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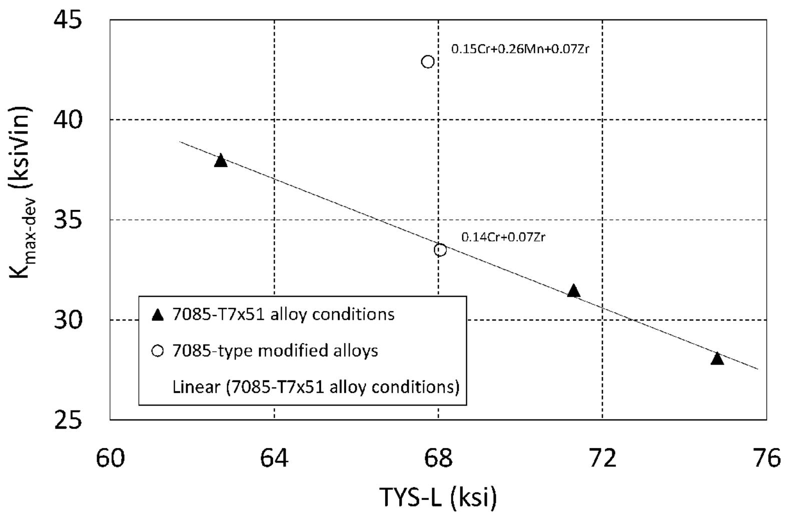
(54) **Title**: IMPROVED THICK WROUGHT 7XXX ALUMINUM ALLOYS, AND METHODS FOR MAKING THE SAME

FIG. 5 - $K_{max-dev}$ vs. TYS-L at T/2 for ~5.3in thick plate



(57) **Abstract**: Improved wrought 7xxx aluminum alloy products are disclosed. The improved wrought 7xxx aluminum alloy products generally include 6.0 - 10.0 wt. % Zn, 1.4 - 2.2 wt. % Mg, 1.3 - 2.5 wt. % Cu and 0.080 - 0.250 wt. % Cr. The improved wrought 7xxx aluminum alloy products generally have a thickness of from 3.0 inches to 12 inches, and realize an improved combination of properties, such an improved combination of crack deviation resistance, strength, fracture toughness and corrosion resistance.

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IMPROVED THICK WROUGHT 7XXX ALUMINUM ALLOYS, AND METHODS FOR MAKING THE SAME

BACKGROUND

[001] Aluminum alloys are useful in a variety of applications. However, improving one property of an aluminum alloy without degrading another property is elusive. For example, it is difficult to increase the strength of a wrought aluminum alloy without affecting other properties such as fracture toughness or corrosion resistance. Another property of interest is "crack deviation", where a crack abruptly changes direction from the intended or expected fracture plane under fatigue loading (e.g., Mode I loading). Crack deviation can be a problem for aircraft manufacturers in some applications because it is difficult to take into account during design. FIG. 13 shows crack deviation of a constant load amplitude fatigue crack growth test specimen.

SUMMARY OF THE DISCLOSURE

[002] Broadly, the present patent application relates to improved thick wrought 7xxx aluminum alloy products, and methods for producing the same. The new thick wrought 7xxx aluminum alloy products may realize an improved combination of crack deviation resistance and at least one of strength, elongation, fracture toughness, and corrosion resistance, among other properties.

[003] The new thick wrought 7xxx aluminum alloy products generally contain 0.080 - 0.250 wt. % Cr and have a nominal thickness of from 3.0 to 12.0 inches (7.62 - 30.48 cm). The new thick wrought 7xxx aluminum alloys also generally contain 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu. The new thick wrought 7xxx aluminum alloys may contain up to 0.50 wt. % Mn, up to 0.15 wt. % Zr, up to 0.15 wt. % Ti, up to 0.15 wt. % Si, and up to 0.15 wt. % Fe, the balance being aluminum and other elements, wherein the wrought 7xxx aluminum alloy product includes not greater than 0.05 wt. % of any one of the other elements, and wherein the wrought 7xxx aluminum alloy product includes not greater than 0.15 wt. % in total of the other elements. In one embodiment, a new wrought 7xxx aluminum alloy product includes 0.080 - 0.250 wt. % Cr and 0.07 - 0.15 wt. % Zr. In another embodiment, a new wrought 7xxx aluminum alloy product includes 0.080 - 0.250 wt. % Cr and 0.15 - 0.50 wt. %

Mn. In yet another embodiment, a new wrought 7xxx aluminum alloy product includes 0.080 - 0.250 wt. % Cr, 0.15 - 0.50 wt. % Mn, and 0.07 - 0.15 wt. % Zr.

[004] As shown by the below examples, the use of chromium, optionally in combination with zirconium and/or manganese, facilitates achievement of improved crack deviation resistance properties. Thus, the new thick wrought 7xxx aluminum alloy products generally contain a sufficient amount of chromium to obtain improved crack deviation resistance properties as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. As used herein, an “equivalent 7xxx aluminum alloy product” is of an equivalent composition, form, thickness and temper as the new thick wrought 7xxx aluminum alloy product, but contains not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. For instance, if a conventional 7085 aluminum alloy plate product, having a nominal thickness of 5.00 inches, is artificially aged to achieve a typical tensile yield strength (L) of about 70 ksi, then an improved new thick wrought 7xxx aluminum alloy according to the invention would have an equivalent composition to the conventional 7085 aluminum alloy plate product, but would also include 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn, as provided below. Such an improved new thick wrought 7xxx aluminum alloy accordingly would also be a plate product, would have a nominal thickness of 5.00 inches, and would also be artificially aged to achieve a typical tensile yield strength (L) of about 70 ksi. The improved new thick wrought 7xxx aluminum alloy, however, would achieve at least 5% better (higher) typical L-S crack deviation resistance $K_{max-dev}$ at a strength of 70 ksi as compared to the conventional 7085 aluminum alloy plate product, and at least partially due to the use of chromium, optionally with manganese and/or zirconium.

[005] During fatigue crack growth testing of C(T) specimens in the L-S orientation, there is a strong driving force for cracks to abruptly deviate at approximately 90 degrees (typically 70-110 degrees) primarily along grain boundaries aligned in the preferred microstructural direction (i.e. longitudinal direction). In the new alloys described herein, Cr-containing and Mn-containing dispersoid phases (fine intermetallic phases typically between ~20 and ~200 nm in size) form in a relatively homogeneous manner across the grain structure during processing of 7xxx aluminum alloys. The likely Cr-containing dispersoid phase in 7xxx alloys is E phase ($Al_{18}Mg_2Cr_3$). Mn can partially substitute for Cr in E phase but will also likely form separate dispersoid phases (e.g., Al_6Mn, $Al_{12}(Mn,Fe)_3Si$]. Such dispersoids are believed to help keep the

fatigue crack stay in plane through void initiation and growth ahead of the crack-tip. Zirconium forms Al_3Zr, which, in combination with the E phase and/or Mn-containing dispersoids, may further facilitate improved crack deviation resistance.

[006] In one embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 10% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 12% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 14% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 16% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 18% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 20% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 22% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 24% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a

26% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 28% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product realizes at least a 30% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In any of these embodiments, a new thick wrought 7xxx aluminum alloy product may realize at least equivalent L-T plane strain fracture toughness to the equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength. In any of these embodiments, a new thick wrought 7xxx aluminum alloy product may realize at least equivalent corrosion resistance (e.g., stress corrosion cracking resistance, exfoliation corrosion resistance) to the equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

[007] As described above, chromium may facilitate improved crack deviation resistance properties. However, too much chromium may result in unnecessary degradation of strength and/or fracture toughness. Thus, the amount of chromium in the new thick wrought 7xxx aluminum alloy products may be limited to facilitate achievement of the improved combination of properties described herein. Further, the amount of chromium required to achieve the improved combination of properties may vary over the different types of 7xxx alloys described herein (e.g., due to magnesium content), but the amount of chromium required generally falls within the range of 0.080 to 0.250 wt. % Cr, keeping in mind to limit the amount of chromium so as to avoid coarse chromium particles.

[008] In one embodiment, the new thick wrought 7xxx aluminum alloy product includes an amount of chromium (in weight percent) falling within the scope of the following equations:

(1) $Cr_{(min)} = 0.251 - 0.082(Mg)$, wherein $Cr_{(min)} \geq 0.080$; and

(2) $Cr_{(max)} = 0.351 - 0.082(Mg)$, wherein $Cr_{(max)} \leq 0.25$;

where Mg is the amount of magnesium (in weight percent) in a new thick wrought 7xxx aluminum alloy product, and where the amount of chromium (in weight percent) in the new thick wrought 7xxx aluminum alloy product is at least as high as $Cr(_{min})$, but the amount of chromium in the new thick wrought 7xxx aluminum alloy product does not exceed $Cr(_{max})$. For instance, if a new thick wrought 7xxx aluminum alloy product includes 1.65 wt. % Mg, then this new thick wrought 7xxx aluminum alloy product may contain from 0.116 to 0.216 wt. % Cr per the above equations. In one embodiment, $Cr_{(max)}$ = 0.341 - 0.082(Mg). In another embodiment, $Cr_{(max)}$ = 0.331 - 0.082(Mg). In yet another embodiment, $Cr_{(max)}$ = 0.321 - 0.082(Mg). In another embodiment, $Cr_{(max)}$ = 0.311 - 0.082(Mg). In yet another embodiment, $Cr_{(max)}$ = 0.301 - 0.082(Mg). In another embodiment, $Cr_{(max)}$ = 0.291 - 0.082(Mg). In yet another embodiment, $Cr_{(max)}$ = 0.281 - 0.082(Mg). In one embodiment, $Cr_{(min)}$ = 0.261 - 0.082(Mg). In another embodiment, $Cr_{(min)}$ = 0.271 - 0.082(Mg).

[009] As noted above, the wrought 7xxx aluminum alloy product may include up to 0.15 wt. % Zr (e.g., 0.07 - 0.15 wt. % Zr). In one embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.09 to 0.13 wt. % Zr. In another embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.09 to 0.11 wt. % Zr. In another embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.10 to 0.12 wt. % Zr. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.07 to 0.09 wt. % Zr. In another embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.11 to 0.13 wt. % Zr. In some embodiments, the new thick wrought 7xxx aluminum alloy products are essentially free of zirconium, containing not greater than 0.03 wt. % Zr, or not greater than 0.01 wt. % Zr, or not greater than 0.005 wt. % Zr, or not greater than 0.001 wt. % Zr.

[0010] As noted above, the new thick wrought 7xxx aluminum alloy product may include up to 0.50 wt. % Mn. The amount of Mn should be limited so as to avoid detrimentally impacting the combination of strength, fracture toughness and crack deviation resistance. As shown by the below examples, some manganese may be included in the new thick wrought 7xxx aluminum alloy product. In one embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.15 to 0.50 wt. % Mn. In another embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.20 to 0.50 wt. % Mn. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product includes from 0.25 to 0.45 wt. % Mn. In other embodiments, the new thick wrought 7xxx aluminum alloy product includes not greater than 0.15 wt. % Mn, such as not greater than 0.10 wt. % Mn, or not greater than 0.05 wt. % Mn, or not greater than 0.02 wt. % Mn.

[0011] The new thick wrought 7xxx aluminum alloy products generally contain an amount of chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 34 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In one embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 35 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 36 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 37 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In yet another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 38 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 39 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In yet another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max-dev}$ of at least 40 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max-dev}$ of at least 41 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In yet another embodiment, the new thick wrought 7xxx aluminum alloy products contain an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max-dev}$ of at least 42 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In another embodiment, a new thick wrought 7xxx aluminum alloy product contains an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max-dev}$ of at least 43 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product contains an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max-dev}$ of at least 44 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn. In another embodiment, a new thick wrought 7xxx aluminum alloy product contains an amount of the chromium sufficient to obtain a typical L-S crack deviation resistance $K_{max-dev}$ of at least 45 ksi√in. as measured on a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, and at least equivalent strength to that of an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn.

[0012] In one approach, a new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize all of (a) a typical L-S crack deviation resistance $K_{max\text{-}dev}$ (L-S $K_{max\text{-}dev}$) of at least 34 ksi√in, (b) a typical L tensile yield strength (TYS(L)) of at least 60 ksi, and (c) a typical L-T plane strain K_{IC} fracture toughness of at least 19 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper. In one embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 92.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.11$, where x is the TYS(L) and y is the L-S K $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$.

[0013] In one embodiment relating to achievement of a typical L tensile yield strength (TYS(L)) of at least 60 ksi and a typical L-T plane strain K_{IC} fracture toughness of at least 19 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, as provided above, the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu, and further the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is selected to comply with (and does contain / comply with) the boundaries of equations (3) and (4), below.

Equation (3) is:

$$Mg \geq \frac{(A3 * Cu + B3 * Zn + C3 * (Cu - 1.9) * (Zn - 8) + D3 * (Cu - 1.9)^2 + E3 * (Zn - 8)^2 + F3)}{(G3 * Cu + H3 * Zn + I3 * (Cu - 1.9) * (Zn - 8) + J3 * (Cu - 1.9)^2 + K3 * (Zn - 8)^2 + 1)}$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (3) coefficients are:

Coefficient	Value		Coefficient	Value
A3	-2.1573		G3	-0.2117
B3	-0.0027		H3	0.1916
C3	-0.1731		I3	-0.0106
D3	2.6269		J3	-0.3406
E3	0.0826		K3	-0.0098
F3	4.4526			

Equation (4) is:

$$Mg \leq (A4 + B4*Zn + C4*(Zn-8)^2 + D4*(Zn-8)^3 + E4*(Zn-8)^4 + F4*Cu + G4*Cu*Zn + H4*Cu*(Zn-8)^2 + I4*Cu*(Zn-8)^3 + J4*Cu*(Zn-8)^4)$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (4) coefficients are:

Coefficient	Value		Coefficient	Value
A4	1.9304		F4	0.6588
B4	0.1087		G4	-0.1282
C4	-0.0158		H4	0.0063

D4	0.0079		I4	-0.0031
E4	-0.0018		J4	0.0007

[0014] In one embodiment, the new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize all of (a) a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 34 ksi√in, (b) a typical L tensile yield strength of at least 63 ksi, and (c) a typical L-T plane strain K_{IC} fracture toughness of at least 21 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper. In one embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 92.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$

and TYS(L) satisfy the expression $y \geq -0.8184x + 95.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$.

[0015] In one embodiment relating to achievement of a typical L tensile yield strength (TYS(L)) of at least 63 ksi and a typical L-T plane strain K_{IC} fracture toughness of at least 21 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, as provided above, the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu, and further the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is selected to comply with (and does contain / comply with) the boundaries of equations (5) and (6), below.

