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(71) Applicant: **Kaiser Aluminum Fabricated Products, LLC**
Foothill Ranch, CA 92610 (US)

(72) Inventors:
- **ARMANIE, Kevin P.**
Amherst, 14228 (US)
- **GERBERICK, Walter**
Westerville, 43081 (US)
- **MATUSKA, Robert A.**
Heath, 43056 (US)

(74) Representative: **FRKelly**
27 Clyde Road
Dublin D04 F838 (IE)

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(54) AL-MG-SI ENERGY ABSORPTION EXTRUSION COMPONENT AND METHOD OF MAKING THEREOF

(57) The present invention relates to an aluminum 6XXX (Al-Mg-Si) alloy extrusion component exhibiting a superior combination of strength and energy absorption for crash management applications in automotive markets and for other applications where energy absorption is a critical property. These components provide yield strengths greater than 260 MPa, and preferably greater than 280 MPa, while simultaneously providing energy absorption per unit cross-sectional area of greater than 20 kJ/mm^2 using the defined crush testing parameters in the present specification.

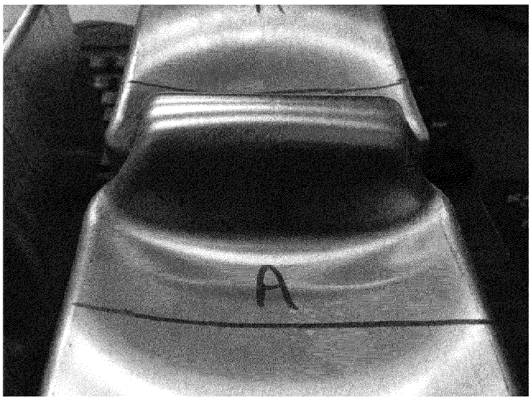

Figure 4

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit, under 35 USC 119(e), of U.S. Provisional Application No. 62/872,384 filed July 10, 2019, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention generally related to an improved aluminum 6XXX alloy extrusion component with high strengths and energy absorption.

Background

[0003] The automotive industry is continuously looking at means to lightweight components in an effort to improve fuel efficiency and meet CAFE (corporate average fuel economy) standards. Simultaneously there is a desire to continuously improve the safety rating of the vehicle with designs and materials that absorb the energy from a crash without transmitting it to the driver or passengers. Aluminum extrusions have been used to achieve these goals for years, but lower strength alloys had to be utilized in certain applications where energy absorption without fracture of the material was required. Higher strength aluminum alloys enable additional fuel efficiency improvements in these applications by allowing thinner sections with reduced cross sectional areas. These alloys, properly processed, provide the energy absorption and fracture performance necessary to attain safety requirements.

SUMMARY OF INVENTION

[0004] The present invention is an improved aluminum 6XXX alloy extrusion component with high strengths and energy absorption produced from an alloy composition including, in weight percent, Si: 0.50-0.80; Fe: <0.40; Cu: 0.15-0.35; Mn: 0.20-0.50; Mg: 0.50-0.80; Cr: 0.10-0.25; Zn: <0.20; with other elements being considered incidental impurities and consisting of less than 0.05 individually and 0.15 in total with the balance being aluminum. In a preferred embodiment, the alloy composition does not require any additions of vanadium, thus reducing cost and also preventing contamination of the recycling scrap stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The features and advantages of the present invention will become apparent from the following detailed description of a preferred embodiment thereof, taken in conjunction with the accompanying drawings, in which:

FIG. 1 shows a three void hollow extrusion design including the alloy composition of the present invention;
FIG. 2 is a photo showing the comparison of microstructures with thin peripheral coarse grain band on the left being acceptable (cast 78 from Example 1) and the thick coarse grain band on the right being unacceptable (cast 77 from Example 1);
FIG. 3 is a photo showing rough deformed surface (orange peel) of material with coarse recrystallized grains;
FIG. 4 is a photo showing smooth deformed surface of material with minimal coarse recrystallized grains;
FIG. 5 is a graph showing the specific energy absorption along the extruded length (data from Example 2);
FIG. 6 is a graph showing the relationship between yield strength and specific energy absorption (data from Example 4);
FIG. 7 is a graph showing the relationship between yield strength and specific energy absorption and Mg + Si (data from Example 4); and
FIG. 8 is a graph showing the relationship between yield strength and specific energy absorption and Mg + Si + Cu (data from Example 4).

DETAILED DESCRIPTION OF THE INVENTION

[0006] The present invention is an aluminum 6XXX alloy extrusion component produced from an alloy composition comprising, optionally consisting essentially of, or optionally consisting of, in weight percent (wt.%): Si: 0.50-0.80; Fe: <0.40; Cu: 0.15-0.35; Mn: 0.20-0.50; Mg: 0.50-0.80; Cr: 0.10-0.25; Zn: <0.20; with other incidental elements being considered impurities and consisting of less than 0.05 individually and 0.15 in total with the balance being aluminum. In one embodiment of the present invention, the alloy composition does not include any intentional additions of vanadium. In one embodiment, the alloy composition includes ≤ 0.04 wt.% vanadium. It should be understood that the recitation of a range of values includes all of the specific values in between the highest and lowest value.

[0007] Silicon is included in the alloy composition of the present invention in the range of 0.50 to 0.80 wt.%. It is understood that within the range of 0.50 to 0.80 wt.% Si, the upper or lower limit for the amount of Si may be selected from 0.50, 0.51, 0.52, 0.53, 0.54, 0.55, 0.56, 0.57, 0.58, 0.59, 0.60, 0.61, 0.62, 0.63, 0.64, 0.65, 0.66, 0.67, 0.68, 0.69, 0.70, 0.71, 0.72, 0.73, 0.74, 0.75, 0.76, 0.77, 0.78, 0.79, and 0.80 wt.% Si.

[0008] In addition to the amounts of silicon provided above, iron may be included in the alloy composition of the present invention in an amount that is <0.40 wt.%. It is understood that within the range of <0.40 wt.%, the upper or lower limit for the amount of Fe may be selected from 0.40, 0.39, 0.38, 0.37, 0.36, 0.35, 0.34, 0.33, 0.32, 0.31, 0.30, 0.29, 0.28, 0.27, 0.26, 0.25, 0.24, 0.23, 0.22, 0.21, 0.20, 0.19, 0.18, 0.17, 0.16, 0.15, 0.14, 0.13, 0.12, 0.11, 0.10, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02, and 0.01 wt.%.

[0009] In addition to the amounts of silicon and iron provided above, copper may be included in the alloy composition of the present invention in the range of 0.15-0.35 wt.%. It is understood that within the range of 0.15-0.35 wt.%, the upper or lower limit for the amount of Cu may be selected from 0.35, 0.34, 0.33, 0.32, 0.31, 0.30, 0.29, 0.28, 0.27, 0.26, 0.25, 0.24, 0.23, 0.22, 0.21, 0.20, 0.19, 0.18, 0.17, 0.16, and 0.15 wt.%.

[0010] In addition to the amounts of silicon, iron, and copper provided above, manganese may be included in the alloy composition of the present invention in the range of 0.20-0.50 wt.%. It is understood that within the range of 0.20-0.50 wt.%, the upper or lower limit for the amount of Mn may be selected from 0.50, 0.49, 0.48, 0.47, 0.46, 0.45, 0.44, 0.43, 0.42, 0.41, 0.40, 0.39, 0.38, 0.37, 0.36, 0.35, 0.34, 0.33, 0.32, 0.31, 0.30, 0.29, 0.28, 0.27, 0.26, 0.25, 0.24, 0.23, 0.22, 0.21, and 0.20 wt.%.

