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(54) **Titre : NOUVEAUX ALLIAGES D'ALUMINIUM 6XXX**
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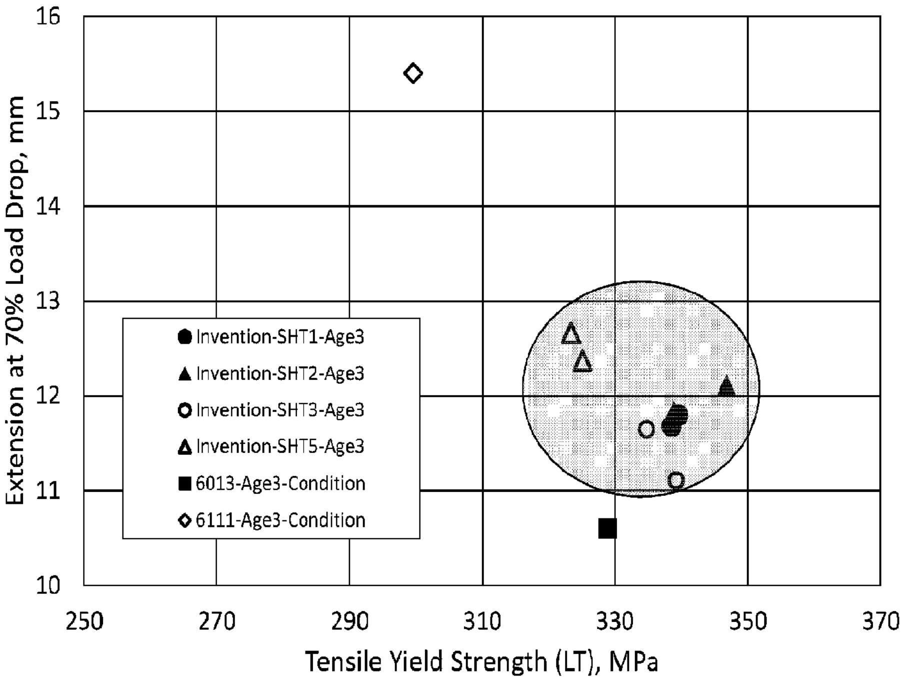

FIG. 1 - VDA Bend Results

(57) **Abrégé/Abstract:**
New 6xxx aluminum alloys are disclosed. In one embodiment, a new 6xxx aluminum alloy sheet product includes from 0.75 to 1.05 wt. % Si, from 0.65 to 0.95 wt. % Mg, wherein (wt. % Mg) / (wt. % Si) is not greater than 0.99:1, from 0.50 to 0.75 wt. % Cu, from 0.02 to 0.40 wt. % Mn, from 0.06 to 0.26 wt. % Cr, wherein (wt. % Mn) + (wt. % Cr) is at least 0.22 wt. %, from 0.01 to 0.30 wt. % Fe, up to 0.25 wt. % Zn, up to 0.20 wt. % Zr, up to 0.20 wt. % V, and up to 0.15 wt. % Ti, the balance being aluminum, optional incidental elements and impurities.

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Abstract:

New 6xxx aluminum alloys are disclosed. In one embodiment, a new 6xxx aluminum alloy sheet product includes from 0.75 to 1.05 wt. % Si, from 0.65 to 0.95 wt. % Mg, wherein (wt. % Mg) / (wt. % Si) is not greater than 0.99:1, from 0.50 to 0.75 wt. % Cu, from 0.02 to 0.40 wt. % Mn, from 0.06 to 0.26 wt. % Cr, wherein (wt. % Mn) + (wt. % Cr) is at least 0.22 wt. %, from 0.01 to 0.30 wt. % Fe, up to 0.25 wt. % Zn, up to 0.20 wt. % Zr, up to 0.20 wt. % V, and up to 0.15 wt. % Ti, the balance being aluminum, optional incidental elements and impurities.

NEW 6XXX ALUMINUM ALLOYS

BACKGROUND

[001] 6xxx aluminum alloys are aluminum alloys having silicon and magnesium to produce the precipitate magnesium silicide (Mg_2Si). The alloy 6061 has been used in various applications for several decades. However, improving one or more properties of an aluminum alloy without degrading other properties is elusive. For automotive applications, a sheet having good formability prior to thermal treatment but with high strength after thermal treatment would be useful.

SUMMARY OF THE DISCLOSURE

[002] Broadly, the present patent application relates to new 6xxx aluminum alloys and methods for making the same. The new 6xxx aluminum alloys generally include from 0.75 to 1.05 wt. % Si, from 0.65 to 0.95 wt. % Mg, wherein the weight ratio of Mg:Si [i.e., (wt. % Mg) / (wt. % Si)] is not greater than 0.99:1, from 0.50 to 0.75 wt. % Cu, from 0.02 to 0.40 wt. % Mn, from 0.06 to 0.26 wt. % Cr, wherein (wt. % Mn) + (wt. % Cr) is at least 0.22 wt. %, from 0.01 to 0.30 wt. % Fe, up to 0.25 wt. % Zn, up to 0.20 wt. % Zr, up to 0.20 wt. % V, and up to 0.15 wt. % Ti, the balance being aluminum, optional incidental elements and impurities. In one embodiment, the new 6xxx aluminum alloy is in the form of a rolled 6xxx aluminum alloy sheet product having a thickness of from 0.5 to 4.0 mm. Products made from the new 6xxx aluminum alloys may realize an improved combination of properties, such as an improved combination of two or more of strength, ductility (elongation), fracture behavior and corrosion resistance. The new aluminum alloys may be used in a variety of applications, such as in automotive applications (e.g., as a sheet product).

i. Composition

[003] As noted above, the 6xxx new aluminum alloys generally comprises (and in some instances consist essentially of, or consist of) from 0.75 to 1.05 wt. % Si, from 0.65 to 0.95 wt. % Mg, wherein (wt. % Mg) / (wt. % Si) is not greater than 0.99:1, from 0.50 to 0.75 wt. % Cu, from 0.02 to 0.40 wt. % Mn, from 0.06 to 0.26 wt. % Cr, wherein (wt. % Mn) + (wt. % Cr) is at least 0.22 wt. %, from 0.01 to 0.30 wt. % Fe, up to 0.25 wt. % Zn, up to 0.20 wt. % Zr, up to 0.20 wt. % V, and up to 0.15 wt. % Ti, the balance being aluminum, optional incidental elements and impurities. Using these specific amounts of elements may result in unique and useful products for use in, for instance, automotive applications, where high strength in combination with good ductility and corrosion resistance are required.

[004] As noted above, the new 6xxx aluminum alloys generally include from 0.75 to 1.05 wt. % Si. Silicon may facilitate strength. In one embodiment, a new aluminum alloy includes at least 0.80 wt. % Si. In another embodiment, a new aluminum alloy includes at least 0.85 wt. % Si. In yet another embodiment, a new aluminum alloy includes at least 0.90 wt. % Si. In one embodiment, a new aluminum alloy includes not greater than 1.0 wt. % Si.

[005] As noted above, the new aluminum alloys generally include from 0.65 to 0.95 wt. % Mg. Magnesium may facilitate strength. In one embodiment, a new aluminum alloy includes at least 0.70 wt. % Mg. In another embodiment, a new aluminum alloy includes at least 0.75 wt. % Mg. In another embodiment, a new aluminum alloy includes at least 0.80 wt. % Mg. In one embodiment, a new aluminum alloy includes not greater than 0.90 wt. % Mg.

[006] As noted above, the weight ratio of Mg:Si is generally not greater than 0.99:1. The appropriate Mg:Si ratio may facilitate high strength and good ductility. In one embodiment, a weight ratio of Mg:Si is not greater than 0.95:1. In another embodiment, a weight ratio of Mg:Si is not greater than 0.9:1. In one embodiment, a weight ratio of Mg:Si is at least 0.7:1. In another embodiment, a weight ratio of Mg:Si is at least 0.8:1.

[007] As noted above, the new aluminum alloys generally include from 0.50 to 0.75 wt. % Cu. Copper may facilitate, for instance, strength, natural aging response and/or formability. In one embodiment, a new aluminum alloy includes at least 0.55 wt. % Cu. In another embodiment, a new aluminum alloy includes at least 0.60 wt. % Cu. In yet another embodiment, a new aluminum alloy includes at least 0.65 wt. % Cu. In one embodiment, a new aluminum alloy includes not greater than 0.73 wt. % Cu. In another embodiment, a new aluminum alloy includes not greater than 0.70 wt. % Cu.

[008] As noted above, the new aluminum alloys generally include from 0.02 to 0.40 wt. % Mn. Manganese may facilitate precipitation of dispersoids that at least partially assist in providing the proper grain structure. The amount of manganese in the alloy should be restricted such that large primary particles are avoided / restricted / limited during production of aluminum alloy products. In one embodiment, a new aluminum alloy includes at least 0.04 wt. % Mn. In another embodiment, a new aluminum alloy includes at least 0.05 wt. % Mn. In another embodiment, a new aluminum alloy includes at least 0.06 wt. % Mn. In yet another embodiment, a new aluminum alloy includes at least 0.08 wt. % Mn. In another embodiment, a new aluminum alloy includes at least 0.10 wt. % Mn. In yet another embodiment, a new aluminum alloy includes at least 0.15 wt. % Mn. In another embodiment, a new aluminum alloy includes at least

0.20 wt. % Mn. In one embodiment, a new aluminum alloy includes not greater than 0.35 wt. % Mn. In another embodiment, a new aluminum alloy includes not greater than 0.30 wt. % Mn.

[009] As noted above, the new aluminum alloys generally include from 0.06 to 0.26 wt. % Cr. Chromium in combination with manganese may facilitate a unique distribution of dispersoid particles, which may facilitate achievement of high strength in combination with high three-point bending (fracture) properties. In one embodiment, a new aluminum alloy includes at least 0.08 wt. % Cr. In another embodiment, a new aluminum alloy includes at least 0.10 wt. % Cr. In yet another embodiment, a new aluminum alloy includes at least 0.12 wt. % Cr. In another embodiment, a new aluminum alloy includes at least 0.14 wt. % Cr. In yet another embodiment, a new aluminum alloy includes at least 0.16 wt. % Cr. In another embodiment, a new aluminum alloy includes at least 0.18 wt. % Cr. In one embodiment, a new aluminum alloy includes not greater than 0.24 wt. % Cr. In another embodiment, a new aluminum alloy includes not greater than 0.22 wt. % Cr. In yet another embodiment, a new aluminum alloy includes not greater than 0.20 wt. % Cr.