Equation (5) is:

$$Mg \geq \frac{(A5 * Cu + B5 * Zn + C5 * (Cu - 1.9) * (Zn - 8) + D5 * (Cu - 1.9)^2 + E5 * (Zn - 8)^2 + F5)}{(G5 * Cu + H5 * Zn + I5 * (Cu - 1.9) * (Zn - 8) + J5 * (Cu - 1.9)^2 + K5 * (Zn - 8)^2 + 1)}$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (5) coefficients are:

Coefficient	Value		Coefficient	Value
A5	-2.676		G5	-0.2805
B5	0.014		H5	0.2631
C5	-0.2327		I5	-0.017
D5	3.2411		J5	-0.5005
E5	0.1016		K5	-0.0148
F5	5.9836			

Equation (6) is:

$$Mg \leq (A6 + B6*Zn + C6*(Zn-8)^2 + D6*(Zn-8)^3 + E6*(Zn-8)^4 + F6*Cu + G6*Cu*Zn + H6*Cu*(Zn-8)^2 + I6*Cu*(Zn-8)^3 + J6*Cu*(Zn-8)^4)$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (6) coefficients are:

Coefficient	Value		Coefficient	Value
A6	2.0238		F6	0.5835
B6	0.0905		G6	-0.121
C6	-0.0072		H6	0.0029

D6	0.0058		I6	-0.0023
E6	-0.0021		J6	0.0008

[0016] In another embodiment, the new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize all of (a) a typical L-S crack deviation resistance $K_{max-dev}$ of at least 34 ksi√in, (b) a typical L tensile yield strength of at least 66 ksi, and (c) a typical L-T plane strain K_{IC} fracture toughness of at least 21 ksi√in. relative to a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper. In one embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 92.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$.

[0017] In one embodiment relating to achievement of a typical L tensile yield strength (TYS(L)) of at least 66 ksi and a typical L-T plane strain K_{IC} fracture toughness of at least 21 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, as provided above, the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu, and further the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is selected to comply with (and does contain / comply with) the boundaries of equations (7) and (8), below.

Equation (7) is:

$$Mg \geq \frac{(A7 * Cu + B7 * Zn + C7 * (Cu - 1.9) * (Zn - 8) + D7 * (Cu - 1.9)^2 + E7 * (Zn - 8)^2 + F7)}{(G7 * Cu + H7 * Zn + I7 * (Cu - 1.9) * (Zn - 8) + J7 * (Cu - 1.9)^2 + K7 * (Zn - 8)^2 + 1)}$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (7) coefficients are:

Coefficient	Value		Coefficient	Value
A7	-3.6882		G7	-0.4299
B7	0.0616		H7	0.4023
C7	-0.343		I7	-0.0255
D7	4.3737		J7	-0.7985
E7	0.1352		K7	-0.0251
F7	8.7149			

Equation (8) is:

$$Mg \leq (A8 + B8*Zn + C8*(Zn-8)^2 + D8*(Zn-8)^3 + E8*(Zn-8)^4 + F8*Cu + G8*Cu*Zn + H8*Cu*(Zn-8)^2 + I8*Cu*(Zn-8)^3 + J8*Cu*(Zn-8)^4)$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (8) coefficients are:

Coefficient	Value		Coefficient	Value
A8	2.0238		F8	0.5835
B8	0.0905		G8	-0.121
C8	-0.0072		H8	0.0029

D8	0.0058		I8	-0.0023
E8	-0.0021		J8	0.0008

[0018] In another embodiment, the new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize all of (a) a typical L-S crack deviation resistance $K_{max-dev}$ of at least 34 ksi√in, (b) a typical L tensile yield strength of at least 66 ksi, and (c) a typical L-T plane strain K_{IC} fracture toughness of at least 24 ksi√in. relative to a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper. In one embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 92.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$.

[0019] In one embodiment relating to achievement of a typical L tensile yield strength (TYS(L)) of at least 66 ksi and a typical L-T plane strain K_{IC} fracture toughness of at least 24 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, as provided above, the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu, and further the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is selected to comply with (and does contain / comply with) the boundaries of equations (9) and (10), below.

Equation (9) is:

$$Mg \geq \frac{(A9 * Cu + B9 * Zn + C9 * (Cu - 1.9) * (Zn - 8) + D9 * (Cu - 1.9)^2 + E9 * (Zn - 8)^2 + F9)}{(G9 * Cu + H9 * Zn + I9 * (Cu - 1.9) * (Zn - 8) + J9 * (Cu - 1.9)^2 + K9 * (Zn - 8)^2 + 1)}$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (9) coefficients are:

Coefficient	Value		Coefficient	Value
A9	-3.6882		G9	-0.4299
B9	0.0616		H9	0.4023
C9	-0.343		I9	-0.0255
D9	4.3737		J9	-0.7985
E9	0.1352		K9	-0.0251
F9	8.7149			

Equation (10) is:

$$Mg \leq (A10 + B10*Zn + C10*(Zn-8)^2 + D10*(Zn-8)^3 + E10*(Zn-8)^4 + F10*Cu + G10*Cu*Zn + H10*Cu*(Zn-8)^2 + I10*Cu*(Zn-8)^3 + J10*Cu*(Zn-8)^4)$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (10) coefficients are:

Coefficient	Value		Coefficient	Value
A10	2.1711		F10	0.457
B10	0.0615		G10	-0.1078
C10	-0.0088		H10	0.0041

D10	0.0046		I10	-0.0023
E10	0.0008		J10	-0.0005

[0020] In another embodiment, the new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize all of (a) a typical L-S crack deviation resistance $K_{max-dev}$ of at least 34 ksi√in, (b) a typical L tensile yield strength of at least 68 ksi, and (c) a typical L-T plane strain K_{IC} fracture toughness of at least 27 ksi√in. relative to a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper. In one embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 92.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 95.61, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 96.11, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 96.61, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 97.11, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 97.61, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 98.11, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 98.61, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 99.11, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression y ≥ -0.8184x + 99.61, where x is the TYS(L) and y is the L-S $K_{max-dev}$.

[0021] In one embodiment relating to achievement of a typical L tensile yield strength (TYS(L)) of at least 68 ksi and a typical L-T plane strain K_{IC} fracture toughness of at least 27 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, as provided above, the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu, and further the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is selected to comply with (and does contain / comply with) the boundaries of equations (11) and (12), below.

Equation (11) is:

$$Mg \geq \frac{(A11 * Cu + B11 * Zn + C11 * (Cu - 1.9) * (Zn - 8) + D11 * (Cu - 1.9)^2 + E11 * (Zn - 8)^2 + F11)}{(G11 * Cu + H11 * Zn + I11 * (Cu - 1.9) * (Zn - 8) + J11 * (Cu - 1.9)^2 + K11 * (Zn - 8)^2 + 1)}$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (11) coefficients are:

Coefficient	Value		Coefficient	Value
A11	-4.8188		G11	-0.6569
B11	0.1379		H11	0.5588
C11	-0.4353		I11	-0.0183
D11	5.4328		J11	-1.1871
E11	0.1644		K11	-0.038
F11	11.5481			

Equation (12) is:

$$Mg \leq (A12 + B12*Zn + C12*(Zn-8)^2 + D12*(Zn-8)^3 + E12*(Zn-8)^4 + F12*Cu + G12*Cu*Zn + H12*Cu*(Zn-8)^2 + I12*Cu*(Zn-8)^3 + J12*Cu*(Zn-8)^4)$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (12) coefficients are:

Coefficient	Value		Coefficient	Value
A12	2.1728		F12	0.4014
B12	0.0471		G12	-0.1016
C12	0.0075		H12	-0.0041

D12	0.0034		I12	-0.002
E12	-0.0002		J12	0

[0022] In another embodiment, the new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize all of (a) a typical L-S crack deviation resistance $K_{max\text{-}dev}$ of at least 34 ksi√in, (b) a typical L tensile yield strength of at least 70 ksi, and (c) a typical L-T plane strain K_{IC} fracture toughness of at least 29 ksi√in. relative to a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper. In one embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 92.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 93.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 94.61$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max\text{-}dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.11$, where x is the TYS(L) and y is the L-S $K_{max\text{-}dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 95.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 96.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 97.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 98.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.11$, where x is the TYS(L) and y is the L-S $K_{max-dev}$. In yet another embodiment, this new thick wrought 7xxx aluminum alloy product contains an amount of the Zn, Mg, Cu and Cr sufficient to realize the above strength and crack deviation properties and such that the realized L-S $K_{max-dev}$ and TYS(L) satisfy the expression $y \geq -0.8184x + 99.61$, where x is the TYS(L) and y is the L-S $K_{max-dev}$.

[0023] In one embodiment relating to achievement of a typical L tensile yield strength (TYS(L)) of at least 70 ksi and a typical L-T plane strain K_{IC} fracture toughness of at least 29 ksi√in. relative to (as measured on) a rolled 5.00 inch version of the wrought 7xxx aluminum alloy product in the T7451 or T7651 temper, as provided above, the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is 6.0 - 10.0 wt. % Zn, 1.3 - 2.3 wt. % Mg, and 1.2 - 2.6 wt. % Cu, and further the amount of Zn, Mg and Cu in the new thick wrought 7xxx aluminum alloy product is selected to comply with (and does contain / comply with) the boundaries of equations (13) and (14), below.

Equation (13) is:

$$Mg \geq \frac{(A13 * Cu + B13 * Zn + C13 * (Cu - 1.9) * (Zn - 8) + D13 * (Cu - 1.9)^2 + E13 * (Zn - 8)^2 + F13)}{(G13 * Cu + H13 * Zn + I13 * (Cu - 1.9) * (Zn - 8) + J13 * (Cu - 1.9)^2 + K13 * (Zn - 8)^2 + 1)}$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (13) coefficients are:

Coefficient	Value		Coefficient	Value
A13	-7.2311		G13	-1.1717
B13	0.3381		H13	0.8888
C13	-0.538		I13	0.0286
D13	7.1904		J13	-2.1298
E13	0.2065		K13	-0.0709
F13	17.0533			

Equation (14) is:

$$Mg \leq (A14 + B14*Zn + C14*(Zn-8)^2 + D14*(Zn-8)^3 + E14*(Zn-8)^4 + F14*Cu + G14*Cu*Zn + H14*Cu*(Zn-8)^2 + I14*Cu*(Zn-8)^3 + J14*Cu*(Zn-8)^4)$$

wherein Zn, Mg, and Cu are the amount of the Zn, the Mg and the Cu contained in the new thick wrought 7xxx aluminum alloy product, and wherein the equation (14) coefficients are:

Coefficient	Value		Coefficient	Value
A14	2.073		F14	0.4186
B14	0.0504		G14	-0.1044
C14	0.012		H14	-0.0073

D14	0.0019		I14	-0.0012
E14	-0.001		J14	0.0006

[0024] As noted above, the new thick wrought 7xxx aluminum alloy product may include up to 0.15 wt. % Ti. Titanium may be used to facilitate grain refining during casting, such as by using TiB_2 or TiC. Elemental titanium may also or alternatively be used. In one embodiment, the new thick wrought 7xxx aluminum alloy product includes from 0.005 to 0.025 wt. % Ti.

[0025] As noted above, the new thick wrought 7xxx aluminum alloy product may include up to 0.15 wt. % Si and up to 0.15 wt. % Fe as impurities. The amount of silicon and iron may be limited so as to avoid detrimentally impacting the combination of strength, fracture toughness and crack deviation resistance. In one embodiment, the new thick wrought 7xxx aluminum alloy product may include up to 0.10 wt. % Si and up to 0.12 wt. % Fe as impurities. In another embodiment, the new thick wrought 7xxx aluminum alloy product may include up to 0.08 wt. % Si and up to 0.10 wt. % Fe as impurities. In yet another embodiment, the new thick wrought 7xxx aluminum alloy product may include up to 0.06 wt. % Si and up to 0.08 wt. % Fe as impurities. In yet another embodiment, the new thick wrought 7xxx aluminum alloy product may include up to 0.04 wt. % Si and up to 0.06 wt. % Fe as impurities. In another embodiment, the new thick wrought 7xxx aluminum alloy product may include up to 0.03 wt. % Si and up to 0.05 wt. % Fe as impurities.

[0026] As noted above, the new thick wrought 7xxx aluminum alloy product has a thickness of from 3.0 to 12.0 inches (7.62 - 30.48 cm). In one embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 3.0 to 10.0 inches (7.62 - 25.4 cm). In another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 3.0 to 8.0 inches (7.62 - 20.3 cm). In yet another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 3.0 to 6.0 inches (7.62 - 15.24 cm). In another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 3.0 to 5.0 inches (7.62 - 12.7 cm).

[0027] In one embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 4.0 to 12.0 inches (10.16 - 30.48 cm). In one embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 4.0 to 10.0 inches (10.16 - 25.4 cm). In another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 4.0 to 8.0 inches (10.16 - 20.3 cm). In yet another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 4.0 to 6.0 inches (10.16 - 15.24 cm). In another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 4.0 to 5.0 inches (10.16 - 12.7 cm).

[0028] In one embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 5.0 to 12.0 inches (12.7 - 30.48 cm). In one embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 5.0 to 10.0 inches (12.7 - 25.4 cm). In another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 5.0 to 8.0 inches (12.7 - 20.3 cm). In yet another embodiment, the new thick wrought 7xxx aluminum alloy product has a thickness of from 5.0 to 6.0 inches (12.7 - 15.24 cm).

[0029] In one embodiment, a new thick wrought 7xxx aluminum alloy product is a rolled product. In another embodiment, a new thick wrought 7xxx aluminum alloy product is an extruded product. In yet another embodiment, a new thick wrought 7xxx aluminum alloy product is a forged product (e.g., a hand forged product, a die forged product).

[0030] In one embodiment, the new 7xxx aluminum alloy is a 7085 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.08 - 0.15 wt. % Zr specified in alloy 7085. In one embodiment, the new 7085 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7085 alloy includes 0.104 - 0.250 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7085 alloy includes all of 0.104 - 0.250 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. In one embodiment, the new 7085 alloy includes from 1.40 to 1.60 wt. % Mg, and thus includes from 0.120 to 0.236 wt. % Cr. The teachings of this paragraph also apply to other 7x85 alloys, such as 7185.

[0031] In one embodiment, the new 7xxx aluminum alloy is a 7065 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.05 - 0.15 wt. % Zr specified in alloy 7065. In one embodiment, the new 7065 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7065 alloy includes 0.104 - 0.228 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b)

0.15 - 0.50 wt. % Mn. In another embodiment, the new 7065 alloy includes all of 0.104 - 0.228 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. In one embodiment, the 7065 alloy includes from 1.55 to 1.75 wt. % Mg, and thus includes from 0.107 to 0.224 wt. % Cr. The teachings of this paragraph also apply to other 7x65 alloys.

[0032] In one embodiment, the new 7xxx aluminum alloy is a 7040 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.05 - 0.12 wt. % Zr specified in alloy 7040. In one embodiment, the new 7040 alloy includes 0.08 - 0.228 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7040 alloy includes all of 0.08 - 0.228 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. In one embodiment, the new 7040 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. The teachings of this paragraph also apply to other 7x40 alloys, such as 7140.

[0033] In one embodiment, the new 7xxx aluminum alloy is a 7050 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.08 - 0.15 wt. % Zr specified in alloy 7050. In one embodiment, the new 7050 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7050 alloy includes 0.08 - 0.193 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7050 alloy includes all of 0.08 - 0.193 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. In one embodiment, the 7050 alloy includes from 1.95 to 2.30 wt. % Mg, and thus includes from 0.080 to 0.191 wt. % Cr. The teachings of this paragraph also apply to other 7x50 alloys, such as 7150 and 7250.