[0011] In addition to the amount of silicon, iron, copper, and manganese provided above, magnesium may be included in the alloy composition of the present invention in the range of 0.50 to 0.80 wt.%. It is understood that within the range of 0.50 to 0.80 wt.% Mg, the upper or lower limit for the amount of Mg may be selected from 0.50, 0.51, 0.52, 0.53, 0.54, 0.55, 0.56, 0.57, 0.58, 0.59, 0.60, 0.61, 0.62, 0.63, 0.64, 0.65, 0.66, 0.67, 0.68, 0.69, 0.70, 0.71, 0.72, 0.73, 0.74, 0.75, 0.76, 0.77, 0.78, 0.79, and 0.80 wt.%.

[0012] In addition to the amounts of silicon, iron, copper, manganese, and magnesium provided above, chromium may be included in the alloy composition of the present invention in the range of 0.10-0.25 wt.%. It is understood that within the range of 0.10-0.25 wt.%, the upper or lower limit for the amount of Cr may be selected from 0.25, 0.24, 0.23, 0.22, 0.21, 0.20, 0.19, 0.18, 0.17, 0.16, 0.15, 0.14, 0.13, 0.12, 0.11, and 0.10 wt.%.

[0013] In addition to the amounts of silicon, iron, copper, manganese, magnesium, and chromium provided above, zinc may be included in the alloy composition of the present invention in an amount that is <0.20 wt.%. It is understood that within the range of <0.20 wt.%, the upper or lower limit for the amount of Zn may be selected from 0.20, 0.19, 0.18, 0.17, 0.16, 0.15, 0.14, 0.13, 0.12, 0.11, 0.10, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02, and 0.01 wt.%.

[0014] In addition to the amounts of silicon, iron, copper, manganese, magnesium, chromium, and zinc provided above, it is understood that vanadium is not intentionally added to the alloy composition of the present invention. Vanadium may exist in the alloy composition of the present invention as a result of a non-intentionally added element. In one embodiment, the alloy composition of the present invention includes ≤ 0.04 wt.% vanadium. It is understood that within the range of <0.04 wt.%, the upper or lower limit for the amount of V may be selected from 0.04, 0.03, 0.02, 0.01, and 0.005 wt.%

[0015] In addition to the amounts of silicon, iron, copper, manganese, magnesium, chromium, zinc, and vanadium, Sn may be intentionally added within the range of 0.02-0.10% by weight to improve adhesive bond durability performance. It is understood that within the range of 0.02-0.10 wt.%, the upper or lower limit for the amount of Sn may be selected from 0.10, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, and 0.02 wt.%.

[0016] In addition to the amounts of silicon, iron, copper, manganese, magnesium, chromium, zinc, vanadium, and tin, Sr may be intentionally added within the range of up to 0.30 % by weight. It is understood that within the range of up to 0.30 wt.%, the upper or lower limit for the amount of Sr may be selected from 0.30, 0.29, 0.28, 0.27, 0.26, 0.25, 0.24, 0.23, 0.22, 0.21, 0.20, 0.19, 0.18, 0.17, 0.16, 0.15, 0.14, 0.13, 0.12, 0.11, 0.10, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02, and 0.01 wt.%.

[0017] The alloy composition of the present invention may also include low level of "incidental elements" that are not included intentionally. The "incidental elements" means any other elements except the above described Al, Si, Fe, Cu, Mn, Mg, Cr, Zn, Sn, Sr and V.

[0018] The alloy composition may be used to produce an automotive crush can, front rail, rear rail, upper rail, rocker, header, A-pillar, or roof rail.

[0019] The extrusion component may be produced by i) homogenizing a billet including the present alloy composition at a billet temperature between 527 - 566°C, ii) followed by fan cooling, iii) followed by either a) extruding at a billet temperature of 455°C to 510°C or b) heating to a billet temperature of 491°C - 535°C, then water quenching to a billet temperature of 388°C - 496°C, and then extruding, and iv) followed by cold water quenching, stretching and artificial aging with the extrusion component having a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 260 MPa, or 280 MPa, while providing no fragmentation or surface cracks greater than 10 mm during defined crush testing (as defined herein). In an alternate embodiment, the end product has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 280 MPa, while providing no fragmentation or surface cracks greater than 20 mm during defined crush testing (as defined herein). In another alternate embodiment, the end product has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 300 MPa, while providing no fragmentation or surface cracks greater than 30 mm during defined crush testing (as defined herein). The superior combination of strength and energy absorption for crash management applications is a basic and novel characteristic of the present invention.

[0020] The crash worthiness of an automotive component is typically assessed by the amount of energy absorbed in a crush test, without having any unacceptable fracturing of the component. "Crush testing" as used herein is conducted by taking a 300mm long sample and crushing in the longitudinal direction to 100mm at a rate of 100mm / minute. The force required through the stroke of the crush testing is recorded and the area under the force displacement curve is the energy absorption. Once the crush testing is complete, the sample is visually examined for fractures and surface cracking. Fractures resulting in fragmentation are not acceptable and surface cracks are not desirable, but may be acceptable for certain applications provided they are not too severe. Surface cracks are typically limited to a maximum observable length, perhaps 10 mm, or 20 mm, or 30 mm. For some applications longer surface cracks may be deemed acceptable with a corresponding increase in yield strength or energy absorption. A sample that does not pass the visual examination, however, is considered a failed sample, regardless of the energy absorbed. Thus the visual examination is a binary, pass / fail assessment. Samples passing the visual examination can thus be compared quantitatively relative to the energy absorption. This is the crush testing basis for all results reported herein.

[0021] Energy absorption is not exclusively a material property. There is a shape design component as well. Clearly the greater the cross sectional area, the greater the energy required to crush a component with a given strength level. This can be overcome by providing a specific energy absorption, determined by dividing the energy absorbed by the extruded component's cross sectional area. This still does not define an absolute material property, as there are mechanical advantages of some shape designs that predispose their ability to absorb more energy than other designs for a given material. In order to overcome these difficulties and provide an assessment of the material, the energy absorption is expressed as specific energy absorption (energy absorbed / cross sectional area) and is limited to a common crash management component design, which for the purposes of this study, is a three void hollow extrusion with wall thicknesses from 1.5mm to 4mm and a rectangular or trapezoidal perimeter being 75mm to 175mm in the long direction and 40mm to 100mm in the shorter direction as shown in Figure 1. Using these boundaries, materials can be compared even with slightly different shape configurations.

[0022] Aluminum extrusions have been utilized in the construction of crash management systems for many years. Successfully attaining a component that absorbs energy without fracture, that could threaten injury to passengers, involves complex management of the composition, grain structure, precipitate structure and mechanical properties. The composition of the extrusions helps to determine the potential strength. In 6XXX alloys under the present invention, precipitation hardening occurs with Mg-Si phases (Mg_2Si). The proportion of the Mg and Si (in terms of being balanced, excess Si or excess Mg relative to the stoichiometry) can significantly influence the strength and crush performance as well. The Mg and Si are often assessed in these terms:

Mg/Si Ratio; Calculated by: Mg / (Si - (0.25(Fe+Mn)))
Excess Si; Calculated by: Si - ((0.58Mg)+(Fe+Mn)/4)
Mg_2Si Content; Calculated by:

if Excess Si is greater than 0 then: 1.58 Mg
if Excess Si is less than 0 then: 2.742(Si-((Fe+Mn)/4)))

Additions of Cu also considerably impart strength to the material. The addition of Sn can also be considered to provide improved adhesive bond durability to the product, but is not necessary from an energy absorption perspective. The addition of Sr can also be considered as it is well known that Sr will modify the Si phase to a more rounded morphology that will be less prone to act as a fracture initiation site. Elements such as Cr and Mn form dispersoids that can be used to retard recrystallization, thus increasing strength and toughness. These dispersoids also act as locations to stack-up dislocations, distributing the matrix dislocation density throughout the structure and helping to reduce the tendency for void growth, void consolidation and ultimately fracture. While the dispersoids retard recrystallization, the thermo-mechanical process history of the material also plays a major role in determining the final grain size.