[0010] As noted above, chromium in combination with manganese may facilitate a unique distribution of dispersoid particles, which may facilitate achievement of high strength in combination with high three-point bending (fracture) properties. Accordingly, the new aluminum alloys generally include at least 0.22 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.22 wt. %, as noted above. In one embodiment, a new aluminum alloy includes at least 0.24 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.24 wt. %. In another embodiment, a new aluminum alloy includes at least 0.25 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.25 wt. %. In yet another embodiment, a new aluminum alloy includes at least 0.26 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.26 wt. %. In another embodiment, a new aluminum alloy includes at least 0.27 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.27 wt. %. In yet another embodiment, a new aluminum alloy includes at least 0.28 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.28 wt. %. In another embodiment, a new aluminum alloy includes at least 0.29 wt. % (Mn+Cr), i.e., (wt. % Mn) + (wt. % Cr) is at least 0.29 wt. %.

[0011] As noted above, the new aluminum alloys generally include from 0.01 to 0.30 wt. % Fe. Iron may facilitate a proper grain structure and using more than 0.10 wt. % Fe iron may be cost effective. The amount of iron in the alloy should be restricted such that large primary particles are avoided / restricted / limited during production of aluminum alloy products. In one embodiment, a new aluminum alloy includes at least 0.05 wt. % Fe. In another embodiment, a new aluminum alloy includes at least 0.10 wt. % Fe. In yet another embodiment, a new aluminum alloy includes at least 0.12 wt. % Fe. In one embodiment, a new aluminum alloy includes not greater than 0.28 wt. % Fe. In another embodiment, a new aluminum alloy includes not greater than 0.26 wt. % Fe.

[0012] As noted above, the new aluminum alloys may include up to 0.25 wt. % Zn. In one embodiment, a new aluminum alloy includes not greater than 0.20 wt. % Zn. In another embodiment, a new aluminum alloy includes not greater than 0.15 wt. % Zn. In yet another embodiment, a new aluminum alloy includes not greater than 0.10 wt. % Zn. In another embodiment, a new aluminum alloy includes not greater than 0.08 wt. % Zn. In yet another embodiment, a new aluminum alloy includes not greater than 0.05 wt. % Zn. In another embodiment, a new aluminum alloy includes not greater than 0.03 wt. % Zn. In one embodiment, a new aluminum alloy includes at least 0.01 wt. % Zn.

[0013] As noted above, the new aluminum alloys include not greater than 0.20 wt. % Zr. Zirconium is less preferred than manganese and chromium, but still may be useful. The amount of zirconium in the alloy should be restricted such that large primary particles are avoided / restricted / limited during production of aluminum alloy products. In one embodiment, a new aluminum alloy includes not greater than 0.15 wt. % Zr. In another embodiment, a new aluminum alloy includes not greater than 0.10 wt. % Zr. In yet another embodiment, a new aluminum alloy includes not greater than 0.08 wt. % Zr. In another embodiment, a new aluminum alloy includes not greater than 0.03 wt. % Zr. In yet another embodiment, a new aluminum alloy includes not greater than 0.01 wt. % Zr. In one embodiment, a new aluminum alloy includes at least 0.01 wt. % Zr (e.g., when Zr is added/used to the alloy for grain structure control.) In another embodiment, a new aluminum alloy includes at least 0.05 wt. % Zr. In one embodiment, a new aluminum alloy includes from 0.07 to 0.15 wt. % Zr.

[0014] As noted above, the new aluminum alloys include not greater than 0.20 wt. % V. Vanadium is less preferred than manganese and chromium, but still may be useful. The amount of vanadium in the alloy should be restricted such that large primary particles are avoided / restricted / limited during production of aluminum alloy products. In one embodiment, a new aluminum alloy includes not greater than 0.15 wt. % V. In another embodiment, a new aluminum alloy includes not greater than 0.10 wt. % V. In yet another embodiment, a new aluminum alloy includes not greater than 0.08 wt. % V. In another embodiment, a new aluminum alloy includes not greater than 0.03 wt. % V. In yet another embodiment, a new aluminum alloy includes not greater than 0.01 wt. % V. In one embodiment, a new aluminum alloy includes at least 0.01 wt. % V (e.g., when V is added/used to the alloy for grain structure control.) In another embodiment, a new aluminum alloy includes at least 0.05 wt. % V. In one embodiment, a new aluminum alloy includes from 0.07 to 0.15 wt. % V.

[0015] As noted above, the new aluminum alloys include not greater than 0.25 wt. % Ti. Titanium may be used during casting for grain refinement. Higher levels of titanium may also facilitate corrosion resistance. The amount of titanium in the alloy should be restricted such that large primary particles are avoided / restricted / limited during production of alloy products. In one embodiment, a new aluminum alloy includes at least 0.005 wt. % Ti. In another embodiment, a new aluminum alloy includes at least 0.01 wt. %Ti. In yet another embodiment, a new aluminum alloy includes at least 0.02 wt. %Ti. In yet another embodiment, a new aluminum alloy includes at least 0.05 wt. % Ti. In one embodiment, a new a new aluminum alloy includes not greater than 0.20 wt. %Ti. In another embodiment, a new a new aluminum alloy includes not greater than 0.15 wt. %Ti. In another embodiment, a new aluminum alloy includes not greater than 0.12 wt. % Ti. In yet another embodiment, a new a new aluminum alloy includes not greater than 0.10 wt. %Ti. In another embodiment, a new a new aluminum alloy includes not greater than 0.08 wt. %Ti. In yet another embodiment, a new a new aluminum alloy includes not greater than 0.05 wt. %Ti. In another embodiment, a new a new aluminum alloy includes not greater than 0.03 wt. %Ti. In one embodiment, a new a new aluminum alloy includes from 0.005 to 0.10 wt. % Ti. In another embodiment, a new aluminum alloy includes from 0.01 to 0.05 wt. % Ti. In yet another embodiment, a new aluminum alloy includes from 0.01 to 0.03 wt. % Ti. The titanium may be in elemental form or in the form of compounds (e.g., TiB_2 or TiC).

[0016] As noted above, the balance of the aluminum alloys is generally aluminum, optional incidental elements and impurities. As used herein, “incidental elements” means those elements or materials, other than the above listed elements, that may optionally be added to the alloy to assist in the production of the alloy. Examples of incidental elements include casting aids, such as grain refiners and deoxidizers. Optional incidental elements may be included in the alloy in a cumulative amount of up to 1.0 wt. %. As one non-limiting example, one or more incidental elements may be added to the alloy during casting to reduce or restrict (and is some instances eliminate) ingot cracking due to, for example, oxide fold, pit and oxide patches. These types of incidental elements are generally referred to herein as deoxidizers. Examples of some deoxidizers include Ca, Sr, and Be. When calcium (Ca) is included in the alloy, it is generally present in an amount of up to about 0.05 wt. %, or up to about 0.03 wt. %. In some embodiments, Ca is included in the alloy in an amount of about 0.001-0.03 wt. %, such as 0.001-0.008 wt. % (or 10 to 80 ppm). Strontium (Sr) may be included in the alloy as a substitute for Ca (in whole or in part), and thus may be included in the alloy in the same or similar amounts as Ca. Traditionally, beryllium (Be) additions have helped to reduce the tendency of ingot cracking, though for environmental, health and safety reasons, some embodiments of the alloy are substantially Be-free. When Be is included in the alloy, it is generally present in an amount of up to about 20 ppm. Incidental elements may be present in minor amounts, or may be present in significant amounts, and may add desirable or other characteristics on their own without departing from the alloy described herein, so long as the alloy retains the desirable characteristics described herein. It is to be understood, however, that the scope of this disclosure should not/cannot be avoided through the mere addition of an element or elements in quantities that would not otherwise impact on the combinations of properties desired and attained herein.

[0017] The new aluminum alloys may contain low amounts of impurities. In one embodiment, a new aluminum alloy includes not greater than 0.15 wt. %, in total, of the impurities, and wherein the new aluminum alloy includes not greater than 0.05 wt. % of each of the impurities. In another embodiment, a new aluminum alloy includes not greater than 0.10 wt. %, in total, of the impurities, and wherein the new aluminum alloy includes not greater than 0.03 wt. % of each of the impurities.

ii. Processing

[0018] The new aluminum alloys may be useful in a variety of product forms, including ingot or billet, wrought product forms (sheet, plate, forgings and extrusions), shape castings, additively manufactured products, and powder metallurgy products, for instance. For example, the new aluminum alloys may be processed into a variety of wrought forms, such as in rolled form (sheet, plate), as an extrusion, or as a forging, and in a variety of tempers. In this regard, the new aluminum alloys may be cast (e.g., direct chill cast or continuously cast), and then worked (hot and/or cold worked) into the appropriate product form (sheet, plate, extrusion, or forging). After working, the new aluminum alloys may be processed to one of a T temper, a W temper, O temper, or an F temper as per ANSI H35.1 (2009). In one embodiment, a new aluminum alloy is processed to a "T temper" (thermally treated). In this regard, the new aluminum alloys may be processed to any of a T1, T2, T3, T4, T5, T6, T7, T8, T9 or T10 temper as per ANSI H35.1 (2009). In one embodiment, the product is processed to a T43 temper. In another embodiment, the product is processed to a T6 temper. In other embodiments, a new aluminum alloy is processed to a "W temper" (solution heat treated). In another embodiment, no solution heat treatment is applied after working the aluminum alloy into the appropriate product form, and thus the new aluminum alloys may be processed to an "F temper" (as fabricated) or "O temper" (annealed).

[0019] In one embodiment, a new aluminum alloy is in the form of a sheet product. In one embodiment, the sheet product has a thickness of from 0.5 to 4.0 mm, or a thickness of from 1.0 to 4.0 mm. In one embodiment, the sheet product is processed to a T4 temper. In one embodiment, the sheet product is processed to a T43 temper. In one embodiment, the sheet product is processed to a T4 or T43 temper and then paint baked (e.g., by heating at 180°C for 20 minutes). In another embodiment, the sheet product is processed to a T4 or T43 temper, then paint baked, and then artificially aged (e.g., by heating at 180°C for 8 hours). In yet another embodiment, the sheet product is processed to a T4 or T43 temper, then artificially aged and then paint baked. Such paint baked sheet products may be useful in automotive applications, as described in further detail below.

[0020] As used herein, the T43 temper refers to products that have been processed by pre-aging, whether by cooling from an elevated temperature to a pre-aging temperature (e.g., after quench), or by reheating to the pre-aging temperature or otherwise. For instance, a T43 temper product may be solution heat treated, then quenched to a suitable cooled temperature (e.g., below approximately 104.4°C (220°F)), then pre-aged at a suitable pre-aging temperature (e.g., between 50-180°C), and then slowly cooled to room temperature (e.g., coil cooled or Newtonian cooling), after which the product is allowed to naturally age for several days or weeks. Alternatively, the product may be cooled to room temperature or thereabouts and then reheated to a pre-aging temperature and then slowly cooled. Multiple pre-aging times / temperatures may be used.

iii. Microstructure

[0021] The new aluminum alloys may realize a unique microstructure. In one embodiment, a new aluminum alloy is at least 60% recrystallized, i.e., contains at least 60 vol. % recrystallized grains as determined in accordance with the *Microstructure Assessment Procedure*, described in the *Definitions* section, below. In another embodiment, a new aluminum alloy sheet is at least 70% recrystallized. In yet another embodiment, a new aluminum alloy sheet is at least 80% recrystallized. In another embodiment, a new aluminum alloy sheet is at least 90% recrystallized. For purposes of the present patent application, an aluminum alloy sheet product is "fully recrystallized" when it is determined to have at least 90 vol. % recrystallized grains.