[0034] In one embodiment, the new 7xxx aluminum alloy is a 7055 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.08 - 0.25 wt. % Zr specified in alloy 7055. In one embodiment, the new 7055 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7055 alloy includes 0.08 - 0.203 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7055 alloy includes all of 0.08 - 0.203 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. In one embodiment, the 7055 alloy includes from 1.85 to 2.05 wt. % Mg, and thus includes from 0.083 to 0.200 wt. % Cr. The teachings of this paragraph also apply to other 7x50 alloys, such as 7150 and 7250.

[0035] In one embodiment, the new 7xxx aluminum alloy is a 7136 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.10 - 0.20 wt. % Zr specified in alloy 7136. In one embodiment, the new 7136 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7136 alloy includes 0.08 - 0.203 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7136 alloy includes all of 0.08 - 0.203 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x36 alloys, such as 7036.

[0036] In one embodiment, the new 7xxx aluminum alloy is a 7010 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.10 - 0.16 wt. % Zr specified in alloy 7010. In one embodiment, the new 7010 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7010 alloy includes 0.08 - 0.179 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7010 alloy includes all of 0.08 - 0.179 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x10 alloys.

[0037] In one embodiment, the new 7xxx aluminum alloy is a 7081 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.06 - 0.15 wt. % Zr specified in alloy 7081. In one embodiment, the new 7081 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7081 alloy includes 0.08 - 0.203 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7081 alloy includes all of 0.08 - 0.203 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x81 alloys, such as 7181.

[0038] In one embodiment, the new 7xxx aluminum alloy is a 7099 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to

0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.05 - 0.15 wt. % Zr specified in alloy 7099. In one embodiment, the new 7099 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7099 alloy includes 0.08 - 0.220 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7099 alloy includes all of 0.08 - 0.220 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x99 alloys, such as 7199.

[0039] In one embodiment, the new 7xxx aluminum alloy is a 7449 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the new 7449 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7449 alloy includes 0.08 - 0.203 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7449 alloy includes all of 0.08 - 0.203 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x49 alloys, such as 7049, 7149, 7249, and 7349.

[0040] In one embodiment, the new 7xxx aluminum alloy is a 7075 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the new 7075 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7075 alloy includes 0.08 - 0.179 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7075 alloy includes all of 0.08 - 0.179 wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x75 alloys, such as 7175 and 7475.

[0041] In one embodiment, the new 7xxx aluminum alloy is a 7097 alloy (as defined by the Aluminum Association *Teal Sheets* document, described below) modified to include 0.080 to 0.250 wt. % Cr. In one embodiment, the chromium is a substitute for (in whole or in part) the 0.08 - 0.15 wt. % Zr specified in alloy 7097. In one embodiment, the new 7097 alloy includes chromium within the $Cr_{(min)}$ and $Cr_{(max)}$ limits, described above. In one embodiment, the new 7075 alloy includes 0.08 - 0.220 wt. % Cr and at least one of (a) 0.07 - 0.15 wt. % Zr and (b) 0.15 - 0.50 wt. % Mn. In another embodiment, the new 7097 alloy includes all of 0.08 - 0.220

wt. % Cr, 0.07 - 0.15 wt. % Zr and 0.15 - 0.50 wt. % Mn. The teachings of this paragraph also apply to other 7x97 alloys.

Definitions

[0042] As used herein, "typical longitudinal (L) tensile yield strength" or TYS(L) is determined in accordance with ASTM B557-10 and by measuring the tensile yield strength (TYS) in the longitudinal direction (L) at the T/4 location from at least three different lots of material, and with at least duplicate specimens being tested for each lot, for a total of at least 6 different measured specimen values, with the typical TYS(L) being the average of the at least 6 different measured specimen values.

[0043] As used herein, typical plane strain fracture toughness (K_{IC}) (L-T)" or L-T K_{IC} is determined in accordance with ASTM E399-12, by measuring the plane strain fracture toughness in the L-T direction at the T/4 location from at least three different lots of material using a C(T) specimen, where "W" is 4.0 inches and "B" is 2.0 inches, with at least duplicate specimens being tested for each lot, for a total of at least 6 different measured specimen values, and with the typical plane strain fracture toughness (K_{IC}) (L-T) being the average of the at least 6 different valid K_{IC} measured specimen values.

[0044] As used herein, "typical L-S crack deviation resistance $K_{max\text{-}dev}$" is determined by preparing at least triplicate C(T) specimens in accordance with ASTM E647-13e01, entitled "Standard Test Method for Measurement of Fatigue Crack Growth Rates" ("ASTM E647"). The at least triplicate C(T) specimens are taken in the L-S direction from between width/3 and 2width/3 of the material, where the "B" dimension of the specimen is 0.25 inch (6.35 mm) and the "W" dimension of the specimen is 3.0 inches (7.62 cm), and with the notch tip at T/2. The test specimens are tested per the constant load amplitude test method of ASTM E647, with R = 0.1 (equal to P_{min}/P_{max}), high humidity air (relative humidity of > 90%), at room temperature. The pre-crack must meet all validity requirements of ASTM E647, and the pre-cracking must be performed at the same loading conditions as the test. The test is started using a $K_{max} > 10$ ksi√in. (11.1 MPa√m), and the starting force must be large enough that crack deviation occurs before the ASTM E647 C(T) specimen validity requirement $((W-a) \geq (4/\pi)*(K_{max\text{-}dev}/TYS)^2)$ is no longer met for the test. The test must be valid per ASTM E647 up to the point of crack deviation. A crack "deviates" when the crack of the C(T) specimen substantially deviates from the intended fracture plane (e.g., by 70-110°) in any direction, and the deviation leads to specimen separation along an unintended fracture plane. The average crack length at deviation (a_{dev}) is derived by using the weighted average of (i) the two surface values (front and back values) and (ii) one mid-thickness value (center value); weighted average (a_{dev}) = (front + back + 2* center)/4). $K_{max-dev}$ is the maximum stress-intensity factor calculated by using the average crack length at deviation (a_{dev}), maximum applied force (P_{max}), and the stress-intensity factor expression per ASTM E647 A1.5.1.1 for the C(T) specimen (Note: ΔK and ΔP should be replaced by $K_{max-dev}$ and P_{max}, respectively, per the stress ratio relationship $R = K_{min}/K_{max}$ and $\Delta K = K_{max} - K_{min}$ as defined in ASTM E647 3.2.14).

[0045] In order to set a baseline to determine whether an aluminum alloy contains an amount of Zn, Mg, Cu and/or Cr, optionally supplementing the Cr with Mn and/or Zr, sufficient to achieve the above-noted properties, the typical TYS(L), the typical L-T K_{IC}, and/or the typical L-S $K_{max-dev}$ are generally required to be determined on a rolled 5.00 inch version of the 7xxx aluminum alloy product in the T7451 and the T7651 tempers. Thus, even though an actual product may not be 5.00 inches thick, or may not be rolled, this actual product would still have a sufficient amount of Zn, Mg, Cu and Cr, optionally with Mn and/or Zr, as per this patent application, if that actual product would meet the property requirements when in the form of a rolled 5.00 inch version of the 7xxx aluminum alloy product in either the T7451 or the T7651 temper. As used herein, a “rolled 5.00 inch version of the 7xxx aluminum alloy product” means a 7xxx aluminum alloy product, having a composition within the scope of the Zn, Mg and Cu limits described herein, that has been conventionally rolled to a nominal thickness of 5.00 inches, within thickness tolerance limits per ANSI H35.2-2001, table 7.7b.

[0046] All references to specific aluminum alloys (e.g., 7085, 7050, 7040) means the alloys described in the document “*International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys*”, by The Aluminum Association (2015, and subsequent versions), A.K.A., the “*Teal Sheets*”.

[0047] As used herein, “T76 temper” means the T76 temper described in ANSI H35.1-2009, and further requiring SCC resistance (stress corrosion cracking resistance), wherein the SCC resistance is tested in accordance with ASTM G47(2011) using three specimens, wherein all three specimens survive the alternate immersion test for a period of 20 days at a net stress of 25 ksi in the short-transverse (ST) direction. As used herein, the "T7651" temper means the T76 temper where the plate is stress-relieved 1.5 - 3.0% by stretching prior to artificial aging.

[0048] As used herein, "T74 temper" means the T74 temper described in ANSI H35.1-2009, and further requiring SCC resistance (stress corrosion cracking resistance), wherein the SCC resistance is tested in accordance with ASTM G47(2011) using three specimens, wherein all three specimens survive the alternate immersion test for a period of 20 days at a net stress of 35 ksi in the short-transverse (ST) direction. As used herein, the "T7451" temper means the T74 temper where the plate is stress-relieved 1.5 - 3.0% by stretching prior to artificial aging.

BRIEF DESCRIPTION OF THE DRAWINGS

[0049] FIGS. 1-3 are graphs illustrating properties of Example 1 alloys.

[0050] FIG. 4 is a graph illustrating one embodiment of a property boundary requirement for tensile yield strength (L) and crack deviation resistance L-S $K_{max-dev}$.

[0051] FIGS. 5-6 are graphs illustrating properties of plant produced 5.3 inch (approx.) gauge plate.

[0052] FIGS. 7-8 are graphs illustrating properties of plant produced 6.5 inch (approx.) gauge plate.

[0053] FIGS. 9-10 are graphs illustrating properties of the alloys of Example 3.

[0054] FIGS. 11-12 are graphs illustrating properties of the alloys of Example 4.

[0055] FIG. 13 is a photograph showing a C(T) specimen having a crack deviating from the intended crack plane.

DETAILED DESCRIPTION

Example 1

[0056] Various 7xxx aluminum alloys were cast as six inch (15.24 cm) thick ingots (nominal). The actual compositions of the cast ingots are shown in Table 1, below. Alloy 1 is a conventional aluminum alloy, registered with the Aluminum Association as aluminum alloy 7085. The registered version of the 7085 alloy requires, among other things, 0.08 - 0.15 wt. % Zr, not greater than 0.04 wt. % Mn and not greater than 0.04 wt. % Cr, as shown by the document "International Alloy Designations and Chemical Composition Limits for Wrought

Aluminum and Wrought Aluminum Alloys", The Aluminum Association (2009), page 12. Commonly-owned U.S. Patent No. 6,972,110 (among others) also relates to the 7085 alloy. Alloys 2-3 are new variants of the 7085 alloy having manganese (Mn) and/or low or no zirconium (Zr).

Table 1 - Composition of Example 1 Alloys (wt. %) - Lab Scale Materials

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
1	0.02	0.05	1.65	0.04	1.44	0	7.35	0.03	0.11
2	0.02	0.05	1.68	***0.25***	1.46	0	7.52	0.02	***0.07***
3	0.02	0.06	1.70	***0.50***	1.42	0	7.47	0.04	0

The balance of each alloy was aluminum and unavoidable impurities (≤ 0.03 wt. % each, ≤ 0.10 wt. % total). After casting, the ingots were stress-relieved, sawed into multiple sections, scalped, homogenized, and then hot rolled to plate having a final gauge of about 1.75 inches (4.445 cm). The alloy plates were then solution heat treated and then hot water quenched in 190°F water (87.8°C) to simulate cooling conditions at T/2 (mid-thickness) for 5 inch plate relative to cold water (ambient) quenching. The plates were then stretched about 2.25% and then artificially aged in accordance with a standard T7651-type aging practice (*see*, ANSI H35.1 and AMS 4329A).

[0057] Various properties of the aluminum alloy plates were then tested. Specifically, the strength and elongation properties were tested in accordance with ASTM E8 and B557 at the T/2 location of the material. Plane strain fracture toughness properties were tested in the L-T direction and in accordance with ASTM E399 using a C(T) specimen taken from the T/2 location of the material, where the "B" dimension of the specimen was 0.25 inch (6.35 mm) and the "W" dimension of the specimen was 2.5 inches (63.5 mm). The typical L-S crack deviation resistance properties ($K_{max-dev}$) were determined per the test procedure described above, except the "W" dimension of the specimen was 1.3 inches (33.02 mm). The test is started using a K_{max} of approximately 20 ksi√in.

[0058] The test results are shown in Tables 2-3, below. Table 2 provides the measured values in standard metric units, and Table 3 provides the measured values in English units. The shown strength and elongation values are averages of duplicate specimens. The fracture toughness values are taken from a single specimen. The crack deviation values are averages of triplicate specimens.

Table 2 - Measured Properties (metric units)

Alloy	TYS (L) (MPa)	UTS (L) (MPa)	Elong (L) (%)	Fracture Toughness L-T K_Q (MPa√m)	$K_{max-dev}$ (MPa√m)
1	505	541	14.0	40.9	33.0
2	503	542	14.0	40	37.0
3	484	529	12.5	41.1	37.0

Table 3 - Measured Properties (English units)

Alloy	TYS (L) (ksi)	UTS (L) (ksi)	Elong (L) (%)	Fracture Toughness L-T K_Q (ksi√in)	$K_{max-dev}$ (ksi√in)
1	73.2	78.5	14.0	37.2	30.0
2	73.0	78.7	14.0	36.4	33.7
3	70.3	76.7	12.5	37.4	33.6

[0059] Properties of various plant produced materials were also tested. The compositions of these plant materials are shown in Table 4, below.

Table 4 - Composition of Example 1 Alloys (wt. %) - Plant Materials

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
4	0.024	0.032	1.63	0	1.52	0	7.44	0.018	0.11
5	0.020	0.036	1.643	0	1.51	0	7.28	0.020	0.10

The balance of each alloy was aluminum and unavoidable impurities (≤ 0.03 wt. % each, ≤ 0.10 wt. % total). After casting, the plant-scale ingots were scalped, homogenized, and then hot rolled to final gauge. The alloy plates were then solution heat treated and then cold water quenched. The plates were then stretched about 2.25% and then artificially aged. Alloy 4 is a conventional 7085-style plate product rolled to a final gauge of 5.4 inches (137.2 mm). Alloy 5 is a conventional 7085-style plate product rolled to a final gauge of 5.2 inches (132.1 mm). Alloy 4 was aged to a T7651-style temper. Alloy 5 was aged to two different aging conditions, (a) a T7451-style temper (*see*, ANSI H35.1 and AMS 4470A) and (b) an aging condition overaged relative to the T7451-style temper. After artificial aging, the mechanical properties of Alloys 4-5 were tested as per the testing of the lab-scale materials, except the strength and elongation properties were measured at T/4, the L-S $K_{max-dev}$ C(T) specimen "W" dimension was 3.0 inches, and the tests were started using a K_{max} of approximately 10 ksi√in. The test results are shown in Tables 5-6, below. Table 5 provides the measured values in standard metric units, and Table 6 provides the measured values in English units.