[0023] Thus control of processes such as homogenization, billet temperature, use of billet quenches, extrusion die design, extrusion speed and quench rate post extrusion all play a critical role in the final achieved grain size in the product. Extrusion of the product can be accomplished by either a) heating the billet directly to the extrusion temperature or b) using a process referred to as super-heating, where the billet is heated beyond the desired extrusion temperature to facilitate the solutionizing of hardening phases, and is then rapidly quenched to desired extrusion temperature. Both billet heating strategies have been employed successfully in this work. Post extrusion, the material is artificially aged to increase its strength. The artificial age time and temperature can strongly influence the size, distribution of the precipitate particles, and even precipitation type in the matrix, which not only affects the potential strength, but can also significantly impact the energy absorption and crash worthiness of the component. Artificial aging can be delayed to provide an extrusion that has better formability, with the artificial aging cycle being conducted after the component is formed. In one embodiment, the artificial aging is conducted at billet temperatures between 174 - 191°C for 5-10 hours. The artificial aging can also include multi-step aging to improve corrosion resistance. The artificial aging may be a two-step age cycle with the second aging step being hotter than the first aging step and either aging step ranging between 100-204 °C. In one embodiment, the two-step age cycles involve a lower temperature step 1 from 100 - 177°C and a second step from 172 - 204°C. The artificial aging can also intentionally be under-aged (less than peak strength), with the intention of subsequent thermal operations, such as paint baking, completing the remainder of the artificial aging cycle. Alternatively, the component is unaged (T4) to provide better formability of the component with artificial aging being conducted post forming.

[0024] All of these factors must be balanced in order to meet multiple objectives simultaneously. In the case of the present invention, for example, that is an automotive crash management component with high yield strength and excellent energy absorption without exhibiting a tendency for fragmentation. This is achieved with a predominantly unrecrystallized extruded grain structure in a 6XXX (Al-Mg-Si alloy) hollow extruded material. In a preferred embodiment, the coarse surface grain depth is controlled to less than 0.5 mm in depth from the surface.

[0025] The following examples illustrate various aspects of the invention and are not intended to limit the scope of the invention.

Example 1

[0026] Most incumbent alloy compositions used for crash management systems have lower strengths and few dispersoids elements (like Cr and Mn). These alloys include 6060 and 6063 for example. The fine recrystallized structure attainable in these alloys is known to be preferable for formability and crush applications, although it does not provide the higher strength levels of other alloys (for example 6082). Alloy 6063 has a typical yield strength of 214 MPa and when tested using the crush test procedures outlined above, only has an energy absorption of 19.468 kJ / mm^2. In an effort to increase the strength and determine the influence of Cr as a dispersoid element the compositions in Table 1 were cast, homogenized between 980°F and 1060°F (527°C - 566°C) and then forced air cooled. Billets from the logs were preheated to 880°F to 940°F (471 °C - 504 °C), extruded into the three void hollow shape of Figure land cold water quenched.

Table 1: Composition of Production Cast Billet (weight percent)

Cast	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
77	0.75	0.26	0.30	0.40	0.74	0.00	0.09	0.03
78	0.73	0.28	0.29	0.39	0.74	0.19	0.10	0.01

[0027] The grain structure of the materials is shown in Figure 2. The coarse grain structure resulting from the cast 77 composition resulted in fragmentation and excessive cracking and rough deformed surfaces (often referred to as orange peel), while the higher dispersoid content and subsequent reduced coarse recrystallized grain of cast 78 prevented fragmentation and excessive cracking while also providing a smooth deformed surface. The differences in deformed surfaces are demonstrated in Figures 3 and 4. These results demonstrate the importance of controlling the coarse recrystallized grains with dispersoids in order to prevent fragmentation, surface cracking and rough deformed surfaces that precede these unacceptable conditions.

Example 2

[0028] The composition shown in Table 2 was cast into 10" (254 mm) diameter log using development scale equipment.

Table 2: Composition of Production Cast Billet (weight percent)							
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.66%	0.24%	0.29%	0.40%	0.68%	0.19%	0.04%	0.02%

[0029] The logs were homogenized between 980°F and 1060°F (527°C - 566°C) and then forced air cooled. The billets were then extruded into the three void hollow shape of Figure 1, described previously, by heating the billets between 915°F and 995°F (491°C - 535°C) then quenching the billets to between 730°F and 925°F (388°C - 496°C) prior to extruding and water quenching the resulting extrusions. The extrusions were stretch straightened / stress relieved and artificially aged between 345 - 375°F (174 - 191°C) for 5-10 hours. Extrusion and artificial aging was conducted twice, one month apart, to assess reproducibility. The resulting tensile properties are shown in Table 3.

Table 3: Average Mechanical Properties					
	Ultimate Tensile Strength		Yield Strength (0.2% Offset)		Elongation
Trial Run	KSI	MPa	KSI	MPa	%
1	44.7	308	41.1	284	10.7
2	43	296	39	268	10.8

[0030] From both of these extrusion runs, the crash worthiness was assessed with 100 individual tests throughout the extrusion run. The statistics of these tests for the specific energy absorption are shown in Table 4. The energy absorption along the length of the extrusion billet is also shown in Figure 5.

Table 4: Specific Energy Absorption (kJ/mm^2)	
Average	25.495
Minimum	22.843
Maximum	27.412
Standard Deviation	1.053

[0031] The qualitative visual examination of these tests were all deemed to be acceptable, meeting the criteria for the tests to be considered acceptable with no fragmentation or excessive cracking. In addition to this, the extrusion process parameters were deemed to be acceptable in terms of providing consistent results along the extruded length as demonstrated in Figure 5.

Example 3

[0032] Extrusion billet was produced using conventional direct chill casting methods in 10" (254 mm) diameter log using production scale equipment to validate reproducibility. The composition of this material is shown in Table 5.

Table 5: Composition of Production Cast Billet (weight percent)							
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.65%	0.29%	0.29%	0.37%	0.60%	0.18%	0.09%	0.03%

[0033] The logs were homogenized between 980°F and 1050°F (527°C - 566°C) and then forced air cooled. The billets were then extruded into the three void hollow shape of Figure 1, described previously, by heating the billets between 915°F and 995°F (491°C - 535°C) then quenching the billets to between 730°F and 925°F (388°C - 496°C) followed by extrusion and water quenching. The extrusions were then stretch straightened / stress relieved and artificially aged between 345 - 375°F (174 - 191°C). Billets were extruded in two separate runs to help assure reproducibility. The resulting tensile properties are shown in Table 6.

