensile Results for C416. (concluded)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 166L-25 | L | 15,000 | 275 | -65 | 72.38 | 60.17 | 9.42 | 10.73 |
| 166L-26 | L | 15,000 | 275 | -65 | 71.11 | 59.47 | 9.29 | 10.82 |
| Avg. | | | | | 71.75 | 59.82 | 9.36 | 10.78 |
| 166T-25 | T | 15,000 | 275 | -65 | 72.88 | 61.52 | 9.80 | 10.67 |
| 166T-26 | T | 15,000 | 275 | -65 | 72.76 | 61.01 | 9.95 | 10.74 |
| Avg. | | | | | 72.82 | 61.27 | 9.88 | 10.71 |
| 166X-25 | 45 | 15,000 | 275 | -65 | 71.69 | 59.51 | 10.16 | 10.44 |
| 166X-26 | 45 | 15,000 | 275 | -65 | 72.18 | 59.67 | 9.10 | 10.55 |
| Avg. | | | | | 71.94 | 59.60 | 9.63 | 10.50 |
| 306L-1 | L | 30,000 | 225 | 72 | 76.18 | 71.81 | 9.87 | 10.50 |
| 306L-2 | L | 30,000 | 225 | 72 | 76.13 | 71.86 | 8.60 | 10.51 |
| Avg. | | | | | 76.16 | 71.84 | 9.24 | 10.51 |
| 306T-1 | T | 30,000 | 225 | 72 | 75.38 | 70.07 | 8.48 | 10.42 |
| 306T-2 | T | 30,000 | 225 | 72 | 75.90 | 70.57 | 10.23 | 10.37 |
| Avg. | | | | | 75.64 | 70.32 | 9.36 | 10.40 |

## Table A3. Tensile Results for ML377.

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| MLL-1 | L | - | - | 72 | 78.3 | 76.9 | 8.8 | 10.5 |
| MLL-2 | L | - | - | 72 | 77.8 | 76.0 | 8.6 | 10.4 |
| Avg. | | | | | 78.1 | 76.5 | 8.7 | 10.5 |
| MLT-1 | T | - | - | 72 | 81.7 | 75.4 | 8.6 | 10.7 |
| MLT-2 | T | - | - | 72 | 82.1 | 75.5 | 8.5 | 10.7 |
| Avg. | | | | | 81.9 | 75.5 | 8.6 | 10.7 |
| ML45-1 | 45 | - | - | 72 | 81.6 | 76.3 | 7.6 | 10.7 |
| ML45-2 | 45 | - | - | 72 | 81.2 | 75.6 | 7.9 | 10.7 |
| Avg. | | | | | 81.4 | 76.0 | 7.8 | 10.7 |
| MLL-3 | L | - | - | 200 | 73.8 | 73.6 | 9.5 | 10.4 |
| MLL-4 | L | - | - | 200 | 74.1 | 73.8 | 9.9 | 10.4 |
| Avg. | | | | | 74.0 | 73.7 | 9.7 | 10.4 |
| MLT-3 | T | - | - | 200 | 77.1 | 73.1 | 10.1 | 10.6 |
| MLT-4 | T | - | - | 200 | 77.6 | 73.7 | 9.4 | 10.7 |
| Avg. | | | | | 77.4 | 73.4 | 9.8 | 10.7 |
| MLL-5 | L | - | - | 225 | 72.4 | 72.4 | 11.4 | 10.4 |
| MLL-6 | L | - | - | 225 | 72.0 | 72.0 | 10.4 | 10.4 |
| Avg. | | | | | 72.2 | 72.2 | 10.9 | 10.4 |
| MLT-5 | T | - | - | 225 | 76.0 | 72.6 | 12.2 | 10.7 |
| MLT-6 | T | - | - | 225 | 76.2 | 72.7 | 10.6 | 10.7 |
| Avg. | | | | | 76.1 | 72.7 | 11.4 | 10.7 |
| ML45-3 | 45 | - | - | 225 | 74.5 | 71.7 | 9.0 | 10.0 |
| MLL-7 | L | - | - | 275 | 70.4 | 70.3 | 12.2 | 10.3 |
| MLL-8 | L | - | - | 275 | 70.3 | 70.2 | 11.4 | 10.2 |
| Avg. | | | | | 70.4 | 70.3 | 11.8 | 10.3 |
| MLT-7 | T | - | - | 275 | 72.2 | 69.9 | 12.3 | 10.5 |
| MLT-8 | T | - | - | 275 | 72.7 | 70.6 | 11.8 | 10.5 |
| Avg. | | | | | 72.5 | 70.3 | 12.1 | 10.5 |
| ML45-4 | 45 | - | - | 275 | 70.7 | 69.3 | 10.3 | 10.3 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| MLL-17 | L | - | - | -65 | 82.3 | 80.0 | 9.7 | 10.9 |
| MLL-18 | L | - | - | -65 | 82.1 | 79.7 | 9.6 | 11.1 |
| Avg. | | | | | 82.2 | 79.9 | 9.7 | 11.0 |
| MLT-24 | T | - | - | -65 | 85.8 | 78.2 | 9.4 | 11.1 |
| MLT-25 | T | - | - | -65 | 85.9 | 78.4 | 8.9 | 11.8 |
| Avg. | | | | | 85.9 | 78.3 | 9.2 | 11.5 |
| ML45-5 | 45 | - | - | -65 | 85.1 | 78.2 | 8.4 | 10.9 |
| MLL-22 | L | 301 | 200 | 72 | 76.7 | 74.6 | 9.1 | 10.2 |
| MLL-23 | L | 301 | 200 | 72 | 77.1 | 75.3 | 9.0 | 10.3 |
| Avg. | | | | | 76.9 | 75.0 | 9.0 | 10.3 |
| MLT-16 | T | 301 | 200 | 72 | 80.7 | 74.8 | 8.9 | 10.4 |
| MLT-17 | T | 301 | 200 | 72 | 80.9 | 74.8 | 9.1 | 10.5 |
| Avg. | | | | | 80.8 | 74.8 | 9.0 | 10.5 |
| MLL-9 | L | 301 | 225 | 72 | 77.9 | 76.1 | 9.4 | 10.3 |
| MLL-10 | L | 301 | 225 | 72 | 77.3 | 75.7 | 9.7 | 10.2 |
| Avg. | | | | | 77.6 | 75.9 | 9.6 | 10.3 |
| MLT-11 | T | 301 | 225 | 72 | 81.5 | 75.1 | 9.4 | 10.5 |
| MLT-12 | T | 301 | 225 | 72 | 81.3 | 75.2 | 9.6 | 10.4 |
| Avg. | | | | | 81.4 | 75.2 | 9.5 | 10.5 |
| MLL-15 | L | 1006 | 200 | 72 | 80.2 | 78.5 | 9.1 | 10.7 |
| MLL-16 | L | 1006 | 200 | 72 | 80.2 | 78.6 | 9.4 | 10.6 |
| Avg. | | | | | 80.2 | 78.6 | 9.3 | 10.7 |
| MLT-13 | T | 1006 | 200 | 72 | 83.6 | 77.1 | 9.2 | 10.8 |
| MLT-14 | T | 1006 | 200 | 72 | 83.0 | 76.8 | 9.1 | 10.7 |
| Avg. | | | | | 83.3 | 77.0 | 9.2 | 10.8 |
| MLL-11 | L | 1006 | 225 | 72 | 80.6 | 79.2 | 8.9 | 10.7 |
| MLL-13 | L | 1006 | 225 | 72 | 81.0 | 79.4 | 8.9 | 10.7 |
| Avg. | | | | | 80.8 | 79.3 | 8.9 | 10.7 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| MLT-9 | T | 1006 | 225 | 72 | 84.8 | 78.4 | 8.7 | 10.9 |
| MLT-10 | T | 1006 | 225 | 72 | 83.8 | 77.3 | 8.8 | 10.7 |
| Avg. | | | | | 84.3 | 77.9 | 8.8 | 10.8 |
| MLL-12 | L | 1006 | 275 | 72 | 79.5 | 77.7 | 8.4 | 10.5 |
| MLL-14 | L | 1006 | 275 | 72 | 80.1 | 78.1 | 8.4 | 10.6 |
| Avg. | | | | | 79.8 | 77.9 | 8.4 | 10.6 |
| MLL-30 | L | 3000 | 200 | 72 | 79.5 | 78.2 | 8.7 | 10.5 |
| MLL-31 | L | 3000 | 200 | 72 | 79.7 | 78.4 | 8.9 | 10.4 |
| Avg. | | | | | 79.6 | 78.3 | 8.8 | 10.5 |
| MLL-32 | L | 3000 | 200 | 200 | 75.5 | 75.2 | 9.6 | 10.5 |
| MLL-33 | L | 3000 | 200 | 200 | 75.1 | 74.8 | 11.2 | 10.4 |
| Avg. | | | | | 75.3 | 75.0 | 10.4 | 10.5 |
| MLL-34 | L | 3000 | 225 | 72 | 79.8 | 78.7 | 8.4 | 10.4 |
| MLL-35 | L | 3000 | 225 | 72 | 79.9 | 78.8 | 8.6 | 10.5 |
| Avg. | | | | | 79.9 | 78.8 | 8.5 | 10.5 |
| MLL-36 | L | 3000 | 225 | 225 | 74.3 | 74.2 | 8.0 | 10.3 |
| MLL-37 | L | 3000 | 225 | 225 | 74.1 | 73.7 | 8.7 | 10.3 |
| Avg. | | | | | 74.2 | 74.0 | 8.4 | 10.3 |
| MLL-38 | L | 3000 | 275 | 72 | 77.6 | 75.7 | 7.8 | 10.4 |
| MLL-39 | L | 3000 | 275 | 72 | 78.3 | 76.4 | 8.0 | 10.4 |
| Avg. | | | | | 78.0 | 76.1 | 7.9 | 10.4 |
| MLL-41 | L | 3000 | 275 | 275 | 68.8 | 68.8 | 11.5 | 10.3 |
| Avg. | | | | | 68.8 | 68.8 | 11.5 | 10.3 |
| 2212L1 | L | 5,000 | 200 | 72 | 79.5 | 81.6 | 9.63 | 11.14 |
| 2212L2 | L | 5,000 | 200 | 72 | 79.2 | 81.2 | 9.77 | 11.03 |
| Avg. | | | | | 79.4 | 81.4 | 9.70 | 11.09 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 2212T1 | T | 5,000 | 200 | 72 | 77.2 | 84.2 | 8.11 | 11.24 |
| 2212T2 | T | 5,000 | 200 | 72 | 78.2 | 85.2 | 8.50 | 11.37 |
| Avg. | | | | | 77.7 | 84.7 | 8.31 | 11.31 |
| 2207L1 | L | 5,000 | 225 | 72 | 79.1 | 80.8 | 8.36 | 11.09 |
| 2207L2 | L | 5,000 | 225 | 72 | 80.7 | 78.8 | 8.83 | 10.97 |
| Avg. | | | | | 79.9 | 79.8 | 8.60 | 11.03 |
| 2207T1 | T | 5,000 | 225 | 72 | 77.2 | 84.2 | 8.30 | 11.26 |
| 2207T2 | T | 5,000 | 225 | 72 | 77.0 | 84.4 | 9.00 | 11.33 |
| Avg. | | | | | 77.1 | 84.3 | 8.65 | 11.29 |
| MLL-50 | L | 10,000 | 200 | 72 | 80.5 | 79.1 | 10.0 | 10.5 |
| MLL-51 | L | 10,000 | 200 | 72 | 80.6 | 79.3 | 9.3 | 10.6 |
| Avg. | | | | | 80.6 | 79.2 | 9.7 | 10.6 |
| MLT-33 | T | 10,000 | 200 | 72 | 83.9 | 78.3 | 8.1 | 10.7 |
| MLT-34 | T | 10,000 | 200 | 72 | 84.1 | 78.7 | 8.0 | 10.7 |
| Avg. | | | | | 84.0 | 78.5 | 8.1 | 10.7 |
| MLL-52 | L | 10,000 | 200 | 200 | 75.3 | 75.3 | 8.4 | 10.3 |
| MLL-53 | L | 10,000 | 200 | 200 | 75.3 | 75.2 | 8.3 | 10.4 |
| Avg. | | | | | 75.3 | 75.3 | 8.4 | 10.4 |
| MLT-35 | T | 10,000 | 200 | 200 | 78.3 | 74.5 | 8.8 | 10.5 |
| MLT-36 | T | 10,000 | 200 | 200 | 78.3 | 74.6 | 8.8 | 10.4 |
| Avg. | | | | | 78.3 | 74.6 | 8.8 | 10.5 |
| MLL-54 | L | 10,000 | 200 | -65 | 84.9 | 82.5 | 9.1 | 11.2 |
| MLL-55 | L | 10,000 | 200 | -65 | 84.7 | 82.3 | 8.3 | 11.2 |
| Avg. | | | | | 84.8 | 82.4 | 8.7 | 11.2 |
| MLT-37 | T | 10,000 | 200 | -65 | 87.9 | 80.4 | 7.5 | 11.2 |
| MLT-38 | T | 10,000 | 200 | -65 | 88.3 | 80.0 | 7.5 | 11.4 |
| Avg. | | | | | 88.1 | 80.2 | 7.5 | 11.3 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| MLL-42 | L | 10,000 | 225 | 72 | 80.1 | 78.7 | 8.2 | 10.5 |
| MLL-43 | L | 10,000 | 225 | 72 | 80.3 | 78.9 | 8.1 | 10.6 |
| Avg. | | | | | 80.2 | 78.8 | 8.2 | 10.6 |
| MLT-26 | T | 10,000 | 225 | 72 | 84.1 | 78.2 | 7.5 | 10.7 |
| MLT-27 | T | 10,000 | 225 | 72 | 84.0 | 78.2 | 7.9 | 10.6 |
| Avg. | | | | | 84.1 | 78.2 | 7.7 | 10.7 |
| MLL-44 | L | 10,000 | 225 | 225 | 74.1 | 74.1 | 8.3 | 10.0 |
| MLL-45 | L | 10,000 | 225 | 225 | 74.3 | 74.2 | 7.8 | 10.2 |
| Avg. | | | | | 74.2 | 74.2 | 8.1 | 10.1 |
| MLT-28 | T | 10,000 | 225 | 225 | 76.6 | 73.7 | 9.6 | 10.2 |
| MLT-29 | T | 10,000 | 225 | 225 | 76.6 | 73.5 | 9.2 | 10.4 |
| Avg. | | | | | 76.6 | 73.6 | 9.4 | 10.3 |
| MLL-46 | L | 10,000 | 225 | -65 | 84.5 | 82.5 | 7.9 | 11.3 |
| MLL-47 | L | 10,000 | 225 | -65 | 84.8 | 82.9 | 8.3 | 11.4 |
| Avg. | | | | | 84.7 | 82.7 | 8.1 | 11.4 |
| MLT-30 | T | 10,000 | 225 | -65 | 88.7 | 81.2 | 6.5 | 11.1 |
| MLT-31 | T | 10,000 | 225 | -65 | 88.7 | 81.7 | 7.0 | 11.4 |
| Avg. | | | | | 88.7 | 81.5 | 6.8 | 11.3 |
| MLL-58 | L | 10,000 | 275 | 72 | 76.7 | 73.4 | 7.5 | 10.4 |
| MLL-59 | L | 10,000 | 275 | 72 | 75.9 | 72.6 | 8.0 | 10.4 |
| Avg. | | | | | 76.3 | 73.0 | 7.8 | 10.4 |
| MLT-40 | T | 10,000 | 275 | 72 | 78.9 | 73.6 | 6.5 | 10.5 |
| MLT-41 | T | 10,000 | 275 | 72 | 79.1 | 73.7 | 7.0 | 10.6 |
| Avg. | | | | | 79.0 | 73.7 | 6.8 | 10.6 |
| MLL-60 | L | 10,000 | 275 | 275 | 66.0 | 66.0 | 10.4 | 10.3 |
| MLL-61 | L | 10,000 | 275 | 275 | 65.9 | 65.8 | 10.7 | 10.1 |
| Avg. | | | | | 66.0 | 65.9 | 10.6 | 10.2 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| MLT-42 | T | 10,000 | 275 | 275 | 68.2 | 66.7 | 10.1 | 10.2 |
| MLT-43 | T | 10,000 | 275 | 275 | 68.3 | 66.7 | 10.4 | 10.0 |
| Avg. | | | | | 68.3 | 66.7 | 10.3 | 10.1 |
| MLL-62 | L | 10,000 | 275 | -65 | 80.0 | 76.3 | 6.9 | 10.9 |
| MLL-63 | L | 10,000 | 275 | -65 | 80.3 | 76.5 | 7.0 | 10.8 |
| Avg. | | | | | 80.2 | 76.4 | 7.0 | 10.9 |
| MLT-44 | T | 10,000 | 275 | -65 | 83.8 | 77.0 | 5.9 | 11.0 |
| MLT-45 | T | 10,000 | 275 | -65 | 83.6 | 77.0 | 5.7 | 11.2 |
| Avg. | | | | | 83.7 | 77.0 | 5.8 | 11.1 |
| 15ML-1 | L | 15,000 | 200 | 72 | 80.86 | 79.21 | 8.83 | 10.64 |
| 15ML-2 | L | 15,000 | 200 | 72 | 81.04 | 79.47 | 8.42 | 10.64 |
| Avg. | | | | | 80.95 | 79.34 | 8.63 | 10.64 |
| 15MT-1 | T | 15,000 | 200 | 72 | 84.15 | 78.51 | 8.24 | 10.77 |
| 15MT-2 | T | 15,000 | 200 | 72 | 84.27 | 78.41 | 8.17 | 10.81 |
| Avg. | | | | | 84.21 | 78.46 | 8.21 | 10.79 |
| 15MX-1 | 45 | 15,000 | 200 | 72 | 84.40 | 79.30 | 7.82 | 10.75 |
| 15MX-2 | 45 | 15,000 | 200 | 72 | 84.20 | 79.04 | 7.70 | 10.73 |
| Avg. | | | | | 84.30 | 79.17 | 7.76 | 10.74 |
| 15ML-3 | L | 15,000 | 200 | 200 | 75.52 | 75.23 | 8.33 | 10.13 |
| 15ML-4 | L | 15,000 | 200 | 200 | 75.75 | 75.43 | 8.17 | 10.24 |
| Avg. | | | | | 75.64 | 75.33 | 8.25 | 10.19 |
| 15MT-3 | T | 15,000 | 200 | 200 | 78.64 | 74.39 | 9.63 | 10.24 |
| 15MT-4 | T | 15,000 | 200 | 200 | 78.50 | 74.35 | 9.51 | 10.57 |
| Avg. | | | | | 78.57 | 74.37 | 9.57 | 10.41 |
| 15MX-3 | 45 | 15,000 | 200 | 200 | 78.27 | 74.55 | 7.82 | 10.25 |
| 15MX-4 | 45 | 15,000 | 200 | 200 | 78.55 | 74.96 | 8.47 | 10.48 |
| Avg. | | | | | 78.41 | 74.76 | 8.15 | 10.37 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 15ML-5 | L | 15,000 | 200 | -65 | 85.45 | 83.64 | 8.88 | 10.77 |
| 15ML-6 | L | 15,000 | 200 | -65 | 85.84 | 83.99 | 8.95 | 11.17 |
| Avg. | | | | | 85.65 | 83.82 | 8.92 | 10.97 |
| 15MT-5 | T | 15,000 | 200 | -65 | 88.66 | 81.35 | 7.62 | 10.88 |
| 15MT-6 | T | 15,000 | 200 | -65 | 88.41 | 81.09 | 7.75 | 10.99 |
| Avg. | | | | | 88.54 | 81.22 | 7.69 | 10.94 |
| 15MX-5 | 45 | 15,000 | 200 | -65 | 88.82 | 82.28 | 7.57 | 11.04 |
| 15MX-6 | 45 | 15,000 | 200 | -65 | 88.75 | 81.88 | 7.29 | 10.85 |
| Avg. | | | | | 88.79 | 82.08 | 7.43 | 10.95 |
| M15L-11 | L | 15,000 | 225 | 72 | 80.99 | 79.12 | 9.10 | 10.61 |
| M15L-12 | L | 15,000 | 225 | 72 | 80.91 | 79.00 | 9.00 | 10.69 |
| Avg. | | | | | 80.95 | 79.06 | 9.05 | 10.65 |
| M15T-11 | T | 15,000 | 225 | 72 | 84.65 | 78.39 | 7.62 | 10.79 |
| M15T-12 | T | 15,000 | 225 | 72 | 84.70 | 78.84 | 7.73 | 10.81 |
| Avg. | | | | | 84.68 | 78.62 | 7.68 | 10.80 |
| M15X-11 | 45 | 15,000 | 225 | 72 | 83.63 | 78.17 | 7.14 | 10.74 |
| M15X-12 | 45 | 15,000 | 225 | 72 | 83.58 | 78.20 | 6.69 | 10.74 |
| Avg. | | | | | 83.61 | 78.19 | 6.92 | 10.74 |
| M15L-13 | L | 15,000 | 225 | 225 | 74.01 | 73.88 | 8.28 | 10.04 |
| M15L-14 | L | 15,000 | 225 | 225 | 74.44 | 74.22 | 8.63 | 10.14 |
| Avg. | | | | | 74.23 | 74.05 | 8.46 | 10.19 |
| M15T-13 | T | 15,000 | 225 | 225 | 77.58 | 74.44 | 9.71 | 10.52 |
| M15T-14 | T | 15,000 | 225 | 225 | 77.42 | 74.41 | 9.51 | 10.22 |
| Avg. | | | | | 77.50 | 74.43 | 9.61 | 10.37 |
| M15X-13 | 45 | 15,000 | 225 | 225 | 76.80 | 73.36 | 9.14 | 10.13 |
| M15X-14 | 45 | 15,000 | 225 | 225 | 76.52 | 73.97 | 8.24 | 10.17 |
| Avg. | | | | | 76.66 | 73.67 | 8.69 | 10.15 |

Table A3. Tensile Results for ML377. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| M15L-15 | L | 15,000 | 225 | -65 | 85.60 | 83.21 | 8.52 | 10.98 |
| M15L-16 | L | 15,000 | 225 | -65 | 85.43 | 83.12 | 8.42 | 10.95 |
| Avg. | | | | | 85.52 | 83.17 | 8.47 | 10.97 |
| M15T-15 | T | 15,000 | 225 | -65 | 89.43 | 82.27 | 7.22 | 11.11 |
| M15T-16 | T | 15,000 | 225 | -65 | 89.37 | 82.01 | 7.16 | 11.21 |
| Avg. | | | | | 89.40 | 82.14 | 7.19 | 11.16 |
| M15X-15 | 45 | 15,000 | 225 | -65 | 88.59 | 81.95 | 6.34 | 11.31 |
| M15X-16 | 45 | 15,000 | 225 | -65 | 88.56 | 82.20 | 6.11 | 11.17 |
| Avg. | | | | | 88.58 | 82.08 | 6.23 | 11.24 |
| M15L-21 | L | 15,000 | 275 | 72 | 74.47 | 69.93 | 7.79 | 10.53 |
| M15L-22 | L | 15,000 | 275 | 72 | 74.20 | 69.94 | 8.01 | 10.47 |
| Avg. | | | | | 74.34 | 69.94 | 7.90 | 10.50 |
| M15T-21 | T | 15,000 | 275 | 72 | 78.08 | 71.70 | 6.93 | 10.70 |
| M15T-22 | T | 15,000 | 275 | 72 | 78.07 | 71.74 | 6.64 | 10.73 |
| Avg. | | | | | 78.08 | 71.72 | 6.79 | 10.72 |
| M15X-21 | 45 | 15,000 | 275 | 72 | 77.38 | 71.32 | 6.19 | 10.64 |
| M15X-22 | 45 | 15,000 | 275 | 72 | 77.53 | 71.83 | 6.23 | 10.55 |
| Avg. | | | | | 77.46 | 71.58 | 6.21 | 10.60 |
| M15L-23 | L | 15,000 | 275 | 275 | 63.77 | 63.46 | 10.74 | 10.77 |
| M15L-24 | L | 15,000 | 275 | 275 | 63.77 | 63.55 | 12.35 | 10.16 |
| Avg. | | | | | 63.77 | 63.51 | 11.55 | 10.47 |
| M15T-23 | T | 15,000 | 275 | 275 | 66.84 | 65.23 | 11.14 | 10.49 |
| M15T-24 | T | 15,000 | 275 | 275 | 67.34 | 65.08 | 11.94 | 10.53 |
| Avg. | | | | | 67.09 | 65.16 | 11.54 | 10.51 |
| M15X-23 | 45 | 15,000 | 275 | 275 | 66.44 | 64.98 | 9.55 | 10.18 |
| M15X-24 | 45 | 15,000 | 275 | 275 | 66.38 | 64.96 | 9.84 | 10.71 |
| Avg. | | | | | 66.41 | 64.97 | 9.70 | 10.45 |

Table A3. Tensile Results for ML377. (concluded)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| M15L-25 | L | 15,000 | 275 | -65 | 78.91 | 73.79 | 7.64 | 10.89 |
| M15L-26 | L | 15,000 | 275 | -65 | 79.01 | 73.96 | 7.51 | 10.93 |
| Avg. | | | | | 78.96 | 73.88 | 7.58 | 10.91 |
| M15T-25 | T | 15,000 | 275 | -65 | 82.84 | 75.15 | 6.18 | 10.94 |
| M15T-26 | T | 15,000 | 275 | -65 | 83.12 | 75.09 | 6.37 | 11.15 |
| Avg. | | | | | 82.98 | 75.12 | 6.28 | 11.05 |
| M15X-25 | 45 | 15,000 | 275 | -65 | 82.41 | 76.11 | 5.46 | 11.15 |
| M15X-26 | 45 | 15,000 | 275 | -65 | 82.34 | 75.29 | 5.76 | 11.08 |
| Avg. | | | | | 82.38 | 75.70 | 5.61 | 11.12 |
| M30L-1 | L | 30,000 | 225 | 72 | 80.66 | 79.09 | 8.26 | 10.70 |
| M30L-2 | L | 30,000 | 225 | 72 | 80.89 | 79.24 | 8.37 | 10.79 |
| Avg. | | | | | 80.78 | 79.17 | 8.32 | 10.75 |
| M30T-1 | T | 30,000 | 225 | 72 | 84.20 | 78.91 | 7.33 | 10.81 |
| M30T-2 | T | 30,000 | 225 | 72 | 84.23 | 78.46 | 7.63 | 10.75 |
| Avg. | | | | | 84.22 | 78.69 | 7.48 | 10.78 |

Table A4. Tensile Results for RX818.