Table 5 - Measured Properties (metric units)

Alloy	TYS (L) (MPa)	UTS (L) (MPa)	Elong (L) (%)	Fracture Toughness L-T K_Q (MPa√m)	$K_{max-dev}$ (MPa√m)
4	516	536	10.5	41.3	30.9
5a	492	522	13.0	N/A	34.6
5b	432	479	14.5	N/A	41.7

Table 6 - Measured Properties (English units)

Alloy	TYS (L) (ksi)	UTS (L) (ksi)	Elong (L) (%)	Fracture Toughness L-T K_Q (ksi√in)	$K_{max-dev}$ (ksi√in)
4	74.8	77.7	10.5	37.6	28.1
5a	71.3	75.7	13.0	N/A	31.5
5b	62.7	69.5	14.5	N/A	38.0

[0060] FIGS. 1-3 are graphs illustrating the properties of the alloys based on the above data. As shown in FIGS. 1-3, the plant and lab-scale 7085 T7651-style materials have generally similar properties, indicating that the slow quench conditions for the lab-scale materials appropriately model the behavior of the plant produced thick gauge products. Furthermore, the addition of manganese in alloys 2-3 appears to have a limited impact on improving the combination of crack deviation resistance and tensile yield strength.

Example 2

[0061] Additional plant materials were produced and tested. The compositions of these plant materials are shown in Table 7, below.

Table 7 - Composition of Example 2 Alloys (wt. %) - Plant Materials

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
6	0.02	0.03	1.65	0	1.52	0	7.48	0.02	0.10
7	0.03	0.04	1.75	0	1.53	***0.14***	7.54	0.02	***0.07***
8	0.03	0.05	1.65	***0.26***	1.50	***0.15***	7.48	0.02	***0.07***

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
9	0.03	0.05	1.65	***0.26***	1.50	***0.15***	7.48	0.02	***0.07***

The balance of each alloy was aluminum and unavoidable impurities (≤ 0.03 wt. % each, ≤ 0.10 wt. % total). After casting, the plant-scale ingots were scalped, homogenized, and then hot rolled to final gauge. The alloy plates were then solution heat treated and then cold water quenched. The plates were then stretched about 2.25% and then artificially aged in accordance with a T7651-type aging practice (*see*, ANSI H35.1 and AMS 4329A).

[0062] Alloy 6 is a conventional 7085-style plate product rolled to a final gauge of 6.5 inches (165.1 mm). Alloys 7-9 are new variants of the 7085 alloy having manganese (Mn), chromium (Cr), and/or low zirconium (Zr). Alloys 7-8 were rolled to a final gauge of 5.4 inches (137.2 mm). Alloy 9 was rolled to a final gauge of 6.5 inches (165.1 mm).

[0063] After artificial aging, various properties of the aluminum alloy plates were then tested. Specifically, the strength and elongation properties were tested in accordance with ASTM E8 and B557 at the T/4 location of the material. Plane strain fracture toughness properties were tested in the S-L direction and in accordance with ASTM E399 using a C(T) specimen taken from the T/2 location of the material, where the "B" dimension of the specimen was 2.0 inch (5.08 cm) and the "W" dimension of the specimen was 4.0 inches (10.16 cm). Triplicate C(T) specimens were samples between width/3 and 2*width/3 except for alloys 8-9, where specimens were sampled two thicknesses away from the plate edge. The typical L-S crack deviation resistance properties ($K_{max-dev}$) were determined per the test procedure described above, except the "W" dimension of the specimen was 2.0 inches (5.08 cm). The test is started using a K_{max} of approximately 15 ksi√in. The test results are shown in Tables 8-9, below. Table 8 provides the measured values in standard metric units, and Table 9 provides the measured values in English units.

Table 8 - Measured Properties (metric units)

Alloy	TYS (L) (MPa)	UTS (L) (MPa)	Elong (L) (%)	Fracture Toughness S-L K_{IC} (MPa√m)	$K_{max-dev}$ (MPa√m)
6	516	536	8.2	29.5	30.5
7	469	507	13.0	36.4	36.8

Alloy	TYS (L) (MPa)	UTS (L) (MPa)	Elong (L) (%)	Fracture Toughness S-L K_{IC} (MPa√m)	$K_{max-dev}$ (MPa√m)
8	467	506	13.5	36.3	47.2
9	454	498	13.5	39.8	44.7

Table 9 - Measured Properties (English units)

Alloy	TYS (L) (ksi)	UTS (L) (ksi)	Elong (L) (%)	Fracture Toughness S-L K_{IC} (ksi√in)	$K_{max-dev}$ (ksi√in)
6	74.9	77.8	8.2	26.8	27.7
7	68.1	73.6	13.0	33.1	33.5
8	67.8	73.5	13.5	33.05	42.9
9	65.9	72.2	13.5	36.2	40.7

[0064] FIGS. 5-8 are graphs illustrating the properties of the plant based materials. As shown, the new materials having chromium, manganese, and zirconium realize a large improvement in crack deviation resistance relative to the conventional material. The new materials also realize a similar or improved strength-toughness trade-off. FIG. 4 illustrates one embodiment of a property requirement boundary for the new thick wrought 7xxx alloys based on data herein.

Example 3

[0065] Additional lab-scale materials were produced and tested. The compositions of these plant materials are shown in Table 10, below.

Table 10 - Composition of Example 3 Alloys (wt. %) - Lab-Scale

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
10	0.02	0.04	1.67	0	1.51	0	7.64	0.02	0.11
11	0.03	0.03	1.65	0	1.57	***0.15***	7.46	0.02	***0***
12	0.02	0.04	1.63	***0.45***	1.49	***0.15***	7.47	0.02	***0***
13	0.02	0.05	1.74	***0.46***	1.40	***0.16***	7.48	0.02	0.12
14	0.02	0.04	1.65	0	***2.11***	0	7.65	0.02	0.11
15	0.03	0.03	1.64	0	***2.05***	***0.14***	7.40	0.02	***0***
16	0.03	0.03	1.69	0	***2.03***	***0.15***	7.57	0.02	***0***
17	0.03	0.03	1.67	0	***2.02***	***0.17***	7.56	0.02	***0***

18	0.02	0.04	1.66	0	1.47	0	***6.32***	0.02	0.11
19	0.03	0.02	1.63	0	1.48	***0.15***	***6.39***	0.02	***0***
20	0.03	0.02	1.70	0	1.56	***0.21***	***6.25***	0.02	***0***
21	0.02	0.04	1.68	0	1.45	0	***9.68***	0.02	0.11
22	0.02	0.04	1.66	0	1.53	***0.15***	***9.32***	0.02	***0***
23	0.02	0.05	1.64	0	1.48	***0.21***	***9.46***	0.02	***0***
24	0.02	0.04	***2.48***	0	1.49	0	7.36	0.02	0.11
25	0.03	0.04	***2.39***	0	1.46	***0.17***	7.45	0.02	***0***
26	0.02	0.04	***2.42***	0	1.54	***0.21***	7.56	0.02	***0***

[0066] The balance of each alloy was aluminum and unavoidable impurities (≤ 0.03 wt. % each, ≤ 0.10 wt. % total). Alloy 10 is a conventional 7085-style alloy. Alloys 11-26 are new alloys having varying amounts of zinc (Zn), magnesium (Mg), copper (Cu), manganese (Mn), chromium (Cr), and/or zirconium (Zr).

[0067] After casting, the lab-scale ingot were stress-relieved, sawed into multiple sections, scalped, homogenized, and then hot rolled to plate having a final gauge of about 1.75 inches (4.445 cm). The alloy plates were then solution heat treated and then hot water quenched in 180°F water (82.2°C) to simulate cooling conditions at T/2 (mid-thickness) for 3 inch plate relative to cold water (ambient) quenching. The plates were then stretched about 2.25% and then artificially aged in accordance with a standard T7X51-type aging practice, expected to fall between T7651 and T7451.

[0068] After artificial aging, various properties of the aluminum alloy plates were tested. Specifically, the strength and elongation properties were tested in accordance with ASTM E8 and B557 at the T/2 location of the material. Plane strain fracture toughness properties were tested in the L-T direction and in accordance with ASTM E399 using a C(T) specimen taken from the T/2 location of the material, where the "B" dimension of the specimen was 0.25 inch (6.35 mm) and the "W" dimension of the specimen was 2.5 inches (63.5 mm). The typical L-S crack deviation resistance properties ($K_{max\text{-}dev}$) were determined per the test procedure described above, except the "W" dimension of the specimen was 1.3 inches (33.02 mm). The test is started using a K_{max} of approximately 20 ksi√in. The test results are shown in Tables 11-12, below. Table 11 provides the measured values in standard metric units, and Table 12 provides the measured values in English units.

<u>Table 11 - Measured Properties (metric units)</u>

Alloy	TYS (L) (MPa)	UTS (L) (MPa)	Elong (L) (%)	Fracture Toughness L-T K_Q (MPa√m)	$K_{max-dev}$ (MPa√m)
10	488	533	17.0	50.1	48.2
11	486	535	14.0	46.7	45.5
12	484	535	14.5	45.1	47.5
13	490	540	14.0	49.2	53.4
14	485	540	14.0	36.8	32.9
15	483	537	13.0	38.5	37.2
16	485	539	13.0	40.8	42.6
17	492	547	14.5	43.7	39.8
18	477	523	17.0	50.8	48.4
19	494	540	13.5	35.4	33.7
20	479	528	16.0	51.3	53.6
21	476	513	16.5	41.8	44.9
22	485	527	14.0	43.3	44.4
23	485	529	14.0	45.4	43.8
24	482	529	14.0	47.4	41.4
25	483	529	13.5	42.5	35.7
26	484	532	13.0	42.2	36.0

Table 12 - Measured Properties (English units)

Alloy	TYS (L) (ksi)	UTS (L) (ksi)	Elong (L) (%)	Fracture Toughness L-T K_Q (ksi√in)	$K_{max-dev}$ (ksi√in)
10	70.8	77.4	17.0	45.6	43.8
11	70.6	77.6	14.0	42.5	41.4
12	70.3	77.6	14.5	41	43.2
13	71.1	78.3	14.0	44.8	48.6
14	70.3	78.4	14.0	33.5	29.9
15	70.1	77.9	13.0	35	33.9
16	70.3	78.2	13.0	37.1	38.7
17	71.4	79.4	14.5	39.8	36.2
18	69.2	75.9	17.0	46.2	44.1
19	71.6	78.4	13.5	32.2	30.7
20	69.4	76.6	16.0	46.7	48.7
21	69.1	74.5	16.5	38	40.8
22	70.4	76.4	14.0	39.4	40.4
23	70.4	76.7	14.0	41.3	39.8

Alloy	TYS (L) (ksi)	UTS (L) (ksi)	Elong (L) (%)	Fracture Toughness L-T K_Q (ksi√in)	$K_{max-dev}$ (ksi√in)
24	69.9	76.8	14.0	43.1	37.7
25	70.1	76.7	13.5	38.7	32.5
26	70.3	77.2	13.0	38.4	32.8

[0069] FIGS. 9-10 are graphs illustrating properties of the Example 3 alloys. As shown, the materials respond differently to additions of Cr as a function of Zn, Mg and Cu levels. For a 7085-type alloy (alloys 10-13), the presence of Cr, Mn and Zr facilitates a $K_{max-dev}$ improvement over the conventional 7085 material (alloy 10). For alloys with increased Mg content (alloys 14-17), the addition of Cr in and of itself without the need for Zr facilitates significant increases in $K_{max-dev}$ at equivalent strength levels over an alloy with Zr but no Cr (alloy 14). For alloys with either lower or higher Zn (alloys 18-23), the addition of Cr in and of itself without Zr also appears to show some improvement in either strength or $K_{max-dev}$ over the respective alloys with Zr but no Cr. Finally, for alloys with increased Cu content (alloys 24-26), the addition of Cr in and of itself without Zr also appears to decrease $K_{max-dev}$ over an alloy with Zr but no Cr (alloy 24). Further, FIG. 10 shows that a similar trade-off between fracture toughness and tensile yield strength is achieved for a 7085-type alloy containing Cr, Mn and Zr (alloy 13) over the conventional 7085 material (alloy 10). Similarly, alloys with increased Mg, reduced or increased Zn content with additions of Cr realize similar or improved trade-offs between fracture toughness and tensile yield strength over their Cr-free and Zr-containing base alloys.

Example 4

[0070] Additional lab-scale materials were produced and tested. The compositions of these plant materials are shown in Table 13, below.

Table 13 - Composition of Example 4 Alloys (wt. %) - Lab-Scale

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
27	0.02	0.04	1.68	***0.23***	1.55	0	7.42	0.03	0.11
28	0.02	0.04	1.65	***0.45***	1.50	0	7.48	0.02	0.11
29	0.02	0.04	1.67	***0.24***	1.52	***0.12***	7.37	0.02	0.11
30	0.02	0.05	1.70	***0.45***	1.52	***0.13***	7.40	0.02	0.11
31	0.02	0.04	1.67	0	1.51	0	7.64	0.02	0.11
32	0.02	0.04	1.67	0	1.51	0	7.64	0.02	0.11

[0071] The balance of each alloy was aluminum and unavoidable impurities (≤ 0.03 wt. % each, ≤ 0.10 wt. % total). Alloys 31-32 are conventional 7085-style alloy. Alloys 27-30 are new alloys having varying amounts of manganese (Mn), chromium (Cr), and/or zirconium (Zr).

[0072] After casting, the lab-scale ingots were stress-relieved, sawed into multiple sections, scalped, homogenized, and then hot rolled to plate having a final gauge of about 1.75 inches (4.445 cm). The alloy plates were then solution heat treated and then hot water quenched in 190°F water (87.8°C) to simulate cooling conditions at T/2 (mid-thickness) for 5 inch plate relative to cold water (ambient) quenching. The plates were then stretched about 2.25% and then artificially aged in accordance with a standard T7651-type or T7451-type aging practice.

[0073] After artificial aging, various properties of the aluminum alloy plates were tested. Specifically, the strength and elongation properties were tested in accordance with ASTM E8 and B557 at the T/2 location of the material. Plane strain fracture toughness properties were tested in the L-T direction and in accordance with ASTM E399 using a C(T) specimen taken from the T/2 location of the material, where the "B" dimension of the specimen was 0.25 inch (6.35 mm) and the "W" dimension of the specimen was 2.5 inches (63.5 mm). The typical L-S crack deviation resistance properties ($K_{max-dev}$) were determined per the test procedure described above, except the "W" dimension of the specimen was 1.3 inches (33.02 mm). The test is started using a K_{max} of approximately 20 ksi√in. The test results are shown in Tables 14-15, below. Table 14 provides the measured values in standard metric units, and Table 15 provides the measured values in English units.