[0022] In one embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 50 micrometers as determined in accordance with the *Microstructure Assessment Procedure*, described in the *Definitions* section, below. In another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 45 micrometers. In yet another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 40 micrometers. In another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 38 micrometers. In yet another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 36 micrometers. In another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 34 micrometers. In yet another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 32 micrometers. In another embodiment, a new aluminum alloy realizes an area weighted average grain size of not greater than 30 micrometers. In one embodiment, a new aluminum alloy realizes an area weighted average grain size of at least 20 micrometers. In another embodiment, a new aluminum alloy realizes an area weighted average grain size of at least 25 micrometers. In yet another embodiment, a new aluminum alloy realizes an area weighted average grain size of at least 28 micrometers.

[0023] In one embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.5% as determined in accordance with the *Microstructure Assessment Procedure*, described in the *Definitions* section, below. In another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.55%. In yet another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.6%. In another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.65%. In yet another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.7%. In another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.75%. In yet another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.8%. In another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.85%. In yet another embodiment, a new aluminum alloy realizes a dispersoid area fraction of at least 0.9%. In another embodiment, a new aluminum alloy realizes a dispersoid area fraction of not greater than 1.1%. In yet another embodiment, a new aluminum alloy realizes a dispersoid area fraction of not greater than 1.0%.

[0024] In one embodiment, a new aluminum alloy realizes an f/r value at least 0.05 as determined in accordance with the *Microstructure Assessment Procedure*, described in the

Definitions section, below. In another embodiment, a new aluminum alloy realizes an f/r value at least 0.06. In yet another embodiment, a new aluminum alloy realizes an f/r value at least 0.07. In another embodiment, a new aluminum alloy realizes an f/r value at least 0.08. In one embodiment, a new aluminum alloy realizes an f/r of not greater than 0.11. In another embodiment, a new aluminum alloy realizes an f/r of not greater than 0.10.

[0025] In one embodiment, a new aluminum alloy contains at least 10 vol. % cube texture as determined in accordance with the *Microstructure Assessment Procedure*, described in the *Definitions* section, below. In another embodiment, a new aluminum alloy contains at least 11 vol. % cube texture. In another embodiment, a new aluminum alloy contains at least 12 vol. % cube texture. In another embodiment, a new aluminum alloy contains at least 13 vol. % cube texture. In another embodiment, a new aluminum alloy contains at least 14 vol. % cube texture. In another embodiment, a new aluminum alloy contains at least 15 vol. % cube texture. In one embodiment, a new aluminum alloy contains not greater than 25 vol. % cube texture. In one embodiment, a new aluminum alloy contains not greater than 20 vol. % cube texture.

iv. Properties

[0026] As noted above, the new aluminum alloys may realize an improved combination of properties. For instance, products made from the new 6xxx aluminum alloys may realize an improved combination of two or more of strength, ductility (elongation), fracture behavior and corrosion resistance.

[0027] In one embodiment, the new aluminum alloy is a sheet product having a thickness of from 1.0 to 4.0 mm, and this aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 315 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 320 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In yet another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 325 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 330 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In yet another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 335 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 340 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In yet another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 345 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 350 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In yet another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 355 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 360 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In yet another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 365 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F). In another embodiment, the aluminum alloy sheet product realizes a tensile yield strength (LT) of at least 370 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F).

[0028] In one approach, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing high three-point bend extensions in one or both of (a) the T4 temper or (b) the T6 pre-strained temper as per the "three-point bending test" described in the *Definitions* section, below. As noted below, all three-point bend testing is to be conducted on a sheet having a thickness of 2.0 ± 0.05 mm. Thus, for an aluminum alloy sheet product having a thickness of from 0.5 to 1.94 mm or 2.06 to 4.0 mm, the bend extension for such a product is determined by reproducing the product at 2.0 ± 0.05 mm, after which its three-point bend extension is measured. For purposes of three-point bending testing, the "T4" temper includes both the T4 temper and the T43 temper, and means the final gauge aluminum alloy sheet product is solution heat treated and quenched and then naturally aged for 1-month; pre-aging will occur after solution heat treatment for a T43 temper product. For purposes of three-point bend testing, the "T6 temper" means the final gauge aluminum alloy sheet product is solution heat treated and quenched, then naturally aged for at least 2 weeks, and then artificially aged at 225°C (437°F) for 30 minutes.

[0029] In one embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 16.0 mm in the T4 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 16.2 mm in the T4 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 16.4 mm in the T4 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 16.6 mm in the T4 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 16.8 mm in the T4 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 17.0 mm in the T4 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 17.2 mm in the T4 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 17.4 mm in the T4 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 17.6 mm in the T4 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 17.8 mm in the T4 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 18.0 mm in the T4 temper.

[0030] In one embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 10.0 mm in the T6 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 10.5 mm in the T6 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 11.0 mm in the T6 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 11.2 mm in the T6 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 11.4 mm in the T6 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 11.6 mm in the T6 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 11.8 mm in the T6 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 12.0 mm in the T6 temper.

In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 12.2 mm in the T6 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 12.4 mm in the T6 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 12.6 mm in the T6 temper. In yet another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 12.8 mm in the T6 temper. In another embodiment, a new aluminum alloy sheet product has a thickness of 1.0 to 4.0 mm and is capable of realizing a three-point bend extension of at least 13.0 mm in the T6 temper.

[0031] In one approach, a new aluminum alloy is corrosion resistant, realizing a maximum depth of attack of not greater than 200 micrometers when tested in accordance with ASTM G110-92(2015) for 6 hours.

[0032] In one approach, a new aluminum alloy is strength increase resistant in the T4 or T43 temper, realizing a tensile yield strength (LT) increase of not greater than 15 MPa as measured from the period starting after 2 weeks of natural aging (+/- 12 hours) and ending after 6 months of natural aging (+/- 24 hours) (i.e., the "Test Time Period"). For instance, if an aluminum alloy sheet in the T4 temper realized a tensile yield strength (LT) of 185 MPa after 2 weeks of natural aging and that same aluminum alloy sheet in the T4 temper realized a tensile yield strength (LT) of 189 MPa after 6 months of natural aging, the aluminum alloy sheet in the T4 temper would have realized a tensile yield strength (LT) increase of 4 MPa (189-185 MPa) over the Test Time Period. In one embodiment, the tensile yield strength (LT) increase in the T4/T43 temper is not greater than 13 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) increase in the T4/T43 temper is not greater than 11 MPa over the Test Time Period. In yet another embodiment, the tensile yield strength (LT) increase in the T4/T43 temper is not greater than 9 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) increase in the T4/T43 temper is not greater than 7 MPa over the Test Time Period. In yet another embodiment, the tensile yield strength (LT) increase in the T4/T43 temper is not greater than 5 MPa, or less, over the Test Time Period.

[0033] In one approach, a new aluminum alloy is strength loss resistant relative to the T6 temper, realizing a tensile yield strength (LT) loss of not greater than 21 MPa over the Test Time Period, wherein a first piece of a material is artificially aged after 2 weeks of natural aging and a second piece of that same material is artificially aged after 6 months of natural aging, wherein the same artificially aging practice is used for both the first and second pieces. For instance, if a first portion of an aluminum alloy sheet was artificially aged after 2 weeks of natural aging and realized a tensile yield strength (LT) of 245 MPa in the artificially aged condition, and another portion of that same aluminum alloy sheet was artificially aged after 6 months of natural aging and realized a tensile yield strength (LT) of 235 MPa in the artificially aged condition (using the same artificial aging practice as the 2 week material), the aluminum alloy sheet in the T6 temper would have realized a tensile yield strength (LT) loss of only 10 MPa (235-245 MPa) over the Test Time Period. In one embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 19 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 17 MPa over the Test Time Period. In yet another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 15 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 13 MPa over the Test Time Period. In yet another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 11 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 9 MPa over the Test Time Period. In yet another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 7 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 5 MPa over the Test Time Period. In yet another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 3 MPa over the Test Time Period. In another embodiment, the tensile yield strength (LT) loss relative to the T6 temper is not greater than 1 MPa over the Test Time Period. In one embodiment, the aluminum alloy sheet product realizes no tensile yield strength (LT) loss relative to the T6 temper over the Test Time Period. In another embodiment, the aluminum alloy sheet product realizes an increase in tensile yield strength of at least 2 MPa relative to the T6 temper over the Test Time Period.

v. Product Applications

[0034] The new aluminum alloy described herein may be used in a variety of applications, such as an automotive, rail, aerospace, or consumer electronics application. For example, a new aluminum alloy may be formed into an automotive part. Non-limiting examples of automotive parts include automotive bodies and automotive panels. Non-limiting examples of automotive panels may be outer panels, inner panels for use in car doors, car hoods, or car trunks (deck lids), among others. One example of an automotive body product may be a structural component, which are commonly sheet metal components of a car body (e.g., body-in-white) where additional strength is required to withstand crash requirements. In one embodiment, the new aluminum alloy is an enclosure for a battery, such as a battery used in an electric vehicle. The new aluminum alloys may also be used in other transportation applications, such as light or heavy trucks. Consumer electronic product applications include laptop computer cases, battery cases, among other stamped and formed products.

vi. Definitions

[0035] "Wrought aluminum alloy product" means an aluminum alloy product that is hot worked after casting, and includes rolled products (sheet or plate), forged products, and extruded products.

[0036] "Hot working" such as by hot rolling means working the aluminum alloy product at elevated temperature, and generally at least 121.1°C (250°F). Strain-hardening is restricted / avoided during hot working, which generally differentiates hot working from cold working.

[0037] "Cold working" such as by cold rolling means working the aluminum alloy product at temperatures that are not considered hot working temperatures, generally below about 121.1°C (250°F) (e.g., at ambient).

[0038] "Test Time Period" means the period beginning after two weeks of natural aging (+/- 12 hours) and ending after six months of natural aging (+/- 24 hours). The Test Time Period is applicable to measurement of T4/T43 strength increase (or lack thereof) and to measurement of T6 strength loss (or lack thereof), as explained above. *See also*, Example 3, below.

[0039] Temper definitions are per ANSI H35.1 (2009), entitled "American National Standard Alloy and Temper Designation Systems for Aluminum," published by The Aluminum Association.

[0040] Strength and elongation are measured in accordance with ASTM E8/E8M-16a and B557-15.

