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(54) 6XXX ALLOY WITH HIGH RECYCLED MATERIAL CONTENT

(57) The present invention is directed to a 6xxx series aluminum alloy composition, comprising, consisting essentially of, or consisting of (by weight %) of 0.5-1.5% Si, 0.1-0.7% Cu, 0.5-1.5% Mg, 0.3-1.2% Zn, 0.05-0.35% Cr and allowable impurities of ≤ 0.8% Fe, ≤ 0.8% Mn, ≤ 0.15% Zr, ≤ 0.15% Ti, with other elements restricted as unavoidable impurities limited to ≤ 0.05% each and ≤ 0.15% total with the balance being aluminum. This 6xxx series aluminum alloy is capable of being produced with high amounts of post-consumer recycled material which significantly reduces environmental impact from producing this material, while still meeting and in most cases exceeding material attribute requirements for general engineering applications.

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Description

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit, under 35 U.S.C. 119(e), of U.S. Provisional patent application No. 63/356,070 filed June 28, 2022, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of Invention

[0002] The present invention relates to an aluminum alloy designed to consume high levels of post-consumer recycled material while still meeting or exceeding all the requirements for use in the general engineering market. The alloy is surprisingly resilient and maintains excellent mechanical properties, machinability characteristics while still maintaining reasonable thermal stability performance.

2. Description of Related Art

[0003] There is currently a wide scale initiative to improve sustainability in a number of different industries and one path to improved sustainability is through increased recycling. In the aluminum industry, increasing the amount of post-consumer recycled aluminum greatly reduces the amount of energy that is required to make a given product. This is due to the fact that it takes significantly more energy to refine aluminum ore into pure aluminum than it does to melt recycled material. Per the European Aluminum association, producing one kilogram of prime aluminum creates approximately 18 kg of CO_2 equivalents; however by utilizing post consumer scrap the CO_2 emissions are lowered significantly. If instead 100% post consumer scrap was utilized, the emissions generated from remelting that scrap and casting an ingot or billet could be as low as 0.5 kg of CO_2 equivalents per kg of aluminum. That is a greater than 97% reduction in emissions by utilizing 100% scrap. As seen from the emissions data there is a significant environmental benefit to increasing the percentage of scrap in a given product as much as possible.

[0004] However, there are some complications that come with trying to increase the amount of scrap in a given composition. One of the biggest issues is the difficulty in keeping aluminum scrap segregated. Typically, any post consumer scrap that is available is going to be a mix of different alloys. For example, a common source of post-consumer scrap is shredded cars, the aluminum portion of which is more commonly known as twitch. This type of scrap can contain numerous different aluminum alloys including 4xxx series castings, 5xxx series body sheet, 6xxx series extrusion and finally 7xxx series extrusions. This type of scrap can also contain zinc or magnesium castings depending on how well the various pieces of the vehicle are separated prior to shredding. Without further processing this type of scrap can only be used in limited quantities because of the typical composition or impurity limits for most registered alloys.

[0005] One method for addressing this issue is by improving the sorting of the post-consumer aluminum scrap. There are current technologies for separating aluminum from other metals or any other contaminants such as wood or plastic. Some sorting technologies can even take mixed aluminum scrap and separate it into groups containing only a single alloy family to further improve the amount of scrap that can be utilized. However, the more sorting that is required the more time, cost and energy that is being invested into the scrap.

[0006] Another method of improving the post-consumer scrap utilization in the production of aluminum products is to increase the tolerance of the alloy to impurity elements. This limits the amount of sorting that is required and also increases the amount and types of scrap that can be utilized. Under optimal conditions this type of alloy can be produced with 100% post consumer scrap. This can be accomplished by thoughtfully adjusting the composition limits to tailor the performance of the material to match the use case.

BRIEF SUMMARY OF THE INVENTION

[0007] The present invention is directed to a 6xxx alloy that is capable of being produced with high amounts of recycled content. A preferred application for this 6xxx alloy is in the general engineering market with a specific focus on rod and bar products which benefit significantly from excellent machinability performance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] 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 the mechanical properties from example 1;
FIG. 2 shows the typical grain structure from example 2;
FIG. 3 shows the anodize response from example 3 with Inventive Alloy (left) compared to 6061 (right);
FIG. 4 shows typical chips produced in turn operation on 1" rod; and
FIG. 5 shows parts produced during machinability testing of 2" rod.