Table 14 - Measured Properties (metric units)

Alloy	Temper	TYS (L) (MPa)	UTS (L) (MPa)	Elong (L) (%)	Fracture Toughness L-T K_Q (MPa√m)	$K_{max-dev}$ (MPa√m)
27	T7451	491	537	13.5	35.2	32.3
28	T7451	484	535	13.0	38.1	35.6
29	T7651	483	534	13.0	44.9	38.5
30	T7651	474	528	12.5	42.4	35.8
31	T7651	511	551	14.0	33.2	29.7
32	T7451	480	528	15.5	39.8	36.8

Table 15 - Measured Properties (English units)

Alloy	Temper	TYS (L) (ksi)	UTS (L) (ksi)	Elong (L) (%)	Fracture Toughness L-T K_Q (ksi√in.)	$K_{max-dev}$ (ksi√in.)
27	T7451	71.2	78.0	13.5	32	29.4
28	T7451	70.2	77.6	13.0	34.7	32.4
29	T7651	70.1	77.4	13.0	40.9	35.0
30	T7651	68.7	76.6	12.5	38.6	32.6
31	T7651	74.1	79.9	14.0	30.2	27.0
32	T7451	69.7	76.6	15.5	36.2	33.5

[0074] FIGS. 11-12 are graphs illustrating properties of the Example 4 alloys. As shown, the addition of manganese in alloys 27 & 28 appears to have a limited impact on improving the trade-off between crack deviation resistance and tensile yield strength. Furthermore, the addition of only low levels of Cr (0.12-0.13) in alloys 29 & 30 appears to be insufficient to provide a significant impact on $K_{max-dev}$ relative to conventional 7085 materials (alloys 31 & 32).

[0075] While various embodiments of the present disclosure have been described in detail, it is apparent that modifications and adaptations of those embodiments will occur to those skilled in the art. However, it is to be expressly understood that such modifications and adaptations are within the spirit and scope of the present disclosure.

CLAIMS

What is claimed is:

1. A wrought 7085 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

2. A wrought 7065 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

3. A wrought 7040 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

4. A wrought 7140 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

5. A wrought 7050 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

6. A wrought 7150 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

7. A wrought 7250 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

8. A wrought 7136 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

9. A wrought 7010 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

10. A wrought 7081 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

11. A wrought 7181 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

12. A wrought 7099 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

13. A wrought 7199 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

14. A wrought 7097 aluminum alloy product having a thickness of 3.0 to 12.0 inches and having 0.080 - 0.250 wt. % Cr, optionally with 0.07 - 0.15 wt. % Zr and/or 0.15 - 0.50 wt. % Mn.

15. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 5% increase in $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

16. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 10% increase in $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

17. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 14% increase in $K_{max-dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

18. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 18% increase in $K_{max\text{-}dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

19. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 22% increase in $K_{max\text{-}dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

20. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 26% increase in $K_{max\text{-}dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

21. The wrought aluminum alloy products of any of claims 1-14, wherein the wrought aluminum alloy product includes a sufficient amount of the Cr, optionally with the Zr and/or the Mn, to achieve at least a 30% increase in $K_{max\text{-}dev}$ as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn, at equivalent strength.

22. The wrought aluminum alloy products of any of claims 15-21, wherein the wrought aluminum alloy product achieves at least equivalent L-T plane strain K_{IC} fracture toughness as compared to an equivalent 7xxx aluminum alloy product having not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn.

23. The wrought aluminum alloy products of any of claims 1-22, wherein the wrought aluminum alloy product contains an amount of chromium such that $Cr_{(min)} \leq Cr \leq Cr_{(max)}$, wherein $Cr_{(min)} = 0.251 - 0.082(Mg)$, and wherein $Cr_{(max)} = 0.351 - 0.082(Mg)$.

24. The wrought 7xxx aluminum alloy products of any of claims 1-23, wherein the wrought aluminum alloy product is essentially free of zirconium.

25. The wrought 7xxx aluminum alloy products of any of claims 1-24, wherein the wrought aluminum alloy products include 0.15 - 0.50 wt. % Mn.

26. The wrought 7xxx aluminum alloy products of any of claims 1-23 and 25, wherein the wrought aluminum alloy products include 0.07 - 0.15 wt. % Zr.

27. The wrought 7xxx aluminum alloy products of any of claims 1-23 and 25, wherein the wrought aluminum alloy products include 0.07 - 0.15 wt. % Zr and 0.25 - 0.45 wt. % Mn.

28. The wrought 7xxx aluminum alloy products of any of claims 1-27, wherein the wrought aluminum alloy products have a thickness of at least 4.0 inches.

29. The wrought 7xxx aluminum alloy products of any of claims 1-27, wherein the wrought aluminum alloy products have a thickness of at least 5.0 inches.

30. The wrought 7xxx aluminum alloy products of any of claims 1-27, wherein the wrought aluminum alloy products have a thickness of not greater than 8.0 inches.

31. The wrought 7xxx aluminum alloy products of any of claims 1-27, wherein the wrought aluminum alloy products have a thickness of not greater than 6.0 inches.

32. A wrought 7xxx aluminum alloy product having a thickness of 3.0 - 12.0 inches, comprising:

0.080 - 0.250 wt. % Cr;

6.0 - 10.0 wt. % Zn;

1.3 - 2.3 wt. % Mg;

1.2 - 2.6 wt. % Cu;

up to 0.50 wt. % Mn;

up to 0.15 wt. % Zr;

up to 0.15 wt. % Ti;

up to 0.15 wt. % Si; and

up to 0.15 wt. % Fe;

the balance being aluminum and other elements, wherein the wrought 7xxx aluminum alloy product includes not greater than 0.05 wt. % of any one of the other elements, and wherein the wrought 7xxx aluminum alloy product includes not greater than 0.15 wt. % in total of the other elements;

wherein $Cr_{(min)} \leq Cr \leq Cr_{(max)}$, wherein:

$Cr_{(min)} = 0.251 - 0.082(Mg)$, wherein $Cr_{(min)} \geq 0.080$; and

$Cr_{(max)} = 0.351 - 0.082(Mg)$, wherein $Cr_{(max)} \leq 0.25$.

33. The wrought 7xxx aluminum alloy product of claim 32, comprising 0.15 - 0.50 wt. % Mn.

34. The wrought 7xxx aluminum alloy product of any of claims 32-33, comprising 0.07 - 0.15 wt. % Zr.

35. The wrought 7xxx aluminum alloy product of claim 32, comprising a sufficient amount of the E phase to realize at least a 10% improvement in typical L-S crack deviation resistance $K_{max-dev}$ as compared to an equivalent 7xxx product, wherein the equivalent 7xxx product is of an equivalent composition, form, thickness and temper as the wrought 7xxx aluminum alloy product, but the equivalent 7xxx product contains not greater than 0.01 wt. % Cr and not greater than 0.02 wt. % Mn.

36. The wrought 7xxx aluminum alloy product of claim 35, comprising a sufficient amount of the E phase and Mn containing dispersoids to realize the at least a 10% improvement in typical L-S crack deviation resistance $K_{max-dev}$.

37. The wrought 7xxx aluminum alloy product of any of claims 35-36, comprising a sufficient amount of the E phase and Al_3Zr, optionally with Mn containing dispersoids, to realize the at least a 10% improvement in typical L-S crack deviation resistance $K_{max-dev}$.