Extrusion Run	Table 6: Average Mechanical Properties				
	Ultimate Tensile Strength		Yield Strength (0.2% Offset)		Elongation
	KSI	MPa	KSI	MPa	%
1	46.3	320	41.9	289	9.48
2	47.3	326	42.6	293	9.92

[0034] Samples from the artificially aged material were then tested for crush quality and energy absorption. All samples passed the visual examination criteria. The specific energy absorption from this testing is shown in Table 7.

Table 7: Specific Energy Absorption

Statistic	Extrusion Run 1	Extrusion Run 2	Both Extrusion Runs
	Result (kJ/mm^2)	Result (kJ/mm^2)	Result (kJ/mm^2)
Average	25.658	25.490	25.569
Minimum	24.736	24.634	24.634
Maximum	26.268	26.532	26.532
Standard Deviation	0.534	0.540	0.536

[0035] These results demonstrate the repeatability of the process and compatibility to production scale processes.

Example 4

[0036] The compositions shown in Table 8 were cast and extruded as per the previous examples.

Table 8: Composition of Production Cast Billet (weight percent)

Cast	ID	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
1476	CP2	0.57	0.25	0.27	0.40	0.72	0.20	0.05	0.02
1495	Min	0.57	0.23	0.22	0.40	0.56	0.20	0.05	0.02
1496	Cen	0.65	0.24	0.27	0.36	0.65	0.16	0.05	0.03
1497	CP1	0.56	0.23	0.27	0.40	0.56	0.20	0.05	0.03
1498	CP3	0.73	0.23	0.27	0.40	0.55	0.20	0.05	0.03
1499	CP4	0.75	0.23	0.27	0.40	0.72	0.20	0.05	0.02
1500	Max	0.72	0.24	0.31	0.40	0.73	0.20	0.05	0.03

[0037] The logs were homogenized between 980°F and 1060°F (527°C - 566°C) and then forced air cooled. The billets were then extruded into the three void hollow shape of Figure 1, described previously, by heating the billets between 915°F and 995°F (491°C - 535°C) then quenching the billets to between 730°F and 925°F (388°C - 496°C) prior to extruding and water quenching the resulting extrusions. The extrusions were stretch straightened / stress relieved and artificially aged at 345 - 375°F (174 - 191°C) for 5-10 hours.

[0038] Samples from all of these materials were tested for mechanical properties and tested for energy absorption and crash worthiness. The results of this are shown in Tables 9 and 10 and graphically in Figures 6-8.

Table 9: Specific Energy Absorption Results for Example 4

Cast	Average Specific Energy Absorbed (kJ / mm^2)	Minimum Specific Energy Absorbed (kJ / mm^2)	Maximum Specific Energy Absorbed (kJ / mm^2)
1476	23.7	23.3	23.9
1495	22.2	22.0	22.5

(continued)

Table 9: Specific Energy Absorption Results for Example 4

Cast	Average Specific Energy Absorbed (kJ / mm^2)	Minimum Specific Energy Absorbed (kJ / mm^2)	Maximum Specific Energy Absorbed (kJ / mm^2)
1496	23.8	22.4	24.7
1497	23.4	23.2	23.5
1498	25.0	24.7	25.3
1499	25.3	23.6	26.2
1500	25.9	25.5	26.3

Table 10: Mechanical Properties of Samples Examined in Example 4

Cast	Yield Strength (MPa)			Ultimate Strength (MPa)			% Elongation		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
1476	262	261	263	294	291	297	9.9	9.3	10.5
1495	236	233	240	268	264	275	10.6	9.7	11.6
1496	283	279	286	308	302	314	9.1	8.9	9.4
1497	248	244	253	279	274	285	10.1	9.9	10.5
1498	285	284	286	312	311	313	9.7	9.3	10.2
1499	299	296	301	325	324	326	9.2	8.8	9.7
1500	300	299	300	328	326	329	9.4	9.1	9.8

[0039] The specific energy absorption increases with increasing yield strength and thus the results show that as the amount of solute (as expressed in terms of Mg+Si+Cu) the strength and specific energy absorption increases. Figure 6 through 7 show very good correlation coefficients between the simplified solute summation (Mg+Si+(Cu)) as opposed to breaking it down to the more complex Mg_2Si content and excess Si or Mg as discussed above. Closer examination of the data shows that compositions with approximately the same Mg+Si+Cu content (casts 1476, 1496, 1498) show benefit from having more excess Si content as opposed to more balanced or closer to excess Mg compositions.

[0040] While these results would suggest that specific energy absorption could be improved even further with additional solute additions (along with yield strength), it must be noted that with increasing mechanical properties, the susceptibility of the material failing from a surface cracking perspective increases.

Example 5

[0041] Extrusion billet was produced using conventional direct chill casting methods in 10" (254 mm) diameter log using production scale equipment to validate reproducibility. The composition of this material is shown in Table 11. The logs were homogenized between 980°F and 1050°F (527°C - 566°C) and then forced air cooled.

Table 11: Composition of Production Cast Billet (weight percent)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.66%	0.27%	0.30%	0.39%	0.63%	0.19%	0.09%	0.02%

[0042] Complex extruded shapes can be sensitive to quench rates from the extrusion operation. Faster quench rates can result in dimensional distortion that is considered unacceptable for the final application. It is generally accepted that faster quench rates provide higher strengths and better resistance to surface cracking during crush testing. In an effort to determine the alloy sensitivity to quench rate, the three void hollow shape of Figure 1 was extruded and immediately cold water spray quenched using varying water flow rates. The extrusions were stretch straightened / stress relieved and artificially aged at 345 - 375°F (174 - 191°C) for 5-10 hours. Samples from all of these materials were tested for mechanical properties, energy absorption and crash worthiness. The results are shown in Table 12.

Table 12: Strengths and Energy Absorption at Various Quench Rates

Parameter	Quench Rate		
	15 GPM / Zone	21 GPM / Zone	33 GPM / Zone
Average UTS (MPa)	323.4	330.1	330.1
Average YTS (MPa)	292.2	299.2	298.3
Average %Elongation	10.7	10.7	10.8
Average Energy Absorption (kJ/mm^2)	27.6	26.6	26.8

[0043] While the average ultimate and yield strength were slightly lower at the lowest water flow rates studied, the alloy proves to be surprisingly robust relative to quench sensitivity from an energy absorption perspective.

Example 6

[0044] Complex extruded shapes may be restricted in terms of extrusion speed, with more complex shapes being restricted to slower extrusion speeds than other shapes. More complex shapes also may require greater extrusion force. In some cases, the extrusion force may exceed the capability of the extrusion press and thus higher billet temperatures are required to enable extrusion of the more complex shapes. In order to assure the alloy was robust in providing consistent mechanical properties and energy absorption with these known potential process variations, billet produced in the same batch of material as in example 5 was extruded into the three void hollow shape depicted in Figure 1 at various billet temperatures and extrusion rates. The extrusions were then cold water quenched, stretch straightened / stress relieved and artificially aged at 345 - 375°F (174 - 191°C) for 5-10 hours. Samples from all of these materials were tested for mechanical properties, energy absorption and crash worthiness. The results are shown in Table 13.

Table 13: Strengths and Energy Absorption at Various Extrusion Rates

Trial	1	2	3	4
Furnace Billet Temperature (°C)	499	499	527	527
Extruded Product Speed (mm / min)	3399	7929	3399	7929
Average UTS (MPa)	334.9	337.7	331.3	336.1
Average YTS (MPa)	302.0	303.5	301.5	303.8
Average %Elongation	11.7	11.6	10.6	11.0
Average Energy Absorption (kJ/mm^2)	26.7	25.6	25.9	26.1

[0045] The consistency in mechanical properties and energy absorption shows that this material is also insensitive to both billet temperature variation and extrusion rates.