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| RXL-12 | L | - | - | 72 | 89.1 | 84.6 | 8.6 | 11.0 |
| RXL-14 | L | - | - | 72 | 89.5 | 84.9 | 9.6 | 11.0 |
| RXL-15 | L | - | - | 72 | 89.1 | 84.8 | 9.0 | 10.9 |
| Avg. | | | | | 89.2 | 84.7 | 9.1 | 11.0 |
| RXT-1 | T | - | - | 72 | 85.7 | 81.0 | 10.7 | 11.1 |
| RXT-2 | T | - | - | 72 | 85.5 | 80.7 | 10.7 | 11.1 |
| RXT-11 | T | - | - | 72 | 85.2 | 80.6 | 10.8 | 11.2 |
| Avg. | | | | | 85.5 | 80.8 | 10.7 | 11.1 |
| RX45-1 | 45 | - | - | 72 | 71.6 | 67.9 | 14.9 | 10.5 |
| RX45-2 | 45 | - | - | 72 | 72.1 | 68.5 | >15.00 | 10.7 |
| Avg. | | | | | 71.9 | 68.1 | >15 | 10.6 |
| RXL-13 | L | - | - | 200 | 83.2 | 81.7 | 11.0 | 11.0 |
| RXL-16 | L | - | - | 200 | 83.1 | 81.5 | 11.1 | 11.0 |
| Avg. | | | | | 83.2 | 81.6 | 11.1 | 11.0 |
| RXT-4 | T | - | - | 200 | 79.5 | 77.3 | 12.1 | 11.0 |
| RXT-10 | T | - | - | 200 | 80.4 | 78.0 | 13.3 | 11.0 |
| Avg. | | | | | 80.0 | 77.7 | 12.7 | 11.0 |
| RXL-18 | L | - | - | 225 | 81.20 | 80.2 | 12.1 | 10.9 |
| RXL-19 | L | - | - | 225 | 80.38 | 79.5 | 11.4 | 10.8 |
| Avg. | | | | | 80.79 | 79.9 | 11.8 | 10.9 |
| RXT-5 | T | - | - | 225 | 78.4 | 76.6 | 13.6 | 10.9 |
| RXT.6 | T | - | - | 225 | 78.4 | 76.7 | 14.5 | 10.9 |
| Avg. | | | | | 78.4 | 76.7 | 14.1 | 10.9 |
| RXL-23 | L | - | - | 275 | 76.2 | 76.1 | 14.0 | 10.7 |
| RXL-27 | L | - | - | 275 | 76.5 | 76.3 | 13.2 | 10.7 |
| Avg. | | | | | 76.4 | 76.2 | 13.6 | 10.7 |

Table A4. Tensile Results for RX818. (concluded)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| RXT-7 | T | - | - | 275 | 74.1 | 74.0 | 14.2 | 10.8 |
| RXT-8 | T | - | - | 275 | 74.0 | 73.8 | 14.6 | 10.8 |
| Avg. | | | | | 74.1 | 73.9 | 14.4 | 10.8 |
| RXL-2 | L | 301 | 200 | 72 | 88.1 | 84.2 | 8.9 | 10.7 |
| | | | | | | | | |
| RXL-5 | L | 301 | 225 | 72 | 89.0 | 85.2 | 9.0 | 10.8 |
| RXL-6 | L | 301 | 225 | 72 | 89.0 | 85.3 | 9.0 | 10.8 |
| Avg. | | | | | 89.0 | 85.3 | 9.0 | 10.8 |
| RXL-3 | L | 1006 | 200 | 72 | 89.9 | 86.2 | 9.0 | 11.0 |
| RXL-4 | L | 1006 | 200 | 72 | 89.5 | 85.9 | 9.0 | 11.0 |
| Avg. | | | | | 89.7 | 86.1 | 9.0 | 11.0 |
| RXL-7 | L | 1006 | 225 | 72 | 90.8 | 87.4 | 8.8 | 11.0 |
| RXL-8 | L | 1006 | 225 | 72 | 90.9 | 87.7 | 8.9 | 11.0 |
| Avg. | | | | | 90.9 | 87.6 | 8.9 | 11.0 |
| RXL-9 | L | 1006 | 275 | 72 | 91.1 | 87.9 | 8.1 | 11.0 |
| RXL-10 | L | 1006 | 275 | 72 | 91.1 | 87.7 | 8.4 | 10.9 |
| Avg. | | | | | 91.1 | 87.8 | 8.3 | 11.0 |
| NRX20-1 | L | 3000 | 200 | 72 | 90.2 | 86.5 | 9.3 | 10.8 |
| NRX20-2 | L | 3000 | 200 | 72 | 90.0 | 86.2 | 9.1 | 10.8 |
| Avg. | | | | | 90.1 | 86.4 | 9.2 | 10.8 |
| NRX25-1 | L | 3000 | 225 | 72 | 90.9 | 87.8 | 8.8 | 10.7 |
| NRX25-2 | L | 3000 | 225 | 72 | 91.2 | 87.7 | 9.1 | 10.8 |
| Avg. | | | | | 91.1 | 87.8 | 9.0 | 10.8 |

Table A5. Tensile Results for CM001.

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| CML-1 | L | - | - | 72 | 62.8 | 59.7 | 7.8 | 9.9 |
| CML-2 | L | - | - | 72 | 62.8 | 59.6 | 7.9 | 10.0 |
| CML-3 | L | - | - | 72 | 62.7 | 59.5 | 7.7 | 10.0 |
| Avg. | | | | | 62.8 | 59.6 | 7.8 | 10.0 |
| CMT-1 | T | - | - | 72 | 62.2 | 57.4 | 7.1 | 9.7 |
| CMT-2 | T | - | - | 72 | 62.1 | 57.4 | 7.2 | 9.9 |
| CMT-3 | T | - | - | 72 | 62.2 | 57.1 | 7.3 | 10.0 |
| Avg. | | | | | 62.2 | 57.3 | 7.2 | 9.9 |
| CML-14 | L | - | - | 200 | 58.7 | 56.5 | 7.9 | 9.5 |
| CML-15 | L | - | - | 200 | 59.2 | 57.0 | 7.9 | 9.4 |
| Avg. | | | | | 59.0 | 56.8 | 7.9 | 9.5 |
| CMT-26 | T | - | - | 200 | 58.9 | 55.3 | 7.7 | 9.4 |
| CMT-27 | T | - | - | 200 | 58.9 | 55.0 | 7.6 | 9.4 |
| Avg. | | | | | 58.9 | 55.2 | 7.7 | 9.4 |
| CML-12 | L | - | - | 225 | 58.0 | 56.0 | 8.4 | 9.4 |
| CML-13 | L | - | - | 225 | 58.2 | 56.3 | 8.3 | 9.4 |
| Avg. | | | | | 58.1 | 56.2 | 8.4 | 9.4 |
| CMT-24 | T | - | - | 225 | 57.8 | 54.2 | 7.9 | 9.3 |
| CMT-25 | T | - | - | 225 | 57.7 | 54.5 | 8.0 | 9.2 |
| Avg. | | | | | 57.8 | 54.4 | 8.0 | 9.3 |
| CML-16 | L | - | - | -65 | 65.5 | 62.1 | 8.3 | 10.1 |
| CML-17 | L | - | - | -65 | 65.5 | 62.1 | 8.4 | 10.2 |
| Avg. | | | | | 65.5 | 62.1 | 8.4 | 10.2 |
| CMT-28 | T | - | - | -65 | 64.9 | 59.9 | 7.6 | 10.0 |
| CMT-29 | T | - | - | -65 | 64.9 | 59.4 | 7.2 | 10.1 |
| Avg. | | | | | 64.9 | 59.7 | 7.4 | 10.1 |

Table A5. Tensile Results for CM001. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| CM1L-1 | L | 3300 | 200 | 72 | 62.7 | 59.8 | 7.5 | 9.9 |
| CM1L-2 | L | 3300 | 200 | 72 | 62.6 | 59.9 | 7.3 | 9.8 |
| Avg. | | | | | 62.7 | 59.9 | 7.4 | 9.9 |
| CM1T-1 | T | 3300 | 200 | 72 | 62.6 | 58.0 | 6.9 | 9.9 |
| CM1T-2 | T | 3300 | 200 | 72 | 62.4 | 57.8 | 6.7 | 9.8 |
| Avg. | | | | | 62.5 | 57.9 | 6.8 | 9.9 |
| CM6L-1 | L | 3300 | 225 | 72 | 62.7 | 59.7 | 7.8 | 9.9 |
| CM6L-2 | L | 3300 | 225 | 72 | 62.3 | 59.6 | 7.4 | 9.6 |
| Avg. | | | | | 62.5 | 59.7 | 7.6 | 9.8 |
| CM6T-1 | T | 3300 | 225 | 72 | 62.9 | 60.0 | 7.6 | 9.9 |
| CM6T-2 | T | 3300 | 225 | 72 | 62.2 | 57.7 | 7.0 | 9.7 |
| Avg. | | | | | 62.6 | 58.9 | 7.3 | 9.8 |
| CM0L-1 | L | 10,000 | 200 | 72 | 63.1 | 60.1 | 7.6 | 10.0 |
| CM0L-2 | L | 10,000 | 200 | 72 | 63.0 | 60.2 | 7.8 | 10.0 |
| Avg. | | | | | 63.1 | 60.2 | 7.7 | 10.0 |
| CM0T-1 | T | 10,000 | 200 | 72 | 62.5 | 57.6 | 7.1 | 9.8 |
| CM0T-2 | T | 10,000 | 200 | 72 | 62.3 | 57.5 | 7.1 | 9.9 |
| Avg. | | | | | 62.4 | 57.6 | 7.1 | 9.9 |
| CM0L-3 | L | 10,000 | 200 | 200 | 59.5 | 57.4 | 8.3 | 9.5 |
| CM0L-4 | L | 10,000 | 200 | 200 | 59.6 | 57.5 | 8.1 | 9.6 |
| Avg. | | | | | 59.6 | 57.5 | 8.2 | 9.6 |
| CM0T-3 | T | 10,000 | 200 | 200 | 59.1 | 55.4 | 7.8 | 9.5 |
| CM0T-4 | T | 10,000 | 200 | 200 | 59.1 | 55.4 | 8.1 | 9.5 |
| Avg. | | | | | 59.1 | 55.4 | 8.0 | 9.5 |
| CM0L-5 | L | 10,000 | 200 | -65 | 66.1 | 62.7 | 8.6 | 10.1 |
| CM0L-6 | L | 10,000 | 200 | -65 | 66.1 | 63.0 | 8.2 | 10.3 |
| Avg. | | | | | 66.1 | 62.9 | 8.4 | 10.2 |

Table A5. Tensile Results for CM001. (concluded)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| CM0T-5 | T | 10,000 | 200 | -65 | 65.6 | 60.2 | 8.0 | 10.1 |
| CM0T-6 | T | 10,000 | 200 | -65 | 65.7 | 60.7 | 7.5 | 10.2 |
| Avg. | | | | | 65.7 | 60.5 | 7.8 | 10.2 |
| CM5L-1 | L | 10,000 | 225 | 72 | 62.7 | 59.7 | 7.7 | 9.9 |
| CM5L-2 | L | 10,000 | 225 | 72 | 62.5 | 59.4 | 8.0 | 9.8 |
| Avg. | | | | | 62.6 | 59.6 | 7.9 | 9.9 |
| CM5T-1 | T | 10,000 | 225 | 72 | 62.5 | 57.8 | 7.3 | 9.7 |
| CM5T-2 | T | 10,000 | 225 | 72 | 62.2 | 57.7 | 7.0 | 10.0 |
| Avg. | | | | | 62.4 | 57.8 | 7.2 | 9.9 |
| CM5L-3 | L | 10,000 | 225 | 225 | 57.7 | --- | 9.3 | --- |
| CM5L-4 | L | 10,000 | 225 | 225 | 57.8 | 56.0 | 8.9 | 9.5 |
| Avg. | | | | | 57.8 | 56.0 | 9.1 | 9.5 |
| CM5T-3 | T | 10,000 | 225 | 225 | 57.7 | 54.4 | 7.7 | 9.5 |
| CM5T-4 | T | 10,000 | 225 | 225 | 57.9 | 54.3 | 7.8 | 9.3 |
| Avg. | | | | | 57.8 | 54.4 | 7.8 | 9.4 |
| CM5L-5 | L | 10,000 | 225 | -65 | 65.7 | 62.3 | 8.6 | 10.3 |
| CM5L-6 | L | 10,000 | 225 | -65 | 65.8 | 62.4 | 8.4 | 10.3 |
| Avg. | | | | | 65.8 | 62.4 | 8.5 | 10.3 |
| CM5T-5 | T | 10,000 | 225 | -65 | 65.7 | 60.5 | 7.7 | 10.4 |
| CM5T-6 | T | 10,000 | 225 | -65 | 65.7 | 60.6 | 7.6 | 10.1 |
| Avg. | | | | | 65.7 | 60.6 | 7.7 | 10.3 |

Table A6. Tensile Results for 1143.

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 43L-1 | L | - | - | 72 | 60.1 | 55.4 | 10.8 | 10.3 |
| 43L-2 | L | - | - | 72 | 59.8 | 54.9 | 10.7 | 10.4 |
| 43L-3 | L | - | - | 72 | 59.8 | 55.1 | 10.9 | 10.3 |
| Avg. | | | | | 59.9 | 55.1 | 10.8 | 10.3 |
| 43T-1 | T | - | - | 72 | 60.9 | 54.2 | 9.7 | 10.4 |
| 43T-2 | T | - | - | 72 | 61.3 | 55.1 | 10.2 | 10.5 |
| 43T-3 | T | - | - | 72 | 61.5 | 55.0 | 9.3 | 10.5 |
| Avg. | | | | | 61.2 | 54.8 | 9.7 | 10.5 |
| 43L-14 | L | - | - | 200 | 58.0 | 53.4 | 10.9 | 10.0 |
| 43L-15 | L | - | - | 200 | 58.1 | 53.8 | 10.4 | 9.9 |
| Avg. | | | | | 58.1 | 53.6 | 10.7 | 10.0 |
| 43T-26 | T | - | - | 200 | 59.8 | 53.7 | 10.5 | 10.4 |
| 43T-27 | T | - | - | 200 | 59.6 | 53.4 | 10.1 | 9.7 |
| Avg. | | | | | 59.7 | 53.6 | 10.3 | 10.1 |
| 43L-12 | L | - | - | 225 | 56.9 | 52.8 | 11.3 | 9.8 |
| 43L-13 | L | - | - | 225 | 57.2 | 53.0 | 11.8 | 9.8 |
| Avg. | | | | | 57.1 | 52.9 | 11.6 | 9.8 |
| 43T-24 | T | - | - | 225 | 58.6 | 52.8 | 11.3 | 9.9 |
| 43T-25 | T | - | - | 225 | 58.6 | 52.7 | 11.5 | 9.7 |
| Avg. | | | | | 58.6 | 52.8 | 11.4 | 9.8 |
| 43L-16 | L | - | - | -65 | 62.4 | 56.6 | 12.0 | 10.3 |
| 43L-17 | L | - | - | -65 | 62.4 | 56.5 | 12.0 | 10.6 |
| Avg. | | | | | 62.4 | 56.6 | 12.0 | 10.5 |
| 43T-28 | T | - | - | -65 | 63.5 | 56.4 | 11.6 | 10.2 |
| 43T-29 | T | - | - | -65 | 63.6 | 55.9 | 11.0 | 10.8 |
| Avg. | | | | | 63.6 | 56.2 | 11.3 | 10.5 |

Table A6. Tensile Results for 1143. (continued)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 431L-1 | L | 3300 | 200 | 72 | 61.0 | 56.0 | 10.7 | 10.3 |
| 431L-2 | L | 3300 | 200 | 72 | 60.9 | 55.5 | 10.9 | 10.2 |
| Avg. | | | | | 61.0 | 55.8 | 10.8 | 10.3 |
| 431T-1 | T | 3300 | 200 | 72 | 62.0 | 55.8 | 9.5 | 10.3 |
| 431T-2 | T | 3300 | 200 | 72 | 61.6 | 55.1 | 9.5 | 10.2 |
| Avg. | | | | | 61.8 | 55.5 | 9.5 | 10.3 |
| 435L-1 | L | 3300 | 225 | 72 | 61.6 | 57.0 | 10.7 | 10.3 |
| 435L-2 | L | 3300 | 225 | 72 | 61.4 | 56.3 | 10.4 | 10.4 |
| Avg. | | | | | 61.5 | 56.7 | 10.6 | 10.4 |
| 435T-1 | T | 3300 | 225 | 72 | 62.6 | 56.6 | 9.1 | 10.5 |
| 435T-2 | T | 3300 | 225 | 72 | 61.5 | 57.1 | 10.7 | 10.3 |
| Avg. | | | | | 62.1 | 56.9 | 9.9 | 10.4 |
| 30L-1 | L | 10,000 | 200 | 72 | 61.7 | 56.7 | 11.2 | 10.2 |
| 30L-2 | L | 10,000 | 200 | 72 | 61.8 | 56.6 | 11.4 | 10.4 |
| Avg. | | | | | 61.8 | 56.7 | 11.3 | 10.3 |
| 30T-1 | T | 10,000 | 200 | 72 | 64.4 | 56.8 | 10.3 | 10.1 |
| 30T-2 | T | 10,000 | 200 | 72 | 64.2 | 56.7 | 9.6 | 10.4 |
| Avg. | | | | | 64.3 | 56.8 | 10.0 | 10.3 |
| 30L-3 | L | 10,000 | 200 | 200 | 58.5 | 54.7 | 10.8 | 10.1 |
| 30L-4 | L | 10,000 | 200 | 200 | 58.9 | 54.9 | 11.2 | 10.1 |
| Avg. | | | | | 58.7 | 54.8 | 11.0 | 10.1 |
| 30T-3 | T | 10,000 | 200 | 200 | 61.5 | 55.0 | 11.9 | 10.1 |
| 30T-4 | T | 10,000 | 200 | 200 | 61.3 | 55.0 | 12.3 | 10.3 |
| Avg. | | | | | 61.4 | 55.0 | 12.1 | 10.2 |
| 30L-5 | L | 10,000 | 200 | -65 | 63.8 | 57.8 | 12.2 | 11.4 |
| 30L-6 | L | 10,000 | 200 | -65 | 64.9 | 59.2 | 12.1 | 11.2 |
| Avg. | | | | | 64.4 | 58.5 | 12.2 | 11.3 |

Table A6. Tensile Results for 1143. (concluded)

| Specimen | Orientation | Exposure time, hours | Exposure Temp, °F | Test Temp, °F | UTS, ksi | YS, ksi | % el | E, Msi |
|---|---|---|---|---|---|---|---|---|
| 30T-5 | T | 10,000 | 200 | -65 | 67.0 | 58.7 | 11.2 | 10.5 |
| 30T-6 | T | 10,000 | 200 | -65 | 66.8 | 58.4 | 11.5 | 11.5 |
| Avg. | | | | | 66.9 | 58.6 | 11.4 | 11.0 |
| 35L-1 | L | 10,000 | 225 | 72 | 61.5 | 56.7 | 10.9 | 10.1 |
| 35L-2 | L | 10,000 | 225 | 72 | 62.0 | 57.4 | 10.8 | 10.3 |
| Avg. | | | | | 61.8 | 57.1 | 10.9 | 10.2 |
| 35T-1 | T | 10,000 | 225 | 72 | 62.3 | 56.3 | 9.5 | 10.1 |
| 35T-2 | T | 10,000 | 225 | 72 | 62.3 | 56.2 | 9.9 | 10.2 |
| Avg. | | | | | 62.3 | 56.3 | 9.7 | 10.2 |
| 35L-3 | L | 10,000 | 225 | 225 | 58.0 | 54.6 | 12.0 | 9.7 |
| 35L-4 | L | 10,000 | 225 | 225 | 58.0 | 55.0 | 12.3 | 10.0 |
| Avg. | | | | | 58.0 | 54.8 | 12.2 | 9.9 |
| 35T-3 | T | 10,000 | 225 | 225 | 58.0 | 54.4 | 11.2 | 9.4 |
| 35T-4 | T | 10,000 | 225 | 225 | 58.1 | 54.4 | 12.0 | 9.7 |
| Avg. | | | | | 58.1 | 54.4 | 11.6 | 9.6 |
| 35L-5 | L | 10,000 | 225 | -65 | 64.8 | 58.9 | 12.3 | 10.7 |
| 35L-6 | L | 10,000 | 225 | -65 | 64.9 | 59.2 | 12.1 | 11.2 |
| Avg. | | | | | 64.9 | 59.1 | 12.2 | 11.0 |
| 35T-5 | T | 10,000 | 225 | -65 | 65.3 | 58.9 | 10.7 | 10.3 |
| 35T-6 | T | 10,000 | 225 | -65 | 65.2 | 58.7 | 10.9 | 10.7 |
| Avg. | | | | | 65.3 | 58.8 | 10.8 | 10.5 |

Appendix B. Graphs illustrating trends in tensile properties with test temperature for alloys C415-T8, C416-T8, RX818-T8, ML377-T8, CM001-T6 and 1143-T651.

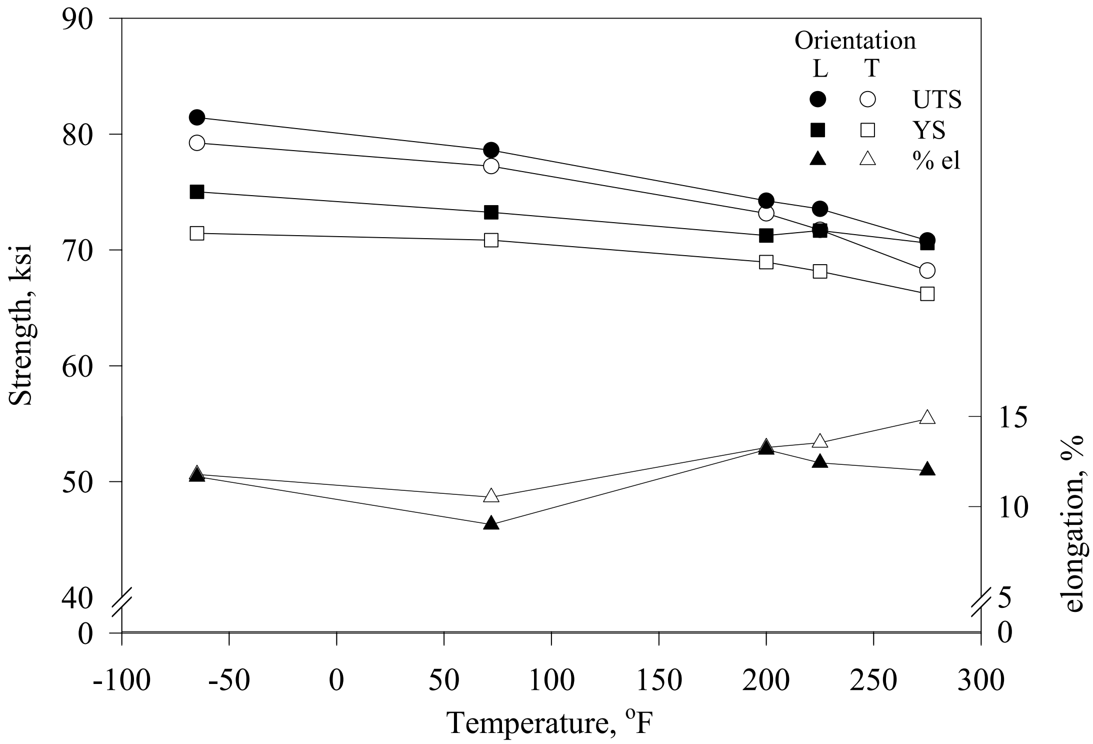



Figure B1. Variation in tensile properties with test temperature for C415-T8.

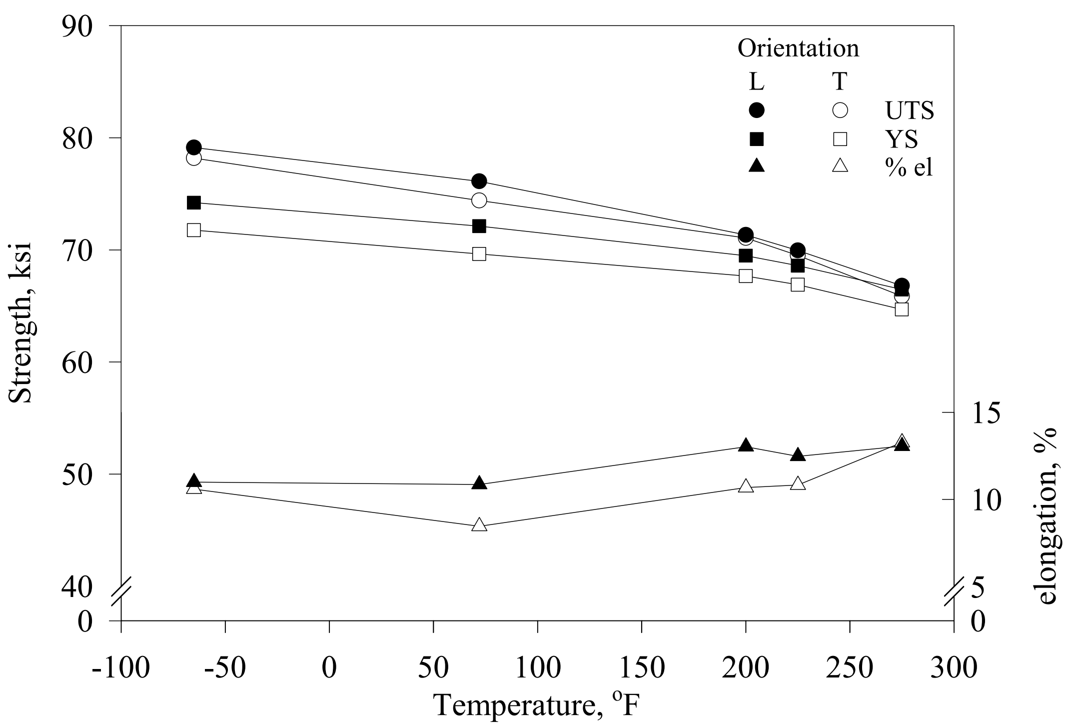



Figure B2. Variation in tensile properties with test temperature for C416-T8.

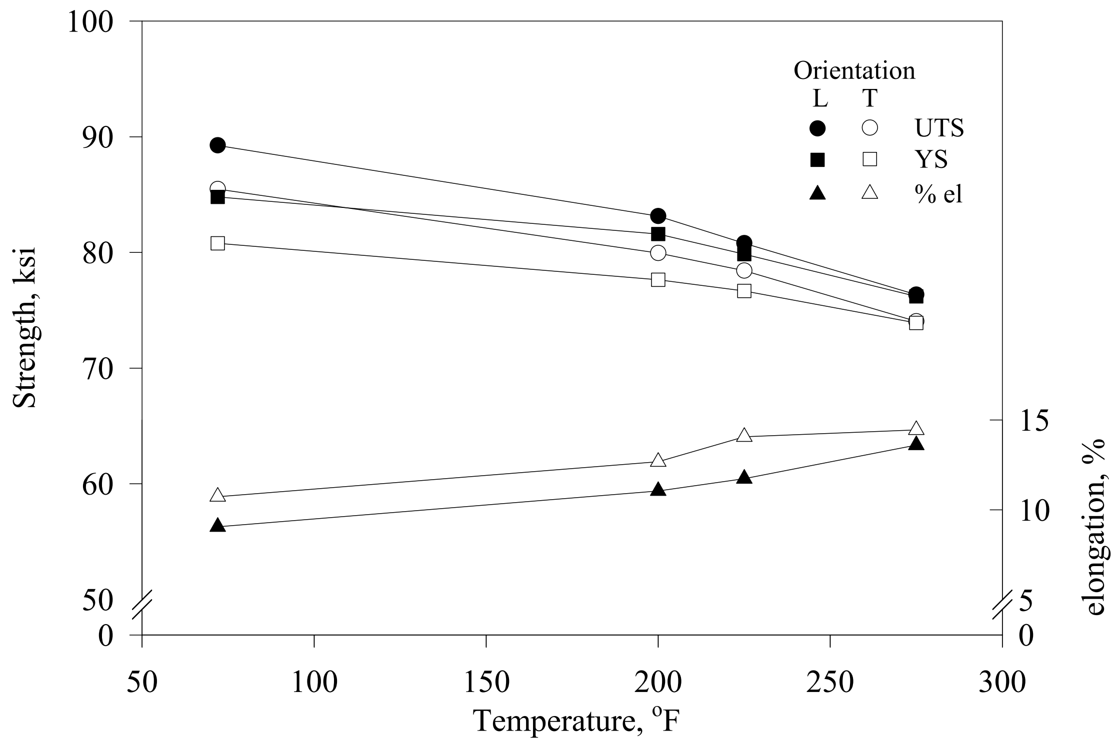



Figure B3. Variation in tensile properties with test temperature for RX818-T8.

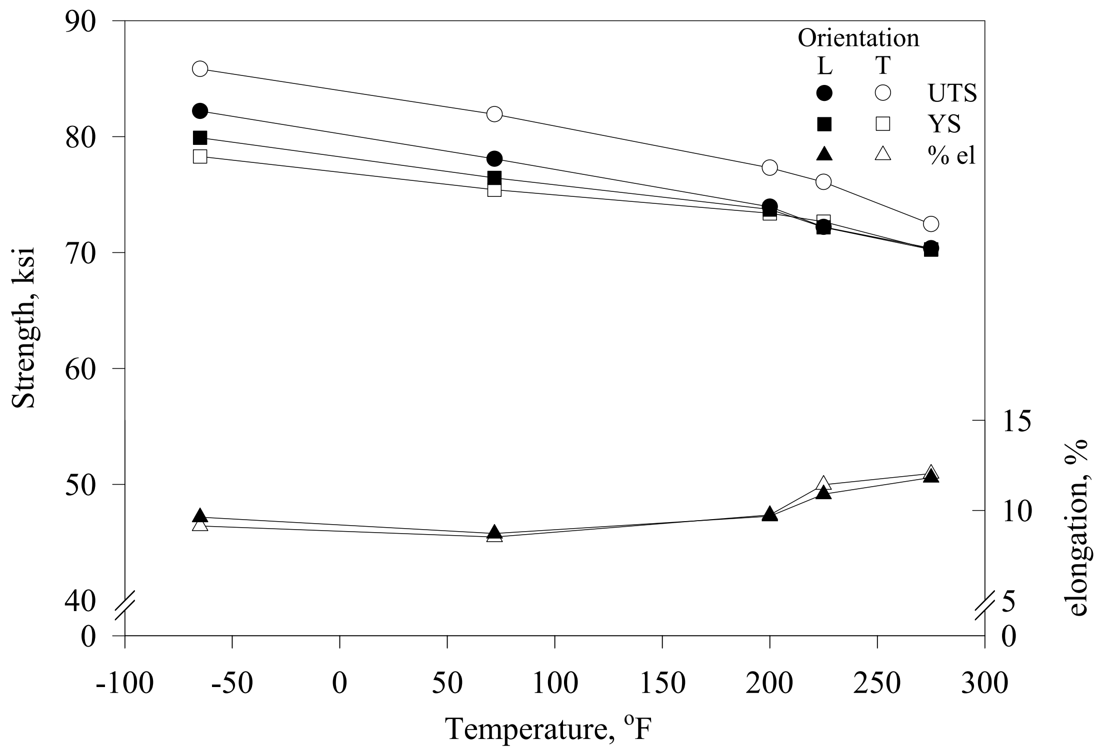



Figure B4. Variation in tensile properties with test temperature for ML377-T8.