FIG. 1 - Example 1 Alloys - $K_{max\text{-}dev}$ v. Tensile Yield Strength

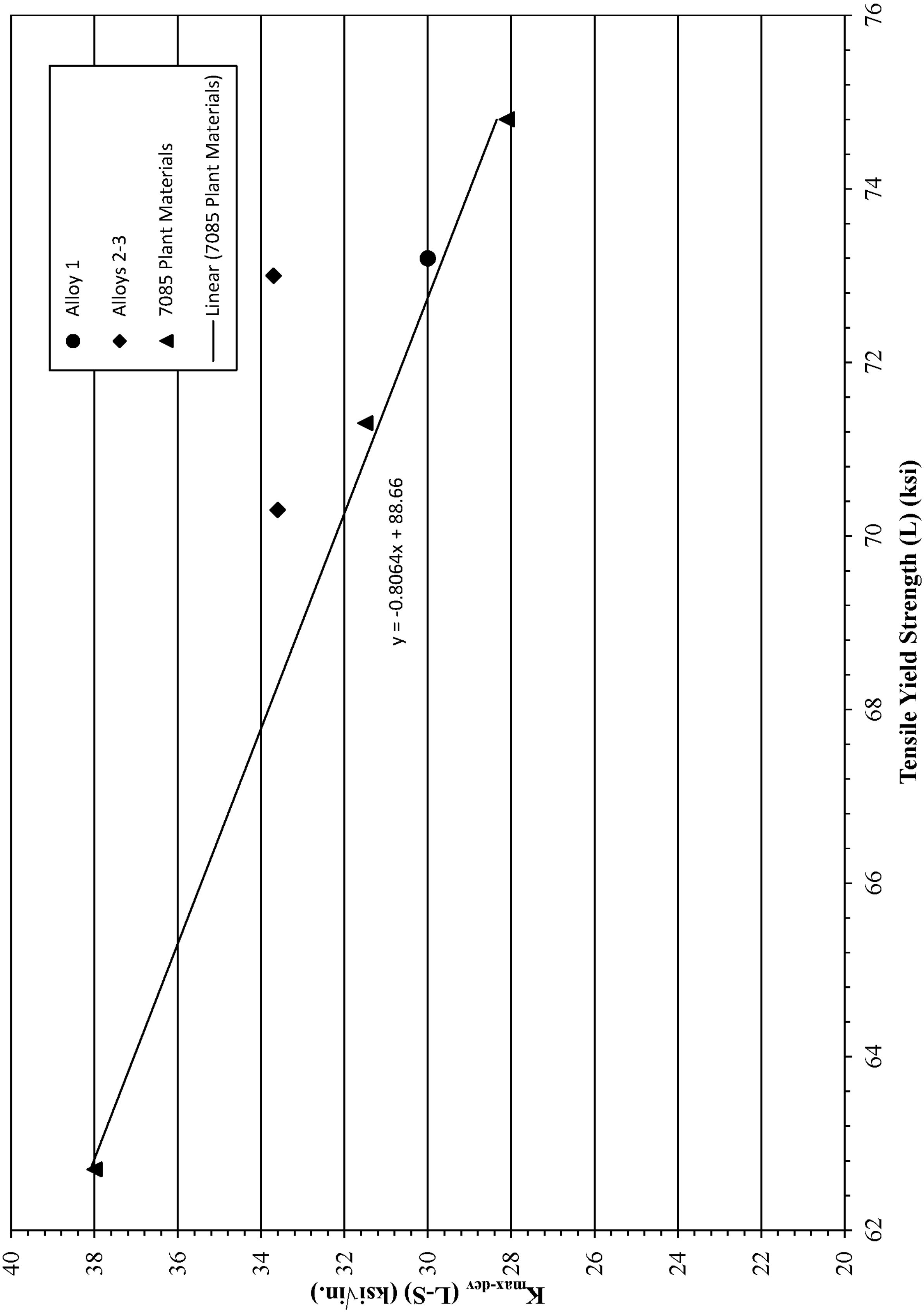


FIG. 2 - Example 1 Alloys - Fracture Toughness v. Tensile Yield Strength

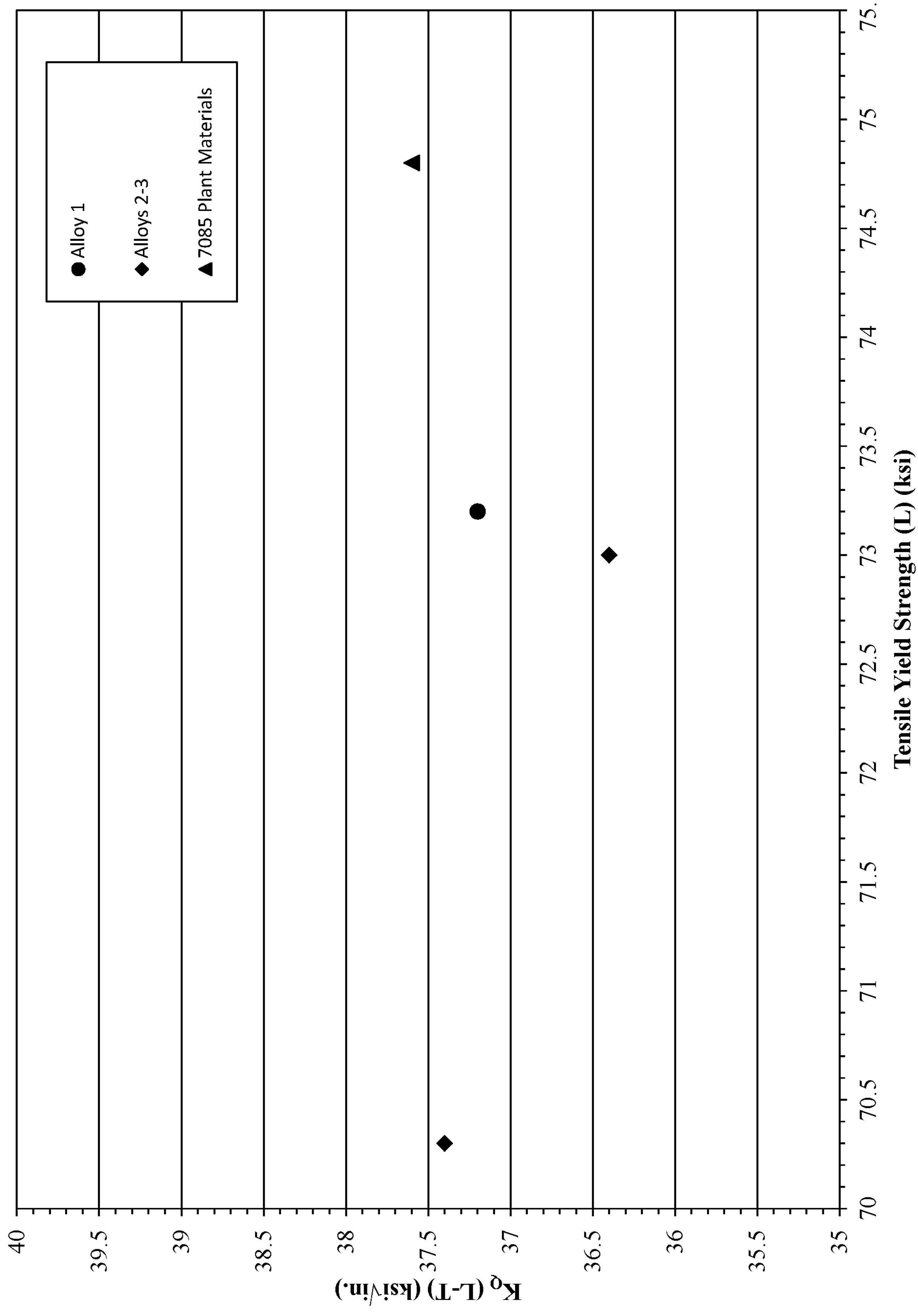


FIG. 3 - Example 1 Alloys - $K_{max\text{-}dev}$ v. Fracture Toughness

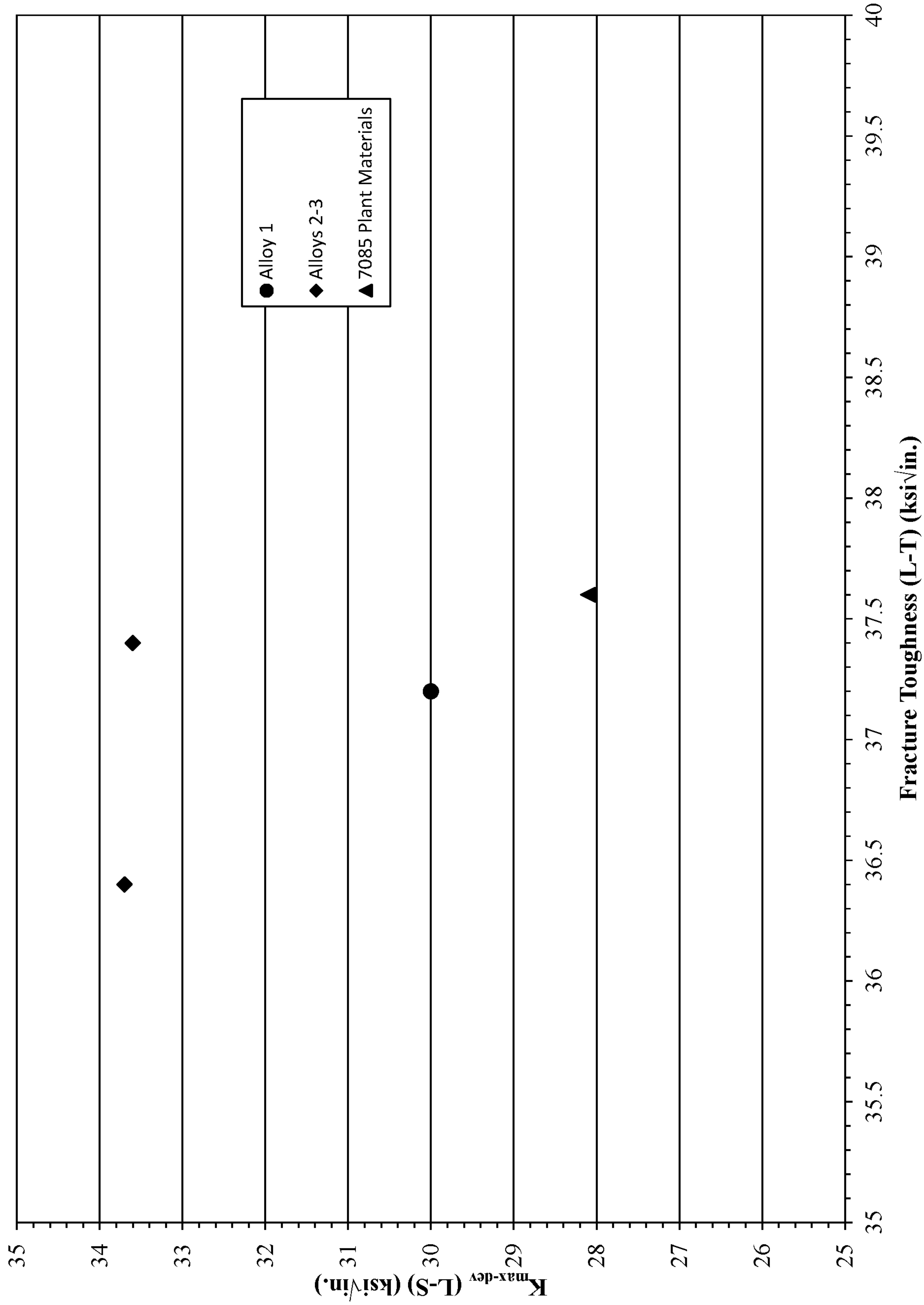


FIG. 4 - Example Property Boundary

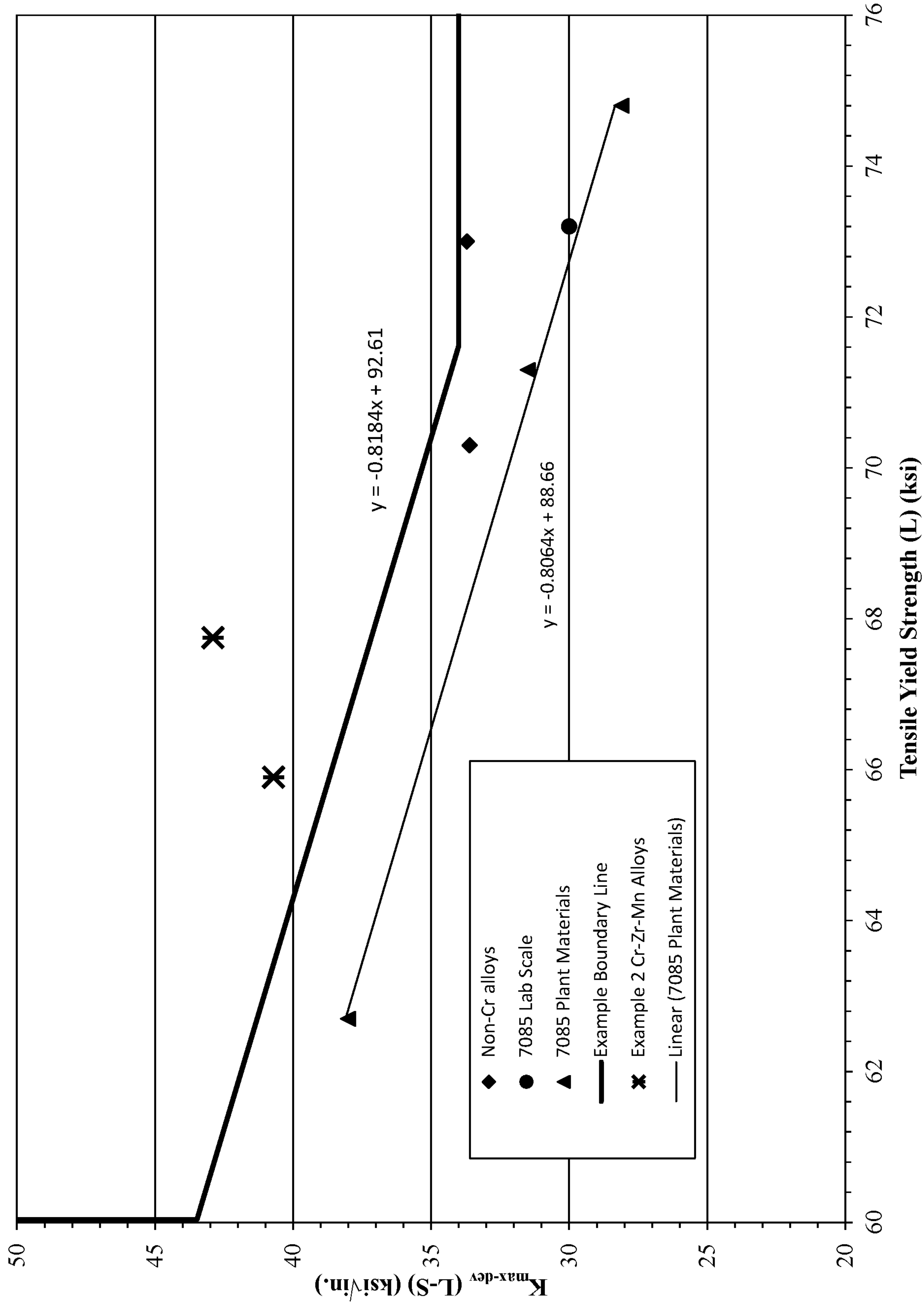


FIG. 5 - $K_{max-dev}$ vs. TYS-L at T/2 for ~5.3in thick plate

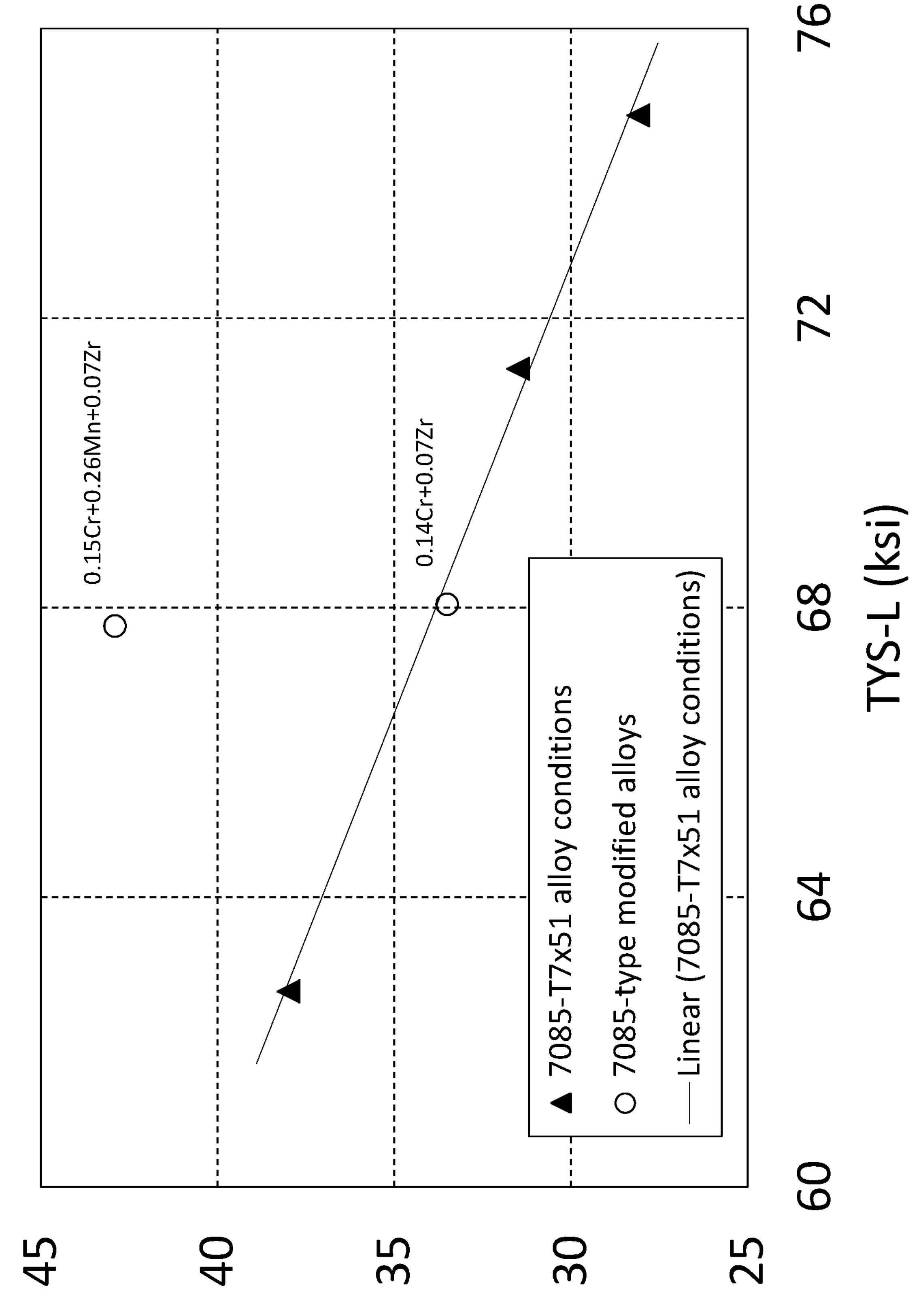


FIG. 6 - K_{Ic} S-L vs. TYS-L at T/2 for ~5.3in thick plate

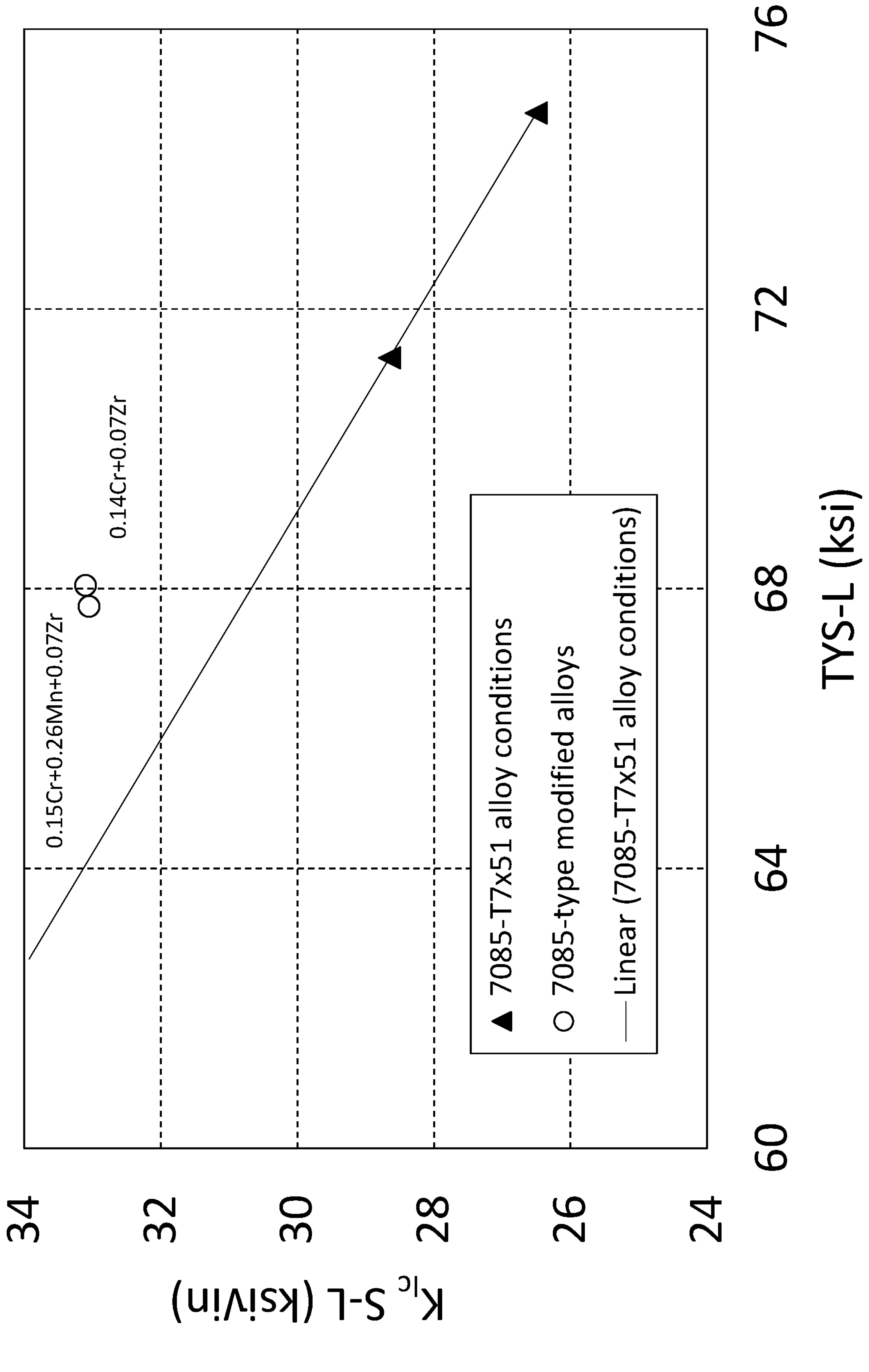


FIG. 7 - $K_{max-dev}$ vs. TYS at T/2 for ~6.5in thick plate

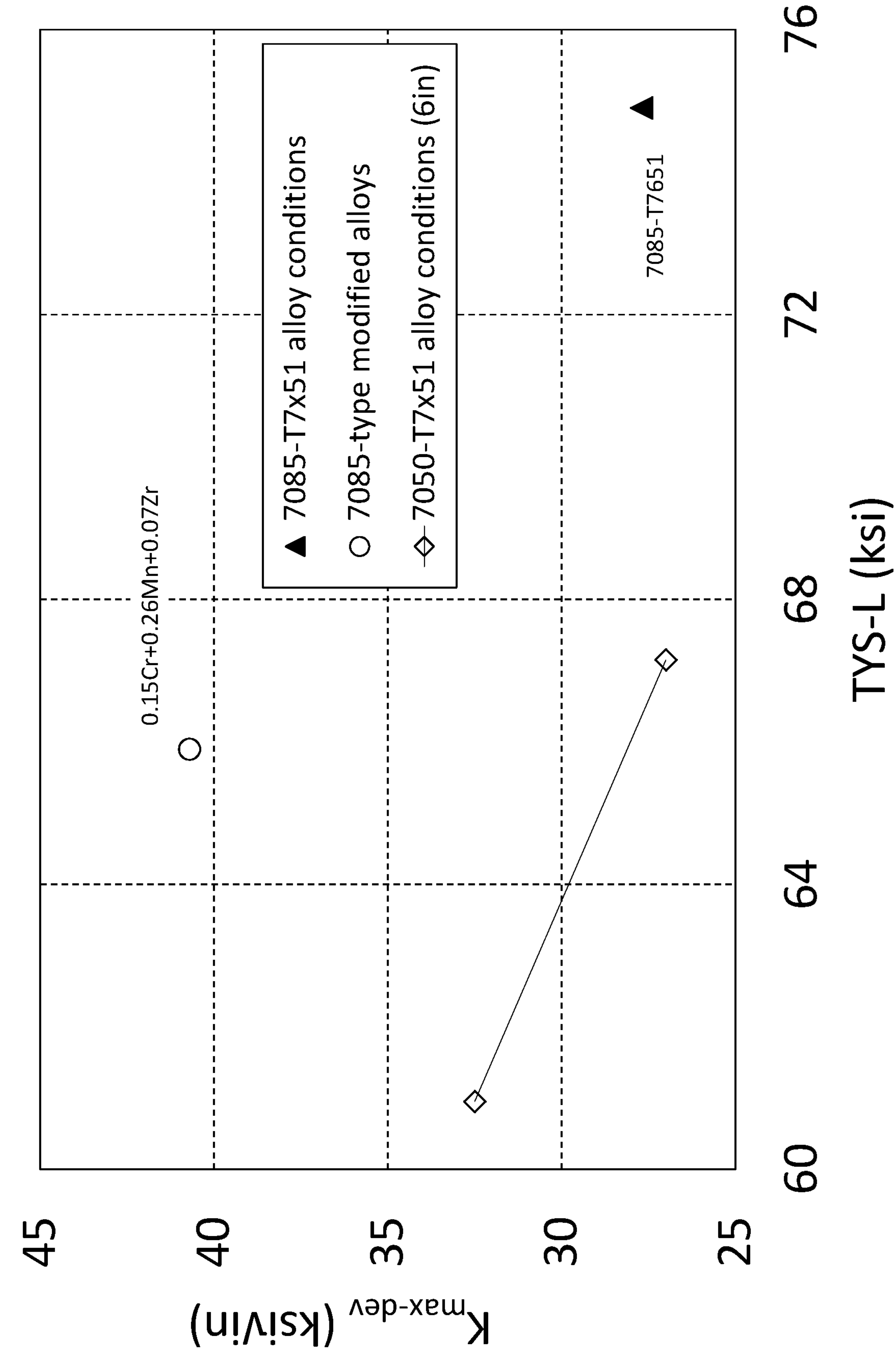


FIG. 8 - K_{Ic} S-L vs. TYS at T/2 for ~6.5in thick plate

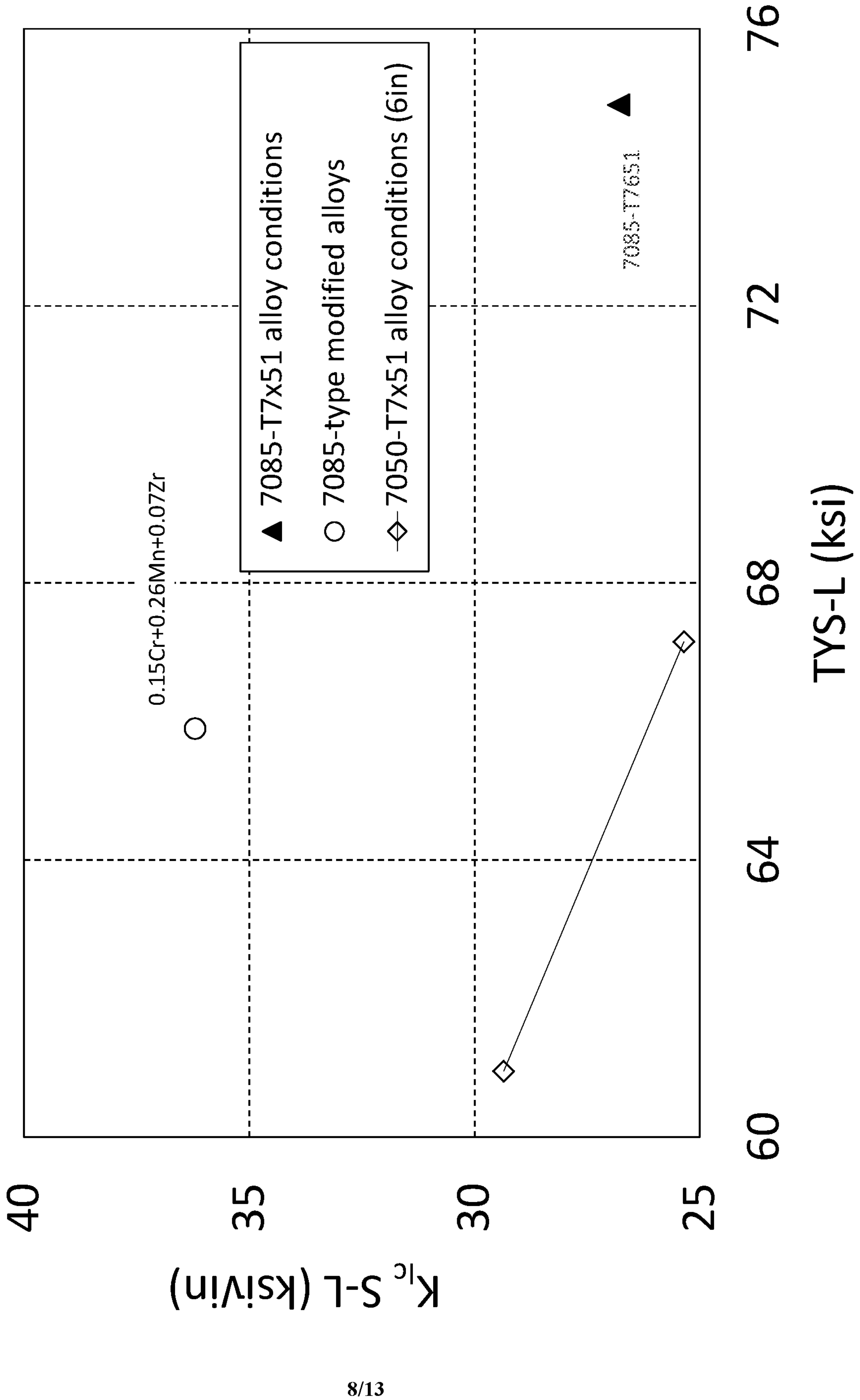


FIG. 9 - $K_{max-dev}$ vs. TYS at T/2 for ~3in simulated thick plate

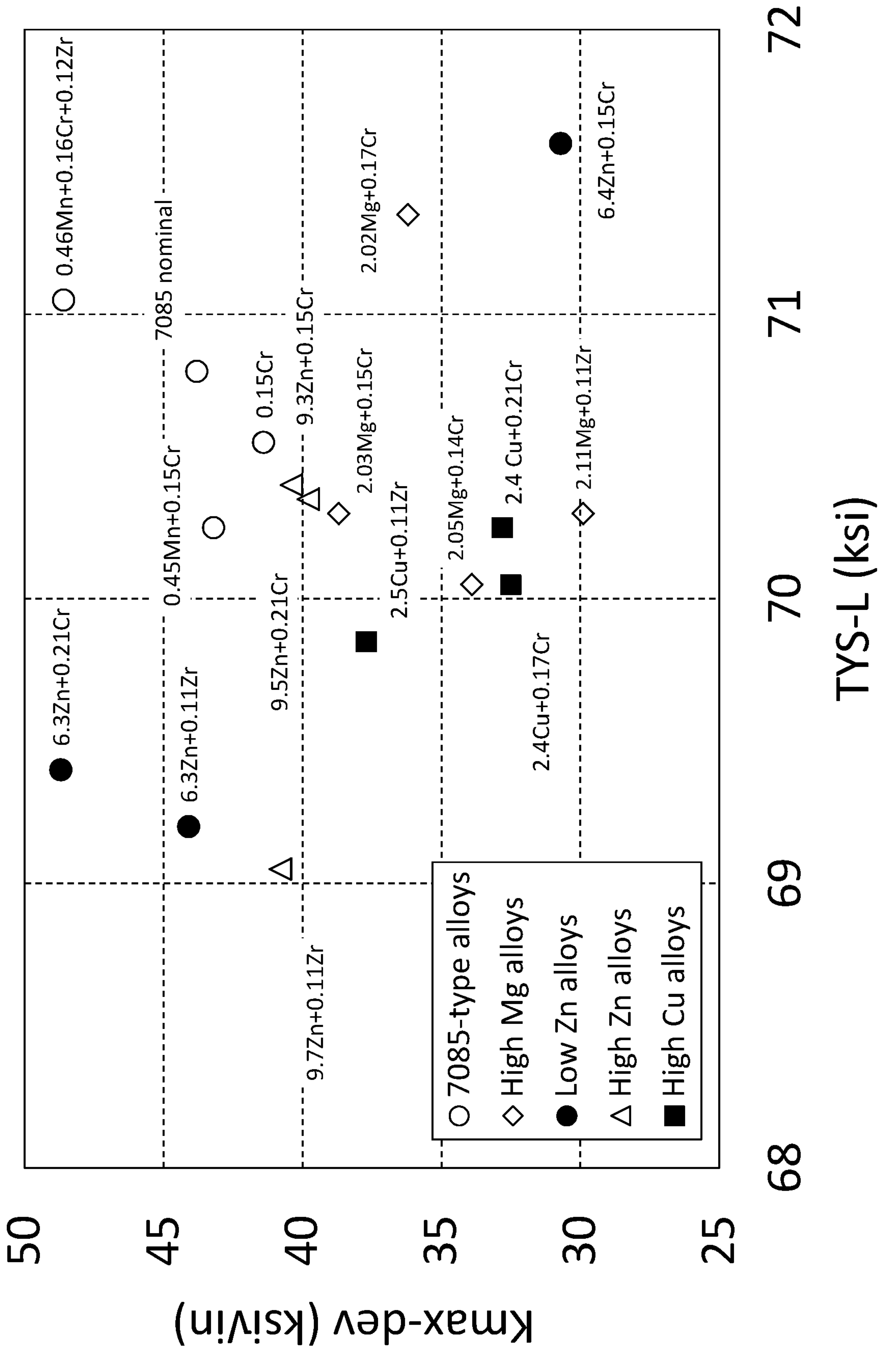


FIG. 10 - K_Q L-T vs. TYS at T/2 for ~3in simulated thick plate

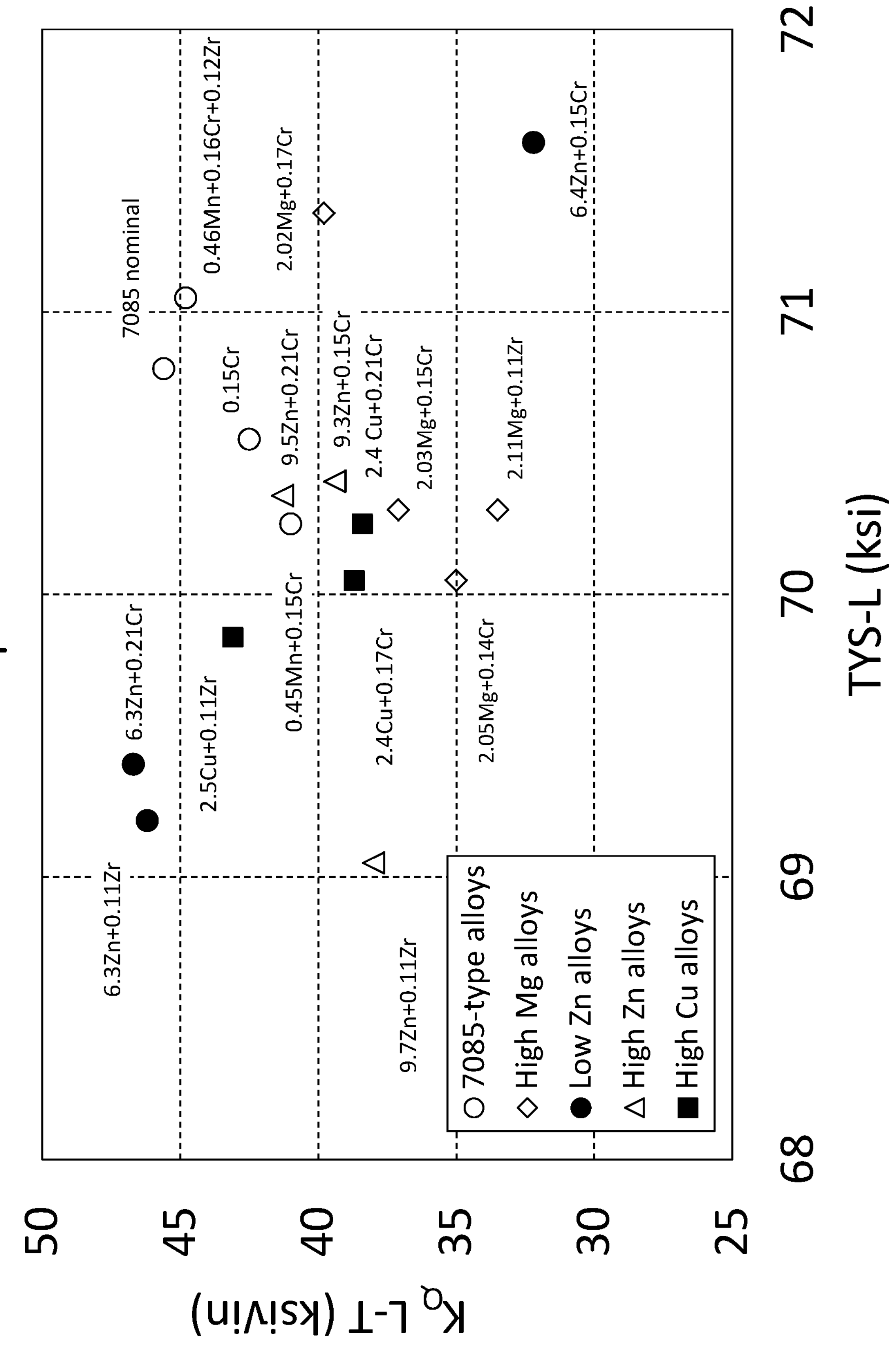


FIG. 11: $K_{max-dev}$ vs. TYS at T/2 for ~5in simulated thick plate

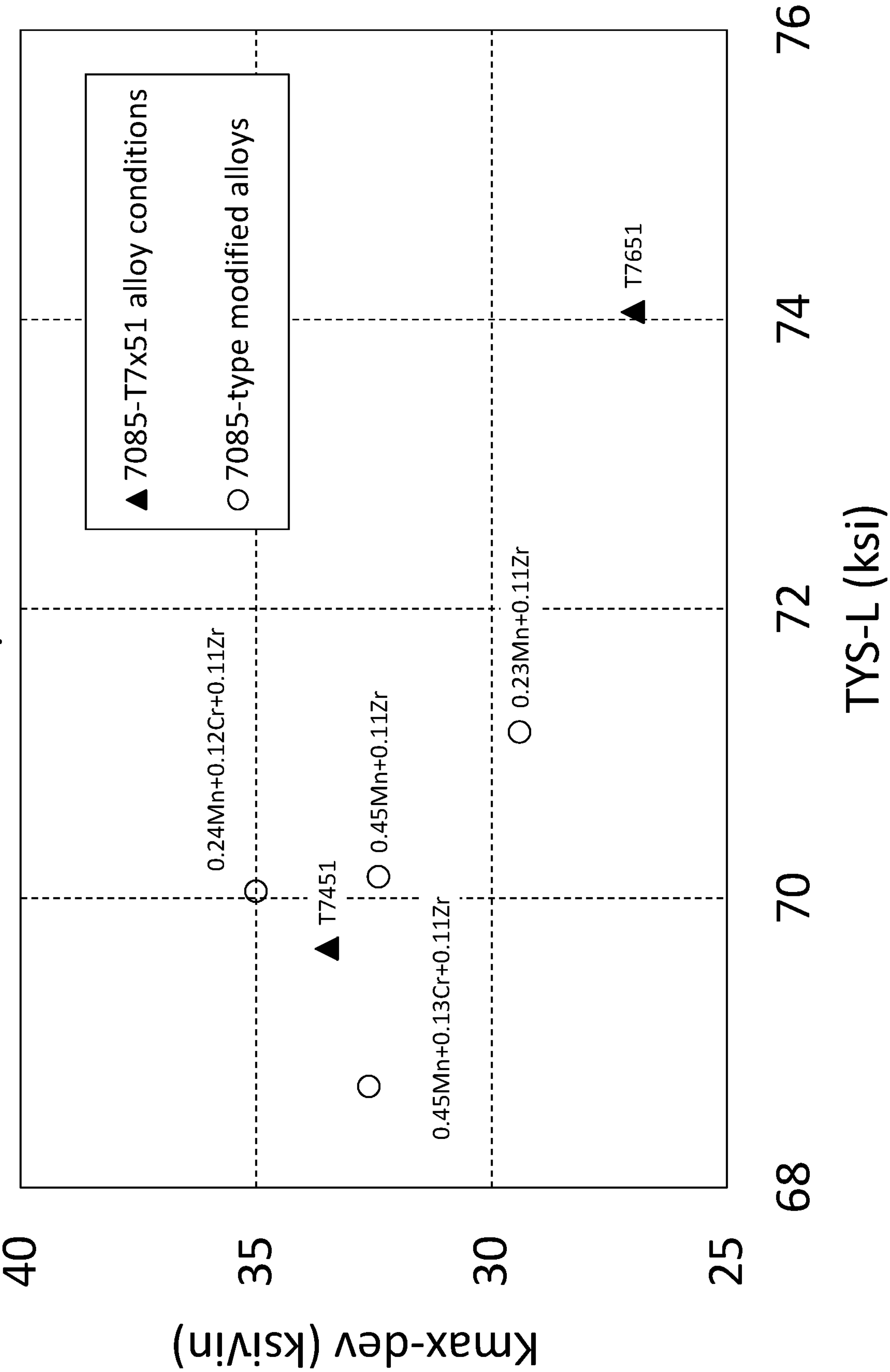


FIG. 12: K_Q L-T vs. TYS at T/2 for ~5in simulated thick plate

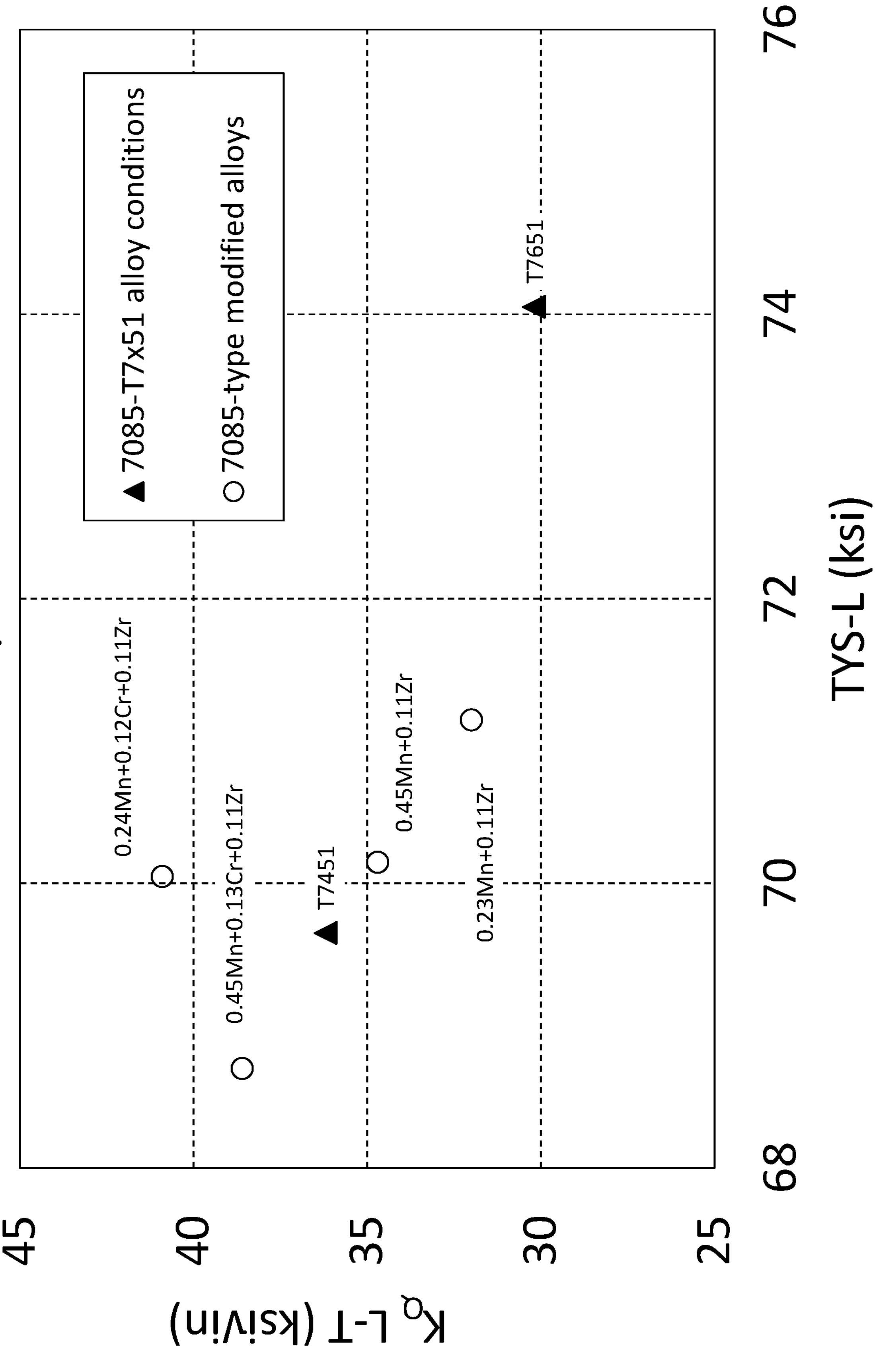