[0041] "Three-point bending tests" (sometimes called 3-point bending tests) are measured in accordance with VDA 238-100, entitled, *Plate bending test for metallic materials,* Validation Rule, 01 June 2017 (*see* https://www.vda.de/en/services/Publications/vda-238-100-plate-bending-test-for-metallic-materials.html), where the final gauge (thickness) of the sheet is 2.0 ± 0.05 mm, the coupon is fixed in the test frame, and a punch radius of 0.2 mm is used, except the VDA test is modified as follows:

- the specimen size is 25 mm wide and 51 mm long;

- the extension at 70% load drop is used as a metric, with higher extensions representing greater fracture toughness or crash resistance (the normal test VDA 238-100 utilizes the bend angle measured after 5% drop in load as a metric for comparing materials).

Ten replicate three-point bending coupons are tested for each test. Longitudinal (L) specimens are oriented such that the bend line is perpendicular to the rolling direction and transverse (LT) specimens are oriented such that the bend line is parallel to the rolling direction.

vii. Microstructure Assessment Procedure

[0042] The following procedures and definitions apply to measuring microstructure features (e.g., percent recrystallization, dispersoid content and size, constituent content and size, texture) for products made in accordance with present patent application.

A. Dispersoids et al.

[0043] "Dispersoid area fraction", f, is the area fraction covered by dispersoid particles divided by the total area examined in a two-dimensional cross section prepared by standard metallographic sample preparation methods.

[0044] "Dispersoid area %" is determined via the formula f x 100.

[0045] "Dispersoid average diameter" is the average of all measured dispersoid diameters, d_i, where each diameter is an effective diameter calculated assuming each dispersoid area, A_i, measured on a two-dimensional cross section is a circle of the effective diameter:

$$d_i = \mathit{square\ root}\ (\frac{4Ai}{\pi})$$

[0046] To measure the dispersoid area fraction, f, and dispersoid average diameters, backscattered electron images should be taken at 2000x on an Apreo S Field Emission Gun (Thermo Fisher Scientific, Waltham, MA, U.S.A) scanning electron microscope, or equivalent, to image dispersoids. The images should be taken using an accelerating voltage 5kV. Beam current should be 3.2 nanoamps. Twenty images are to be collected from metallographically polished specimens for each alloy at both t/2 and the surface. Image analysis is to be used to quantify the images. The pixel size for quantifying dispersoids is 0.021 microns, and only particles containing at least 15 pixels but no more than 300 pixels are to be counted. Pixels are only counted if their gray scale value is 4 standard deviations above the mean pixel gray scale value across entire image. For each dispersoid particle, the number of pixels is converted to a particle area and to a particle effective diameter.

[0047] The quantity "f/r" is the dispersoid area fraction, f, divided by the dispersoid radius, which is determined by taking half of the dispersoid average diameter. This parameter is a measure of the pinning force on grain boundaries, also called Zener drag, (Ref. 1), where higher values may be associated with finer grain size.

- Reference 1. J. W. Martin, *Micromechanisms in Particle-Hardened Alloys*, Cambridge University Press, 1980.

[0048] "Constituent area fraction", cf, is the area fraction covered by constituent particles divided by the total area examined in a two-dimensional cross section prepared by standard metallographic sample preparation methods.

[0049] "Constituent area %" is determined via the formula cf x (times) 100.

[0050] "Constituent average diameter" is the average of all measured constituent diameters, d_i, where each diameter is an effective diameter calculated assuming each constituent area, A_i, measured on a two-dimensional cross section is a circle of the effective diameter:

$$d_i = \mathit{square\ root}\ \left(\frac{4Ai}{\pi}\right)$$

[0051] To measure the constituent area fraction, cf, and constituent average diameters, backscattered electron images should be taken at 500x on an Apreo S Field Emission Gun (Thermo Fisher Scientific, Waltham, MA, U.S.A) scanning electron microscope, or equivalent, to image dispersoids. The images should be taken using an accelerating voltage 5kV. Beam current should be 3.2 nanoamps. Twenty images are to be collected from metallographically polished specimens for each alloy at both t/2 and the surface. Image analysis is to be used to quantify the images. The pixel size for quantifying dispersoids is 0.083 microns, and only particles containing at least 23 pixels are to be counted. Pixels are only counted if their gray scale value is 4 standard deviations above the mean pixel gray scale value across entire image. For each dispersoid particle, the number of pixels is converted to a particle area and to a particle effective diameter.

[0052] "Percent recrystallized" and the like means the volume percent of a wrought aluminum alloy product having recrystallized grains. The amount of recrystallized grains is determined by EBSD (electron backscatter diffraction) analysis of a suitable number of SEM micrographs of the wrought aluminum alloy product, as per the *Recrystallization Determination Procedure*, below. Generally at least 5 micrographs should be analyzed.

B. Recrystallization Determination Procedure

[0053] "Recrystallized grains" means those grains of a crystalline microstructure that meet the "first grain criteria", defined below, and as measured using the OIM (Orientation Imaging Microscopy) sampling procedure, described below.

[0054] The OIM analysis is to be completed through the full thickness of the sheet sample on the L-ST plane, using the OIM sample procedure, below. The size of the sample to be analyzed will generally vary by gauge. Prior to measurement, the OIM samples are prepared by standard metallographic sample preparation methods. For example, the OIM samples are metallographically prepared and then polished (e.g., using 0.05 micron colloidal silica). The samples are then anodized in Barker's reagent, a diluted fluoroboric acid solution, for 90 seconds. The samples are then stripped using an aqueous phosphoric acid solution containing chromium trioxide, and then rinsed and dried.

[0055] The "OIM sample procedure" is as follows:

- The software used is APEX EBSD Collection Software, Version 2 (EDAX Inc., New Jersey, U.S.A.), or equivalent, which is connected to a Velocity EBSD camera (EDAX Inc., New Jersey, U.S.A.), or equivalent. The SEM is an APREO S Field Emission Gun (Thermo Fisher Scientific. Waltham, MA, U.S.A.), or equivalent.
- OIM run conditions are 68° tilt with a 18 mm working distance and an accelerating voltage of 20 kV with dynamic focusing and an instrument-specified beam current of 51 nA (nanoamps). The mode of collection is hexagonal grid. A selection is made such that orientations are collected in the analysis (i.e., Hough peaks information is not collected). The area size per scan (i.e., the frame) is 2.0 mm by 1 mm for 2 mm gauge samples at 1 micron steps at 40X. Different frame sizes can be used depending upon gauge. The collected data is output in an *.osc file. This data may be used to calculate the volume fraction of first type grains, as described below.
- <u>Calculation of volume fraction of first type grains</u>: The volume fraction of first type grains is calculated using the data of the *.osc file and the OIM Analysis Software (EDAX Inc., New Jersey, U.S.A.), version 8.1.0, or equivalent. Prior to calculation, two-step data cleanup may be performed. First, for any points whose confidence index is below a threshold of 0.08, a neighbor orientation correlation clean-up is performed. Second, a grain dilation clean-up is performed for any grain smaller than 3 data points. Then, the amount of first type grains is calculated by the software using the first grain criteria (below).
- <u>First grain criteria</u>: Grain average misorientation (GAM) is calculated. All of "apply partition before calculation", "include edge grains", and "ignore twin

boundary definitions" should be required. Any grain whose GAM is $\leq 1°$ is a first type grain.

[0056] "First grain volume" (FGV) means the volume fraction of first type grains of the crystalline material.

[0057] "Percent Recrystallized" is determined via the formula: FGV * 100%.

[0058] The term "grain" has the meaning defined in ASTM E112 §3.2.2, i.e., "the area within the confines of the original (primary) boundary observed on the two-dimensional plane of-polish or that volume enclosed by the original (primary) boundary in the three-dimensional object".

[0059] "Grain size" is calculated by the following equation:

$$d_i = square\ root\ (\frac{4Ai}{\pi})$$

- wherein A_i is the area of the individual grain as measured using commercial software OIM Analysis Software, version 8.1.0 or equivalent; and
- wherein d_i is the calculated individual grain size assuming the grain is a circle.

[0060] "Area weighted average grain size" is calculated by the following equation:

$$\text{d-bar} = (\sum_{i=1}^{n} A_i d_i)/(\sum_{i=1}^{n} d_i)$$

- wherein A_i is the area of each individual grain as measured using commercial software OIM Analysis Software, version 8.1.0 or equivalent;
- wherein d_i is the calculated individual grain size assuming the grain is a circle; and
- wherein d-bar is the area weighted average grain size.

C. Texture

[0061] "Texture" means a preferred orientation of at least some of the grains of a crystalline structure. Texture components resulting from production of aluminum alloy products may include one or more of copper, S texture, brass, cube, and Goss texture, to name a few. Each of these texture components is defined in Table A, below.

Table A

Texture component	**Miller Indices**	**Bunge (φ1, Φ, φ2)**	**Kocks (Ψ, Θ, Φ)**
copper	$\{112\}\langle 11\bar{1}\rangle$	90, 35, 45	0, 35, 45

Texture component	**Miller Indices**	**Bunge (φ1, Φ, φ2)**	**Kocks (Ψ, Θ, Φ)**
S	$\{123\}\langle 63\bar{4}\rangle$	59, 37, 63	149, 37, 27
brass	$\{110\}\langle \bar{1}12\rangle$	35, 45, 0	55, 45, 0
Cube	{1 0 0} <001>	0, 0, 0	0, 0, 0
Goss	$\{110\}\langle 001\rangle$	0, 45, 0	0, 45, 0

EBSD data for texture quantification are that same data that are generated as described above to determine "grain size" and "percent recrystallized." The quantification of texture components present is done by the EBSD software, i.e. OIM Analysis Software, version 8.1.0 or equivalent. First step is to align the EBSD data from the L-ST plane into the more commonly used L-LT reference plane. Quantification of texture components present (Cube%, Goss%, Brass%, S%, Copper%) is to be determined as the number fraction of measured points assigned to a specific texture component. Points are assigned to a texture component if the misorientation angle deviates from the ideal orientation by less than 15 degrees. This number fraction is multiplied by 100 to find the percentage of each texture component in the sample.

viii. Miscellaneous

[0062] These and other aspects, advantages, and novel features of this new technology are set forth in part in the description that follows and will become apparent to those skilled in the art upon examination of the following description and figures, or may be learned by practicing one or more embodiments of the technology provided for by the present disclosure.

[0063] Among those benefits and improvements that have been disclosed, other objects and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying figures. Detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely illustrative of the invention that may be embodied in various forms. In addition, each of the examples given in connection with the various embodiments of the invention is intended to be illustrative, and not restrictive.

[0064] Throughout the specification and claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise. The phrases "in one embodiment" and "in some embodiments" as used herein do not necessarily refer to the same embodiment(s), though they may. Furthermore, the phrases "in another embodiment" and "in some other embodiments" as used herein do not necessarily refer to a different embodiment, although they may. Thus, various embodiments of the invention may be readily combined, without departing from the scope or spirit of the invention.