[0046] While specific embodiments of the invention have been disclosed, it will be appreciated by those skilled in the art that various modifications and alterations to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention which is to be given the full breadth if the appended claims and any and all equivalents thereof.

Statements

[0047]

1. An energy absorption extrusion component produced from an alloy composition comprising, in weight percent, Si: 0.50-0.80; Fe: <0.40; Cu: 0.15-0.35; Mn: 0.20-0.50; Mg: 0.50-0.80; Cr: 0.10-0.25; Zn: <0.20; with other elements being considered incidental elements and consisting of less than 0.05 individually and 0.15 in total with the balance being aluminum

2. The component of statement 1 wherein said extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 260 MPa while providing no fragmentation or surface cracks greater than 10 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

3. The component of statement 1, wherein said extrusion component has a yield strength greater than 280 MPa.

4. The component of statement 1 wherein said extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength greater than 280 MPa with no fragmentation or surface crack greater than 20 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

5. The component of statement 1 wherein said extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength greater than 300 MPa with no fragmentation or surface crack greater than 30 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

6. The component of statement 1 wherein said alloy composition further comprises Sn that is intentionally added at levels of 0.02-0.10% by weight.

7. The component of statement 1 wherein said alloy composition further comprises Sr that is intentionally added at levels up to 0.30% by weight.

8. The component of statement 1 wherein said alloy composition further comprises V that is not intentionally added.

9. The component of statement 1 wherein said alloy composition further comprises $V \leq 0.04\%$ by weight.

10. The component of statement 1 used as an automotive crush can, front rail, rear rail, upper rail, rocker, header, A-pillar, or roof rail.

11. A method for making the extrusion component of statement 1 comprising,

i) homogenizing a billet including said alloy composition at a billet temperature between 527 - 566°C,
ii) followed by fan cooling,
iii) followed by either a) extruding with a billet temperature between 455°C to 510°C or b) heating to a billet temperature of 491°C - 535°C, then water quenching to a billet temperature of 388°C - 496°C, and then extruding,
iv) followed by cold water quenching; stretching; and artificial aging, wherein the extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 260 MPa while providing no fragmentation or surface cracks greater than 10 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

12. The method of statement 11, wherein the billet is initially heated to 491°C - 535°C, then water quenched to a temperature of 388°C - 496°C prior to extruding.

13. The method of statement 11, wherein the billet is extruding with a billet temperature between 455°C to 510°C after fan cooling

14. The method of statement 11 wherein said extrusion component has a coarse surface grain depth that is controlled to less than 0.5 mm in depth from the surface.

15. The method of statement 11 wherein the artificial aging is conducted using a two-step cycle with a second aging step being hotter than a first aging step and either aging steps ranging between 100 - 204°C.

16. The method of statement 15, wherein the two-step age cycle involves a first aging step from 100 - 177°C and a second aging step from 172 - 204°C.

17. The method of statement 11 wherein the artificial aging is conducted at a billet temperature between 174 - 191°C for 5-10 hours.

18. The method of statement 11 wherein said component is provided in an unaged (T4) condition with artificial aging conducted post forming.

19. The method of statement 11 wherein said component is provided in an under-aged condition with the remaining peak age strengthening accomplished during subsequent thermal operations.

Claims

1. An energy absorption extrusion component produced from an alloy composition comprising, in weight percent, Si: 0.50-0.80; Fe: <0.40; Cu: 0.15-0.35; Mn: 0.20-0.50; Mg: 0.50-0.80; Cr: 0.10-0.25; Zn: <0.20; with other elements being considered incidental elements and consisting of less than 0.05 individually and 0.15 in total with the balance being aluminium.

2. The component of claim 1 wherein said extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 260 MPa while providing no fragmentation or surface cracks greater than 10 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

3. The component of claim 1 or 2, wherein said extrusion component has a yield strength greater than 280 MPa.

4. The component of any one of claims 1 to 3 wherein said extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength greater than 280 MPa with no fragmentation or surface crack greater than 20 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

5. The component of any one of claims 1 to 4 wherein said extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength greater than 300 MPa with no fragmentation or surface crack greater than 30 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

6. The component of any one of claims 1 to 5 wherein said alloy composition further comprises Sn that is intentionally added at levels of 0.02-0.10% by weight; and/or

wherein said alloy composition further comprises Sr that is intentionally added at levels up to 0.30% by weight; and/or
wherein said alloy composition further comprises V that is not intentionally added; and/or
wherein said alloy composition further comprises V ≤ 0.04% by weight.

7. The component of any one of claims 1 to 6 used as an automotive crush can, front rail, rear rail, upper rail, rocker, header, A-pillar, or roof rail.

8. A method for making the extrusion component of any one of claims 1 to 6 comprising,

i) homogenizing a billet including said alloy composition at a billet temperature between 527 - 566°C,
ii) followed by fan cooling,
iii) followed by either a) extruding with a billet temperature between 455°C to 510°C or b) heating to a billet temperature of 491°C - 535°C, then water quenching to a billet temperature of 388°C - 496°C, and then extruding,
iv) followed by cold water quenching; stretching; and artificial aging, wherein the extrusion component has a specific energy absorption of greater than 22 kJ/mm^2 and a yield strength of greater than 260 MPa while providing no fragmentation or surface cracks greater than 10 mm during defined crush testing wherein a 300mm long sample is crushed in the longitudinal direction to 100mm at a rate of 100mm / minute.

9. The method of claim 8, wherein the billet is initially heated to 491°C - 535°C, then water quenched to a temperature of 388°C - 496°C prior to extruding.

10. The method of claim 8 or 9, wherein the billet is extruded with a billet temperature between 455°C to 510°C after fan cooling.

11. The method of any one of claims 8 to 10 wherein said extrusion component has a coarse surface grain depth that is controlled to less than 0.5 mm in depth from the surface.

12. The method of any one of claims 8 to 11 wherein the artificial aging is conducted using a two-step cycle with a second aging step being hotter than a first aging step and either aging steps ranging between 100 - 204°C.

13. The method of claim 12, wherein the two-step age cycle involves a first aging step from 100 - 177°C and a second aging step from 172 - 204°C.

14. The method of any one of claims 8 to 11 wherein the artificial aging is conducted at a billet temperature between 174 - 191°C for 5-10 hours.

15. The method of any one of claims 8 to 14 wherein said component is provided in an unaged (T4) condition with artificial aging conducted post forming;
wherein, optionally, said component is provided in an under-aged condition with the remaining peak age strengthening accomplished during subsequent thermal operations.