DETAILED DESCRIPTION OF THE INVENTION

[0009] The present invention is directed to a 6xxx series aluminum alloy composition comprising, or consisting essentially of, or consisting of (by weight %): 0.50 - 1.50% Si, 0.10 - 0.70% Cu, 0.50 - 1.50% Mg, 0.05 - 0.35% Cr, 0.30 - 1.20% Zn; allowable impurities including ≤ 0.80% Fe, ≤ 0.80% Mn, ≤0.15% Ti, ≤0.15% Zr, and unavoidable impurities to ≤ 0.05% each and ≤0.15% total unavoidable impurities with the remainder being aluminum. The inventive alloy is capable of being produced utilizing high amounts of post-consumer recycled material while still achieving the performance required for use in the general engineering market.
[0010] In an alternate embodiment, the 6xxx series aluminum alloy composition comprising, or consisting essentially of, or consisting of (by weight %): 0.8-1.4% Si, 0.1-0.7% Cu, 0.8-1.4% Mg, 0.3-1.1% Zn, 0.05-0.30% Cr, ≤0.6% Fe, ≤0.8% Mn, ≤0.15% Zr, ≤0.15% Ti, and unavoidable impurities limited to ≤0.05% each and ≤0.15% total with the balance being aluminum.
[0011] The addition of Mg increases the strength of aluminum alloys, especially when combined with the addition of Si. These two elements combine to form a precipitate known as Mg_2Si. This phase is a significant contributor to material strength in precipitation hardening elements. In addition, multiple other precipitation hardening phases are formed due to the high number of alloying elements present in this composition. These additional phases include $MgZn_2$ as well as Al_2CuMg, which is more commonly known as S-Phase. The ratio of these phases will depend on the relative amounts of Mg, Si and Zn that are present in a given composition. Mg_2Si will form preferentially as compared to $MgZn_2$ and as such, $MgZn_2$ will only form if there is enough Mg leftover after the formation of the Mg_2Si phase. As these are the primary strengthening phases present in this alloy the relative amounts of these elements need to be controlled to achieve optimal strength in this type of composition.
[0012] The addition of Cr is done to restrict recrystallization in this structure. Fully unrecrystalized structures are preferred in these applications as the presence of recrystallized grains can lead to poor machinability performance in certain machining operations. The Cr forms a dispersoid (Al12Mg2Cr) phase which restricts recrystallization. This phase helps to limit recrystallization by limiting the grain boundary movement. Limiting the amount of coarse grain present in this material helps to achieve optimal material performance.
[0013] It is understood that the ranges identified above for the 6xxx series aluminum alloy composition includes the upper or lower limits for the element selected and every numerical range provided within the range may be considered as upper or lower limits. For example, it is understood that within the range of 0.5 - 1.5 wt.% Si, the upper or lower limit for Si may be selected from 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4 and 1.5 wt.%. In addition, for example, it is understood that within the range of 0.1 - 0.7 wt.% Cu, the upper or lower limit for Cu may be selected from 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 wt.%. In addition, for example, it is understood that within the range of 0.5 - 1.5 wt.% Mg, the upper or lower limit for Mg may be selected from 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4 and 1.5 wt.%. In addition, for example it is understood that within the range of 0.05 - 0.35 wt.% Cr, the upper or lower limit for Cr may be selected from 0.08, 0.11, 0.14, 0.17, 0.20, 0.23, 0.26, 0.29, 0.32, and 0.35 wt.%. In addition, for example, it is understood that within the range of 0.3 - 1.2 wt.% Zn, the upper or lower limit for Zn may be selected from 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, and 1.2 wt.%. In addition, for example, it is understood that within the range of allowable impurities of ≤ 0.8 wt.% Fe, the upper limit for Fe may be selected from 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, and 0.1 wt.%. In addition, for example, it is understood that within the range of allowable impurities of ≤ 0.8 wt.% Mn, the upper limit for Mn may be selected from 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, and 0.1 wt.%. In addition, for example, it is understood that within the range of allowable impurities of ≤ 0.15 wt.% Ti, the upper limit for Ti may be selected from 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.%. In addition, for example, it is understood that within the range of allowable impurities of ≤ 0.15 wt.% Zr, the upper limit for Zr may be selected from 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.%. It is further understood that any and all permutations of the range identified above are included within the scope of the present invention.
[0014] The 6xxx series aluminum alloy composition of the present invention may also include low level of "unavoidable impurities" that are not included intentionally. The "unavoidable impurities" means any other elements except the above described Al, Si, Cu, Mg, Cr, Zn, Fe, Mn, Ti, and Zr. It is understood that the range of to ≤ 0.05 wt.% each and ≤ 0.15 wt.% total unavoidable impurities, includes the upper or lower limit ≤ 0.05, ≤ 0.04, ≤ 0.03, ≤ 0.02, and ≤ 0.01 wt.% each unavoidable impurities, and 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. % total unavoidable impurities.
[0015] In a preferred embodiment the 6xxx series aluminum alloy composition is manufactured by 1) casting using

conventional direct chill casting methods; 2) then homogenizing at 950 °F to 1060 °F (510 - 571 °C) for 2 to 10 hours; 3) then preheating to 800 °F - 1000 °F (427 - 538 °C) and then hot working; followed by water quenching, optionally stretching for stress relief and straightening, and artificially aging at a temperature between 250 - 375 °F for 6 - 20 hours. The 6xxx series aluminum alloy compositions may be subjected to hot working operation, such as extrusion, forging or rolling. A preferred hot working operation is extrusion.