[0065] In addition, as used herein, the term "or" is an inclusive "or" operator, and is equivalent to the term "and/or," unless the context clearly dictates otherwise. The term "based on" is not exclusive and allows for being based on additional factors not described, unless the context clearly dictates otherwise. In addition, throughout the specification, the meaning of "a," "an," and "the" include plural references, unless the context clearly dictates otherwise. The meaning of "in" includes "in" and "on", unless the context clearly dictates otherwise.

[0066] While a number of embodiments of the present invention have been described, it is understood that these embodiments are illustrative only, and not restrictive, and that many modifications may become apparent to those of ordinary skill in the art. Further still, unless the context clearly requires otherwise, the various steps may be carried out in any desired order, and any applicable steps may be added and/or eliminated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0067] FIG. 1 is a graph illustrating properties of the Example 1 alloys versus conventional 6111 and 6013 alloys.

[0068] FIG. 2 is a graph illustrating properties of the Example 2 alloys.

[0069] FIGS. 3-8 are tables illustrating the results of Example 3.

DETAILED DESCRIPTION

Example 1

[0070] Four DC ingots of the aluminum alloy shown in Table 1 were homogenized and then conventionally scalped / peeled.

Table 1 - Composition of Ex. 1 Alloy (in wt. %)*

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.91	0.23	0.69	0.21	0.80	0.08	0.02	0.03

* The balance of each alloy was incidental elements and impurities, where each alloy contained not greater than 0.03 wt. % of any one impurity, and where each alloy contained not greater than 0.10 wt. %, in total, of all impurities.

Some of the homogenized ingots were hot rolled to 5.842 mm (0.230 inch) followed by cold rolling (without any intermediate anneal) by 66% to a final gauge of 2.007 mm (0.079 inch). Other ingots were hot rolled to 3.531 mm (0.139 inch) followed by cold rolling (without any intermediate anneal) by 43% to a final gauge of 2.007 mm (0.079 inch). The final gauge materials were then solution heat treated in-line at various conditions, as per Table 2, below. The materials were water spray quenched in-line after solution heat treatment.

Table 2 – Solution Heat Treatment (SHT) Conditions

SHT Condition	Residence Time (Sec.)_	Approx. Temp. °C (°F)
1	~150s	521.1-560 (970-1040)
2	~110s	521.1-560 (970-1040)
3	~45s	521.1-548.9 (970-1020)
4	~30s	521.1-543.3 (970-1010)
5	~2s	521.1-523.9 (970-975)

[0071] Some of the materials were pre-aged in-line at about 66.7°C or 72.2°C (152°F or 162°F) for the 43% and 66% cold worked materials, respectively, after the quenching step so as to produce a T43 temper. Other materials were simply naturally aged after quenching to produce a T4 temper. For both the T4 and T43 tempers, all materials were naturally aged for about 1-month. The mechanical properties of the materials are shown in Table 3, below. All properties are relative to the LT (long transverse) direction.

Table 3 - Mechanical Properties (LT) of Naturally Aged Alloys

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	TYS (MPa)	UTS (MPa)	Elong. (%) (Total)
1	3.53	43%	1	T4	186	314	26.3
2	3.53	43%	2	T4	185	313	24.0
3	5.84	66%	1	T4	183	313	26.4
4	5.84	66%	2	T4	183	313	26.2
5	3.53	43%	3	T4	174	312	27.2
6	3.53	43%	5	T4	164	301	26.6
7	5.84	66%	3	T4	172	310	27.6
8	5.84	66%	5	T4	164	300	28.2
9	3.53	43%	3	T43	161	299	26.3

10	3.53	43%	4	T43	159	298	28.2
11	3.53	43%	5	T43	147	281	21.4
12	5.84	66%	3	T43	159	297	27.9
13	5.84	66%	4	T43	155	295	25.8
14	5.84	66%	5	T43	148	286	26.0

[0072] Next, the alloys were artificially aged both with and without pre-strain (stretching) prior to the age. Specifically, the alloys were (i) aged at 185°C (365°F) for 20 minutes without any pre-strain ("Age1"), (ii) stretched 2% (pre-strained) and then aged at 185°C (365°F) for 20 minutes ("Age2"), and (iii) aged at 225°C (437°F) for 30 minutes without any pre-strain ("Age3"). The mechanical property results are shown in Tables 4-6, below. All properties are relative to the LT (long transverse) direction.

Table 4 – Tensile Yield Strength Properties (LT) of Artificially Aged Alloys

Sample No.	SHT Condition	T4 / T43 TYS (MPa)	Age1 TYS (MPa)	Age2 TYS (MPa)	Age3 TYS (MPa)
1	1	186	243	279	340
2	2	185	242	276	347
3	1	183	235	273	339
4	2	183	238	274	339
5	3	174	218	262	339
6	5	164	213	254	325
7	3	172	218	259	335
8	5	164	212	247	323
9	3	161	256	288	340
10	4	159	249	286	337
11	5	147	240	271	319
12	3	159	256	293	338
13	4	155	251	288	333
14	5	148	248	279	322

Table 5 – Ultimate Tensile Strength Properties (LT) of Artificially Aged Alloys

Sample No.	SHT Condition	T4 / T43 UTS (MPa)	Age1 UTS (MPa)	Age2 UTS (MPa)	Age3 UTS (MPa)
1	1	314	341	347	364
2	2	313	340	345	373
3	1	313	336	343	363
4	2	313	338	344	363
5	3	312	327	337	364
6	5	301	319	328	351
7	3	310	326	335	361

8	5	300	319	324	350
9	3	299	353	357	369
10	4	298	348	355	366
11	5	281	336	341	349
12	3	297	353	361	368
13	4	295	350	357	363
14	5	286	344	347	354

Table 6 – Total Elongation Properties (LT) of Artificially Aged Alloys

Sample No.	**SHT Condition**	**T4 / T43 Elong. (%)**	**Age1 Elong. (%)**	**Age2 Elong. (%)**	**Age3 Elong. (%)**
1	1	26.3	23.0	22.6	10.6
2	2	24.0	24.0	22.1	10.8
3	1	26.4	23.4	22.4	11.2
4	2	26.2	21.8	22.2	10.7
5	3	27.2	24.8	21.8	10.9
6	5	26.6	22.0	20.4	10.6
7	3	27.6	24.8	23.2	10.2
8	5	28.2	23.2	23.0	12.0
9	3	26.3	23.8	22.6	11.7
10	4	28.2	23.4	22.3	11.0
11	5	21.4	21.8	19.0	9.9
12	3	27.8	22.8	21.8	11.6
13	4	25.8	22.6	22.4	11.4
14	5	26.0	23.2	20.6	12.4

[0073] Fracture behavior was also evaluated using three-point bending tests (as defined in the *Definitions* section), the test results of which are provided in Tables 7-8, below. These tests are used to assess, *inter alia*, a material's (a) ability to be riveted without cracking and (b) behavior in crash situations. The tests were conducted relative to the transverse orientation (LT), and the reported values are based on the average of ten specimens used for each alloy tested. The properties are in relation to 1-month naturally aged materials.

[0074] In the case of Table 7, three-point bend testing was conducted in the T43 condition after 1-month of natural aging, i.e. no artificial aging was applied because material is riveted in a naturally aged condition. The same materials were also aged to Age condition 2, after which the mechanical properties (strength, elongation) were measured, as this represents the material's condition after a typical paint bake.

[0075] In the case of Table 8, both the three-point bend test results and the mechanical property measurements were taken from samples in the Age3 condition because some materials may be riveted in this condition.

Table 7 – Three-point bend testing results for T43 materials plus Age2 strength results

CR%	**SHT Condition**	**TYS (LT) (MPa) (Age 2)**	**Average Extension @70% (mm) (T43 temper)**
43% CW	3	288	17.8
43% CW	5	271	17.3
43% CW	4	286	17.4
66% CW	3	293	17.4
66% CW	5	279	17.2
66% CW	4	288	17.3

Table 8 – Three-point bend and strength results in Age3 condition

CR%	**SHT Condition**	**TYS (LT) (MPa)**	**Average Extension @70% (mm)**
43% CW	3	339	11.1
43% CW	5	325	12.4
66% CW	3	335	11.6
66% CW	5	323	12.7
43% CW	1	340	11.8
43% CW	2	347	12.1
66% CW	1	339	11.7
66% CW	2	339	11.8

[0076] The corrosion resistance of the artificially aged alloys was also tested, the results of which are provided in Table 9, below.

Table 9 - Intergranular Corrosion Results (ASTM G110)

CR Amount	**SHT Cond.**	**Age Cond.**	**Surface**	**Depth of corrosive attack (µm)**					**Max.**	**Ave.**
				1	**2**	**3**	**4**	**5**	**(µm)**	**(µm)**
66%	3	Agc3	1	72.9	91.8	76.8	80.3	73.6	91.8	71.5
			2	81.5	84.4	51.5	43.2	58.8		
66%	5	Age3	1	78.3	56.5	52.5	82.2	77.6	82.2	60.3
			2	52.9	44.9	42.7	57.6	57.7		
43%	3	Age3	1	76.7	62	49.3	59.5	38.4	79	65.8

			2	79	72.4	69.9	74	76.7		
43%	5	Age3	1	77.7	75.9	68.8	79.7	58.4	79.7	64.5
			2	50.4	49.1	56.5	58.3	70.4		
66%	1	Age3	1	65.6	58.4	74.7	87.6	X	87.6	64
			2	56.5	58.4	70.4	58.5	46.3		
66%	2	Age3	1	77.9	79.7	48.1	63.2	56.5	85.1	67.2
			2	57.7	57.2	63.8	82.7	85.1		
43%	1	Age3	1	58.8	67.4	58.4	70.4	45.7	70.4	60.3
			2	68.6	60.2	54.2	54	65.2		
43%	2	Age3	1	62	58.9	73.6	60	62.5	77.2	60.8
			2	77.2	62.02	59.1	45.5	47.1		
66%	3	Age1	1	57.2	55.8	83.4	93.8	87	93.8	65.6
			2	54.7	63.8	50.4	46.1	63.4		
66%	4	Age1	1	79	103.3	62.7	40	37	103.3	64.4
			2	73	59	62	64.5	63.8		
66%	5	Age1	1	91.8	80.4	82.7	85.2	103.3	103.3	78.9
			2	84	67.9	57.3	74.7	62		
43%	3	Age1	1	89.9	78.3	75.3	94	79.5	94.2	84.5
			2	77.2	91	82.6	94.2	82.8		
43%	4	Age1	1	90.3	84	70.6	69.3	63.3	90.3	74.8
			2	88.1	67	67.4	71.1	77.2		
43%	5	Age1	1	79	95.6	96	87.4	78.5	96	82.4
			2	80.8	81.5	74.7	66.1	84.4		

[0077] Conventional 6111 and 6013 alloys were produced similar to the above, i.e., cast as ingots, hot rolled to an intermediate gauge, cold rolled to final gauge, solution heat treated and then quenched, and then naturally aged for at least two weeks. The compositions of the alloys are shown in Table 10, below.