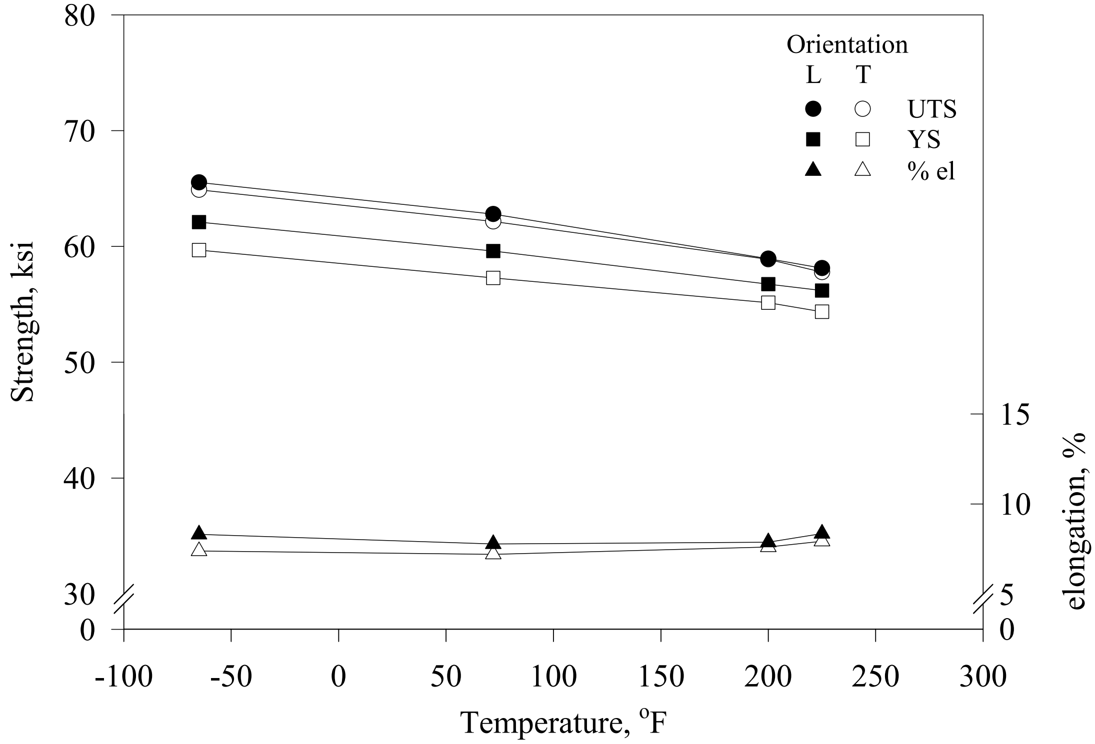



Figure B5. Variation in tensile properties with test temperature for CM001-T6.

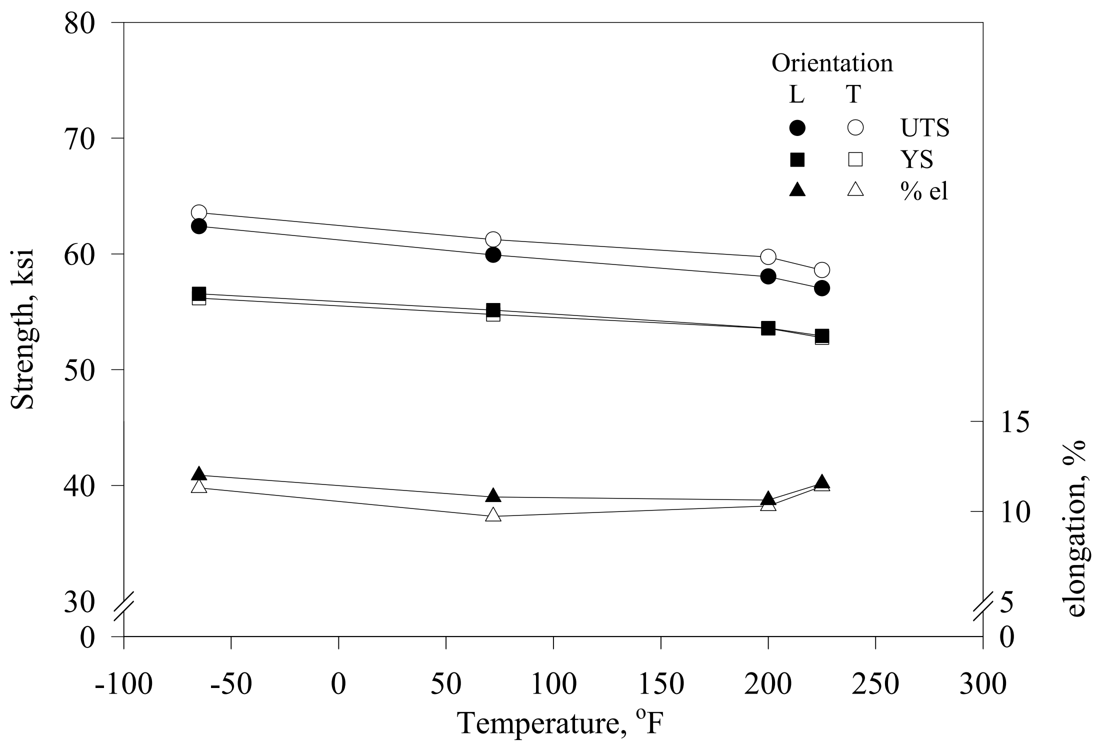



Figure B6. Variation in tensile properties with test temperature for 1143-T651.

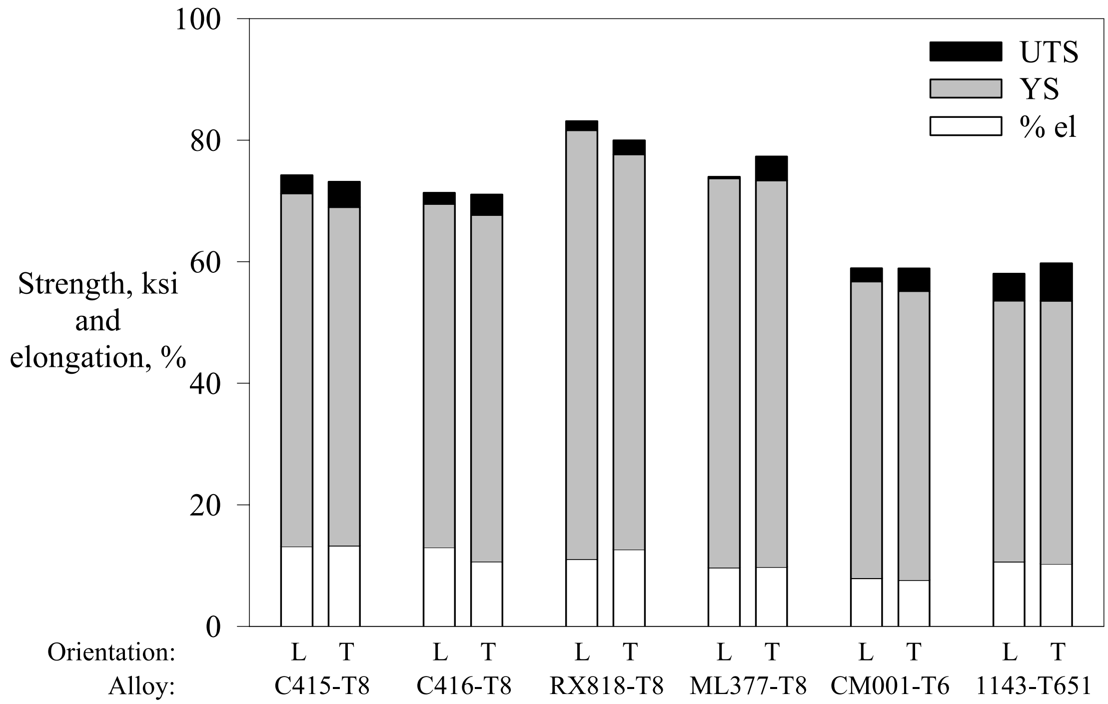



Figure B7. Tensile properties of candidate and baseline alloys at 200ºF.

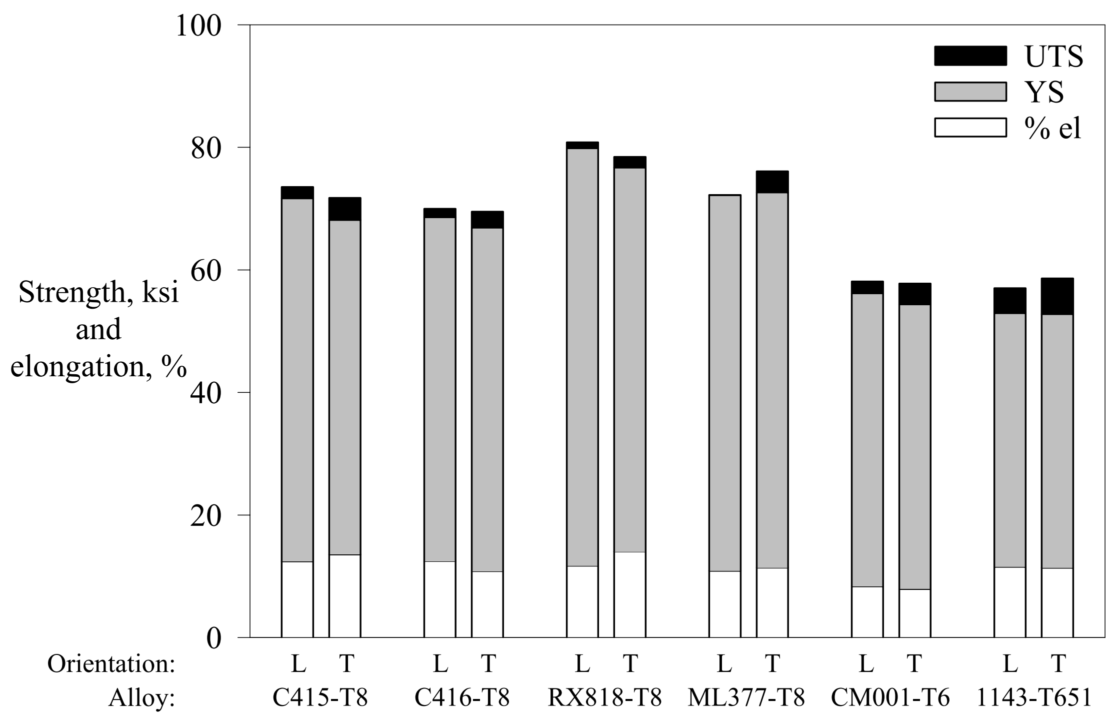



Figure B8. Tensile properties of candidate and baseline alloys at 225ºF.

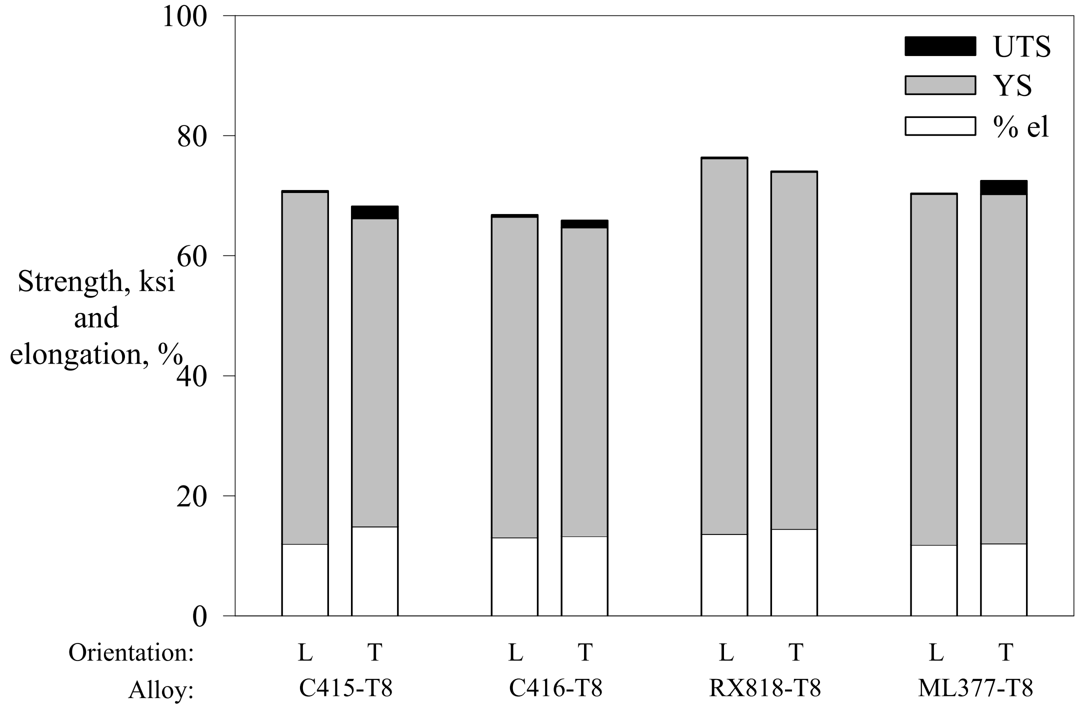



Figure B9. Tensile properties of candidate and baseline alloys at 275ºF.

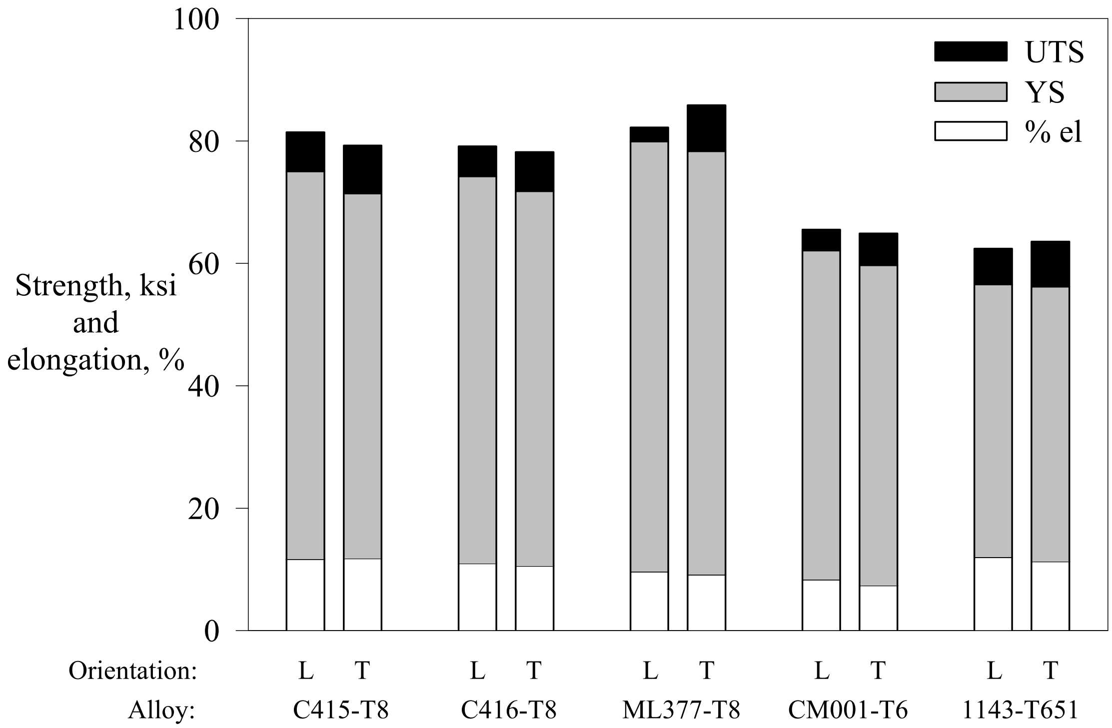
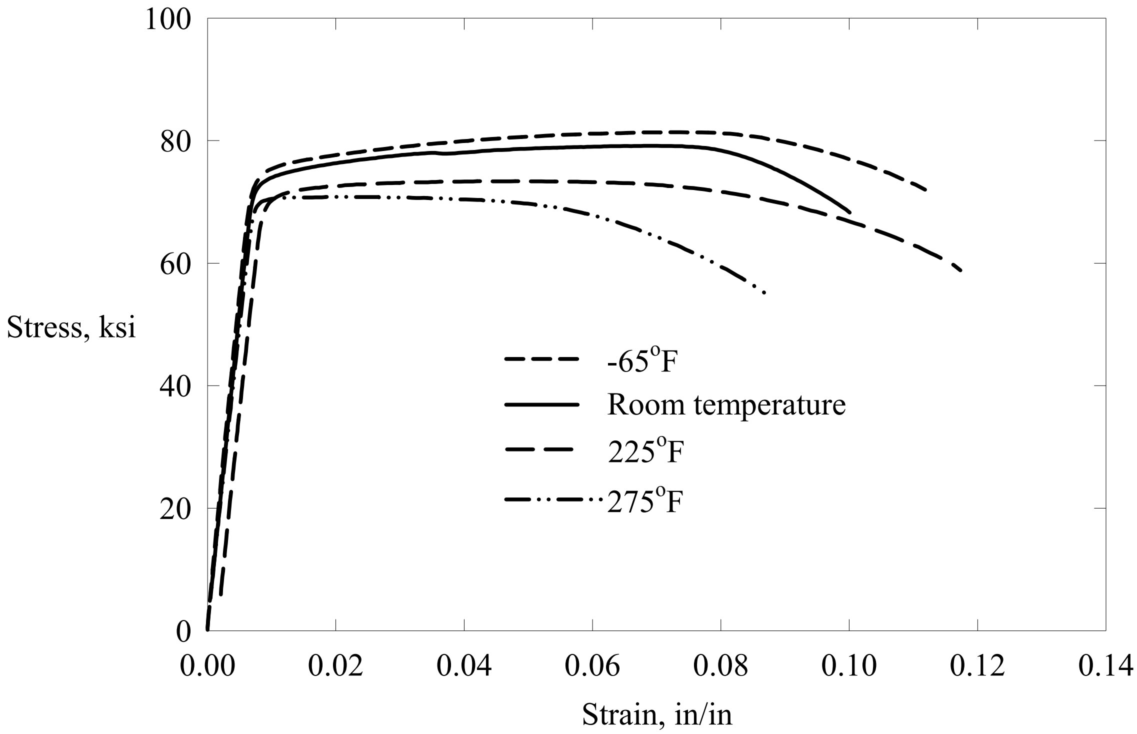
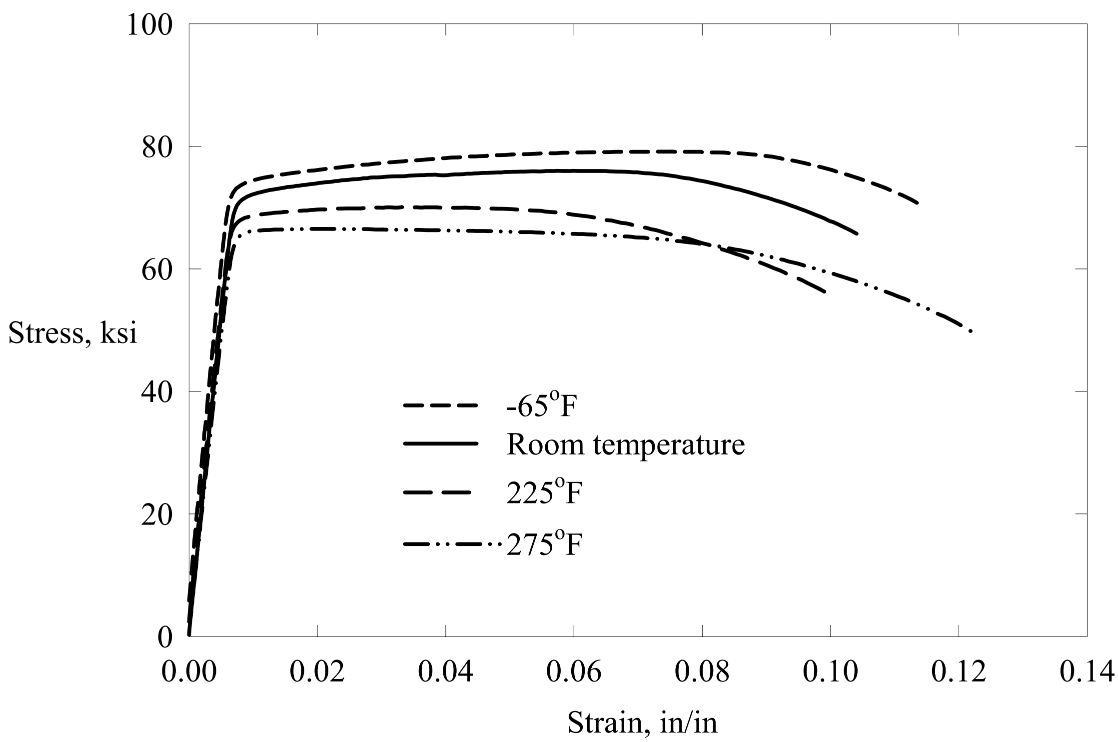


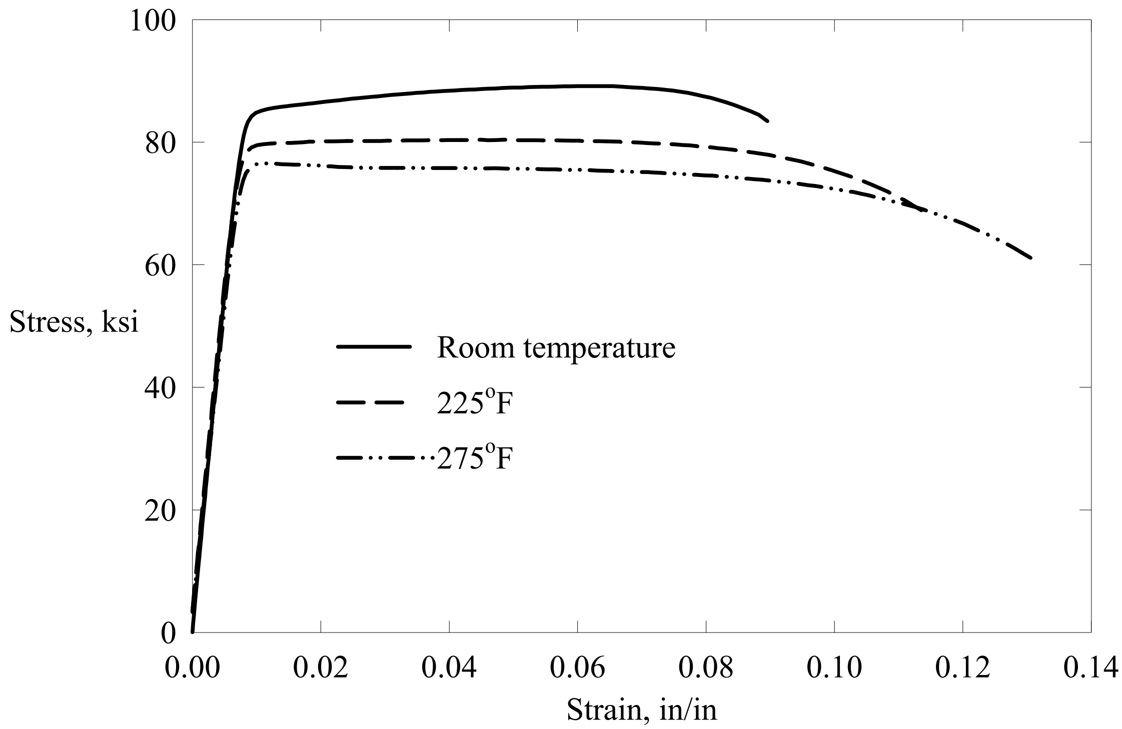

Figure B10. Tensile properties of candidate and baseline alloys at -65ºF.



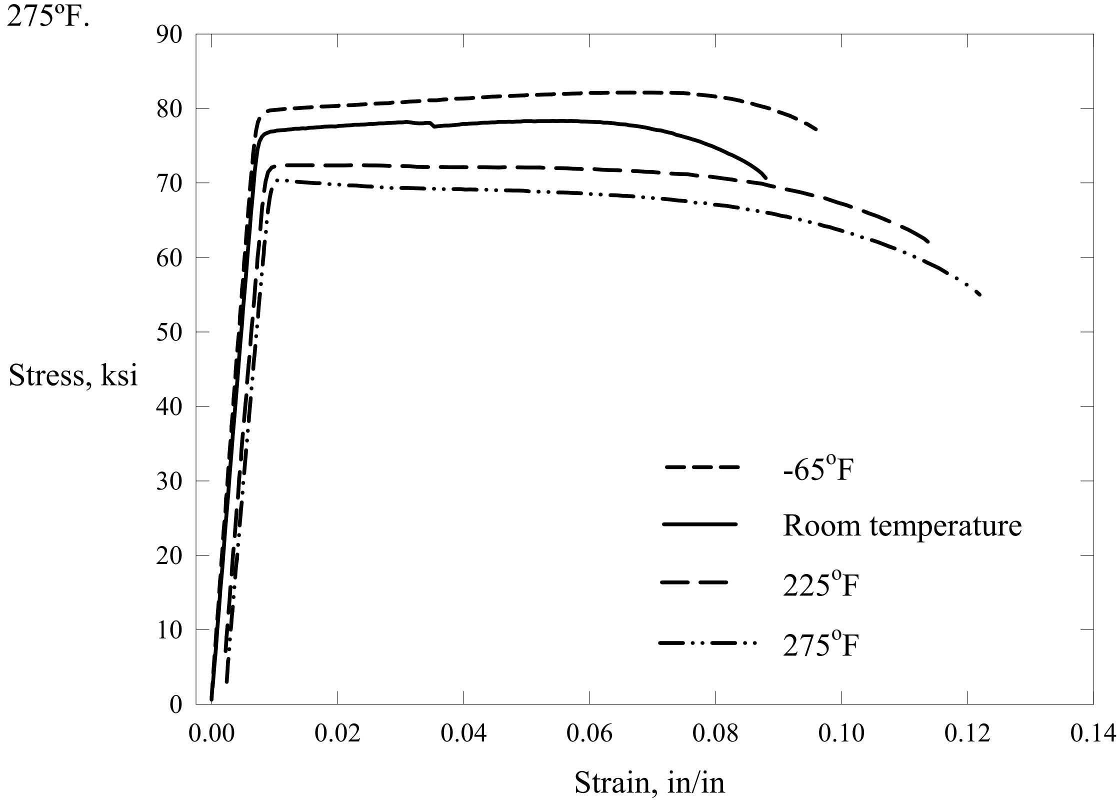

B11. Longitudinal stress-strain curves for C415-T8 tested at -65ºF, room temperature, 225ºF, and 275ºF.