[0016] In another preferred embodiment the 6xxx series aluminum alloy composition is manufactured by 1) casting using conventional direct chill casting methods; 2) then optionally homogenizing at 950 °F to 1060 °F (510 - 571 °C) for 2 to 10 hours; 3) then preheating to a rolling temperature of 600 °F - 1000 °F (316 - 538 °C) and then hot rolling; followed by solution heat treatment at a temperature of 950^{0}F to 1070^{0}F, followed by quenching to room temperature, optionally stretching for stress relief and straightening, and artificially aging at a temperature between 250 - 375 °F for 6 - 20 hours.

[0017] In another preferred embodiment the 6xxx series aluminum alloy composition is manufactured by 1) casting using conventional direct chill casting methods; 2) then homogenizing at 950 °F to 1060 °F (510 - 571 °C) for 2 to 10 hours; 3) then preheating to an extrusion temperature of 450 °F - 1000 °F (232 - 538 °C) and then extruding; optionally drawing the extrusions; followed by solution heat treatment at a temperature of 950^{0}F to 1070^{0}F, followed by quenching to room temperature, optionally stretching for stress relief and straightening, and artificially aging at a temperature between 250 - 375 °F for 6 - 20 hours.

[0018] The final product including the 6xxx series aluminum alloy composition may be a rod, bar, extruded shape, sheet, and/or plate with a thickness of 0.25 - 10 inches. The final product including the 6xxx series aluminum alloy preferably has tensile yield strengths in excess of 295 MPa (43 ksi), or in excess of 300 MPa, or in excess of 310 MPa, or in excess of 325 MPa, or in excess of 330 MPa, or in excess of 339 MPa. In addition to improved tensile yield strength, the final product including the 6xxx series aluminum alloy may have Ultimate Tensile Strength in excess of 340 MPa, or in excess of 345 MPa, or in excess of 349 MPa, or in excess of 355 MPa, or in excess of 360 MPa, or in excess of 364 MPa.

[0019] The 6xxx series aluminum alloy composition may be produced with greater than 75% scrap, or greater than 80% scrap, or greater than 85 % scrap, or greater than 90 % scrap, or greater than 95 % scrap, or with 100% scrap. The scrap used may include, but is not limited to, post-consumer scrap and/or post-industrial scrap. When using greater than 75% scrap to produce the 6xxx series aluminum alloy composition of the present invention, the final product may have excellent machinability performance as defined by achieving a B grade or better in the ASM machinability test detailed in Figure 1 of chapter on Machining of Aluminum and Aluminum Alloys in the ASM Handbook Aluminum and Aluminum Alloys (1993 Revision and Publication), the contents of which are expressly incorporated herein by reference.

[0020] The following examples illustrate various aspects of the invention and are not intended to limit the scope of the invention.

Example 1:

[0021] Extrusion billets were cast in 10" (253 mm) diameter using convention direct chill casting methods. The composition of these billets is shown in Table 1.

Table 1: Compositions of Alloys Studied in Example 1								
Alloy	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
1350	1.01	0.28	0.62	0.57	0.95	0.41	0.15	0.02
1357	1.43	0.22	0.30	0.57	1.06	0.79	0.14	0.00

[0022] The billets were then homogenized at 950 - 1060 °F (510 - 571 °C) for 2 - 10 hours. These billets were then preheated to 800 °F - 1000 °F (427 - 538 °C) and extruded. All samples were then water quenched from the hot working operation. After quenching samples were aged at 250 - 375 °F for 6 - 20 hours. After aging the mechanical properties of the samples were evaluated to determine the potential strength levels that these types of compositions can achieve. The results of the mechanical property evaluation is shown in Table 2.

Table 2: Mechanical Properties of Alloys in Example 1					
Composition	YTS [MPa]	YTS [ksi]	UTS [MPa]	UTS [ksi]	Elong.
6061 AA Minimum	241	35	262	38	10
1350	340.1	49.3	369.1	53.5	12.2

(continued)

Table 2: Mechanical Properties of Alloys in Example 1					
Composition	YTS [MPa]	YTS [ksi]	UTS [MPa]	UTS [ksi]	Elong.
1350	340.5	49.4	366.5	53.2	11.6
1350	341.3	49.5	366.2	53.1	12.4
1350	338.6	49.1	364.7	52.9	12.3
1350	339.6	49.3	364.9	52.9	11.5
1357	327.7	47.5	353.1	51.2	12.4
1357	326.3	47.3	350.7	50.9	11.8
1357	327.1	47.4	351.7	51.0	12.5
1357	325.6	47.2	350.9	50.9	11.7
1357	325.1	47.2	349.4	50.7	11.6

[0023] This shows that these types of compositions are capable of achieving strengths well in excess of what is necessary in the general engineering market, as demonstrated by the difference in properties to a typical general engineering alloy 6061.