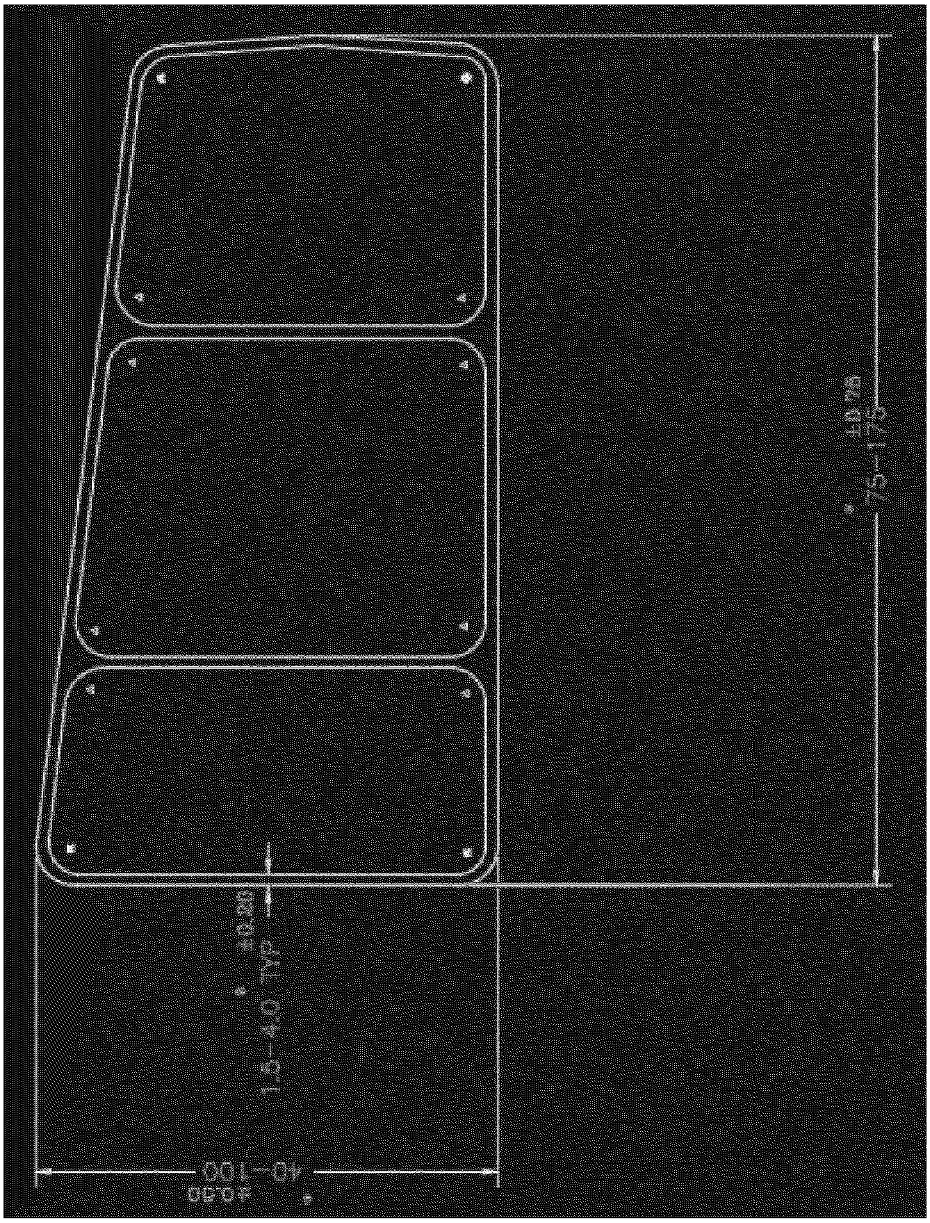

Figure 1

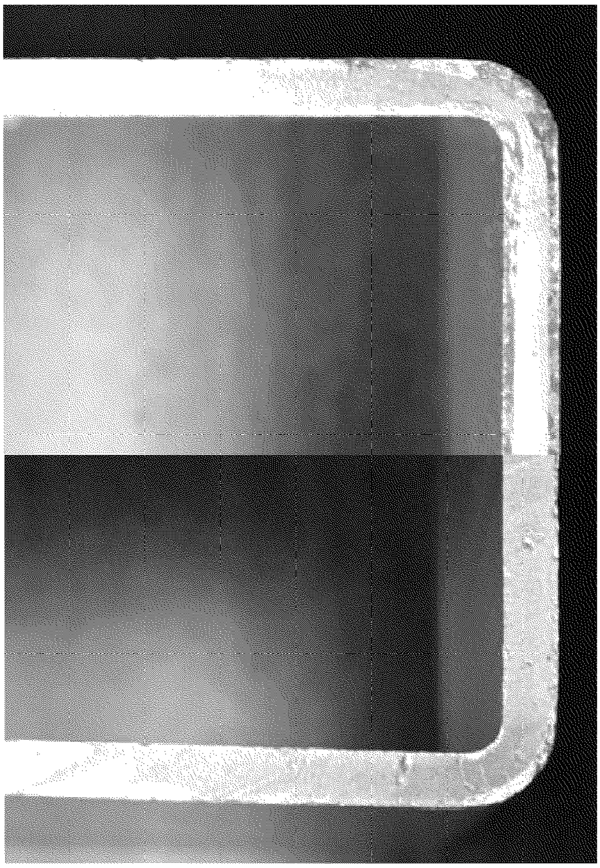

Figure 2

Figure 3

Figure 4

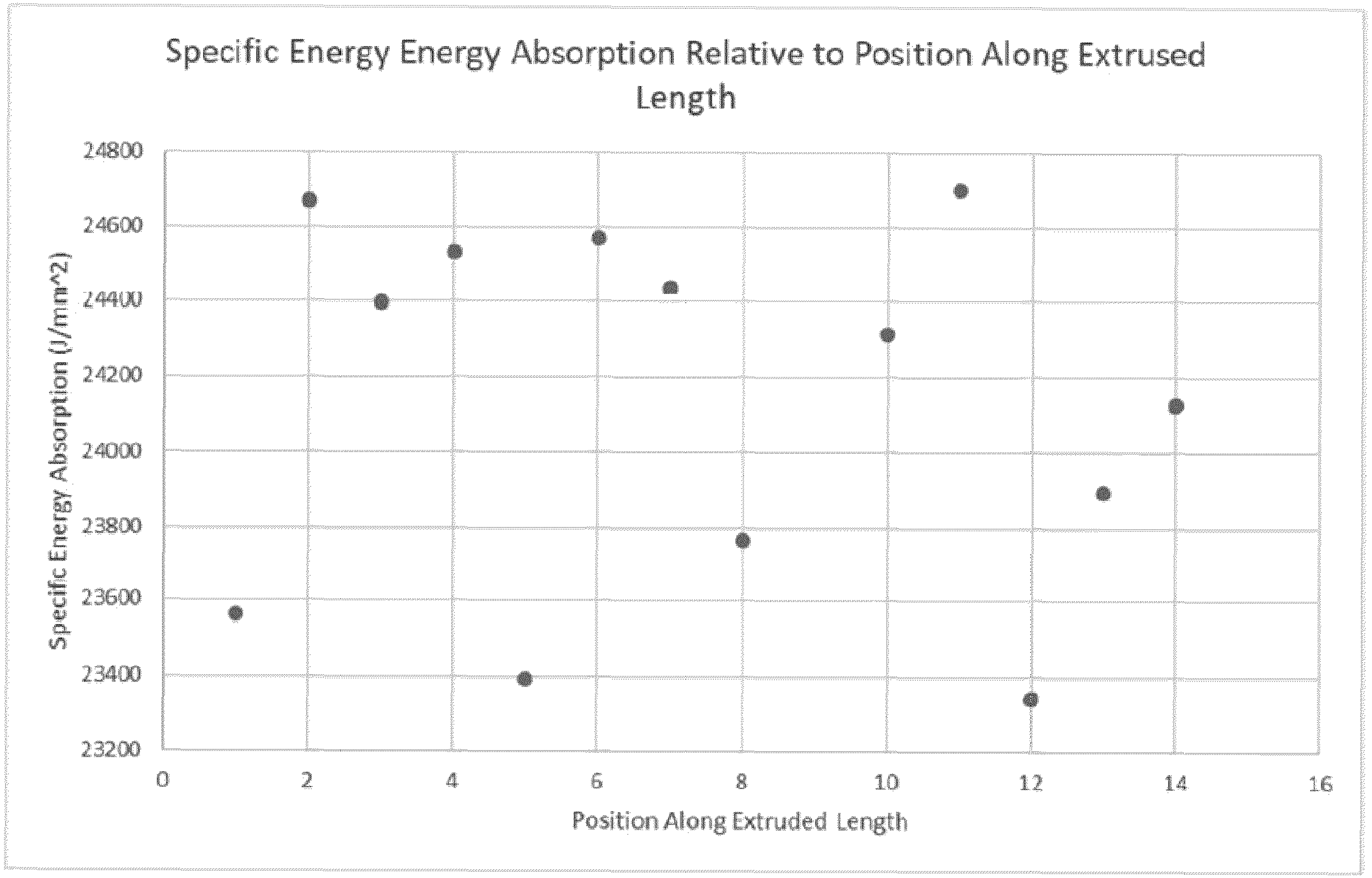
Specific Energy Energy Absorption Relative to Position Along Extrused Length
Specific Energy Absorption (J/mm^2)
24800
24600
24400
24200
24000
23800
23600
23400
23200
0
2
4
6
8
10
12
14
16
Position Along Extruded Length