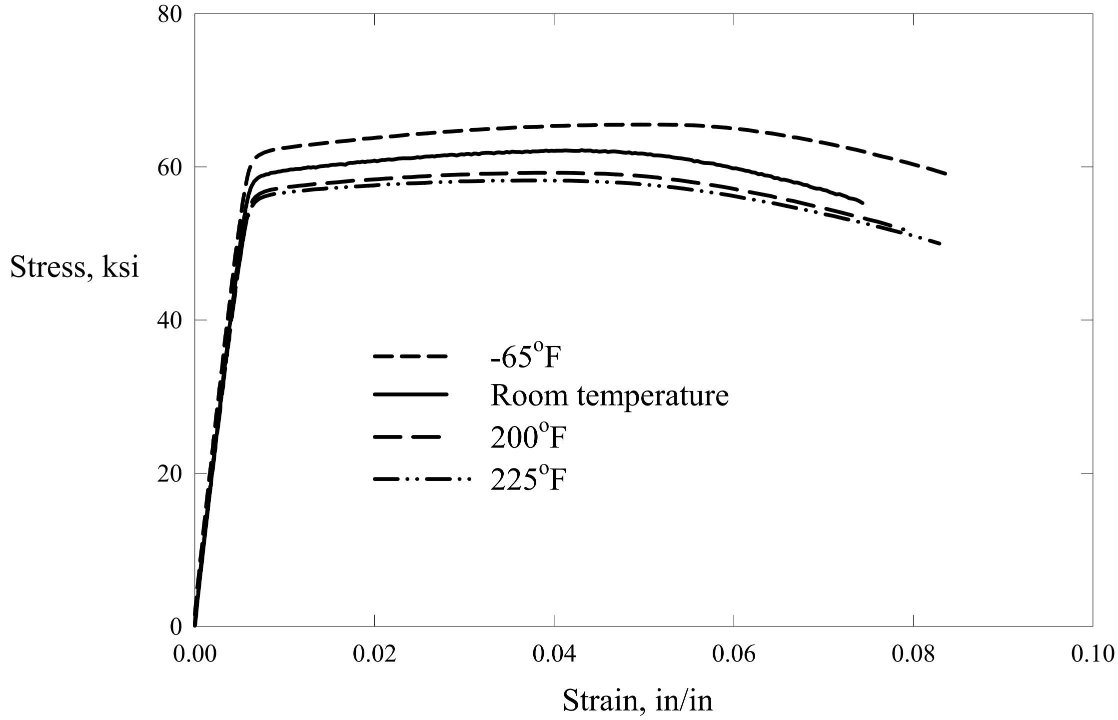

B12. Longitudinal stress-strain curves for C416-T8 tested at -65ºF, room temperature, 225ºF, and 275ºF.



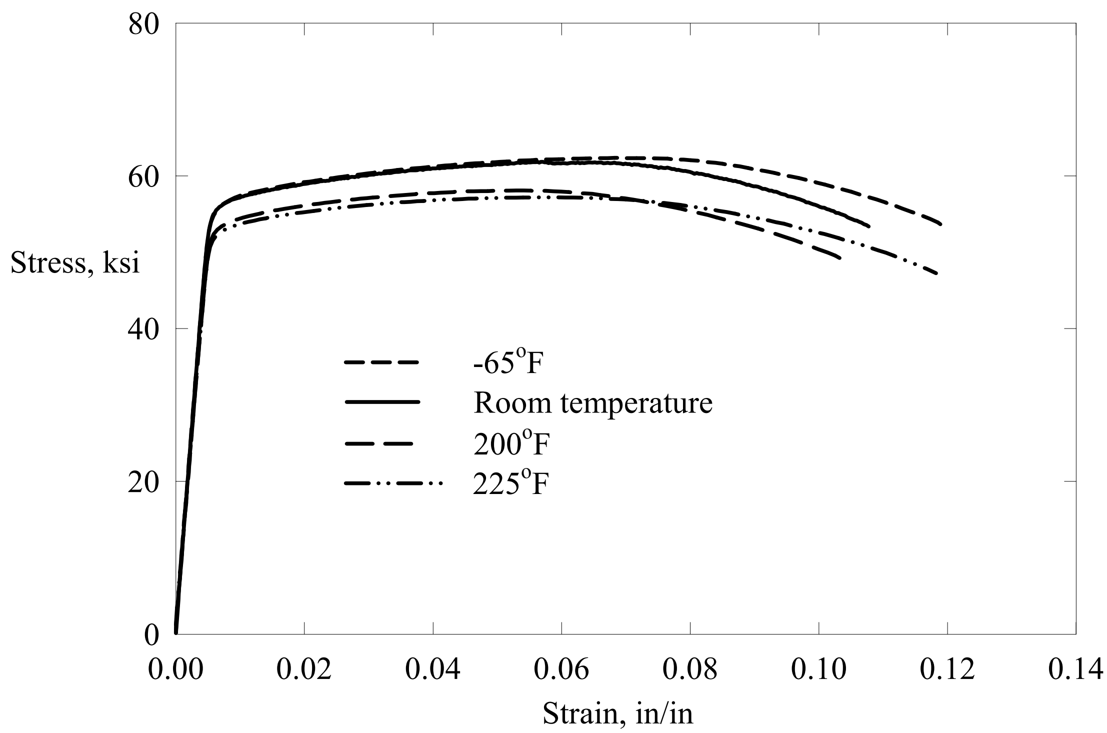

B13. Longitudinal stress-strain curves for RX818-T8 tested at -65ºF, room temperature, 225ºF, and 275ºF.




B14. Longitudinal stress-strain curves for ML377-T8 tested at -65°F, room temperature, 225°F, and 275°F.




B15. Longitudinal stress-strain curves for CM001-T6 tested at -65°F, room temperature, 200°F, and 225°F.




B16. Longitudinal stress-strain curves for 1143-T651 tested at -65°F, room temperature, 200°F, and 225°F.

Appendix C. Graphs illustrating the effect of thermal exposure on tensile properties for alloys C415, C416, RX818, ML377, CM001 and 1143.

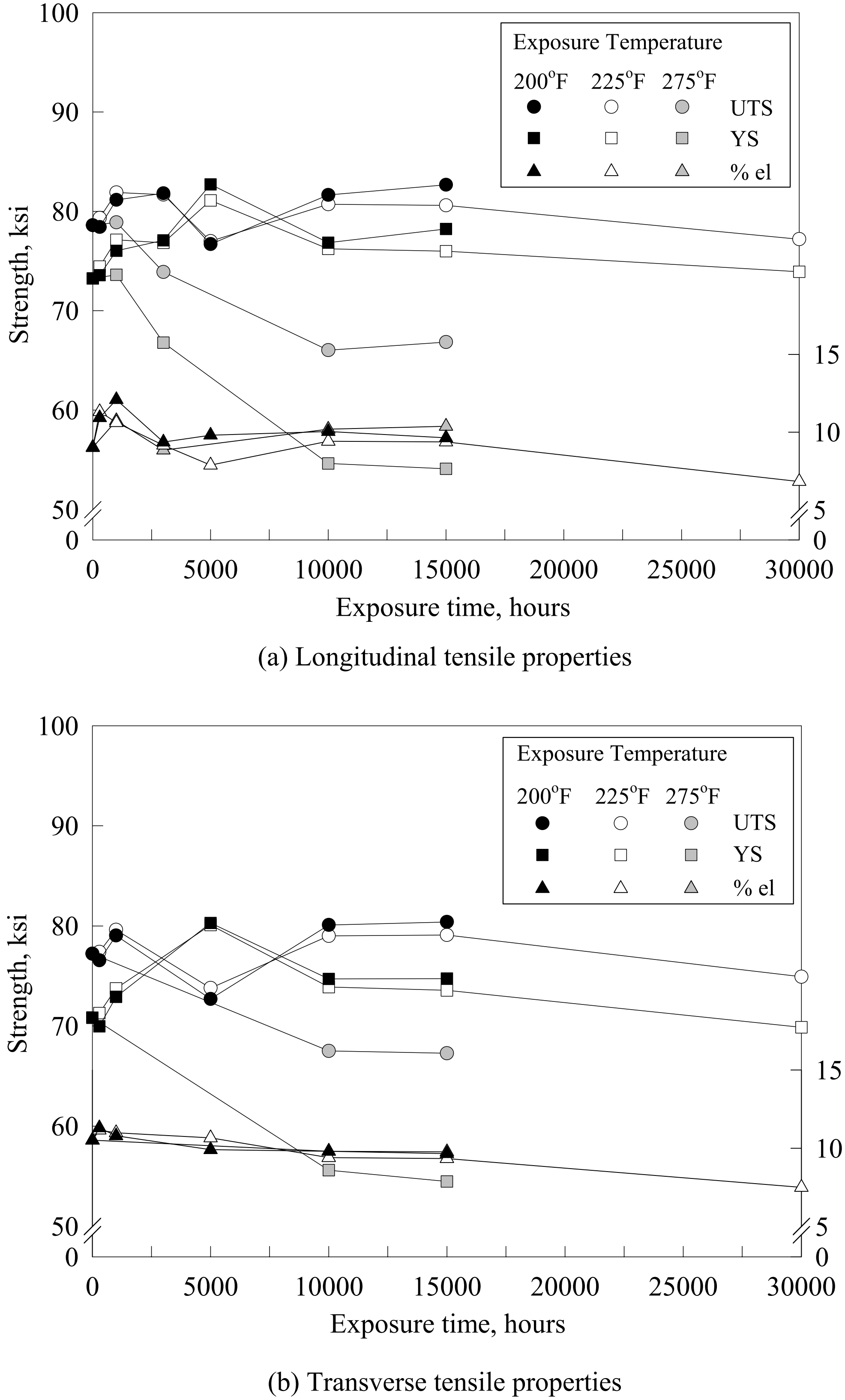
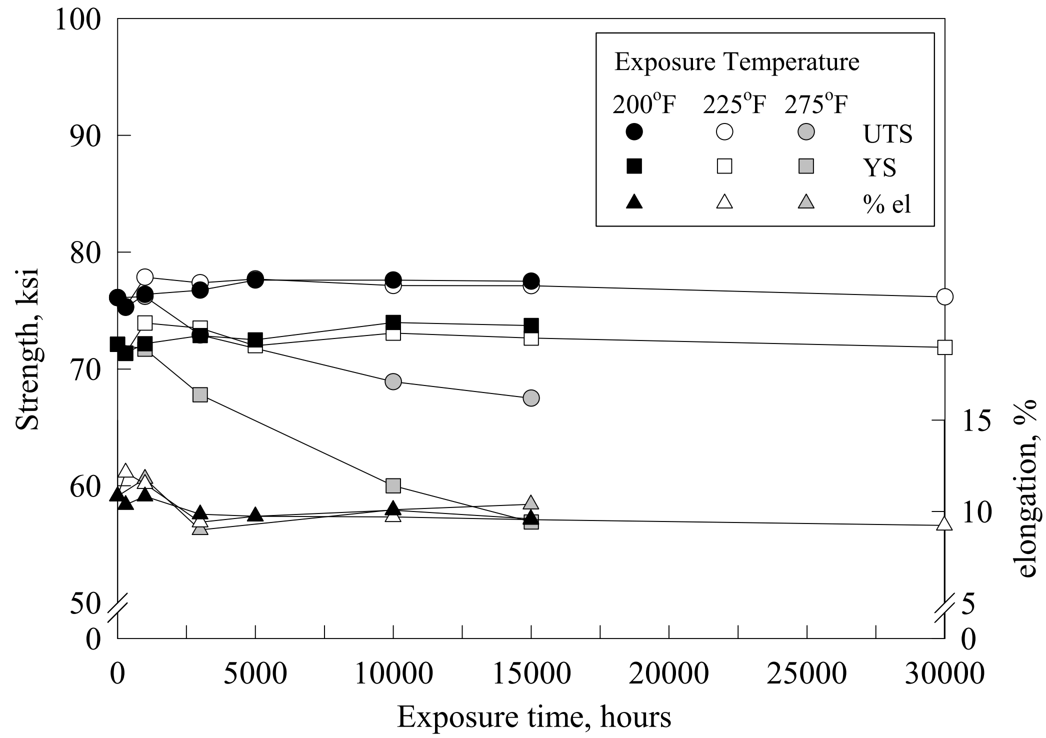
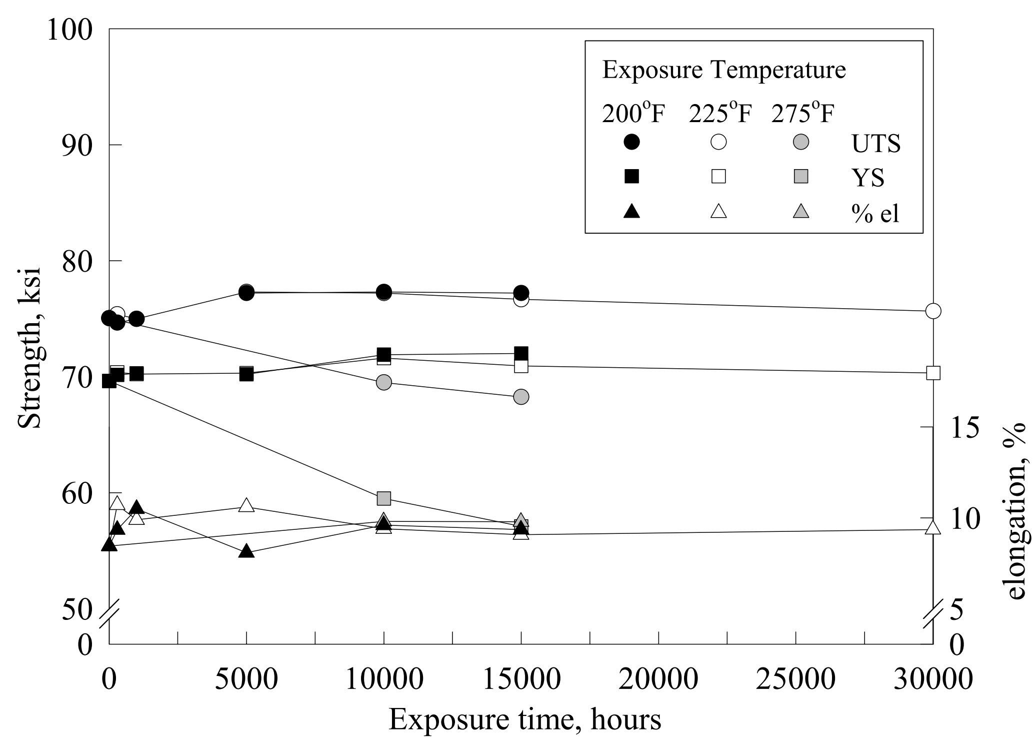



Figure C1. Variation in room temperature tensile properties with thermal exposure for C415.




(a) Longitudinal tensile properties




(b) Transverse tensile properties

Figure C2. Variation in room temperature tensile properties with thermal exposure for C416.

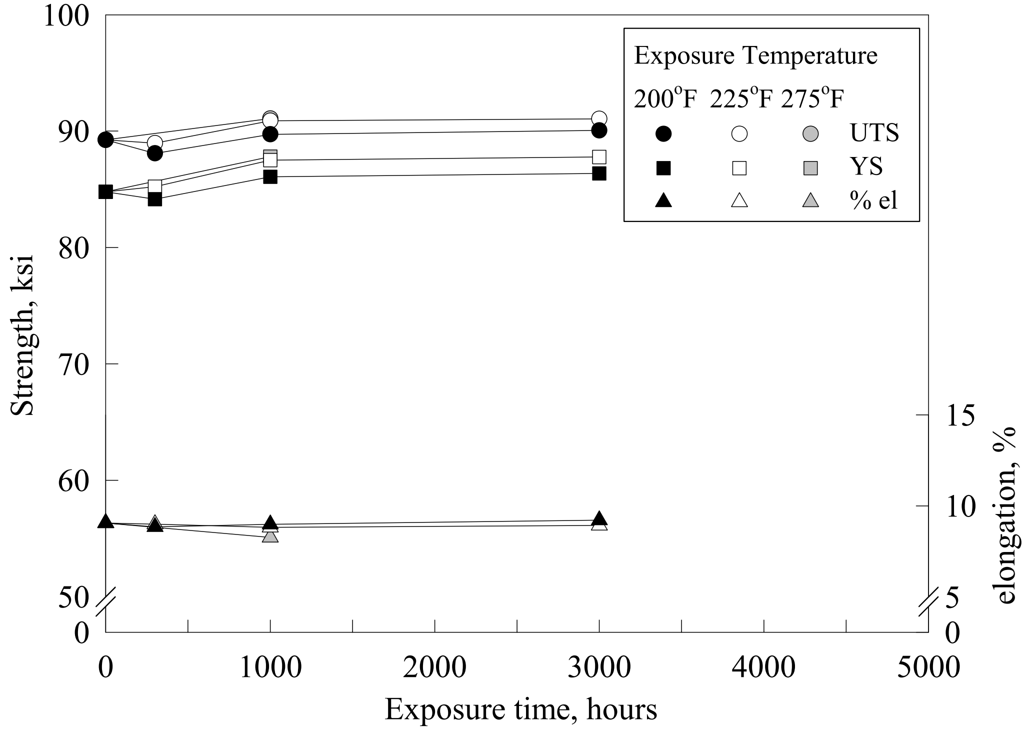
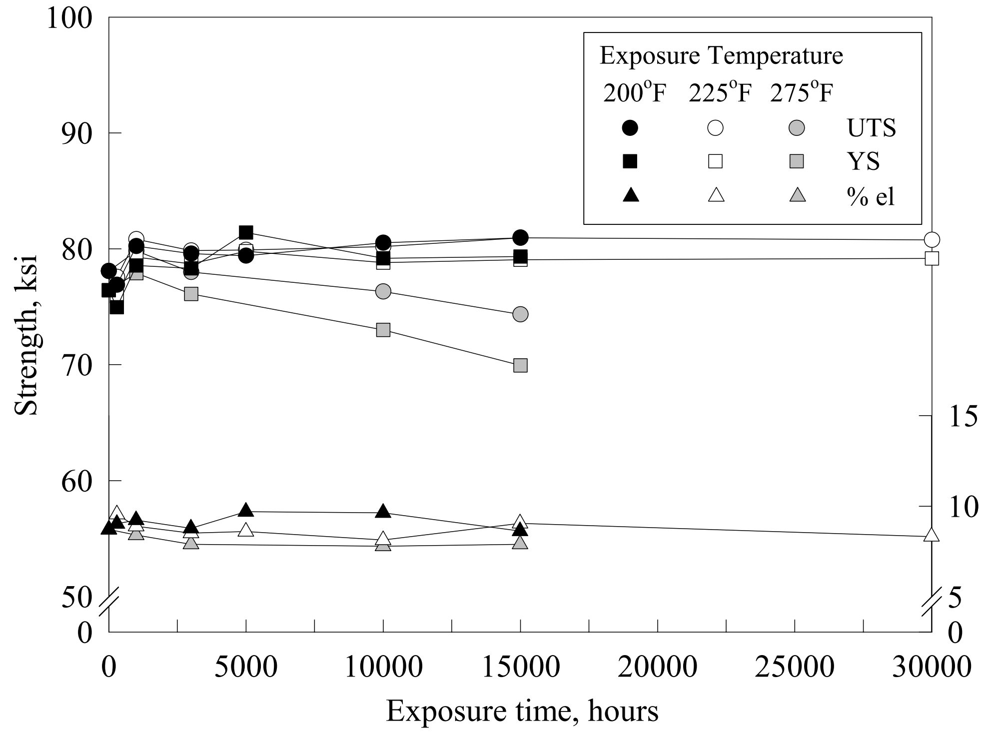
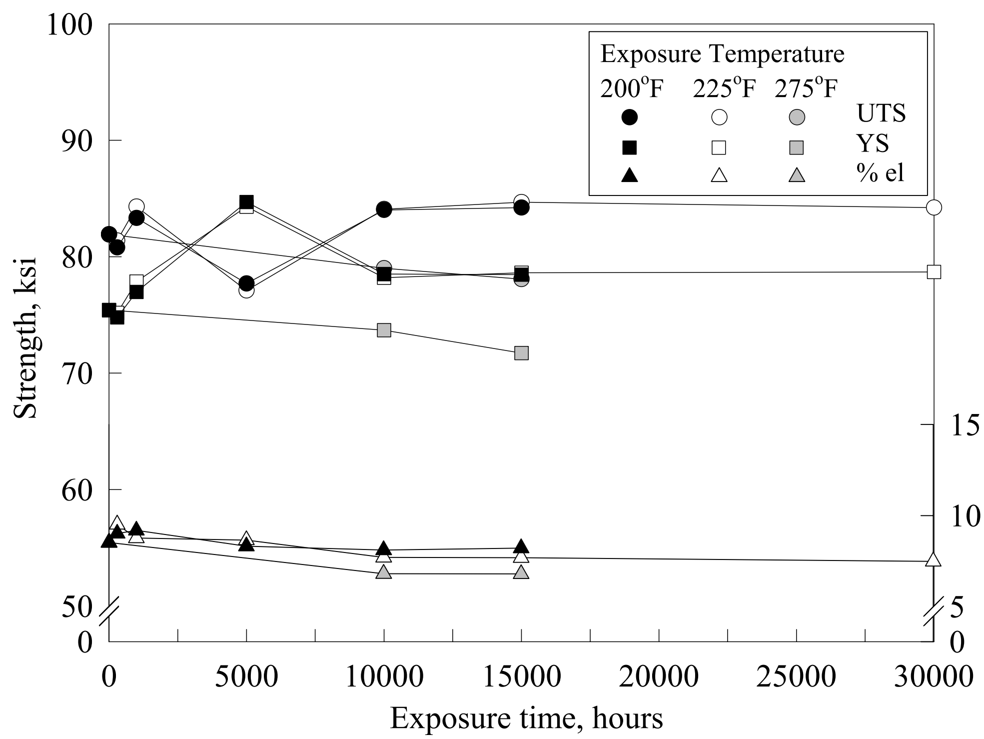



Figure C3. Variation in longitudinal room temperature tensile properties with thermal exposure for RX818.

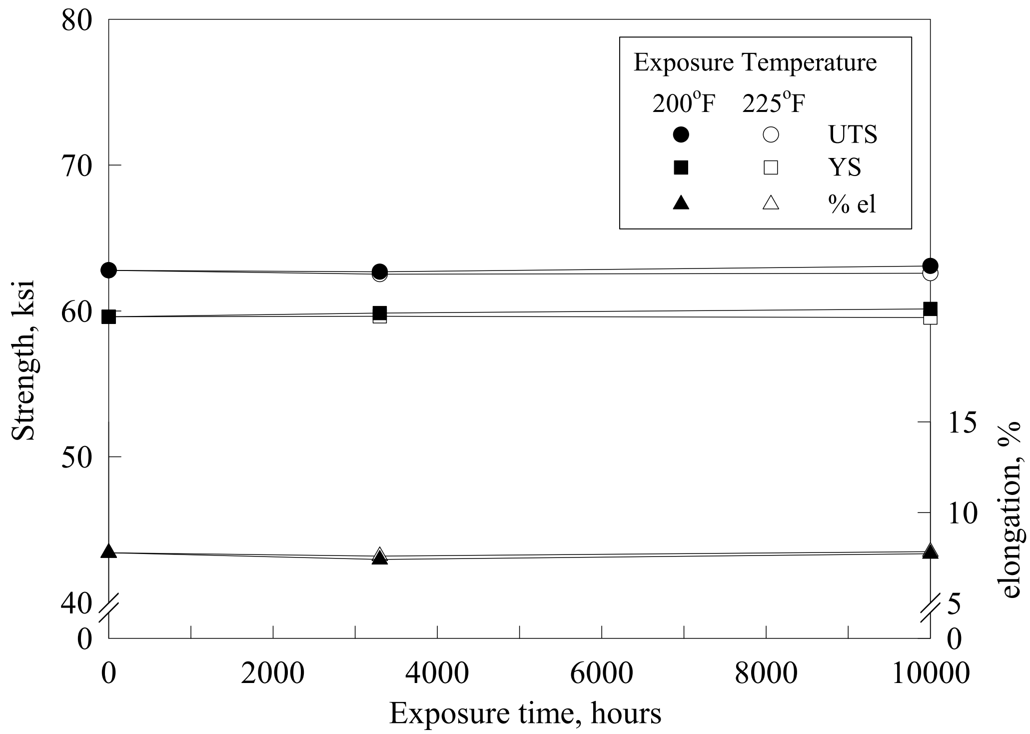



(a) Longitudinal tensile properties

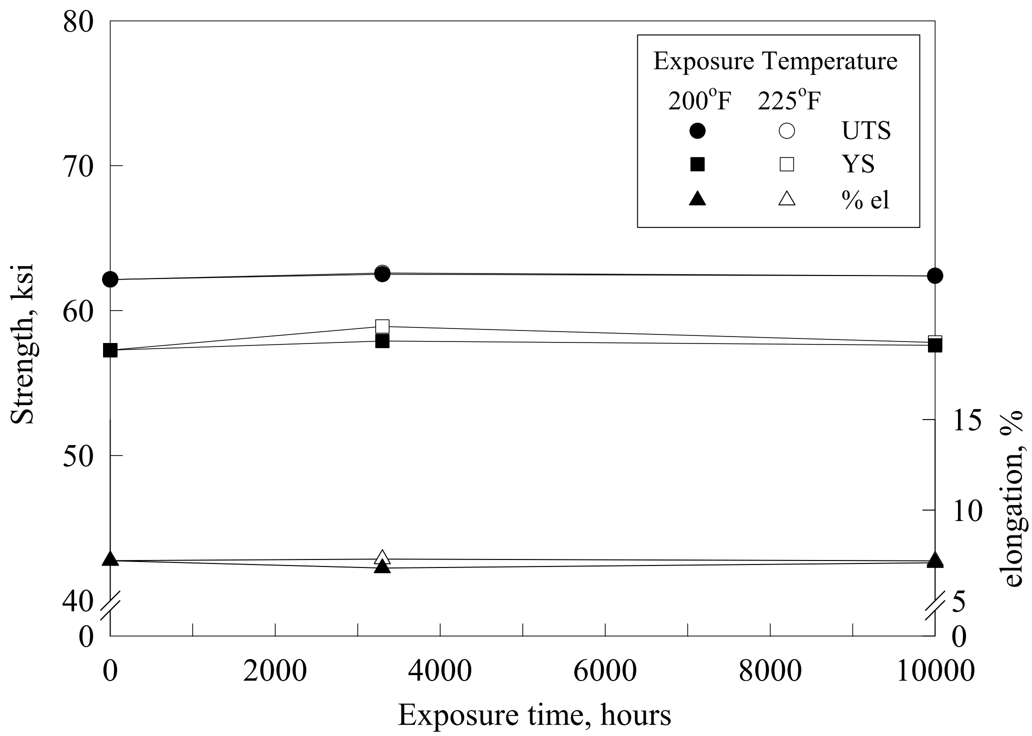



(b) Transverse tensile properties

Figure C4. Variation in room temperature tensile properties with thermal exposure for ML377.