Table 10 – Compositions of the 6111 and 6013 Alloys (wt. %)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
6111	0.75	0.24	0.67	0.20	0.58	0.04	0.01	0.03	Bal.
6013	0.68	0.23	0.85	0.31	0.92	0.03	0.02	0.03	Bal.

[0078] The 6111 and 6013 materials were naturally aged for at least 1.5 months and then aged per Age3. The mechanical properties were then tested, the results of which are shown in Table 11, below. All properties are relative to the LT (long transverse) direction.

Table 11 – Mechanical Property Data for 6111 and 6013 Alloys

Alloy	CR%	Age Condition	UTS (LT) (MPa)	TYS (LT) (MPa)	Elong. (LT) (%)	Average Extension @70% (mm)
6111	43	Age3	329.9	299.6	10.6	15.4
6013	55	Age3	367.1	328.9	12.3	10.6

[0079] As shown in FIG. 1 the 6111 alloy is unable to achieve the strengths achieved by the invention alloys. As also shown in FIG. 1 the 6013 alloy is unable to achieve the high three-point bend properties achieved by the invention alloys.

[0080] The microstructure of the invention alloy materials and the 6111 and 6013 materials were also assessed. Specifically, grain size, texture, dispersoid fraction, and percent recrystallization were determined in accordance with the *Microstructure Assessment Procedure*, included herein. The invention alloy has a higher area fraction of dispersoids than both 6111 and 6013, and both the invention alloy and 6111 have finer dispersoids than 6013, as shown in Table 12. The invention alloys also have a notably higher f/r value than the 6013 and 6111 alloys. In the f/r ratio, f is the fraction of dispersoids (Area %/100) and r is the average dispersoid radius (Diameter/2). A higher f/r tends to result in greater grain boundary pinning, also called Zener drag, which will tend to promote fine grain size.

Table 12 – Recrystallization and Grain Size Data

Alloy	Dispersoid Area %	Dispersoid ave. diameter, micro-meters	f/r	% ReX	Grain Size, micro-meters
Invention	0.77	0.18	0.083	98%	31.4
6111	0.53	0.17	0.061	99%	30.4
6013	0.63	0.21	0.061	99%	34.6

[0081] Texture measurements were also conducted in accordance with the *Microstructure Assessment Procedure*, the results of which are shown in Table 13. As shown, the invention alloy and 6111 both contain notably higher levels of the cube texture, which is the most desirable component for formability and fracture behavior, compared to 6013.

Table 13 – Texture Data

Alloy	Texture (%)					
	Cube	Goss	P	Brass	Copper	S
Invention	14	12	4	3	6	16

Alloy	Texture (%)					
	Cube	Goss	P	Brass	Copper	S
6111	12	11	5	3	7	15
6013	7	10	8	4	6	17

[0082] **Example 2**

[0083] Six pilot scale aluminum alloy ingots (6-inch by 18-inch cross section) were DC cast, then homogenized and then conventionally scalped / peeled. The compositions of the six aluminum alloys are shown in Table 14, below. The alloys generally seek to vary the amount of manganese and chromium while keeping silicon, iron, copper, magnesium, zinc and titanium relatively constant.

Table 14 - Composition of Ex. 2 Alloys (in wt. %)*

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
XA08	0.87	0.22	0.69	0.21	0.79	0.07	<0.005	0.02
XA09	0.87	0.26	0.68	0.05	0.78	0.03	0.03	0.02
XA10	0.91	0.25	0.68	0.05	0.81	0.20	0.01	0.02
XA11	0.91	0.26	0.68	0.20	0.82	0.03	0.02	0.02
XA12	0.90	0.27	0.68	0.22	0.81	0.20	0.01	0.02
XA13	0.92	0.24	0.69	0.13	0.80	0.11	0.01	0.02

* The balance of each alloy was incidental elements and impurities, where each alloy contained not greater than 0.03 wt. % of any one impurity, and where each alloy contained not greater than 0.10 wt. %, in total, of all impurities.

[0084] The homogenized ingots were then hot rolled to 3.531 mm (0.139 inch) followed by cold rolling (without any intermediate anneal) by 43% to a final gauge of 2.007 mm (0.079 inch). The final gauge materials were then solution heat treated at 1040°F, water quenched, stretched for flatness, and then naturally aged for 7 days. The alloys were then either aged (i) according to "Age 3" per Example 1 (i.e., at 437°F (225°C) for 30 minutes) or (ii) at 356°F (180°C) for 8 hours ("Age 4").

[0085] The mechanical properties and microstructures of the alloys were then evaluated, the results of which are shown in Tables 15a-15b and 16-17, below, and FIG. 2. The provided mechanical properties are from the LT direction. The grain size, texture, dispersoid fraction, and percent recrystallization were determined in accordance with the *Microstructure Assessment Procedure* included herein, except as noted below.

Table 15a – Mechanical Properties (LT) of the Example 2 Alloys in Age 3 Condition

Alloy	TYS (MPa)	UTS (MPa)	Total Elong. (%)	Average Extension @70% (mm)
XA08	337	360	9.7	13.2
XA09	352	373	9.3	10.3
XA10	345	370	8.5	13.9
XA11	360	381	9.6	9.0
XA12	339	364	10.6	12.4
XA13	345	368	9.0	13.0

Table 15b – Mechanical Properties (LT) of the Example 2 Alloys in Age 4 Condition

Alloy	TYS (MPa)	UTS (MPa)	Total Elong. (%)	Average Extension @70% (mm)
XA08	358	386	11.5	12.0
XA09	366	394	10.0	9.5
XA10	360	390	10.3	12.3
XA11	375	402	9.9	8.7
XA12	359	390	11.9	11.3
XA13	364	391	11.0	11.1

Table 16 – Microstructure Data of the Example 2 Alloys

Alloy	Dispersoid Area %*	Dispersoid Ave. Dia., Micrometers*	f/r	Constituent Area %	Constituent Diameter, micrometers	% ReX	Area Wt. G.S. (µm) All
XA08	0.866	0.177	0.098	0.644	1.10	100	49.3
XA09	0.403	0.162	0.050	0.631	1.14	99	59.8
XA10	0.995	0.166	0.120	0.49	1.03	100	53.4
XA11	0.646	0.178	0.073	0.714	1.13	99	50.0
XA12	1.165	0.165	0.141	0.732	1.41	99	35.5
XA13	0.907	0.173	0.105	0.623	1.05	99	50.1

*Average values measured at t/2 location only.

Table 17 – Texture Data of the Example 2 Alloys

Alloy	Texture (%)					
	Cube	Goss	P	Brass	Copper	S
XA08	15.9	1.9	4.6	3.8	5.2	11.7
XA09	15.2	1.7	4.4	3.4	5.2	8.5
XA10	12.6	3.7	4.4	4.1	5.6	10.7
XA11	16.6	2.6	4.5	3.9	5.5	10.3

	Texture (%)					
Alloy	Cube	Goss	P	Brass	Copper	S
XA12	11.5	2.6	7.6	4.5	4.6	12.7
XA13	15.6	1.6	4.7	3.7	4.9	11.3

[0086] As the data shows, although all alloys realize high strength and suitable fracture behavior, the XA10 alloy realizes a very high combination of strength and fracture behavior (e.g., as shown in FIG. 2), which may be due to its manganese plus chromium content. For instance, the XA10 alloy realized a significantly lower amount of constituent particles (0.49%) compared to the other alloys (0.623 to 0.732%). This is especially noteworthy considering XA08, XA10, XA11 and XA13 contain similar total amounts of Fe, Si, Cr and Mn, the elements which are incorporated in the constituent particles. As also shown, the Example 2 alloys realize a similar texture to that of the invention alloy of Example 1, i.e., they contain notably high levels of the cube texture, which is the most desirable component for formability and fracture behavior.

[0087] Example 3

[0088] The natural aging and artificial aging response of the alloy of Example 1 was evaluated over a period of several weeks to several months across various conditions. FIGS. 3-5 show the natural aging results and FIGS. 6-8 show the artificial aging results. The artificial aging condition was Age1, i.e., aged at 185°C (365°F) for 20 minutes without any pre-strain. The artificial aging occurred after the specified weeks or months of natural aging. (Note: the data for 1 month of natural aging in FIGS 3-8 are those already reported above in Example 1.)

[0089] As shown, the inventive alloy's properties are highly stable over the Time Test Period, which is important for automotive manufacturers because they can stock/store the invention alloys with confidence in shelf life. For the naturally aged materials, increases in tensile yield strength were less than 13MPa for all lots over the Test Time Period, i.e., as measured from the period starting after 2 weeks of natural aging (+/- 12 hours) and ending after 6 months of natural aging (+/- 24 hours). For most lots, the increase was much less (*see* FIG. 3). Thus, good forming capabilities should be realized over the Test Time Period. Furthermore, the response to a simulated paint bake, i.e. aged at 185°C (365°F) for 20 minutes without any pre-strain ("Age1") was very good. FIG. 6 shows that the tensile yield strength after paint bake is expected to be no less than 21 MPa lower after 6 months of natural aging as compared to values after 2 weeks of natural aging.

[0090] 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 aluminum alloy sheet product comprising:
    - from 0.75 to 1.05 wt. % Si;
    - from 0.65 to 0.95 wt. % Mg;
        - wherein (wt. % Mg) / (wt. % Si) is not greater than 0.99:1;
    - from 0.50 to 0.75 wt. % Cu;
    - from 0.02 to 0.40 wt. % Mn;
    - from 0.06 to 0.26 wt. % Cr;
        - wherein (wt. % Mn) + (wt. % Cr) is at least 0.22 wt. %;
    - from 0.01 to 0.30 wt. % Fe;
    - up to 0.25 wt. % Zn;
    - up to 0.20 wt. % Zr;
    - up to 0.20 wt. % V;
    - up to 0.15 wt. % Ti;
    - the balance being aluminum, optional incidental elements and impurities;

wherein the aluminum alloy sheet product has a thickness of from 1.0 to 4.0 mm;
wherein the aluminum sheet product realizes a tensile yield strength (LT) of at least 315 MPa in a T6 temper, wherein the artificial aging of the T6 temper is 30 minutes at 225°C (437°F).

2. The aluminum alloy sheet product of claim 1, wherein the aluminum alloy includes at least 0.80 wt. % Si, or at least 0.85 wt. % Si, or at least 0.90 wt. % Si.
3. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 1.0 wt. % Si.
4. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.70 wt. % Mg, or at least 0.75 wt. % Mg, or at least 0.80 wt. % Mg.
5. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.90 wt. % Mg.
6. The aluminum alloy sheet product of any of the preceding claims, wherein (wt. % Mg) / (wt. % Si) is not greater than 0.95:1, or not greater than 0.9:1.
7. The aluminum alloy sheet product of any of the preceding claims, wherein (wt. % Mg) / (wt. % Si) is at least 0.7:1, or at least 0.8:1.
8. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.55 wt. % Cu, or at least 0.60 wt. % Cu, or at least 0.65 wt. % Cu.

9. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.73 wt. % Cu, or not greater than 0.70 wt. % Cu.

10. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.04 wt. %Mn, or at least 0.05, or at least 0.06 wt. % Mn, or at least 0.08 wt. % Mn, or at least 0.10 wt. % Mn, or at least 0.15 wt. % Mn, or at least 0.20 wt. % Mn.

11. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.35 wt. % Mn, or not greater than 0.30 wt. % Mn.

12. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.08 wt. % Cr, or at least 0.10 wt. % Cr, or at least 0.12 wt. % Cr, or at least 0.14 wt. % Cr, or at least 0.16 wt. % Cr, or at least 0.18 wt. % Cr.

13. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.24 wt. % Cr, or not greater than 0.22 wt. % Cr, or not greater than 0.20 wt. % Cr.

14. The aluminum alloy sheet product of any of the preceding claims, wherein (wt. % Mn) + (wt. % Cr) is at least 0.24 wt. %, or at least 0.25 wt. %, or at least 0.26 wt. %, or at least 0.27 wt. %, or at least 0.28 wt. %, or at least 0.29 wt. %.

15. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.05 wt. % Fe, or at least 0.10 wt. % Fe, or at least 0.12 wt. % Fe.

16. The aluminum alloy sheet product of claim 1, wherein the aluminum alloy includes not greater than 0.28 wt. % Fe, or not greater than 0.26 wt. % Fe.

17. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.20 wt. % Zn, or not greater than 0.15 wt. % Zn, or not greater than 0.10 wt. % Zn, or not greater than 0.08 wt. % Zn, or not greater than 0.05 wt. % Zn, or not greater than 0.03 wt. % Zn.

18. The aluminum alloy sheet product of any of the preceding claims wherein the aluminum alloy includes at least 0.01 wt. % Zn.

19. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.15 wt. % Zr, or not greater than 0.10 wt. % Zr, or not greater than 0.08 wt. % Zr, or not greater than 0.05 wt. % Zr, or not greater than 0.03 wt. % Zr.

20. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.01 wt. % Zr.

21. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.15 wt. % V, or not greater than 0.10 wt. % V, or not greater than 0.08 wt. % V, or not greater than 0.05 wt. % V, or not greater than 0.03 wt. % V.

22. The aluminum alloy sheet product of claim 1, wherein the aluminum alloy includes at least 0.01 wt. % V.

23. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes not greater than 0.12 wt. % Ti, or not greater than 0.10 wt. % Ti.

24. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy includes at least 0.01 wt. % Ti or at least 0.02 wt. % Ti, or at least 0.05 wt. % Ti.

25. The aluminum alloy sheet product of any of the preceding claims, wherein the tensile yield strength (LT) is at least 320 MPa when artificially aged at 225°C (437°F) for 30 minutes, or at least 325 MPa, or at least 330 MPa, or at least 335 MPa, or at least 340 MPa, or at least 345 MPa, or at least 350 MPa, or at least 355 MPa, or at least 360 MPa, or at least 365 MPa, or at least 370 MPa.

26. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product realizes a three-point bend extension of at least 10.0 mm in the T6 temper, or at least 11.0 mm, or at least 11.2 mm, or at least 11.4 mm, or at least 11.6 mm, or at least 11.8 mm, or at least 12.0 mm, or at least 12.2 mm, or at least 12.4 mm, or at least 12.6 mm, or at least 12.8 mm, or at least 13.0 mm.

27. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product realizes a three-point bend extension of at least 16.0 mm in the T4 temper, or at least 16.2 mm, or at least 16.4 mm, or at least 16.6 mm, or at least 16.8 mm, or at least 17.0 mm, or at least 17.2 mm, or at least 17.4 mm, or at least 17.6 mm, or at least 17.8 mm, or at least 18.0 mm.

28. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product realizes a maximum depth of attack of not greater than 200 micrometers when tested in accordance with ASTM G110-92(2015) for 6 hours.

29. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product is fully recrystallized.

30. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product realizes an area weighted average grain size of not greater than 50 micrometers.

31. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product contains at least 10 vol. % cube texture.

32. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet realizes a dispersoid area fraction of at least 0.5 %.

34. The aluminum alloy sheet product of any of the preceding claims, wherein, in the T4 or T43 temper, the aluminum alloy sheet product realizes an increase of not greater than 15 MPa in tensile yield strength (LT) over the period of 2 weeks of natural aging to 6 months of natural aging.

35. The aluminum alloy sheet product of claim 34, wherein the increase is not greater than 13 MPa, or not greater than 11 MPa, or not greater than 9 MPa, or not greater than 7 MPa, or not greater than 5 MPa.

36. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product realizes not greater than 21 MPa strength loss in tensile yield strength (LT) over the period of 2 weeks of natural aging to 6 months of natural aging relative to the T6 temper.

37. The aluminum alloy sheet product of claim 36, wherein the strength loss is not greater than 19 MPa, or not greater than 17 MPa, or not greater than 15 MPa, or not greater than 13 MPa, or not greater than 11 MPa, or not greater than 9 MPa, or not greater than 7 MPa, or not greater than 5 MPa, or not greater than 3 MPa, or not greater than 1 MPa.

38. The aluminum alloy sheet product of claim 36, wherein the aluminum alloy sheet product realizes no tensile strength loss or realizes an increase in tensile yield strength of at least 2 MPa.

39. The aluminum alloy sheet product of any of the preceding claims, wherein the aluminum alloy sheet product realizes an f/r of at least 0.05, or at least 0.06 or at least 0.07, or at least 0.08.