Figure 5

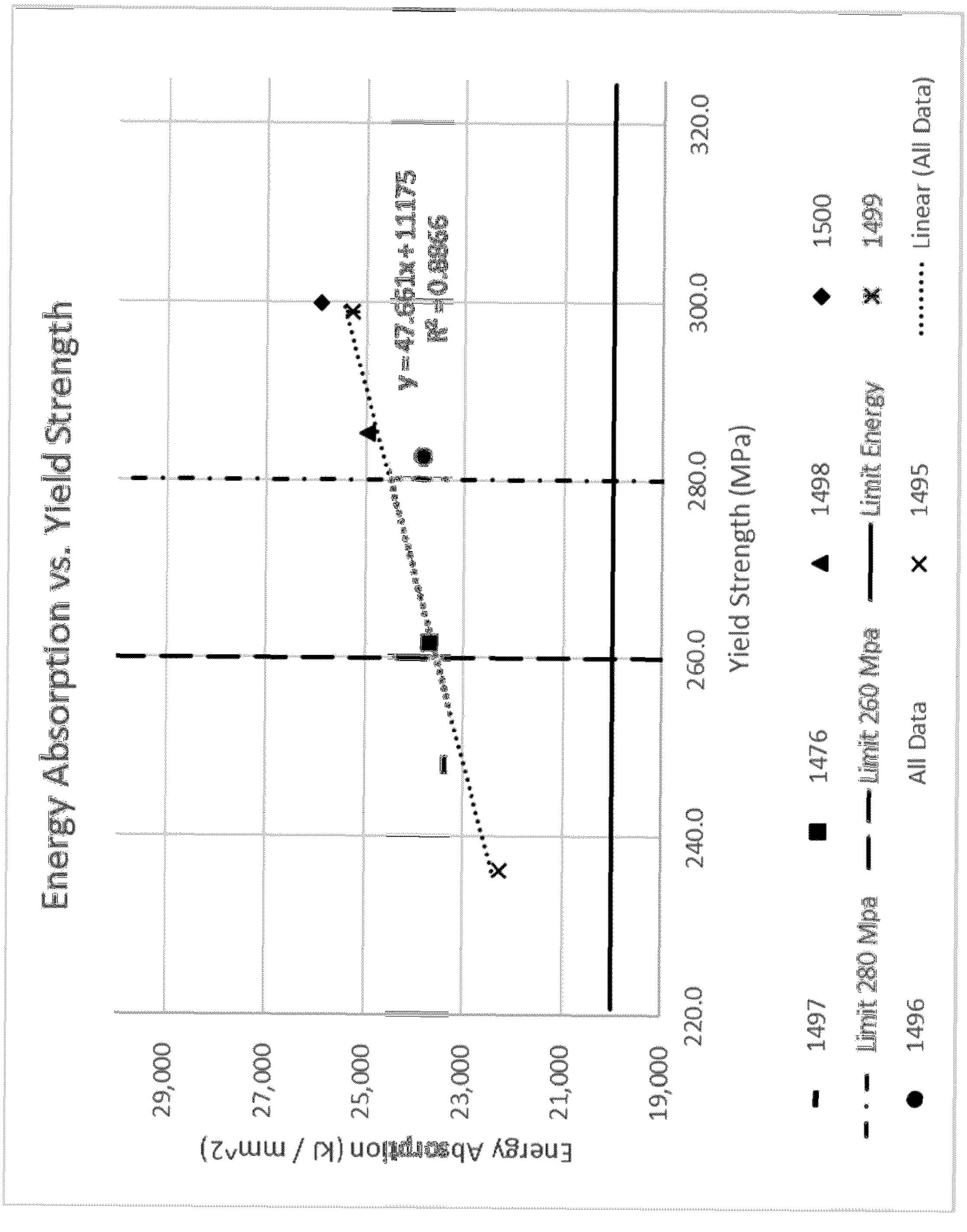
Energy Absorption vs. Yield Strength
y = 47.651x + 11175
R² = 0.8865
Energy Absorption (kJ / mm^2)
29,000
27,000
25,000
23,000
21,000
19,000
220.0
240.0
260.0
280.0
300.0
320.0
Yield Strength (MPa)
1497
1476
1498
1500
Limit 280 Mpa
Limit 260 Mpa
Limit Energy
1499
1496
All Data
1495
Linear (All Data)