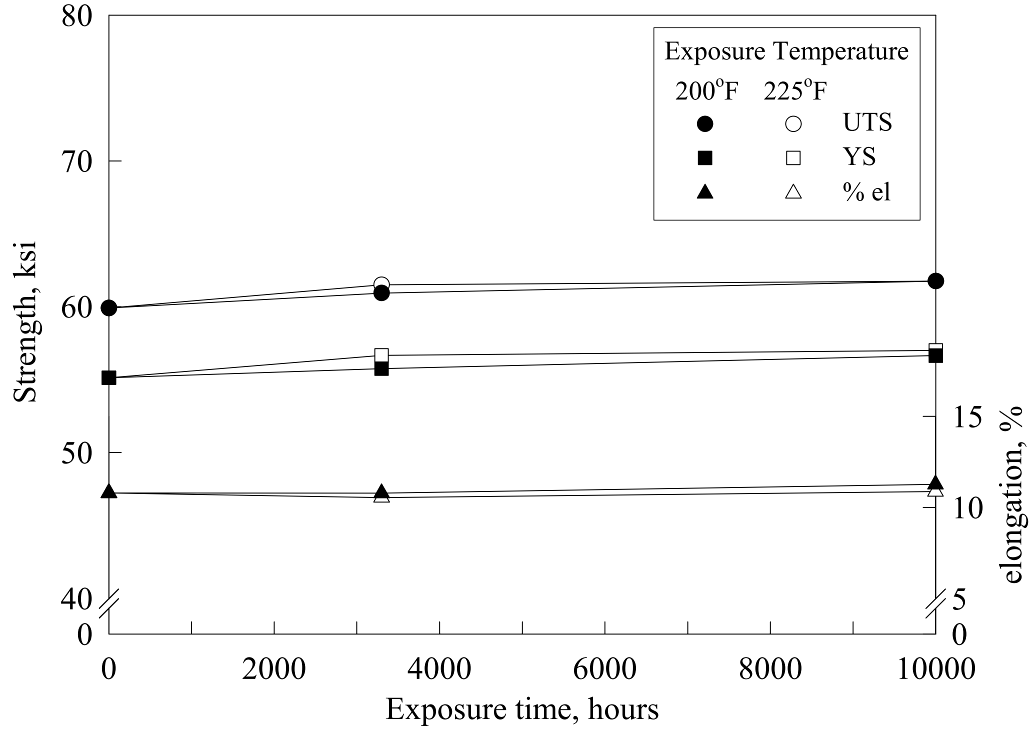



(a) Longitudinal tensile properties

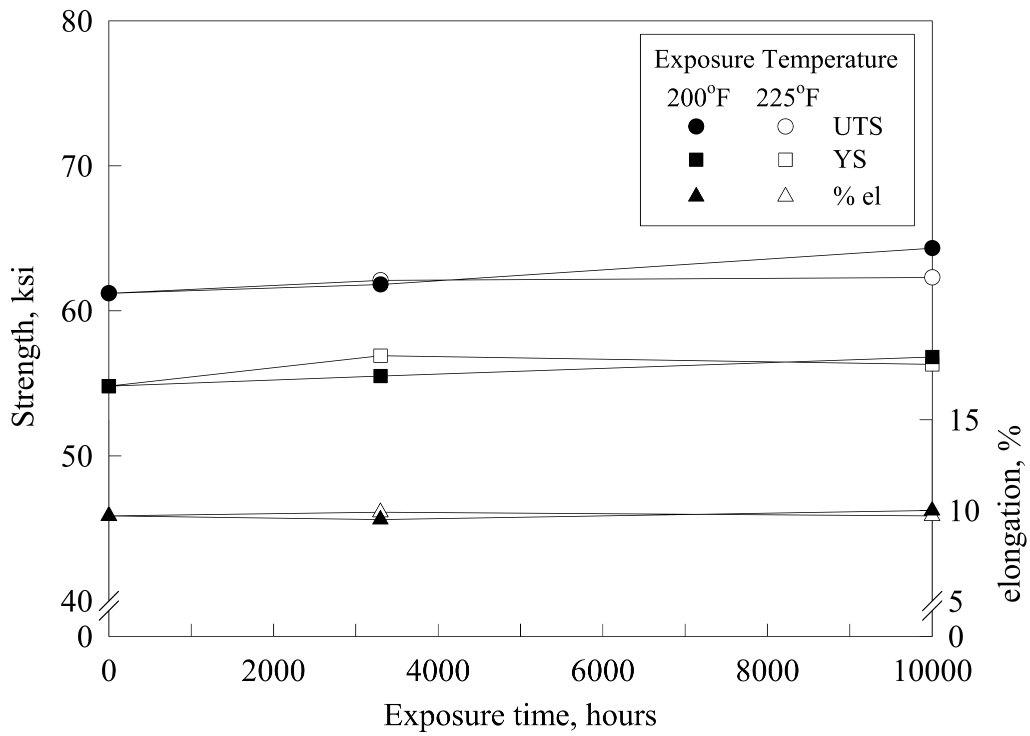



(b) Transverse tensile properties

Figure C5. Variation in room temperature tensile properties with thermal exposure for CM001.

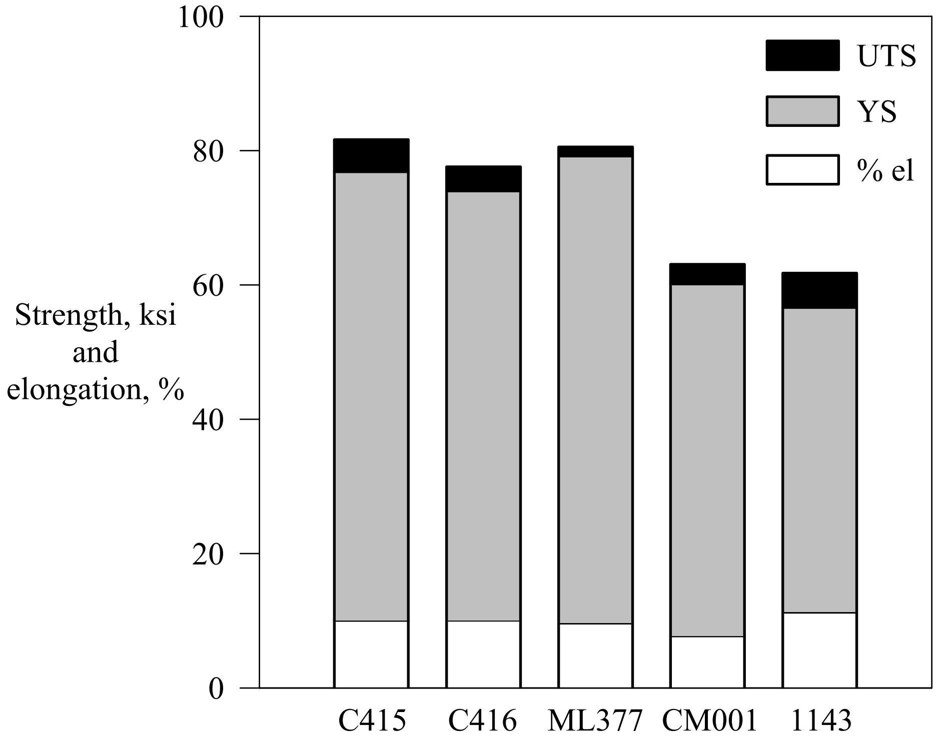



(a) Longitudinal tensile properties

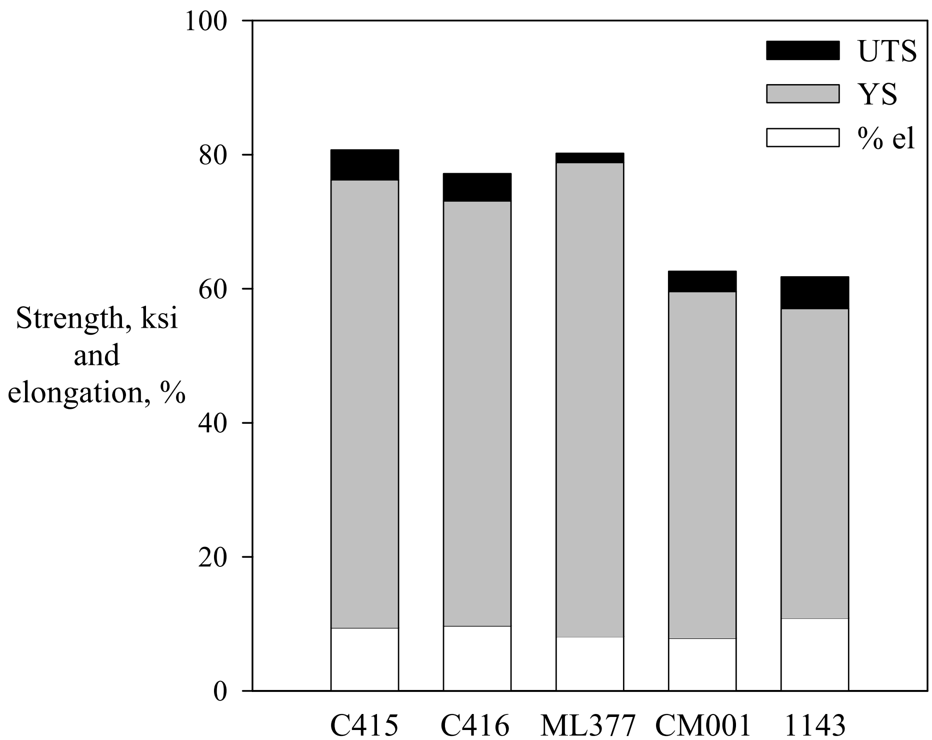



(b) Transverse tensile properties

Figure C6. Variation in room temperature tensile properties with thermal exposure for 1143.

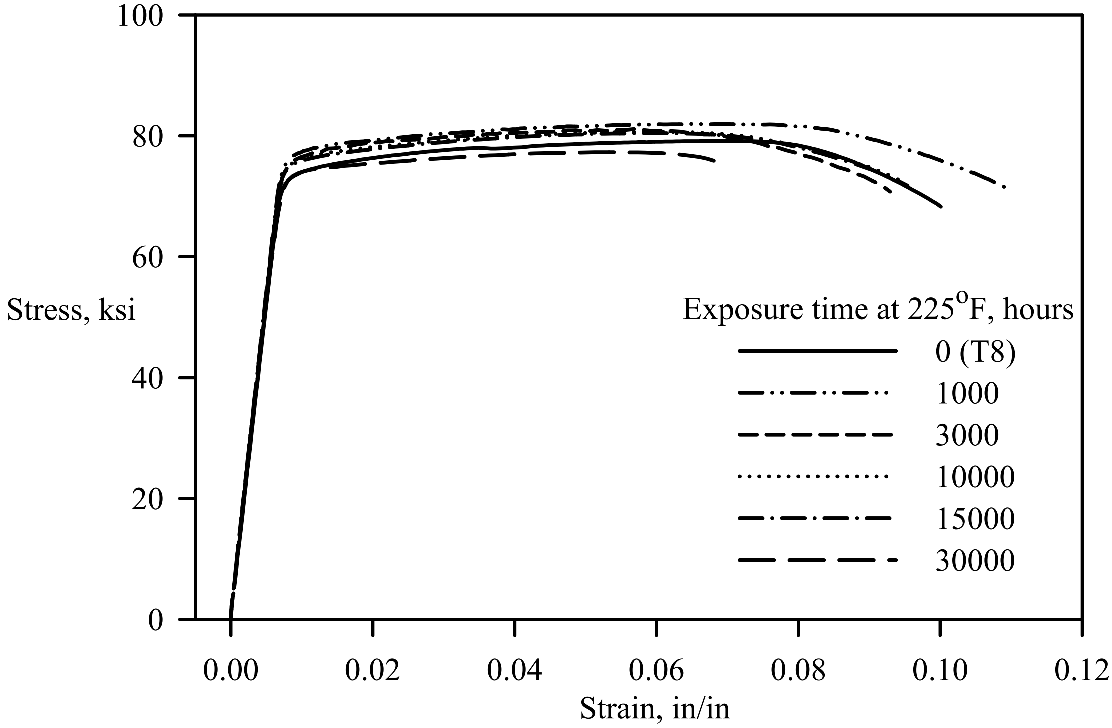



(a) exposure at 200°F

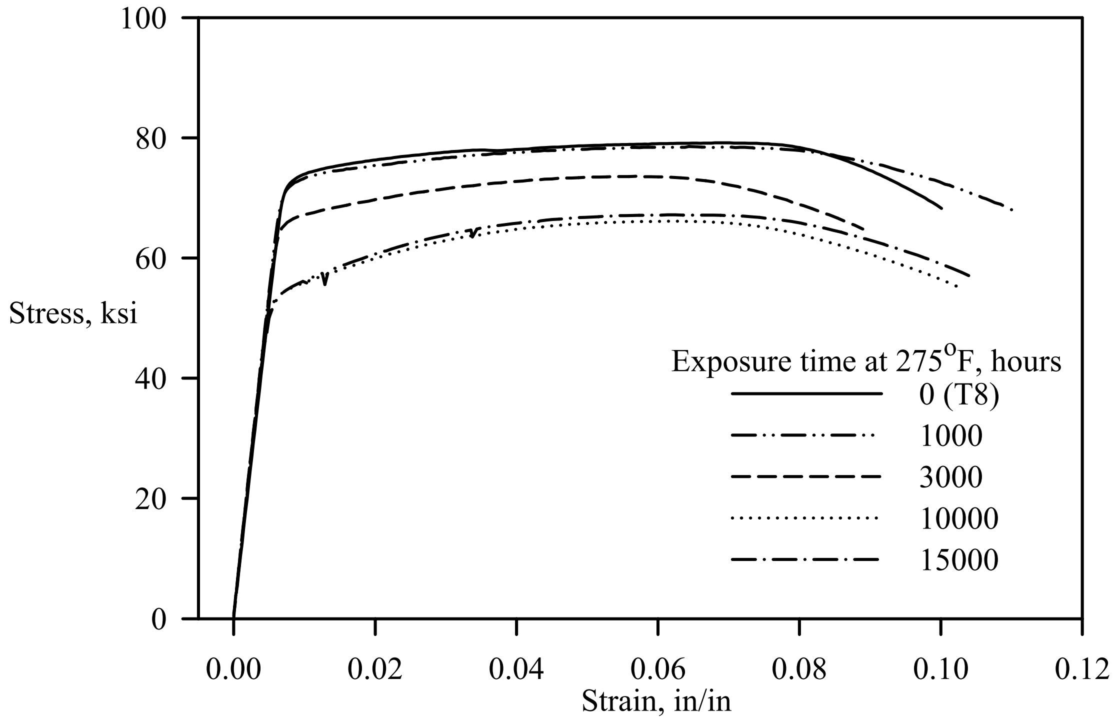



(b) exposure at 225°F

Figure C7. Longitudinal room temperature tensile properties after 10,000 hours thermal exposure.

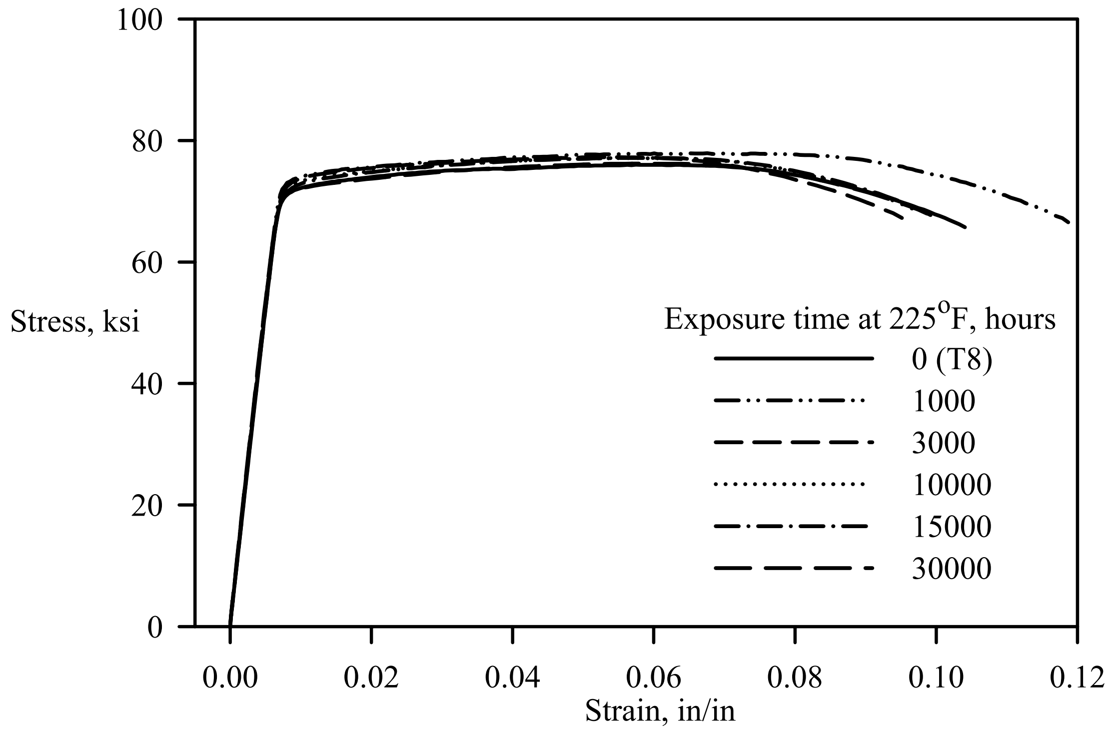



(a) Exposure at 225°F

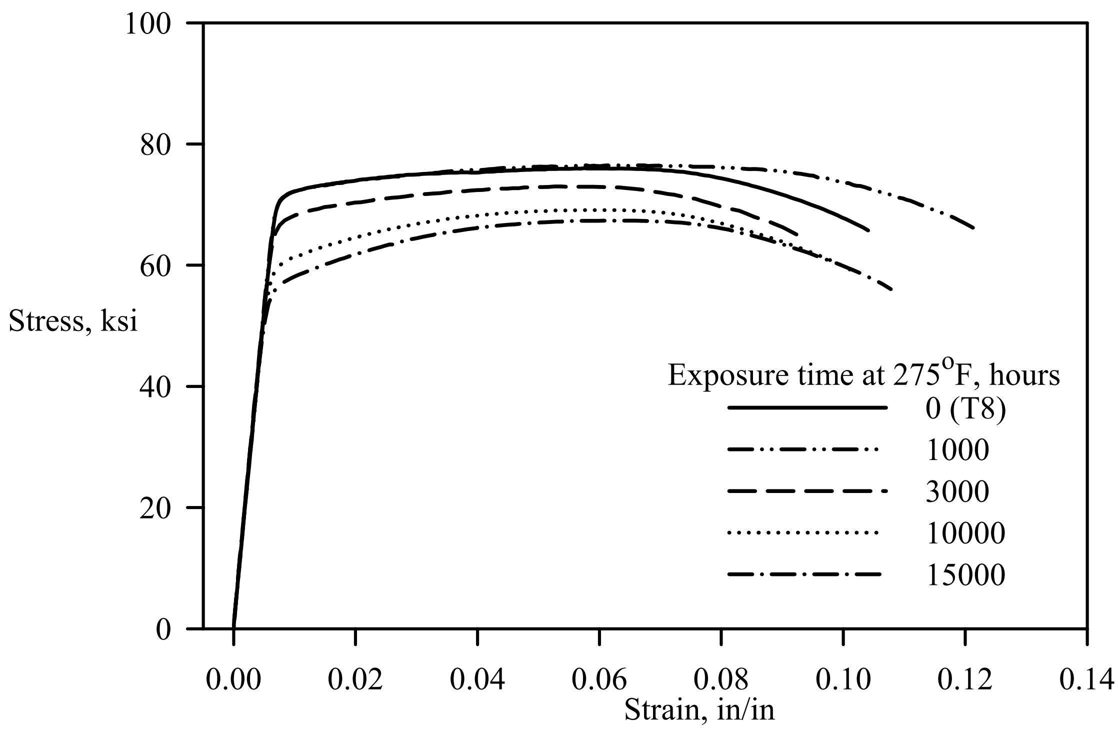



(b) Exposure at 275°F

Figure C8. Variation in room temperature longitudinal stress-strain curves with thermal exposure for C415.

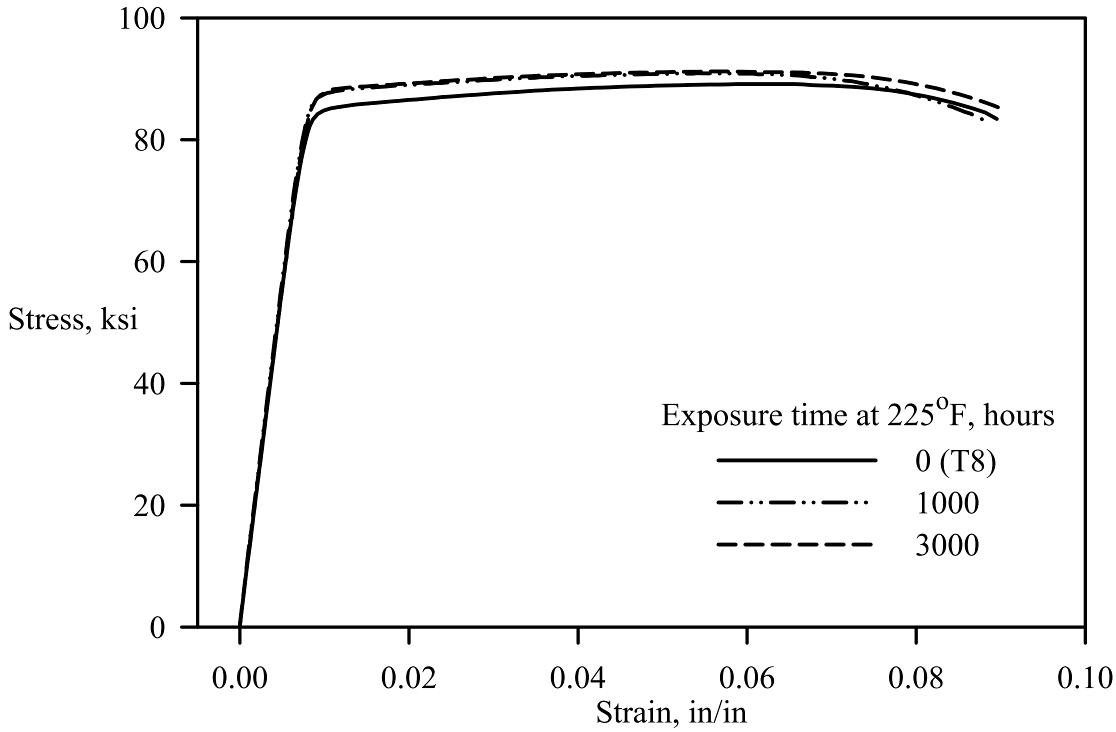



(a) Exposure at 225°F

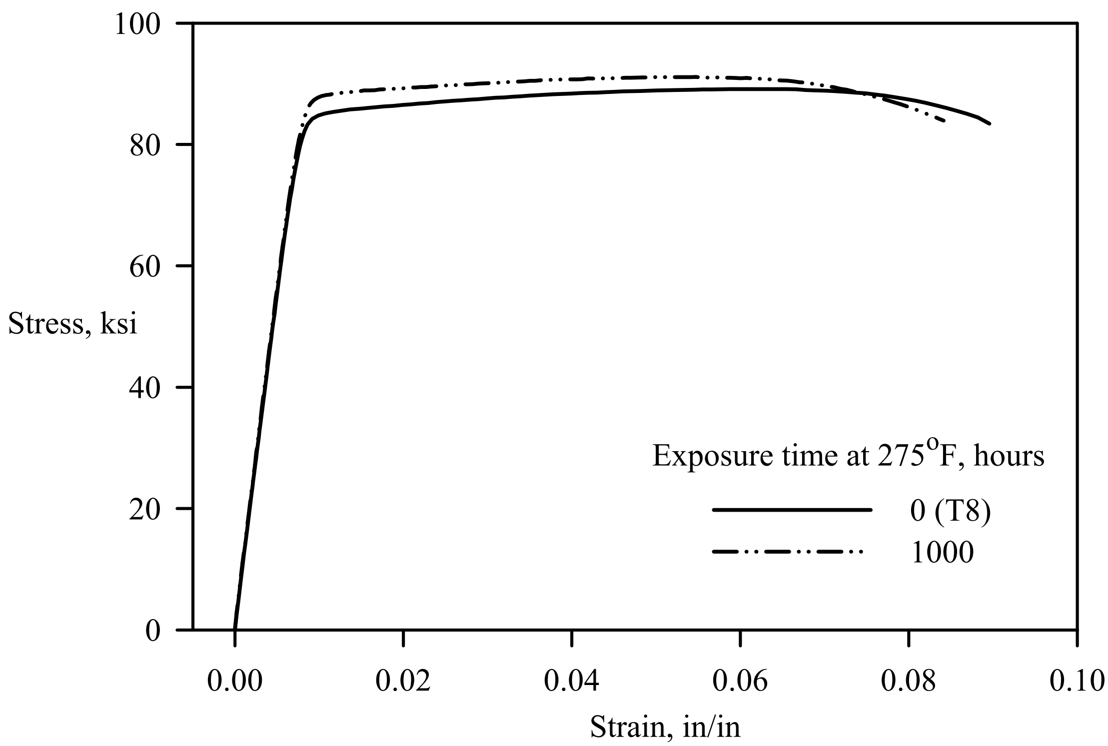



(b) Exposure at 275°F

Figure C9. Variation in room temperature longitudinal stress-strain curves with thermal exposure for C416.

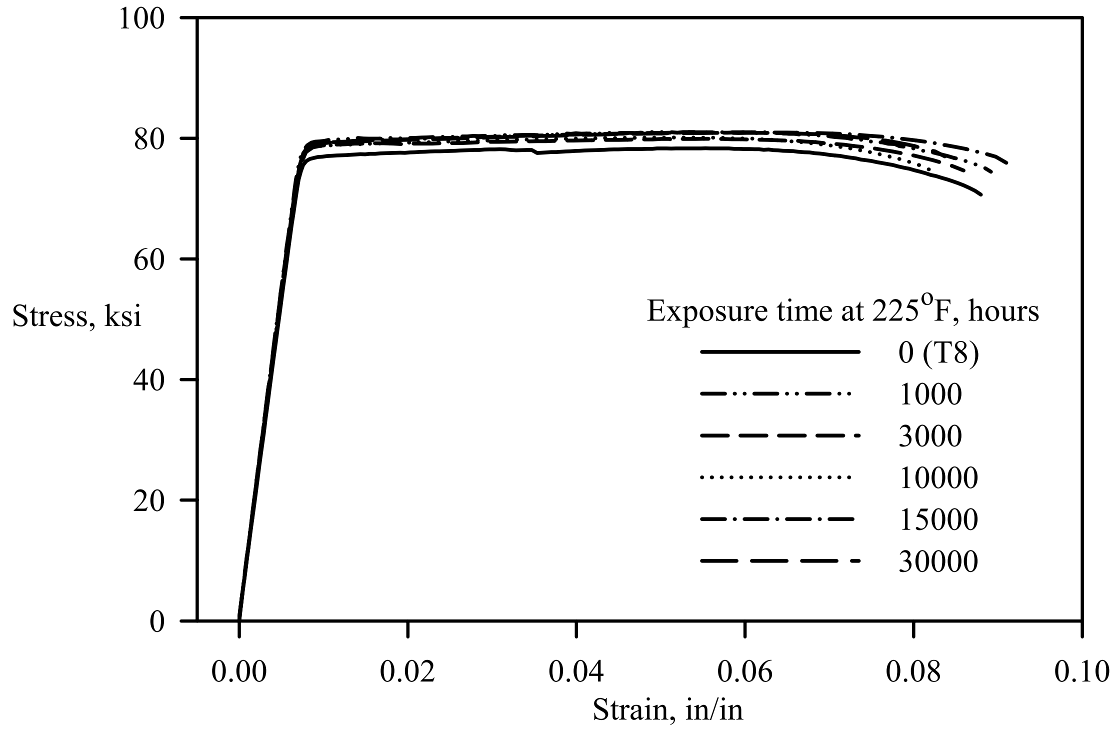



(a) Exposure at 225°F




(b) Exposure at 275°F

Figure C10. Variation in room temperature longitudinal stress-strain curves with thermal exposure for RX818.

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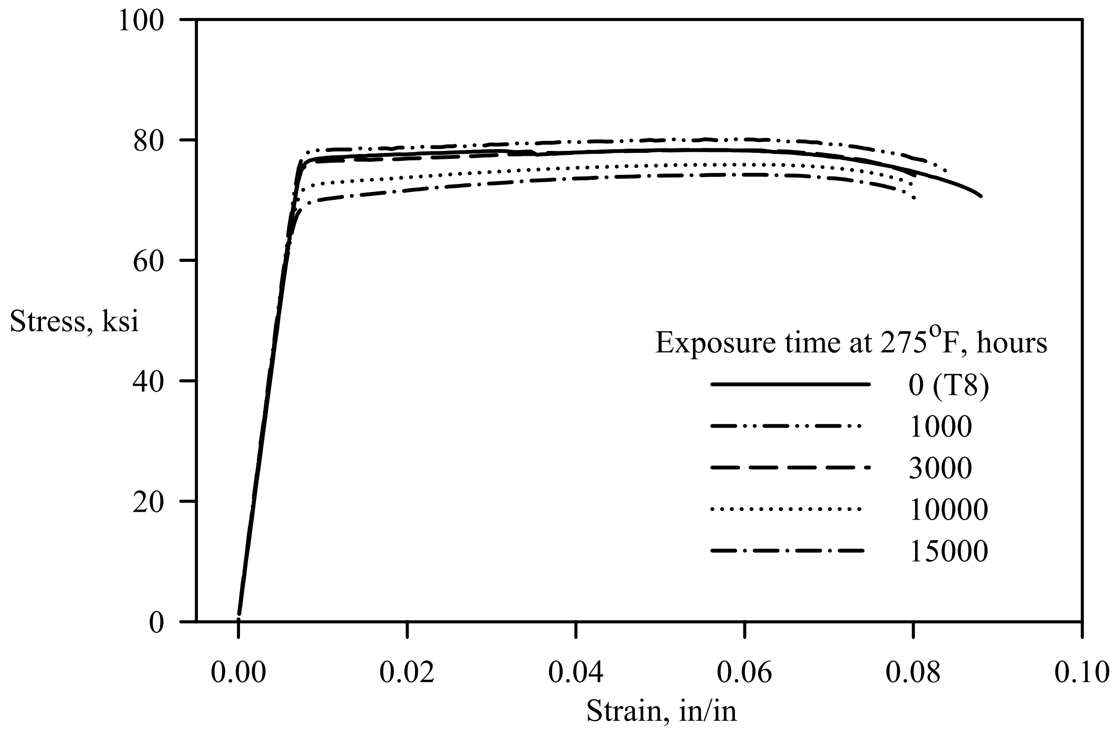



(b) Exposure at 275°F

Figure C11. Variation in room temperature longitudinal stress-strain curves with thermal exposure for ML377.