40. An automotive sheet product made from any of the aluminum alloy products of any of the preceding claims.

FIG. 1 - VDA Bend Results

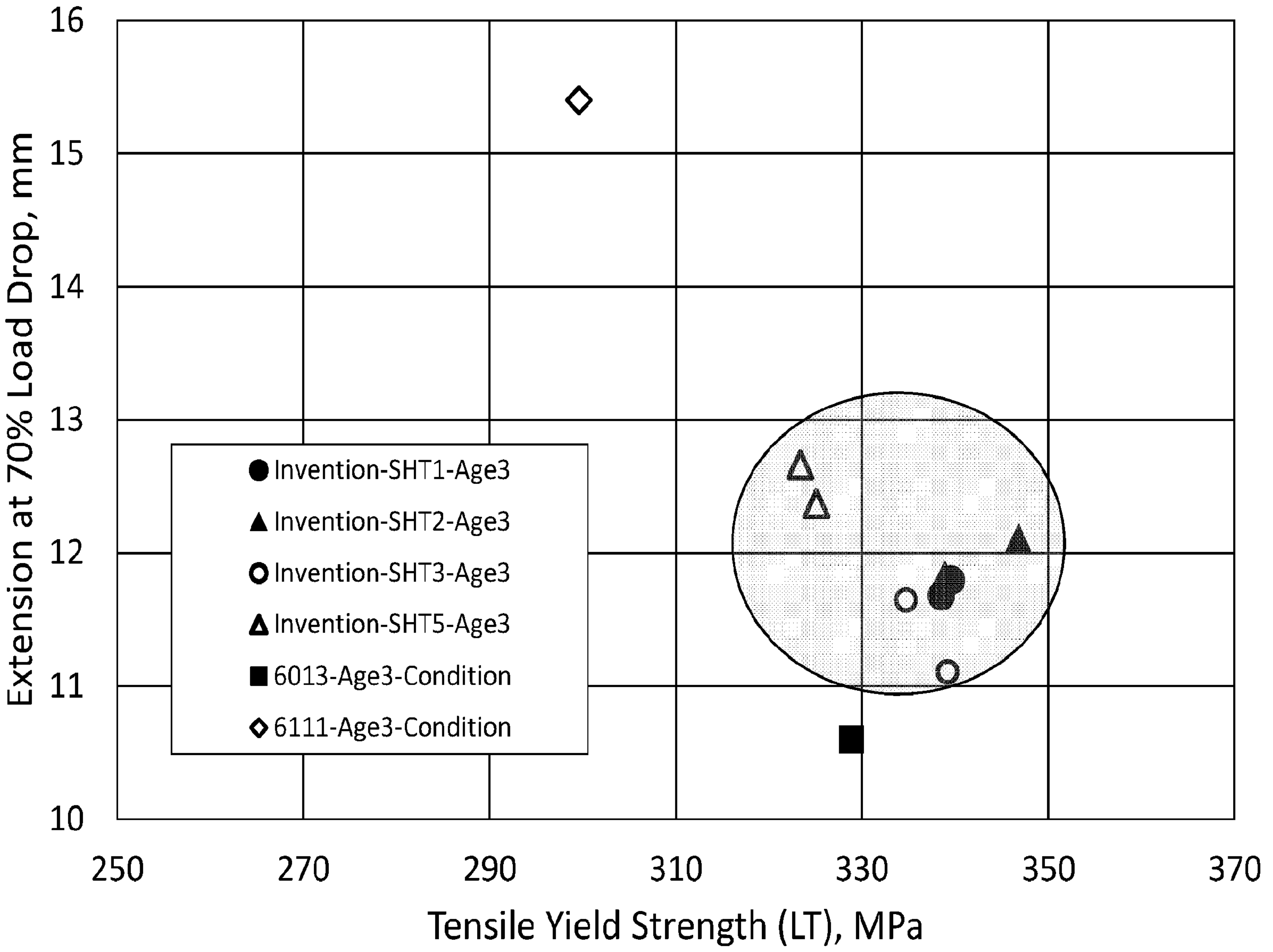

FIG. 2

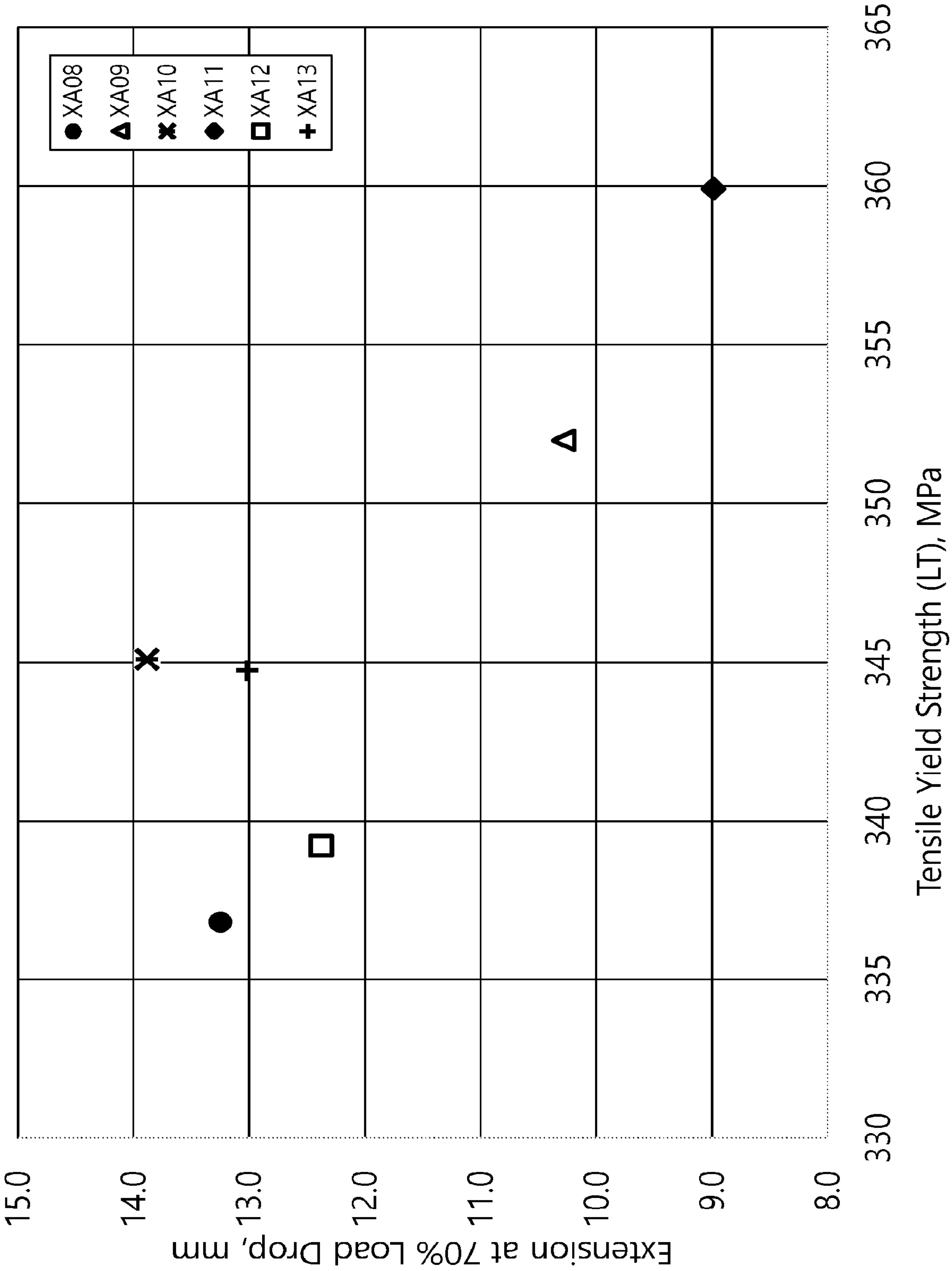
● XA08
▲ XA09
✖ XA10
◆ XA11
□ XA12
+ XA13
Extension at 70% Load Drop, mm
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
Tensile Yield Strength (LT), MPa
330
335
340
345
350
355
360
365

FIG. 3

Example 3 - Natural Aging Results (TYS (MPa), LT)

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	2 weeks	1 month	2 months	3 months	4 months	5 months	6 months
1	3.53	43%	1	T4	188	186	188	192	194	189	188
2	3.53	43%	2	T4	183	185	187	187	189	189	189
3	5.84	66%	1	T4	181	183	185	184	186	187	187
4	5.84	66%	2	T4	182	183	187	186	188	188	188
5	3.53	43%	3	T4	173	174	179	180	181	181	181
6	3.53	43%	5	T4	161	164	167	168	172	171	171
7	5.84	66%	3	T4	171	172	177	177	178	179	179
8	5.84	66%	5	T4	162	164	167	167	170	171	169
9	3.53	43%	3	T43	160	161	163	164	167	167	167
10	3.53	43%	4	T43	156	159	160	161	164	164	167
11	3.53	43%	5	T43	145	147	149	151	154	153	153
12	5.84	66%	3	T43	157	159	161	164	165	166	168
13	5.84	66%	4	T43	153	155	158	160	164	162	164
14	5.84	66%	5	T43	145	148	150	150	153	153	158

FIG. 4

Example 3 - Natural Aging Results (UTS (MPa), LT)

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	2 weeks	1 month	2 months	3 months	4 months	5 months	6 months
1	3.53	43%	1	T4	317	314	318	322	326	320	319
2	3.53	43%	2	T4	311	313	319	316	321	320	319
3	5.84	66%	1	T4	310	313	317	314	319	319	319
4	5.84	66%	2	T4	310	313	318	316	320	319	319
5	3.53	43%	3	T4	312	312	319	318	321	320	319
6	3.53	43%	5	T4	297	301	304	303	309	308	309
7	5.84	66%	3	T4	309	310	316	315	317	318	318
8	5.84	66%	5	T4	298	300	305	304	308	309	306
9	3.53	43%	3	T43	299	299	302	303	307	306	308
10	3.53	43%	4	T43	294	298	299	299	303	303	305
11	3.53	43%	5	T43	280	281	284	285	289	288	290
12	5.84	66%	3	T43	297	297	301	303	306	304	306
13	5.84	66%	4	T43	294	295	299	299	304	302	304
14	5.84	66%	5	T43	282	286	288	287	291	290	295

FIG. 5

Example 3 - Natural Aging Results (Total Elong. (%), LT)

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	2 weeks	1 month	2 months	3 months	4 months	5 months	6 months
1	3.53	43%	1	T4	27.4	26.3	27.2	27.5	27.3	26.3	26.0
2	3.53	43%	2	T4	26.2	24.0	26.9	25.6	28.2	25.5	24.3
3	5.84	66%	1	T4	24.0	26.4	26.9	26.4	26.4	25.9	26.3
4	5.84	66%	2	T4	25.3	26.2	27.0	27.1	26.9	25.9	26.2
5	3.53	43%	3	T4	27.0	27.2	27.5	27.0	26.8	28.5	27.1
6	3.53	43%	5	T4	25.3	26.6	25.1	25.0	25.7	27.8	27.6
7	5.84	66%	3	T4	26.3	27.6	27.3	27.1	26.9	27.9	28.6
8	5.84	66%	5	T4	28.4	28.2	26.7	27.5	27.3	25.7	26.5
9	3.53	43%	3	T43	28.2	26.3	24.8	22.9	24.7	26.5	26.9
10	3.53	43%	4	T43	27.1	28.2	27.7	26.8	26.7	26.0	26.3
11	3.53	43%	5	T43	24.4	21.4	26.3	21.5	25.1	24.9	25.9
12	5.84	66%	3	T43	27.2	27.9	24.3	26.5	23.9	25.3	25.2
13	5.84	66%	4	T43	23.1	25.8	25.8	27.6	27.0	26.9	26.1
14	5.84	66%	5	T43	25.0	26.1	23.8	23.7	25.4	26.2	26.6

FIG. 6

Example 3 – Artificial Aging Results (TYS (MPa), LT)

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	2 weeks of Nat. Age	1 month of Nat. Age	2 months of Nat. Age	3 months of Nat. Age	4 months of Nat. Age	5 months of Nat. Age	6 months of Nat. Age
1	3.53	43%	1	T4	253	243	246	245	249	236	232
2	3.53	43%	2	T4	248	242	247	240	241	235	230
3	5.84	66%	1	T4	243	235	237	234	237	233	227
4	5.84	66%	2	T4	243	238	239	238	240	235	227
5	3.53	43%	3	T4	219	218	224	224	223	221	220
6	3.53	43%	5	T4	211	213	214	215	212	213	210
7	5.84	66%	3	T4	216	218	219	221	220	214	215
8	5.84	66%	5	T4	208	212	214	211	208	209	210
9	3.53	43%	3	T43	256	256	256	249	251	247	239
10	3.53	43%	4	T43	254	249	253	252	250	246	239
11	3.53	43%	5	T43	245	240	241	239	239	231	225
12	5.84	66%	3	T43	253	256	256	257	254	245	243
13	5.84	66%	4	T43	253	251	254	252	249	248	241
14	5.84	66%	5	T43	248	248	246	244	240	237	232

FIG. 7

Example 3 – Artificial Aging Results (UTS (MPa), LT)

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	2 weeks of Nat. Age	1 month of Nat. Age	2 months of Nat. Age	3 months of Nat. Age	4 months of Nat. Age	5 months of Nat. Age	6 months of Nat. Age
1	3.53	43%	1	T4	348	341	344	345	349	339	336
2	3.53	43%	2	T4	343	340	345	340	343	338	334
3	5.84	66%	1	T4	340	336	339	336	339	337	332
4	5.84	66%	2	T4	340	338	340	338	341	338	333
5	3.53	43%	3	T4	329	327	333	332	332	331	330
6	3.53	43%	5	T4	318	319	320	320	321	321	320
7	5.84	66%	3	T4	326	326	329	330	329	325	326
8	5.84	66%	5	T4	316	319	321	319	318	320	318
9	3.53	43%	3	T43	353	353	354	350	354	351	345
10	3.53	43%	4	T43	351	348	352	351	352	348	345
11	3.53	43%	5	T43	339	336	338	337	338	333	329
12	5.84	66%	3	T43	352	353	355	355	357	350	349
13	5.84	66%	4	T43	351	350	353	352	353	351	346
14	5.84	66%	5	T43	343	344	344	341	341	339	337

FIG. 8

Example 3 – Artificial Aging Results (Total Elong. (%), LT)

Sample No.	HR Gauge (mm)	CR Amount	SHT Condition	Temper	2 weeks of Nat. Age	1 month of Nat. Age	2 months of Nat. Age	3 months of Nat. Age	4 months of Nat. Age	5 months of Nat. Age	6 months of Nat. Age
1	3.53	43%	1	T4	22.7	23.0	23.8	24.3	23.2	24.6	23.4
2	3.53	43%	2	T4	23.3	24.1	23.8	23.9	23.9	23.8	23.1
3	5.84	66%	1	T4	24.2	23.5	24.0	25.1	11.6	23.6	24.2
4	5.84	66%	2	T4	23.7	21.9	24.2	22.8	21.6	23.6	23.9
5	3.53	43%	3	T4	24.8	24.9	24.5	23.9	23.9	24.1	24.4
6	3.53	43%	5	T4	24.7	22.0	23.6	24.2	22.2	23.1	23.2
7	5.84	66%	3	T4	24.7	24.8	23.8	25.4	23.1	21.8	23.3
8	5.84	66%	5	T4	25.1	23.2	24.8	24.3	23.5	22.4	23.1
9	3.53	43%	3	T43	23.2	23.8	22.5	23.2	23.6	23.2	22.5
10	3.53	43%	4	T43	22.9	23.5	22.6	22.9	23.1	23.6	23.2
11	3.53	43%	5	T43	22.3	21.8	23.4	22.3	21.3	22.8	21.6
12	5.84	66%	3	T43	22.5	22.8	20.9	23.1	20.5	20.5	23.8
13	5.84	66%	4	T43	22.5	22.6	23.3	23.4	23.1	23.5	23.5
14	5.84	66%	5	T43	21.8	23.2	22.8	21.7	22.8	22.6	23.5

FIG. 1 - VDA Bend Results