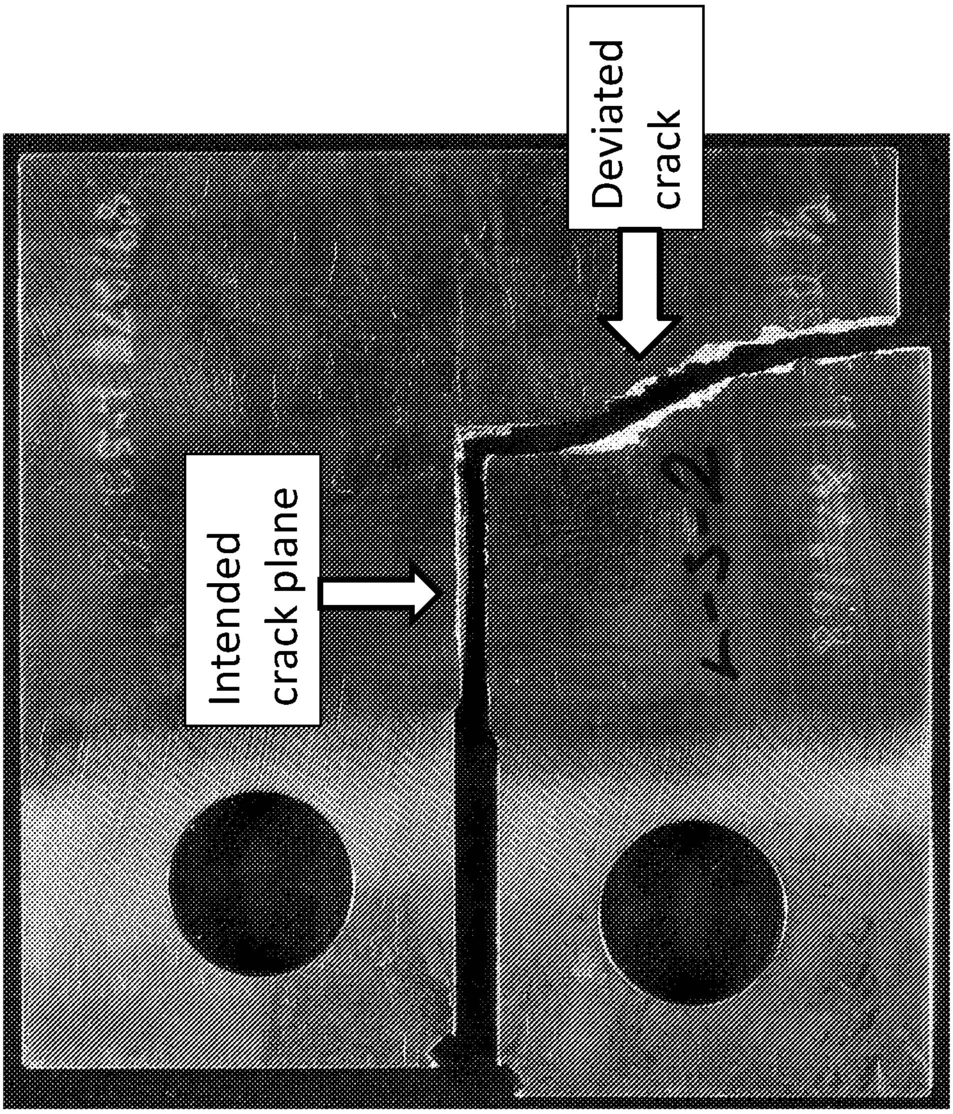


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/031525

A. CLASSIFICATION OF SUBJECT MATTER

C22C 21/10(2006.01)i, C22F 1/053(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C 21/10; C22F 1/053; C22F 1/04; C22C 21/16; C22F 1/043; C22C 21/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: aluminum alloy, wrought, 7xxx, chromium, zirconium, manganese

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002-0150498 A1 (CHAKRABARTI et al.) 17 October 2002 See paragraph [0062]; and claims 47-50.	1-21,32-37
A	US 2014-0209222 A1 (KABUSHIKI KAISHA KOBE SEIKO SHO (KOBE STEEL, LTD.)) 31 July 2014 See paragraph [0039]; and claim 1.	1-21,32-37
A	JP 2014-198899 A (KOBE STEEL LTD.) 23 October 2014 See paragraphs [0028]-[0035]; and claims 1-3.	1-21,32-37
A	US 2007-0029016 A1 (GHEORGHE, IULIAN) 08 February 2007 See paragraphs [0057]-[0059]; and claim 1.	1-21,32-37
A	US 2012-0000578 A1 (WANG et al.) 05 January 2012 See paragraphs [0036]-[0038]; and claim 1.	1-21,32-37

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 August 2016 (16.08.2016)	**16 August 2016 (16.08.2016)**

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/031525

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 22-31