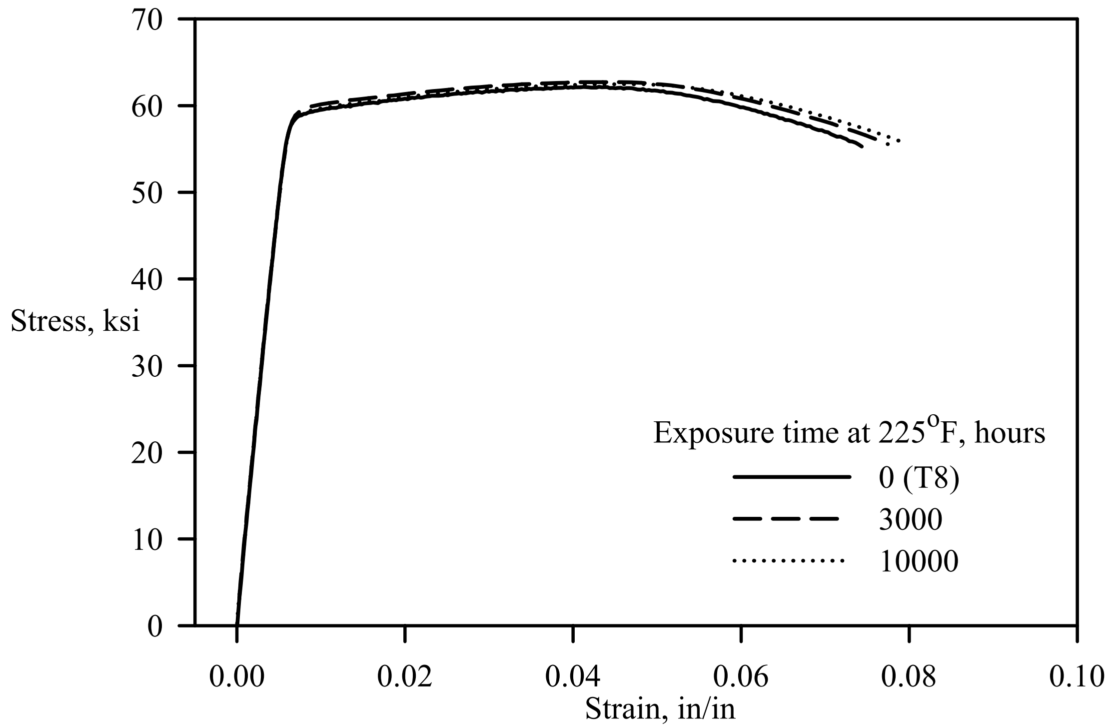



Figure C12. Variation in room temperature longitudinal stress-strain curves with thermal exposure at 225°F for CM001.

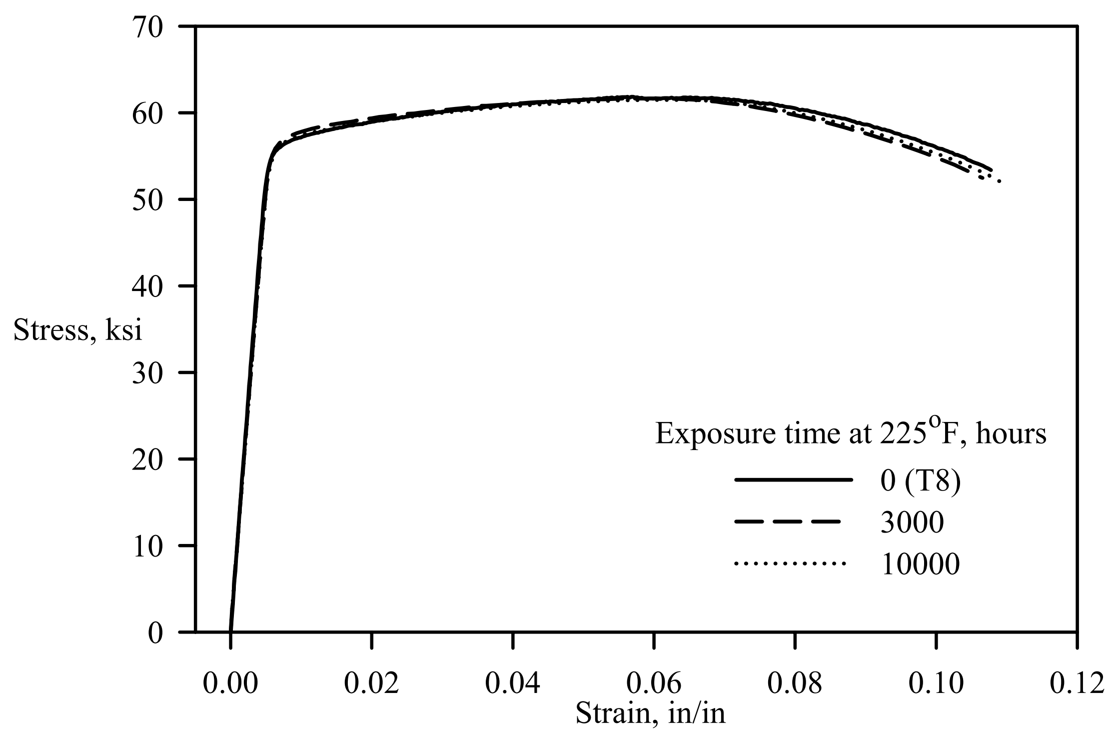
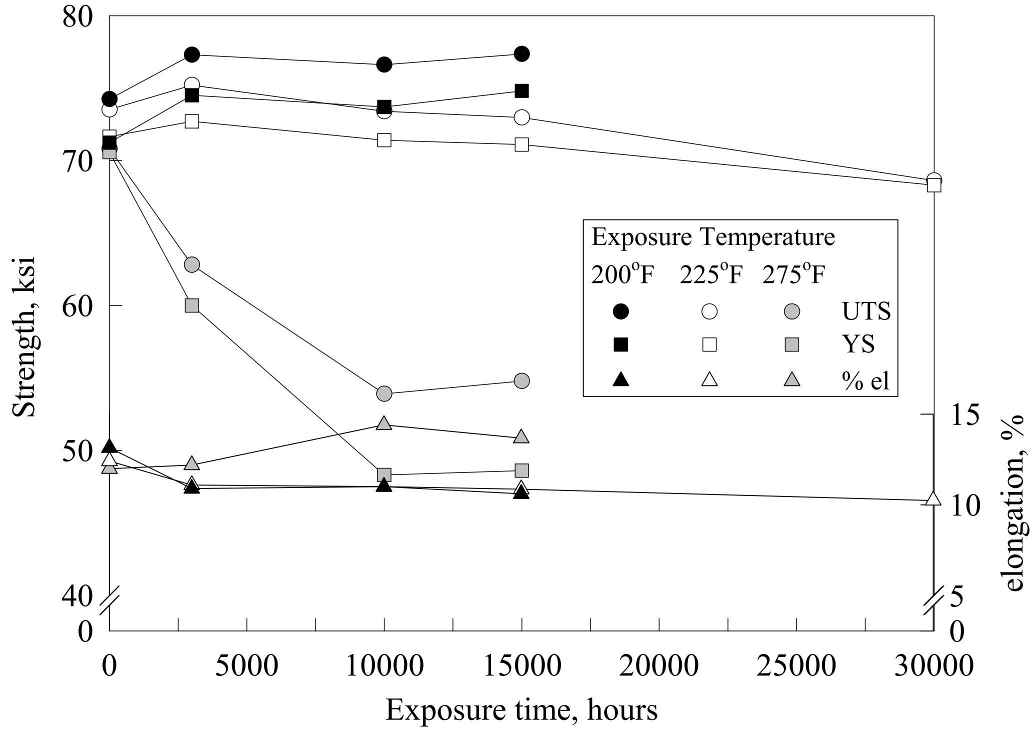
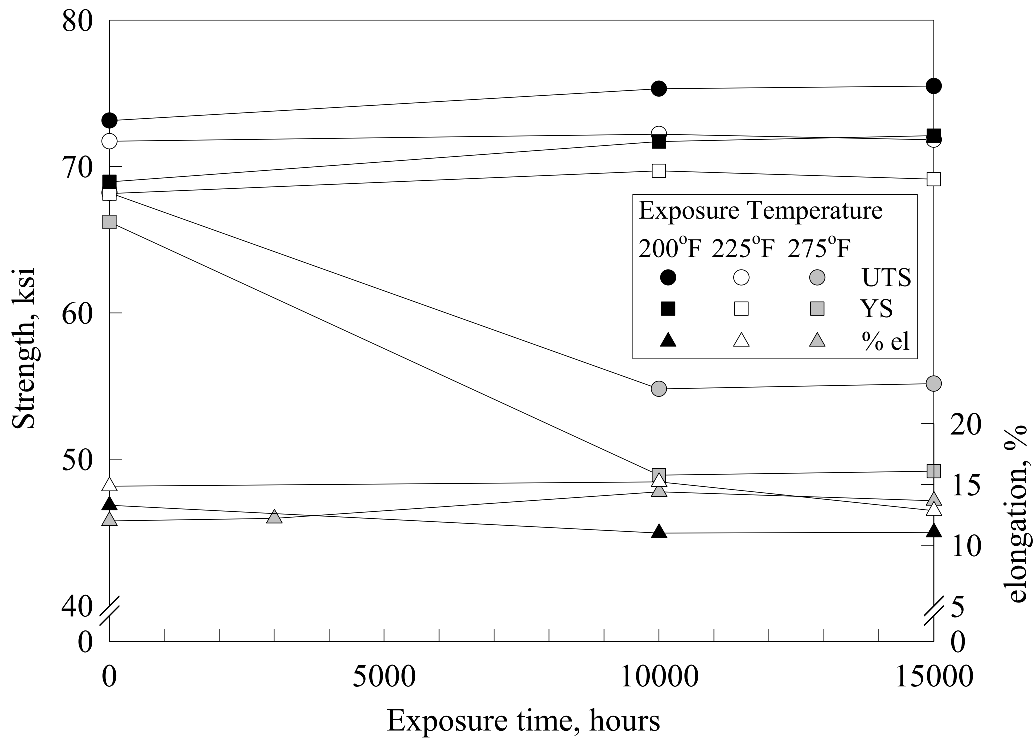



Figure C13. Variation in room temperature longitudinal stress-strain curves with thermal exposure at 225°F for 1143.

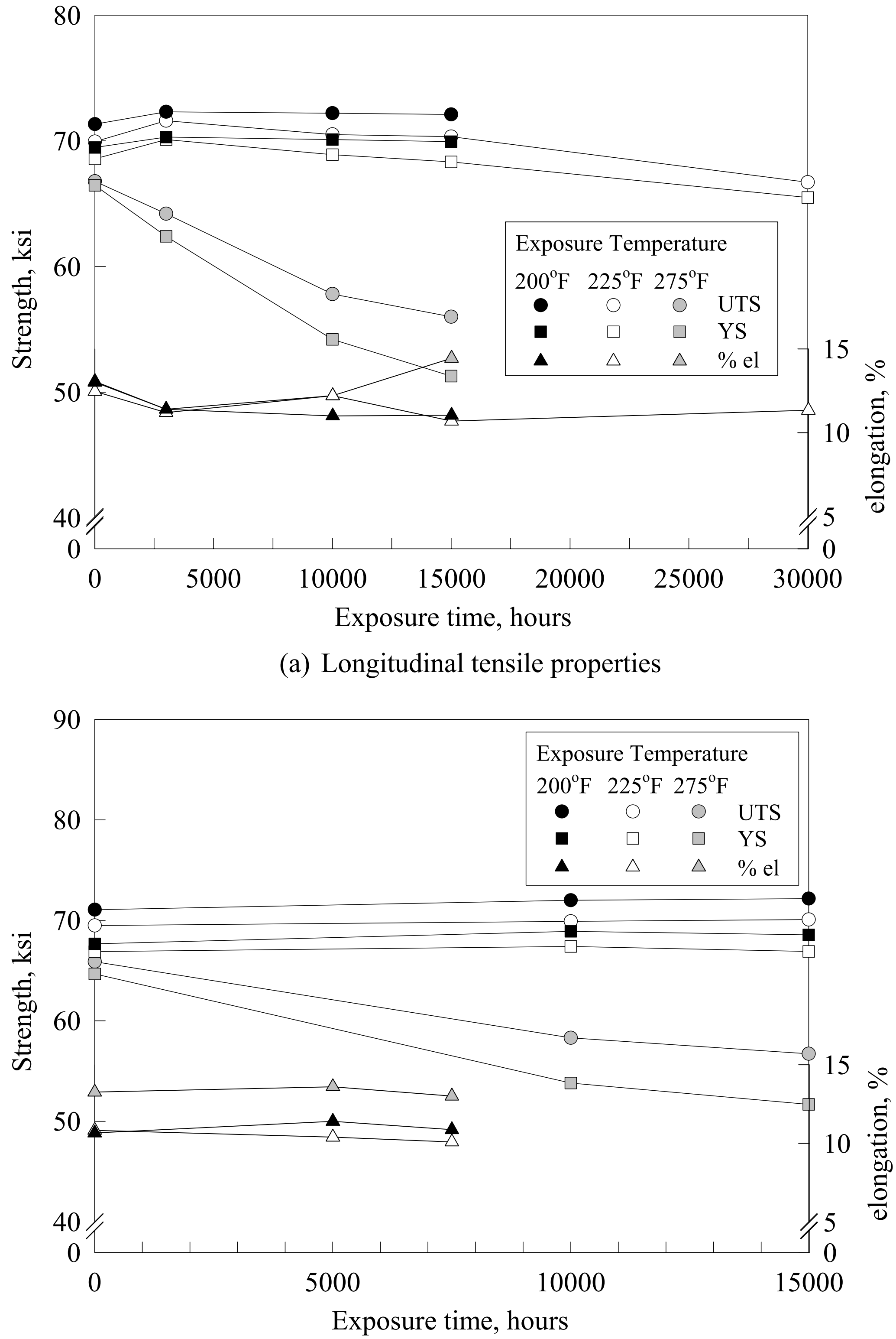



(a) Longitudinal tensile properties




(b) Transverse tensile properties

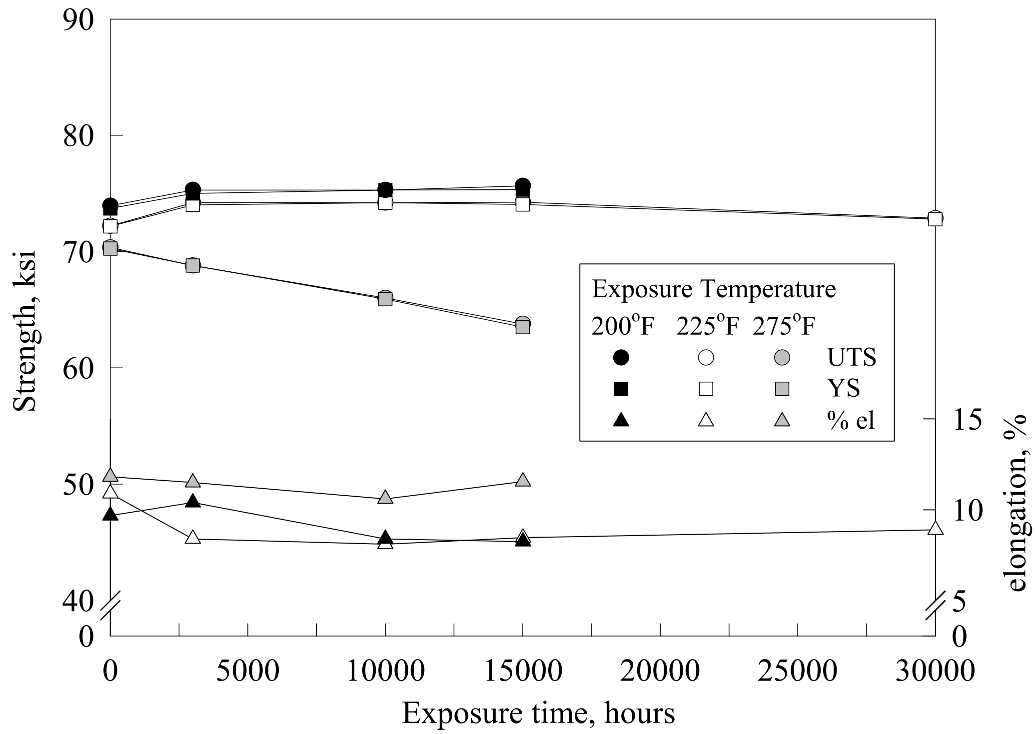
Figure C14. Variation in elevated temperature tensile properties with thermal exposure for C415. (Test temperature is the exposure temperature)



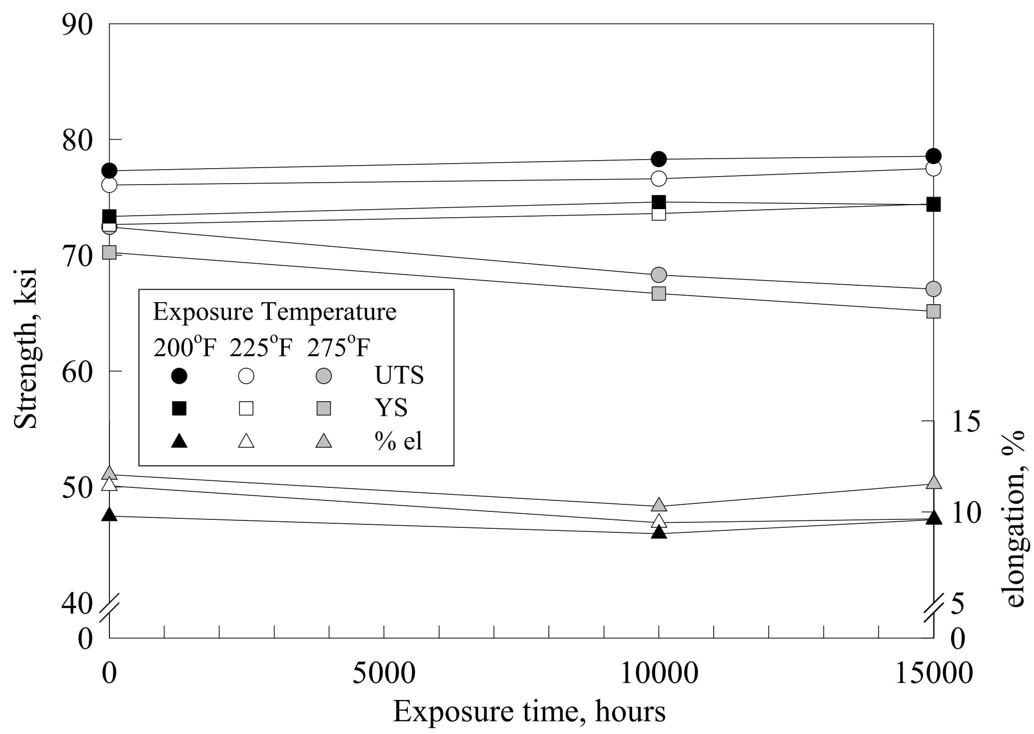

(a) Longitudinal tensile properties

(b) Transverse tensile properties

Figure C15. Variation in elevated temperature tensile properties with thermal exposure for C416. (Test temperature is the exposure temperature)

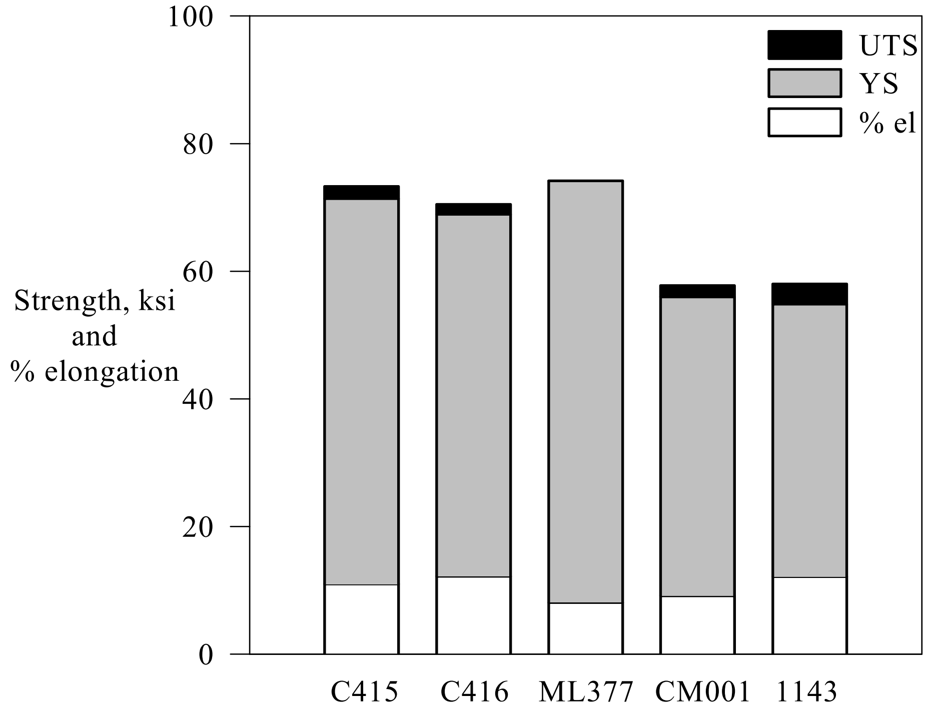



(a) Longitudinal tensile properties

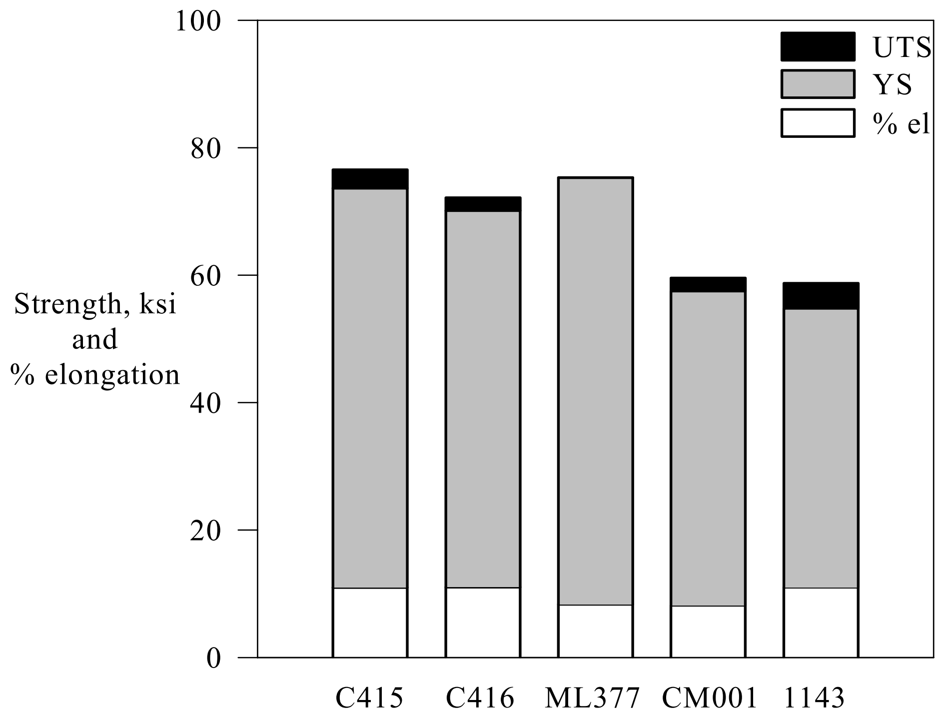



(b) Transverse tensile properties

Figure C16. Variation in elevated temperature tensile properties with thermal exposure for ML377. (Test temperature is the exposure temperature)

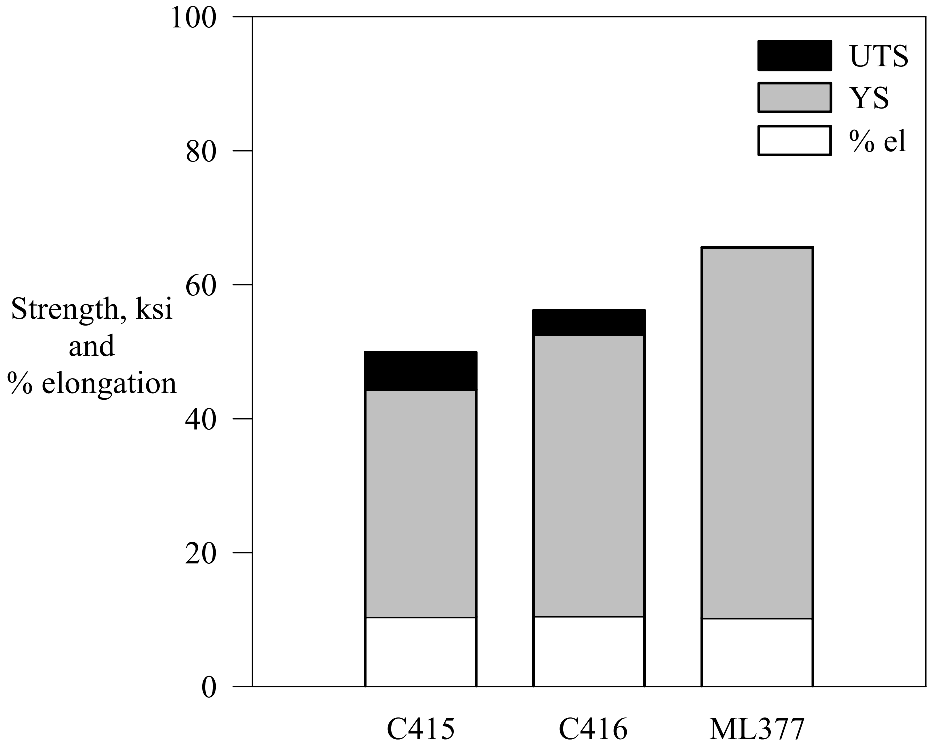



(a) Properties at 200°F after exposure at 200°F



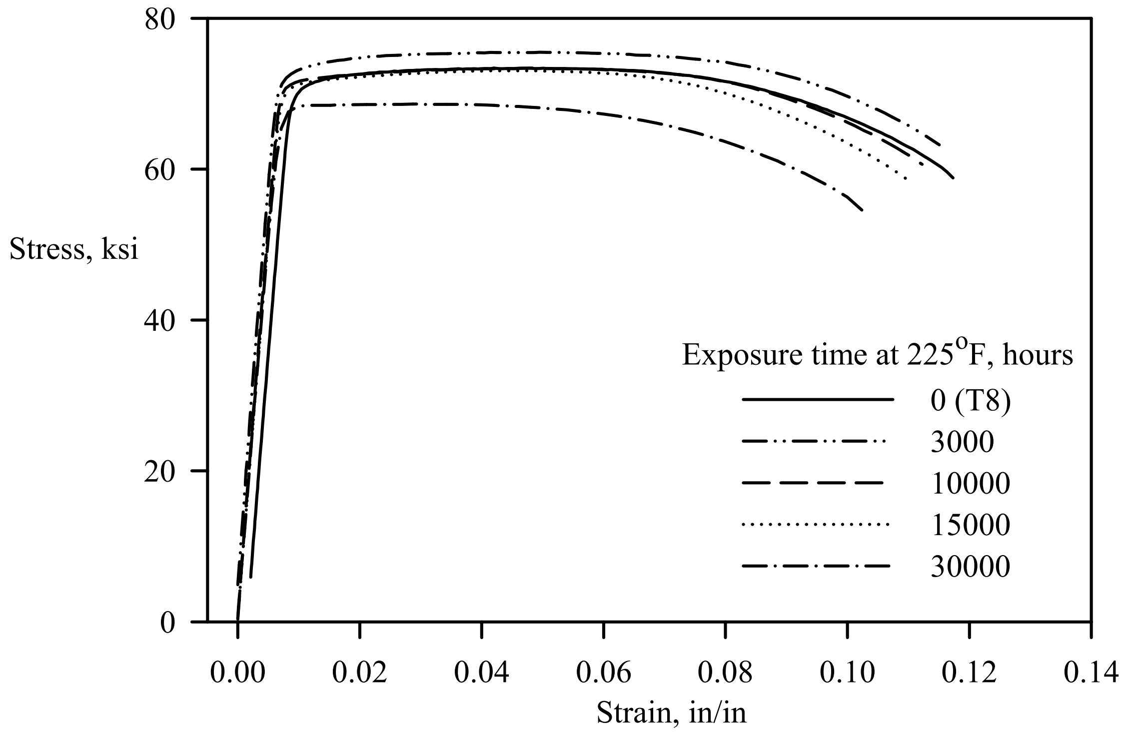

(b) Properties at 225°F after exposure at 225°F

Figure C17. Longitudinal elevated temperature tensile properties after 10,000 hours thermal exposure.