Figure 6

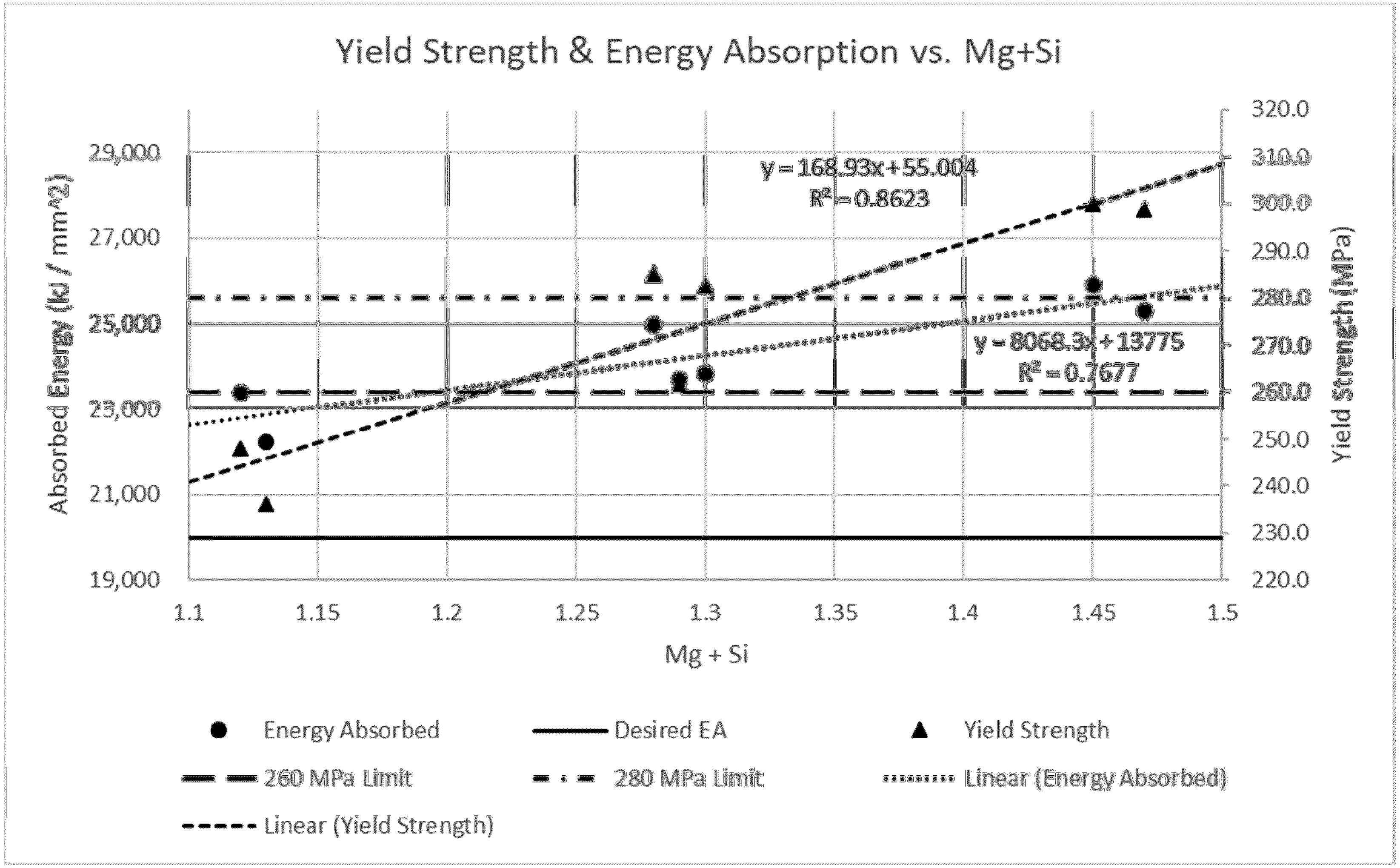
Yield Strength & Energy Absorption vs. Mg+Si
Absorbed Energy (kJ / mm^2)
29,000
27,000
25,000
23,000
21,000
19,000
Yield Strength (MPa)
320.0
310.0
300.0
290.0
280.0
270.0
260.0
250.0
240.0
230.0
220.0
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
Mg + Si
y = 168.93x + 55.004
R² = 0.8623
y = 8068.3x + 13775
R² = 0.7677
Energy Absorbed
Desired EA
Yield Strength
260 MPa Limit
280 MPa Limit
Linear (Energy Absorbed)
Linear (Yield Strength)

Figure 7

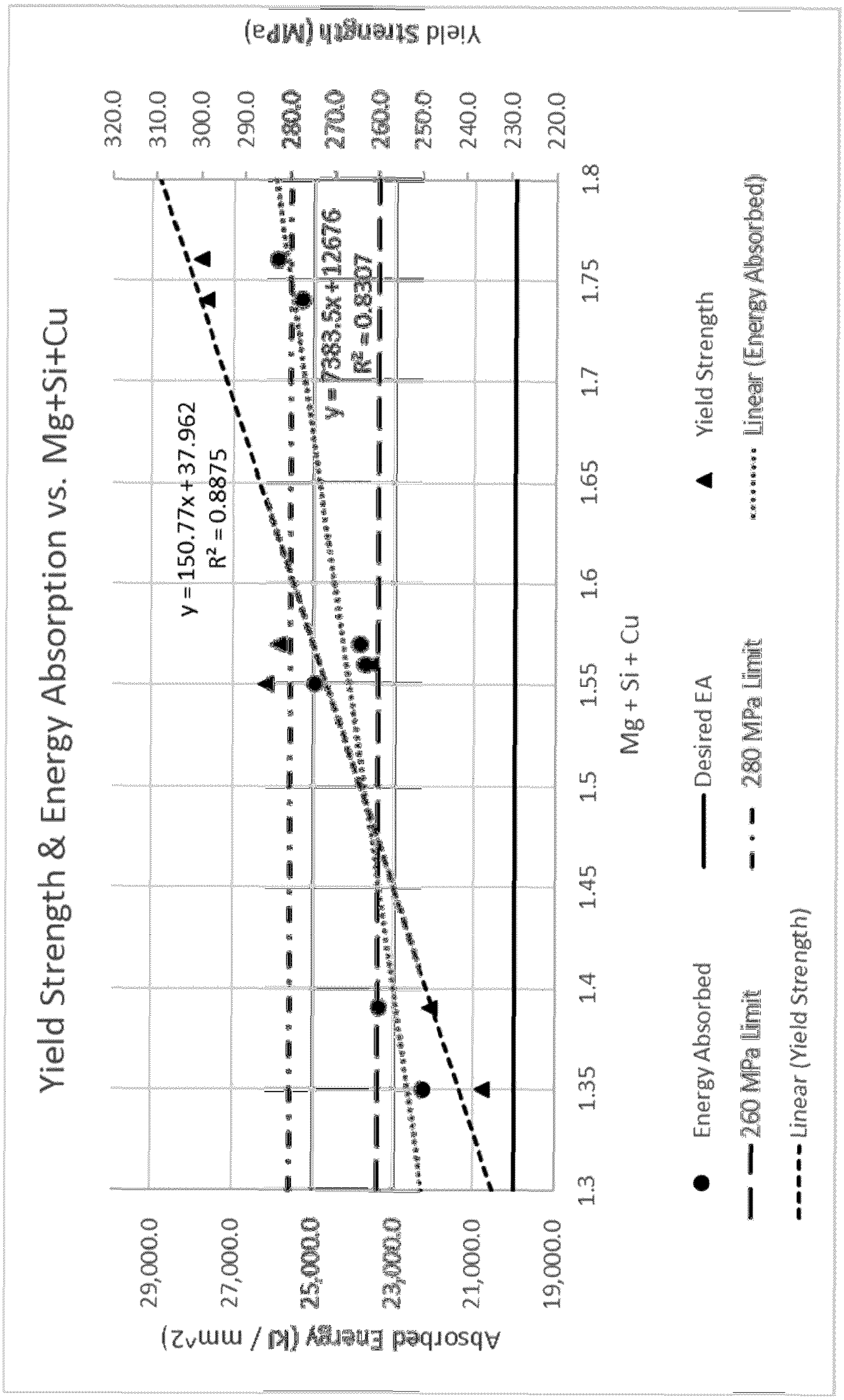
Yield Strength & Energy Absorption vs. Mg+Si+Cu
Absorbed Energy (kJ / mm^2)
29,000.0
27,000.0
25,000.0
23,000.0
21,000.0
19,000.0
Yield Strength (MPa)
320.0
310.0
300.0
290.0
280.0
270.0
260.0
250.0
240.0
230.0
220.0
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
1.7
1.75
1.8
Mg + Si + Cu
y = 150.77x + 37.962
R² = 0.8875
y = 7383.5x + 12676
R² = 0.8307
● Energy Absorbed
Desired EA
▲ Yield Strength
260 MPa Limit
280 MPa Limit
Linear (Energy Absorbed)
Linear (Yield Strength)

Figure 8

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 62872384 **[0001]**