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2002-0150498 A1	17/10/2002	CA 2432089 A1	04/07/2002
		CA 2432089 C	30/04/2013
		CN 102134670 A	27/07/2011
		CN 102134671 A	27/07/2011
		CN 102134671 B	11/12/2013
		CN 103088241 A	08/05/2013
		CN 103088241 B	22/04/2015
		CN 1489637 A	14/04/2004
		EP 1346073 A1	24/09/2003
		EP 1346073 B1	25/04/2012
		EP 2322677 A1	18/05/2011
		EP 2322677 B1	16/12/2015
		EP 2322677 B9	20/04/2016
		JP 2004-517210 A	10/06/2004
		JP 4209676 B2	14/01/2009
		KR 10-0892242 B1	09/04/2009
		US 2002-0121319 A1	05/09/2002
		US 2005-0150579 A1	14/07/2005
		US 2005-0257865 A1	24/11/2005
		US 2006-0083654 A1	20/04/2006
		US 6972110 B2	06/12/2005
		US 7678205 B2	16/03/2010
		US 8083870 B2	27/12/2011
		WO 02-052053 A1	04/07/2002
US 2014-0209222 A1	31/07/2014	CN 103966490 A	06/08/2014
		JP 2014-141728 A	07/08/2014
JP 2014-198899 A	23/10/2014	CN 105143484 A	09/12/2015
		US 2015-0376742 A1	31/12/2015
		WO 2014-142199 A1	18/09/2014
US 2007-0029016 A1	08/02/2007	US 2004-0099352 A1	27/05/2004
		US 2005-0236075 A1	27/10/2005
		US 2007-0187007 A1	16/08/2007
		US 7214281 B2	08/05/2007
US 2012-0000578 A1	05/01/2012	CN 102312135 A	11/01/2012
		CN 102312135 B	09/09/2015
		DE 102011105587 A1	02/02/2012
		DE 102011105587 A8	05/04/2012
		US 8758529 B2	24/06/2014