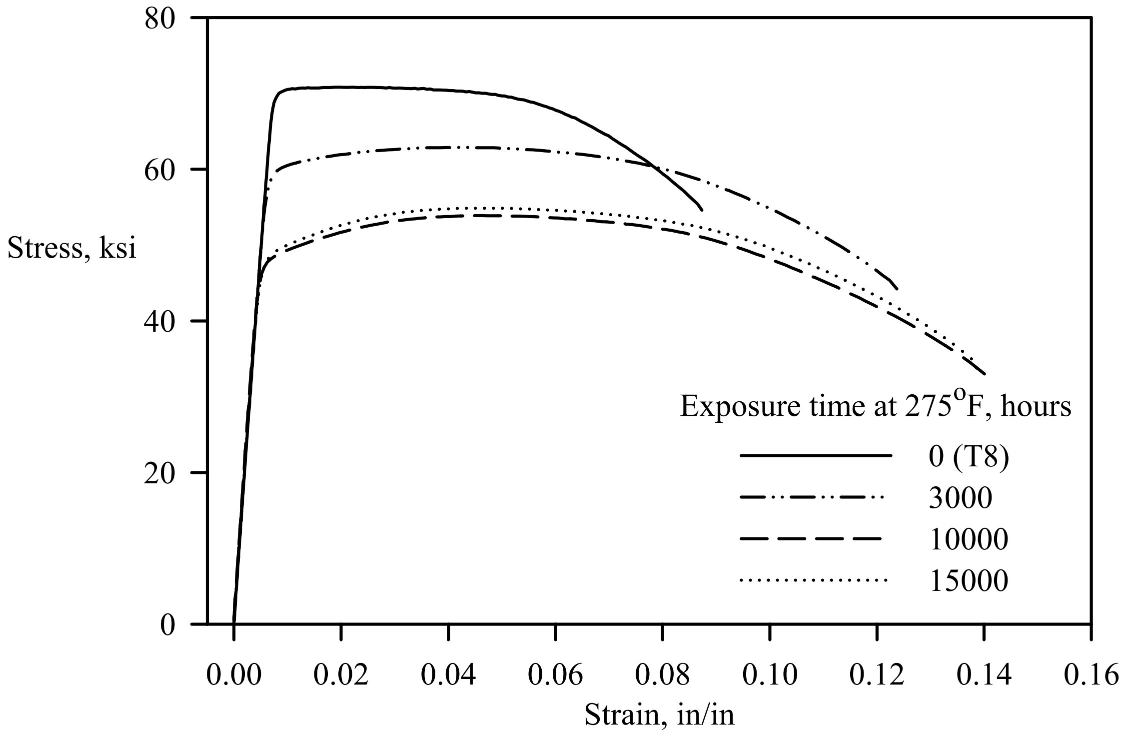



(c) Properties at 275°F after exposure at 275°F

Figure C17. Longitudinal elevated temperature tensile properties after 10,000 hours thermal exposure. (concluded)

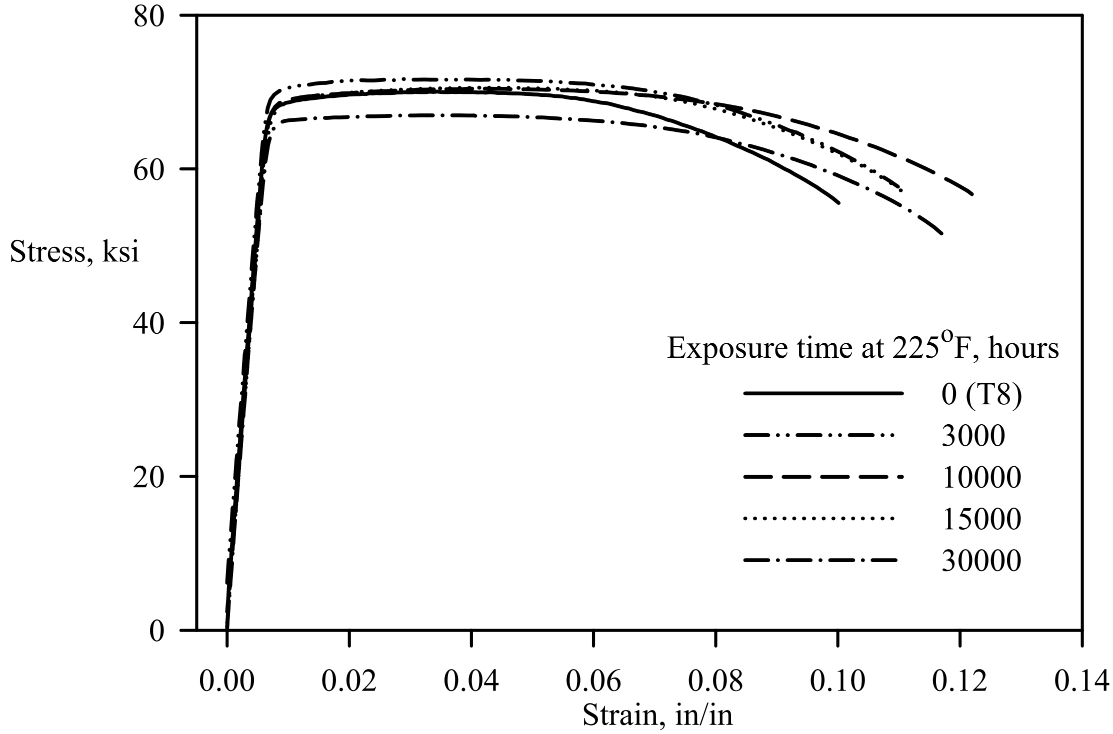



(a) Exposure at 225°F

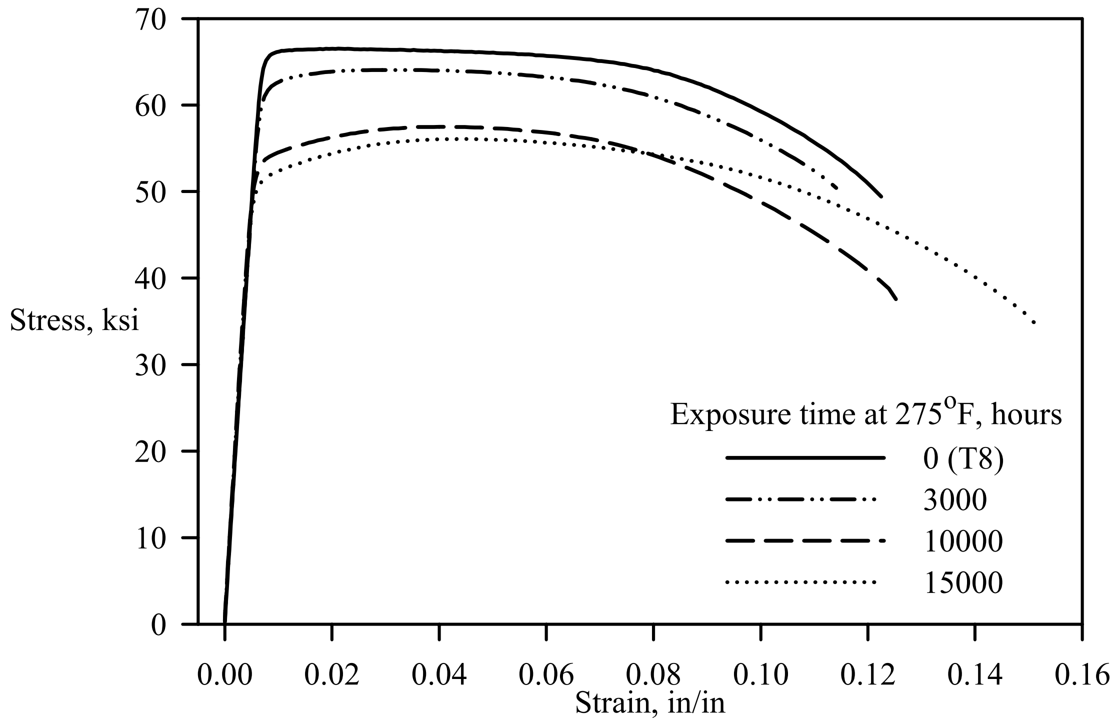



(b) Exposure at 275°F

Figure C18. Variation in elevated temperature longitudinal stress-strain curves with thermal exposure for C415. (Test temperature is the exposure temperature)

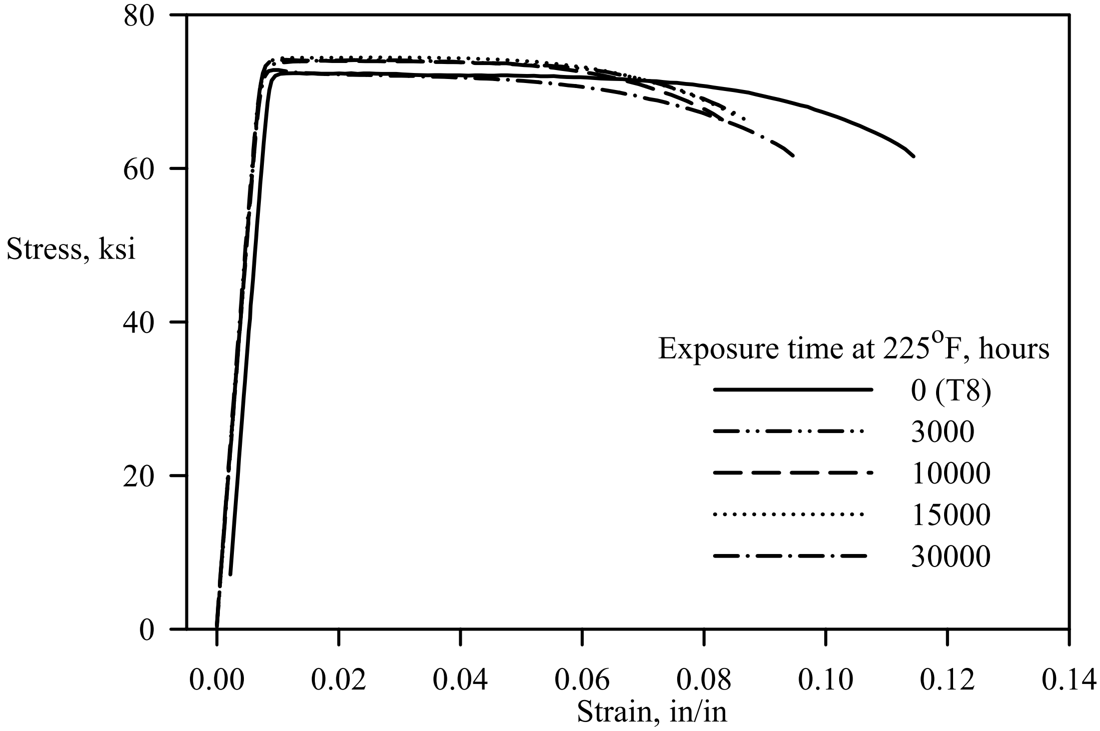



(a) Exposure at 225°F

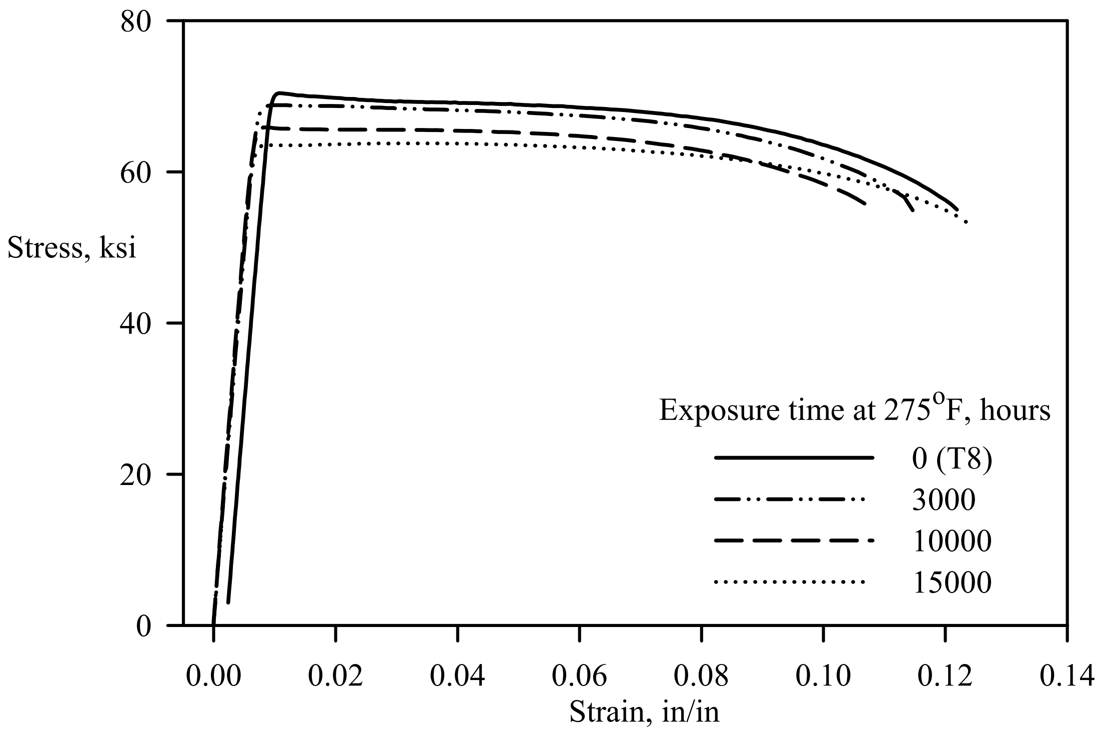



(b) Exposure at 275°F

Figure C19. Variation in elevated temperature longitudinal stress-strain curves with thermal exposure for C416. (Test temperature is the exposure temperature)




(a) Exposure at 225°F




(b) Exposure at 275°F

Figure C20. Variation in elevated temperature longitudinal stress-strain curves with thermal exposure for ML377. (Test temperature is the exposure temperature)

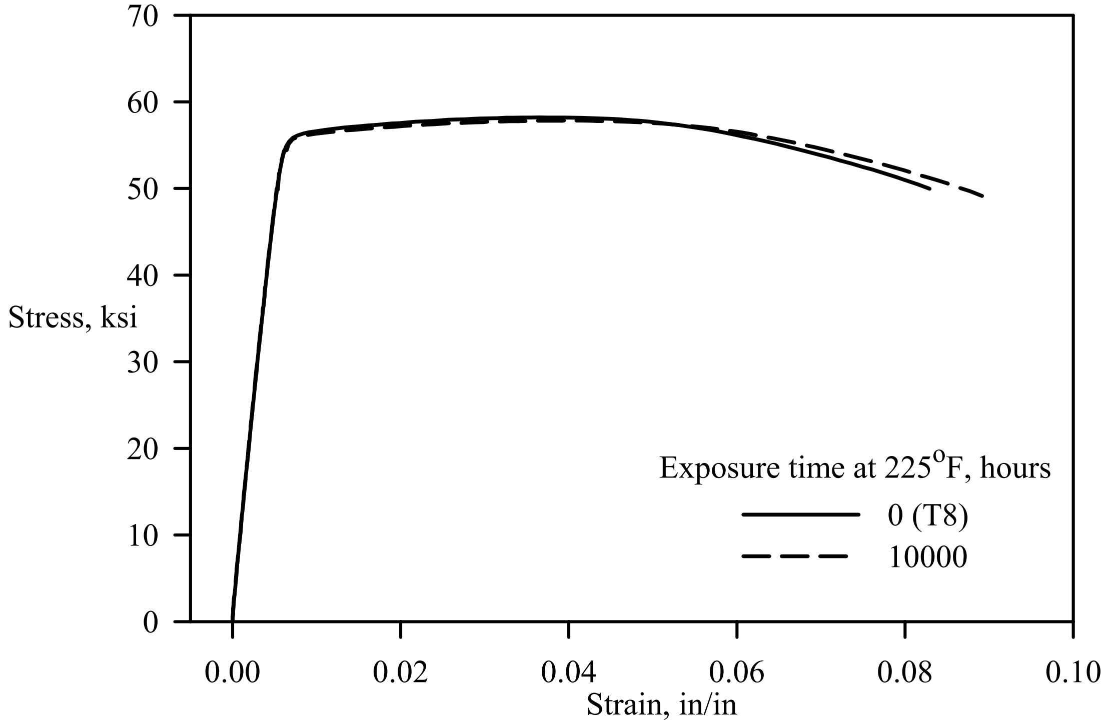



Figure C21. Variation in elevated temperature longitudinal stress-strain curves with thermal exposure at 225°F for CM001. (Test temperature is the exposure temperature)

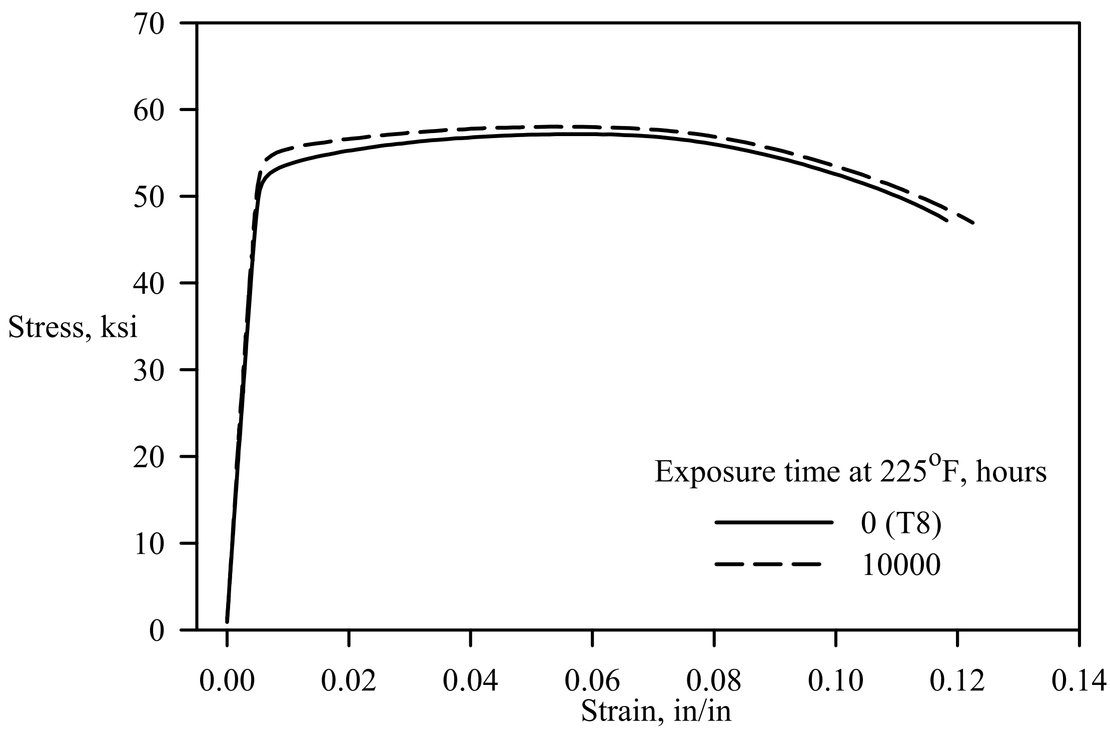
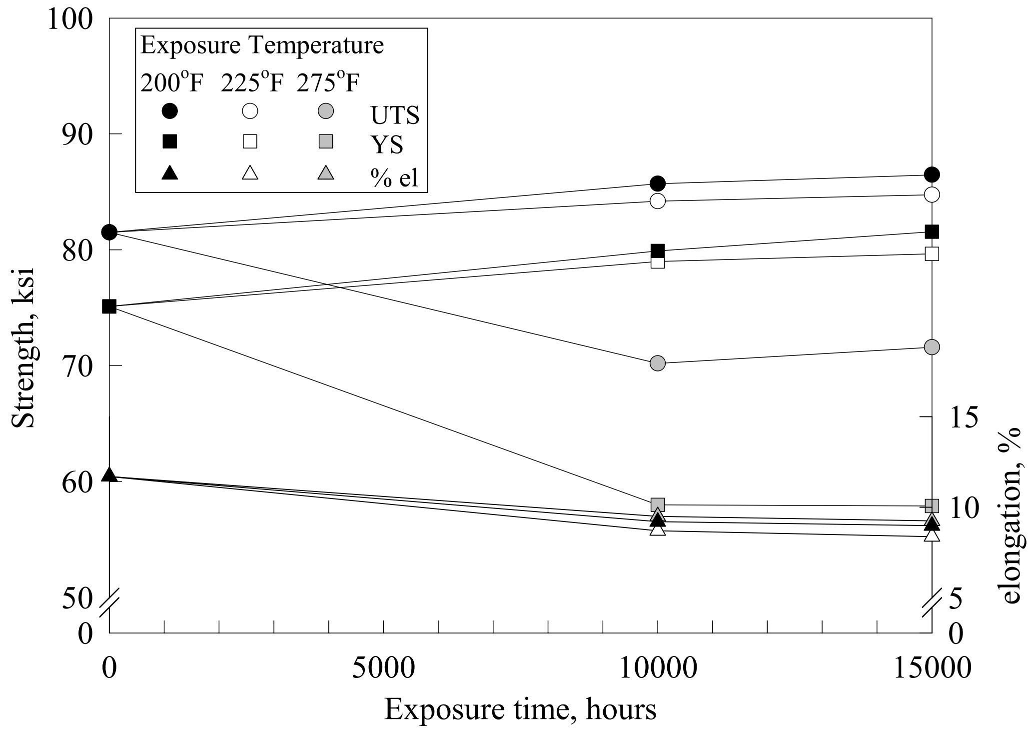
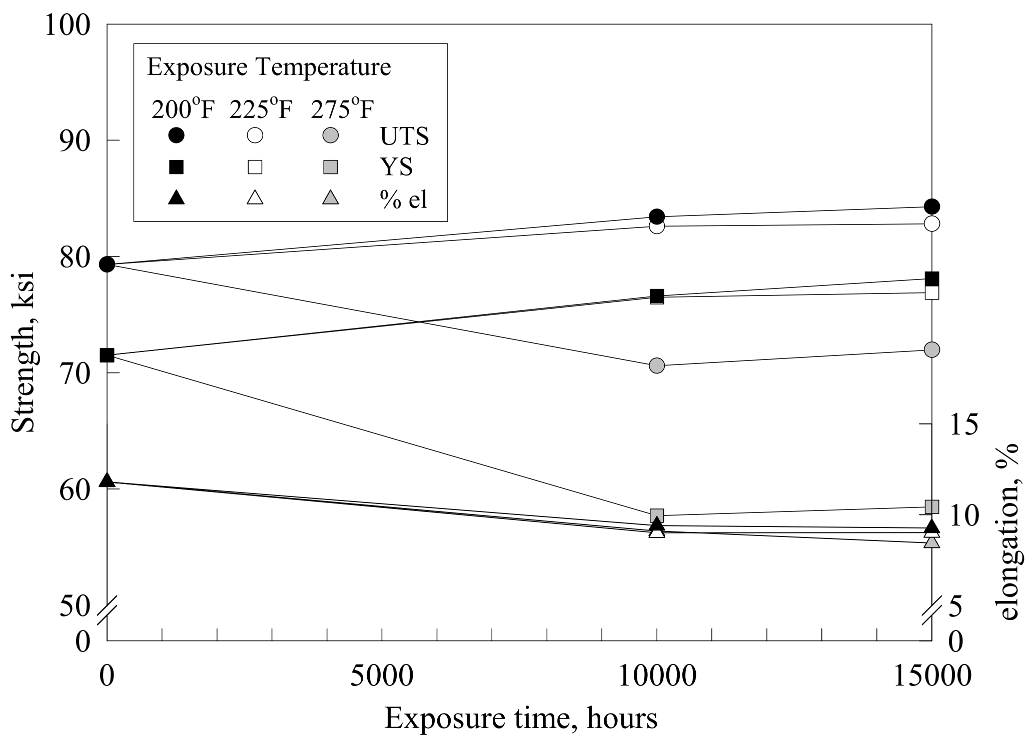



Figure C22. Variation in elevated temperature longitudinal stress-strain curves with thermal exposure at 225°F for 1143. (Test temperature is the exposure temperature)

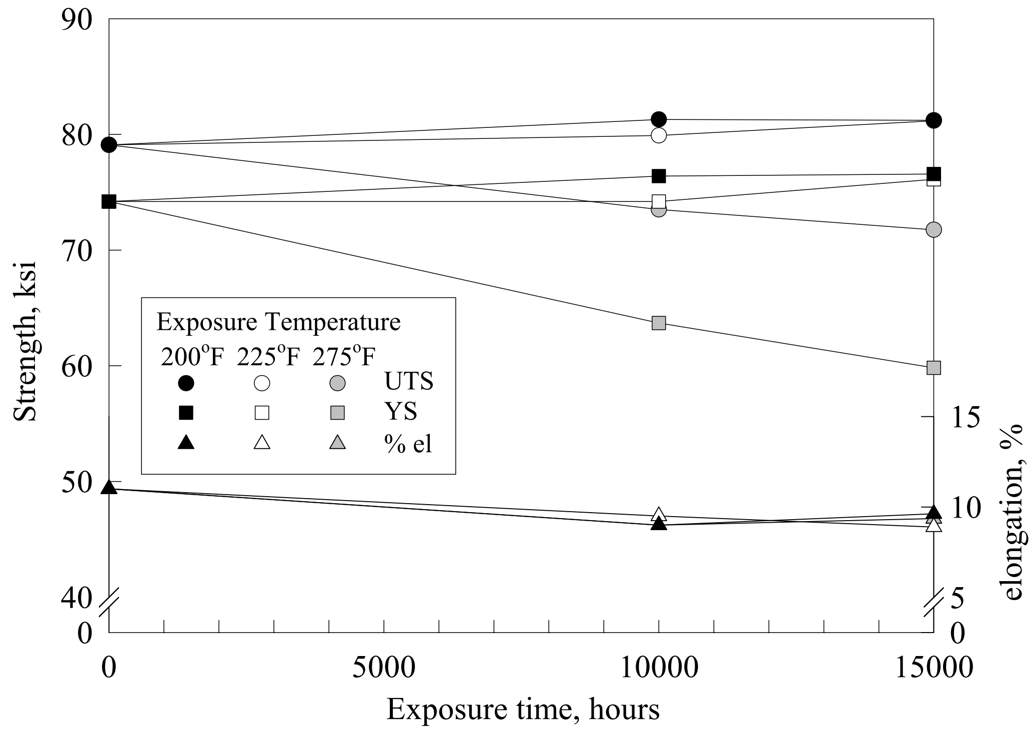



(a) Longitudinal tensile properties

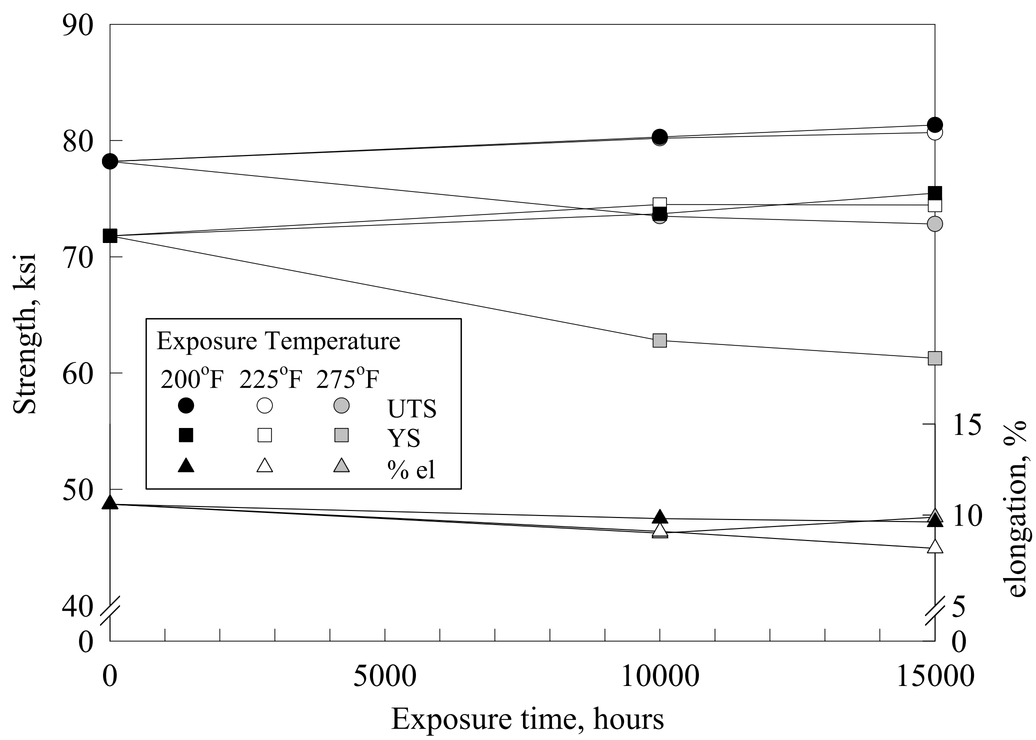



(b) Transverse tensile properties

Figure C23. Variation in tensile properties for C415 measured at -65°F after thermal exposure.

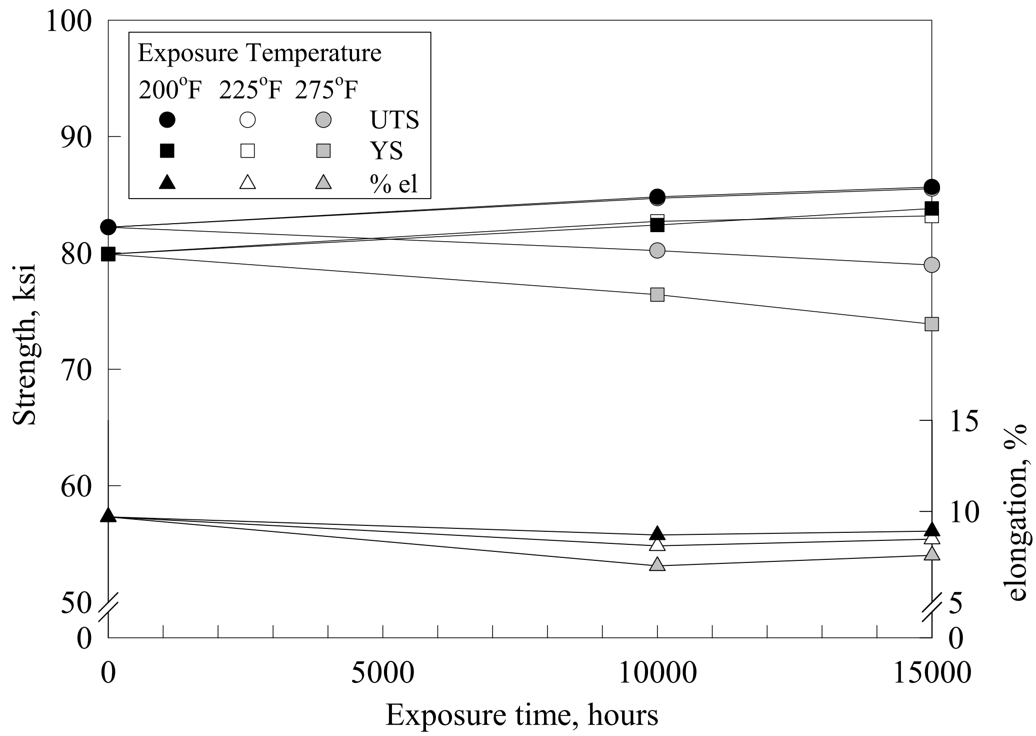



(a) Longitudinal tensile properties

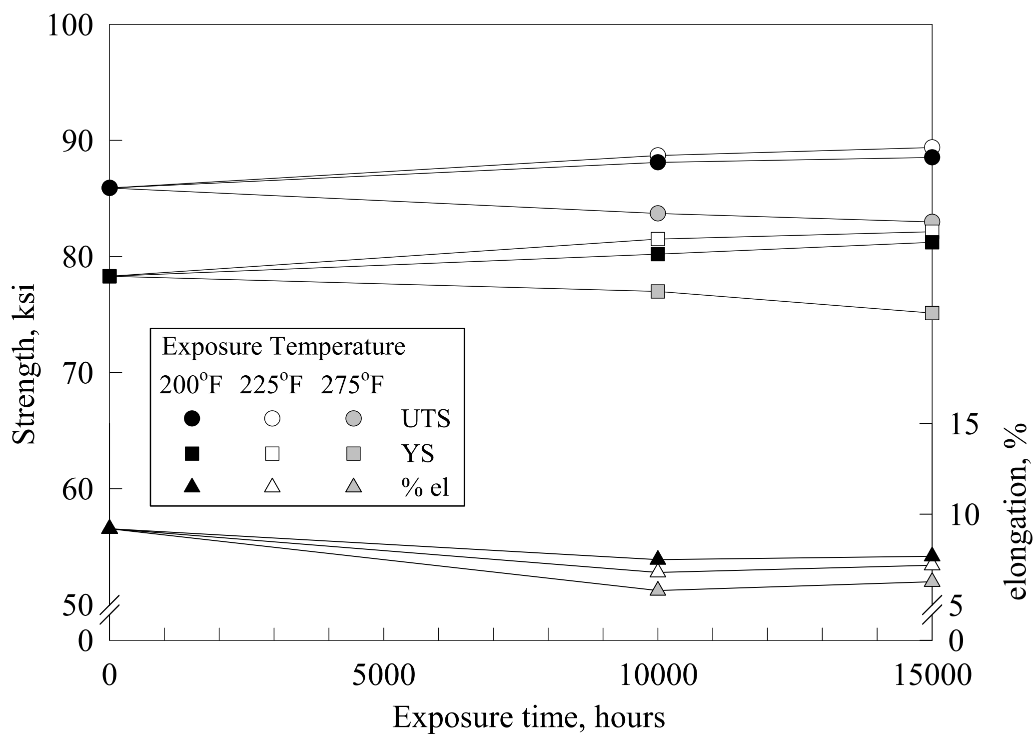



(b) Transverse tensile properties

Figure C24. Variation in tensile properties for C416 measured at -65°F after thermal exposure.

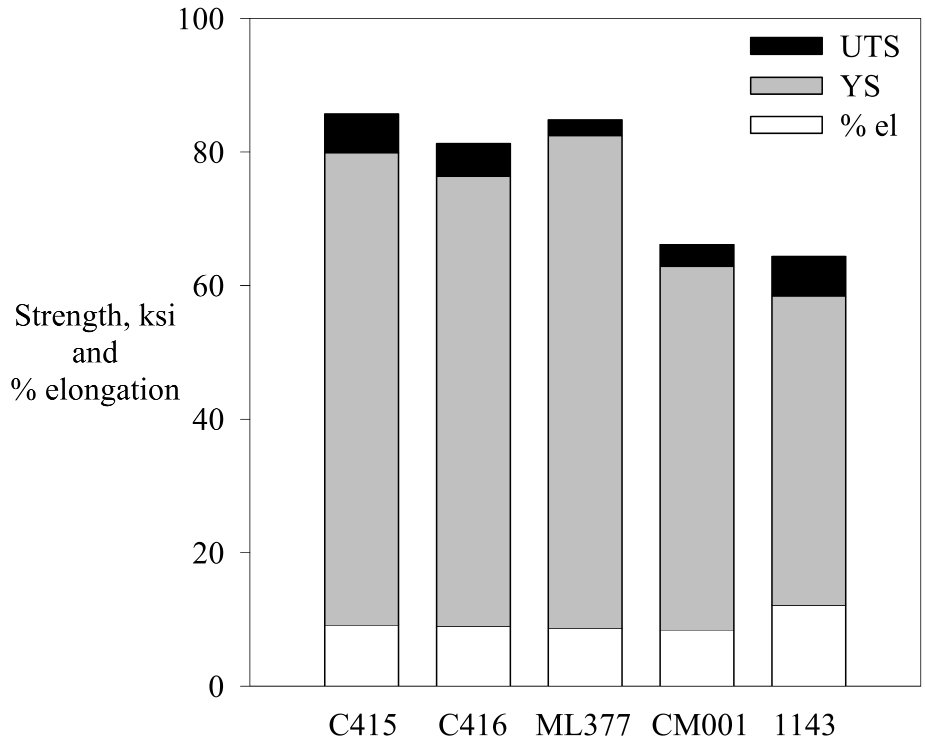



(a) Longitudinal tensile properties

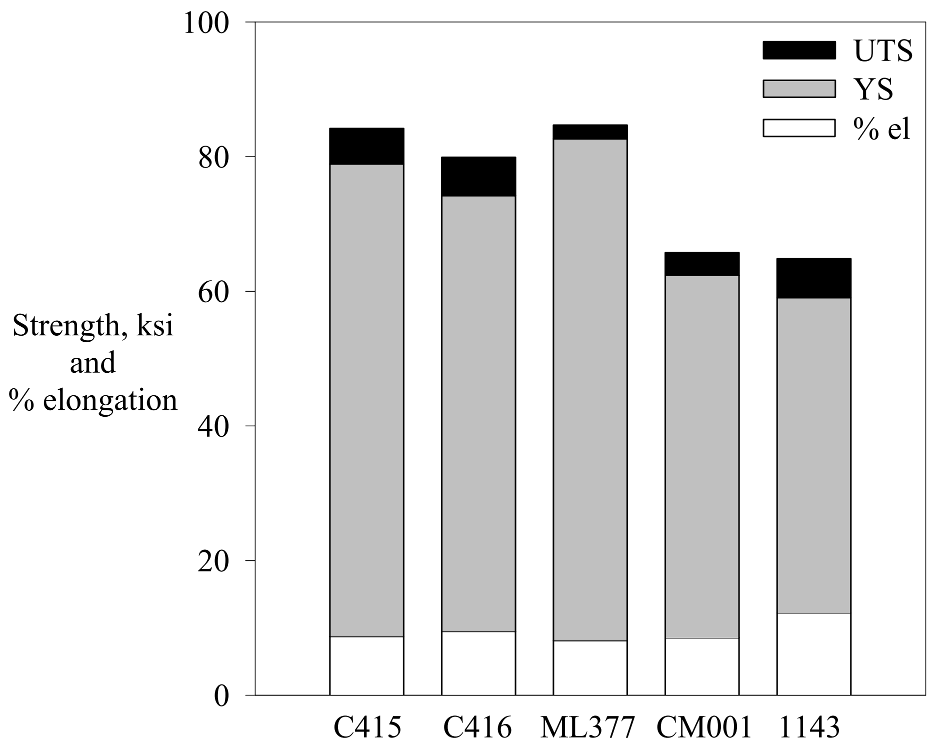



(b) Transverse tensile properties

Figure C25. Variation in tensile properties for ML377 measured at -65°F after thermal exposure.

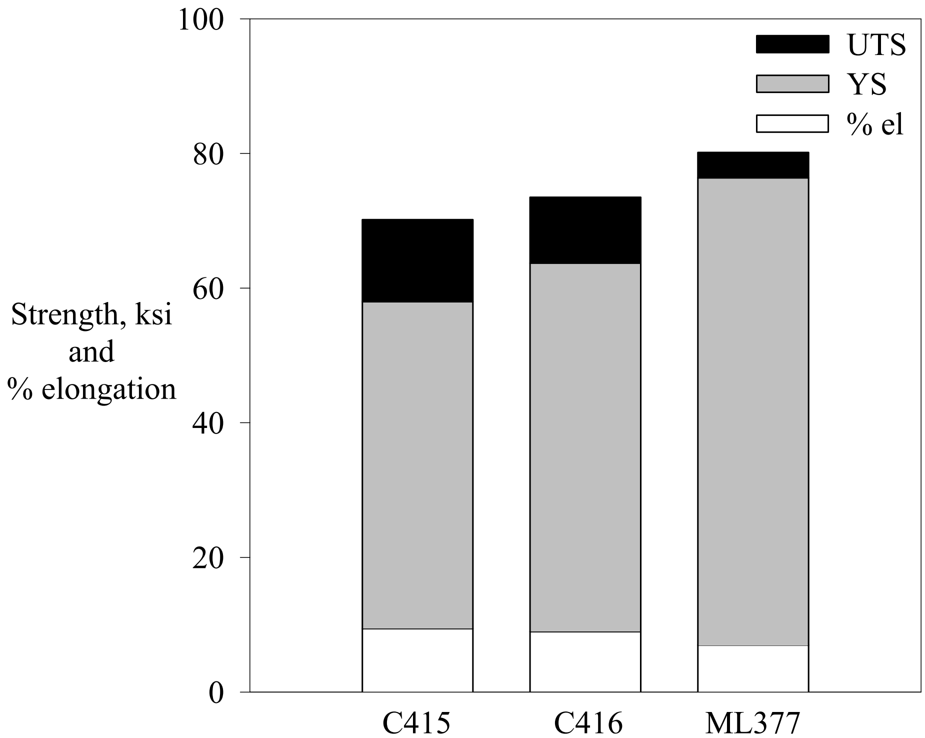



(a) Properties at -65°F after exposure at 200°F.




(b) Properties at -65°F after exposure at 225°F.

Figure C26. Tensile properties measured at -65°F after 10,000 hours thermal exposure.




(c) Properties at -65°F after exposure at 275°F.

Figure C26. Tensile properties measured at -65°F after 10,000 hours thermal exposure. (concluded)

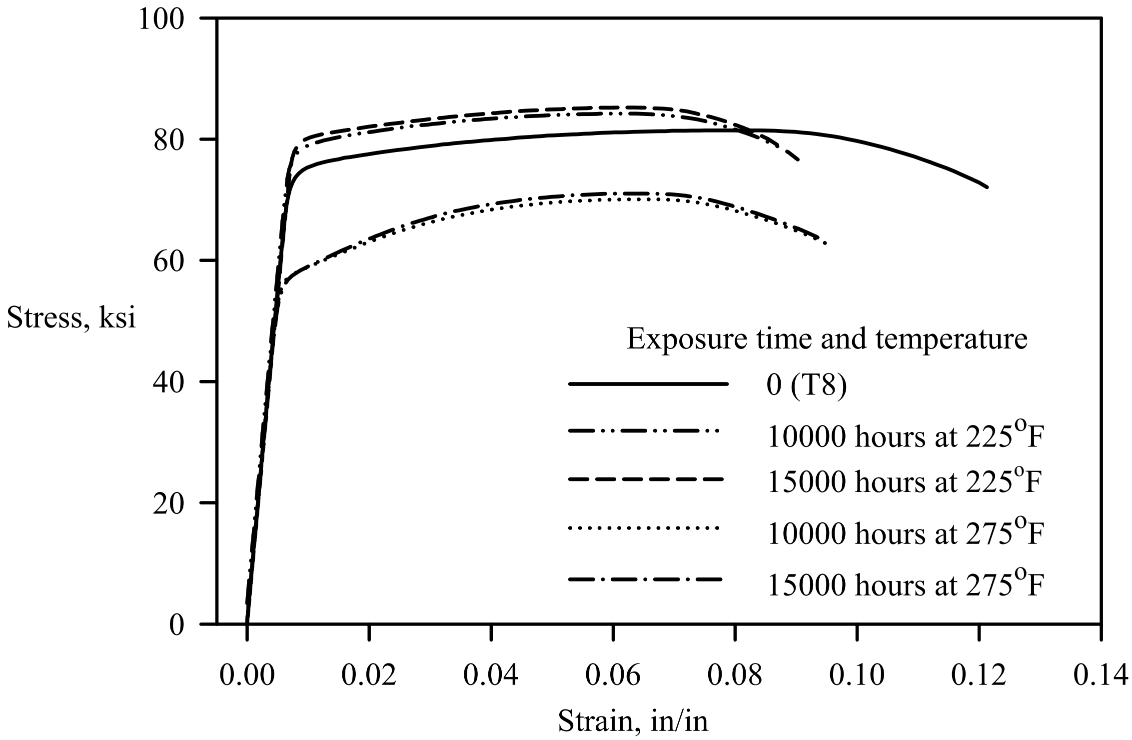



Figure C27. Variation in longitudinal stress-strain curves for C415 measured at -65°F after thermal exposure.

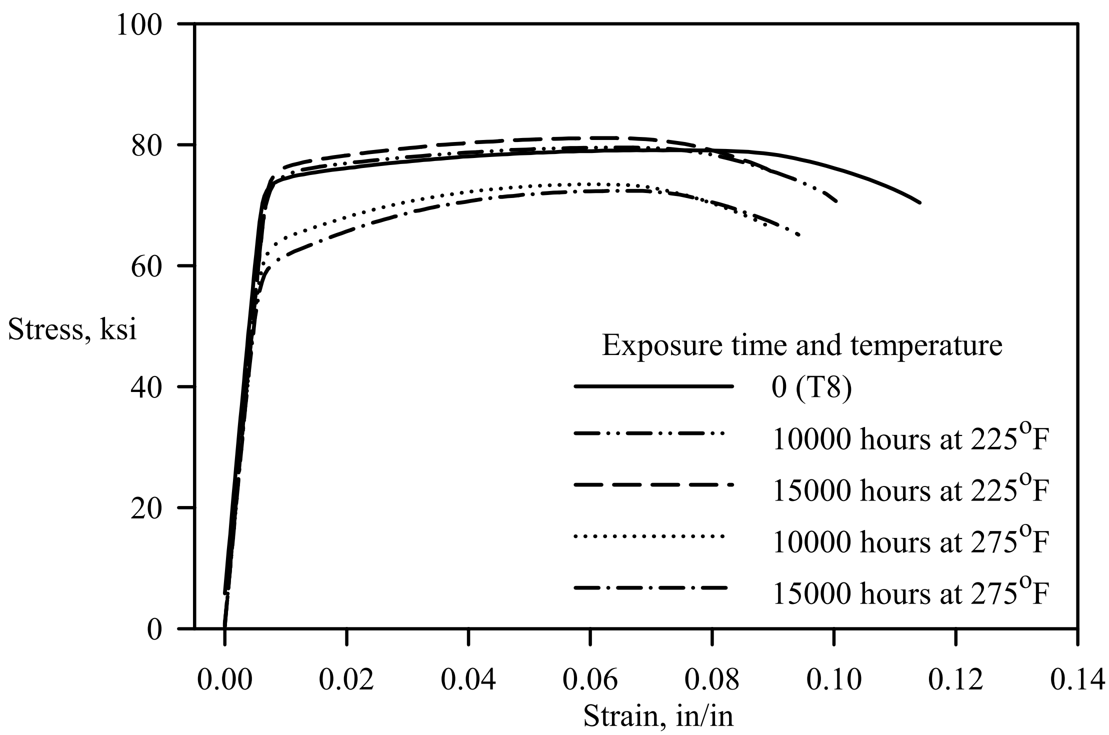



Figure C28. Variation in longitudinal stress-strain curves for C416 measured at -65°F after thermal exposure.

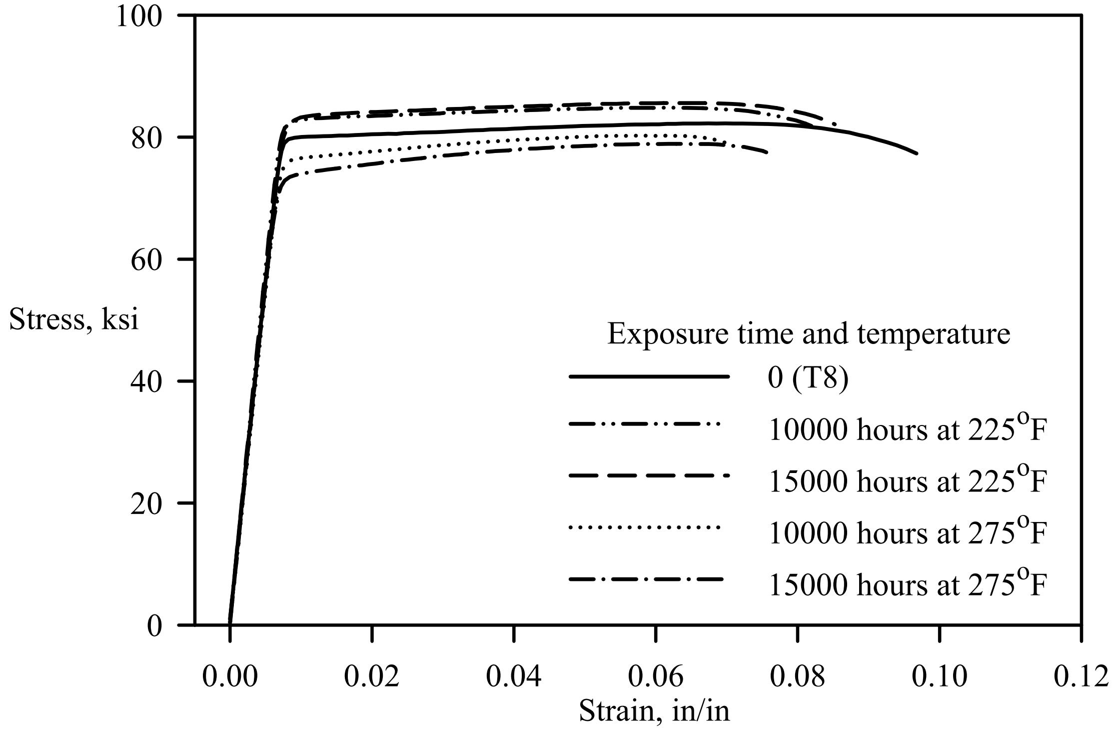



Figure C29. Variation in longitudinal stress-strain curves for ML377 measured at -65°F after thermal exposure.

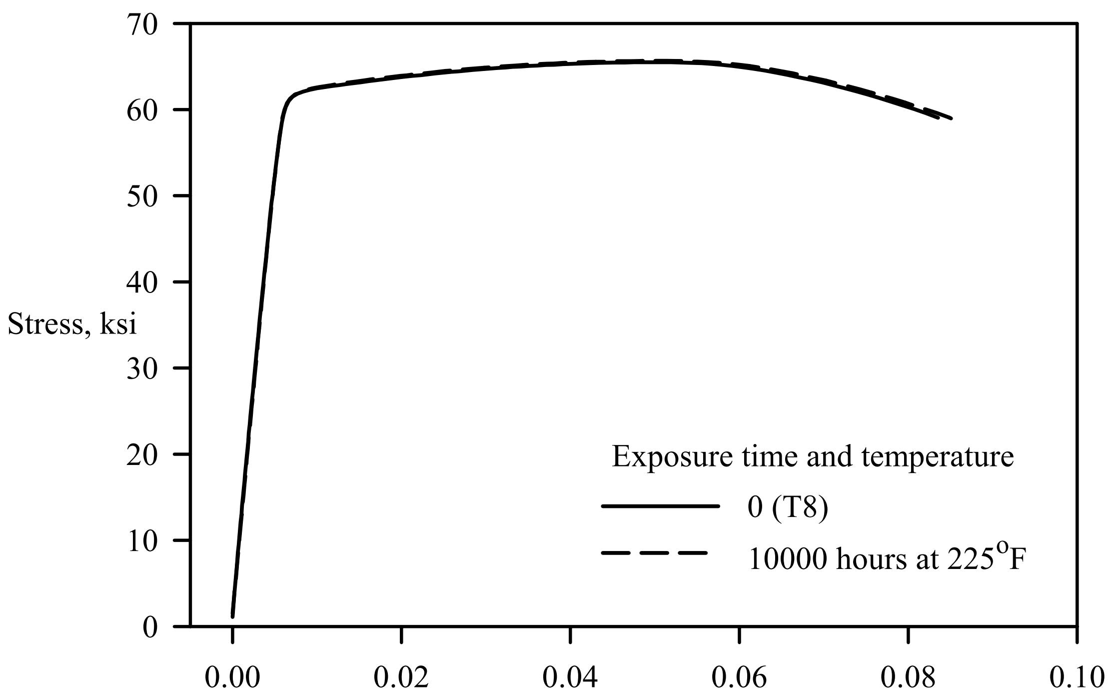



Figure C30. Variation in longitudinal stress-strain curves for CM001 measured at -65°F after thermal exposure.

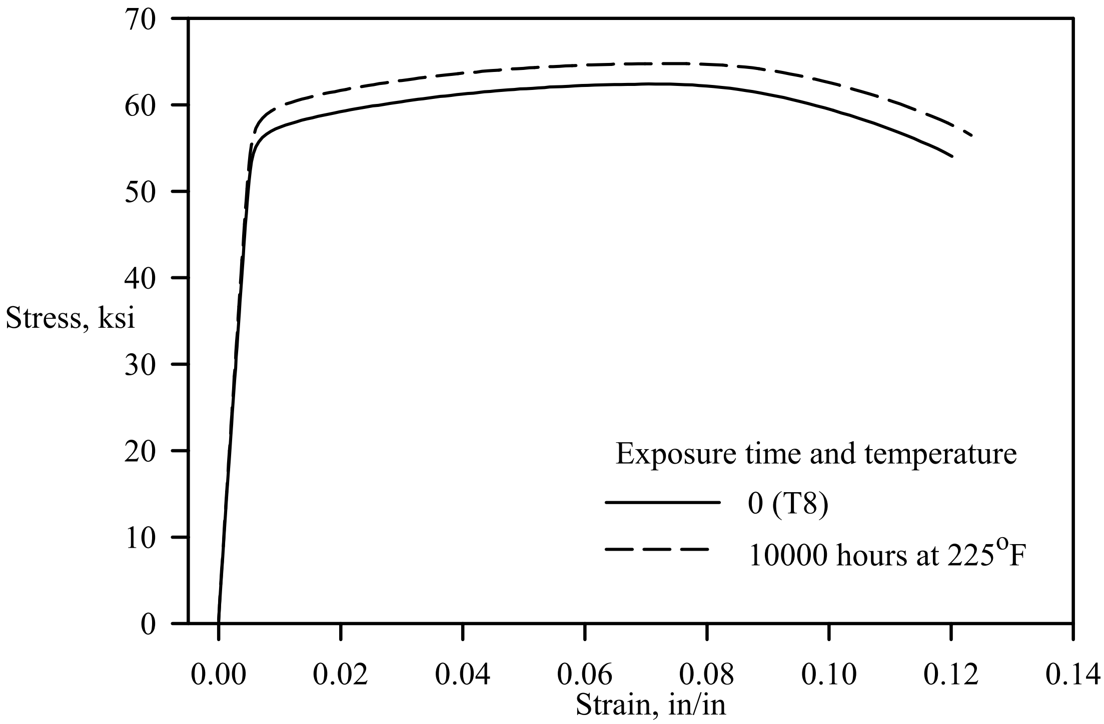



Figure C31. Variation in longitudinal stress-strain curves for 1143 measured at -65°F after thermal exposure.

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**14. ABSTRACT**
Tensile properties were evaluated for aluminum alloys that are candidates for airframe applications on high speed transport aircraft. These alloys included the Al-Cu-Mg-Ag alloys C415 and C416 and the Al-Cu-Li-Mg-Ag alloys RX818 and ML377. The Al-Cu7-Mg alloys CM001, used on the Concorde SST, and 1143, modified from the TU144 Russian supersonic aircraft alloy, were tested for comparison. The alloys were thermally exposed at 200°F, 225°F and 275°F for times up to 30,000 hours. Tensile tests were performed on thermally exposed and as received materials at -65°F, room and elevated temperatures. The candidate alloys showed significant tensile property improvements over CM001 and 1143. Room temperature yield strengths of the candidate alloys were at least 20% greater than for CM001 and 1143, for as received and thermally exposed conditions. After 30,000 hours exposure at 200°F and 225°F, the alloys C415, C416 and ML377 showed minor decreases in yield strength, tensile strength and elongation when compared to the as received properties. Reductions in tensile strength from the as received values were up to 25% for alloys C415, C416 and ML377 after 15,000 hours exposure at 275°F.

**15. SUBJECT TERMS**
Al-Cu-Mg-Ag alloys; Al-Cu-Li-Mg-Ag alloys; Tensile properties; Thermal exposure; C415; C416; RX818; ML377; CM001; 1143

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