Example 2:

[0024] Extrusion billets were produced in 12" (305 mm) and 18" (457 mm) diameter using conventional direct chill casting methods. The compositions of these billets are shown in Table 3.

Table 3: Compositions of Alloys Studied in Example 3									
Alloy	Diameter	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
1681	12"	0.78	0.44	0.30	0.60	0.78	0.49	0.10	0.02
1683	12"	1.04	0.42	0.61	0.58	0.56	0.49	0.10	0.02
1684	12"	0.79	0.44	0.31	0.60	1.21	0.51	0.10	0.02
1687	12"	1.30	0.43	0.30	0.60	1.19	0.50	0.10	0.02
1691	12"	1.28	0.43	0.30	0.60	0.80	0.53	0.10	0.02
1698	12"	1.03	0.43	0.29	0.58	0.99	0.50	0.09	0.01
1699	12"	1.05	0.42	0.30	0.57	1.01	1.00	0.09	0.02
1717	18"	1.05	0.44	0.30	0.60	1.00	0.49	0.09	0.02

[0025] All material was homogenized at 950 - 1060 °F (510 - 571 °C) for 2 - 10 hours. Then the 12" diameter billets were preheated to 800 °F - 1000 °F (427 - 538 °C) and extruded into 1" (25.3 mm) and 2" (50.6 mm) diameter rod as well as 2"x3" (50.6 mm x 76.2 mm) rectangular bar. The 18" material was preheated to the same temperature and extruded into 8" (203 mm) diameter rod as well as 4"x6" (102 mm x 152 mm) rectangular bar. The material was then water quenched from the hot working operation and aged at 250 - 375 °F for 6 - 20 hours.

[0026] The resultant material demonstrated an excellent combination of tensile properties and machinability performance. The average yield and ultimate strengths for each composition and product combination can be seen in Table 4 and Table 5. Again, the improvement in strengths relative to the minimum requirements of a typical general engineering alloy like 6061 listed in Table 2 must be noted.

Table 4: Mechanical Properties of Products Extruded from 12" Diameter Billets									
	Avg. YTS [ksi]			Avg. UTS [ksi]			Avg. Elong.		
Alloy	1"	2"	2"x3"	1"	2"	2"x3"	1"	2"	2"x3"
1681	50.45	49.10	50.15	54.85	53.75	54.65	13.63	13.03	12.60
1683	53.30	55.38	52.25	56.68	58.93	55.98	12.58	10.50	11.50
1684	47.80	49.80	47.55	53.18	55.30	53.10	12.80	13.20	12.65
1687	52.75	54.93	53.40	55.93	58.38	56.60	11.45	11.48	10.93
1691	54.15	56.45	53.23	57.88	60.58	57.38	12.35	11.08	12.68
1698	52.40	56.28	51.58	56.00	60.03	55.43	11.98	11.83	11.73
1699	55.90	55.87	55.33	59.45	60.07	59.15	11.88	11.50	12.08

Table 5: Mechanical Properties of Products Extruded from 18" Diameter Billets						
	Avg. YTS [ksi]		Avg. UTS [ksi]		Avg. Elong.	
Alloy	4"x6"	8"	4"x6"	8"	4"x6"	8"
1717	50.23	47.83	54.55	52.78	9.85	10.23

[0027] The machinability performance of this material was evaluated by performing a number of different common machining operations on the samples and assessing the resultant chips to determine the size and weight characteristics. Smaller overall chips result in improved machining operations as it minimizes issues with the processes by reducing the amount of large messy tangled masses of machining chips. When this occurs, manual intervention by the operator is required to resolve this resulting in equipment downtime. The machining performance of these alloys is detailed in the following tables that show the total chips per gram produced in the various machining operations. These results are equivalent to achieving a grade of B or better in the ASM Handbook machinability test (1993 Revision and Publication).

Table 6: Machinability Results of Products Extruded from 12" Diameter Billet											
	1" Diameter				2" Diameter				2"x3" Rec Bar		
Alloy	Drill	Cutoff	Turn	Form	Drill	Cutoff	Turn	Form	Drill	Mill	0.25" Mill
1681	2.12	2.38	4.33	2.34	2.32	0.39	0.23	0.99	8.31	19.38	44.41
1683	2.56	2.10	4.25	5.01	3.05	0.63	1.15	2.04	10.24	18.76	58.01
1684	2.51	2.48	2.27	2.92	2.13	0.99	0.52	3.34	8.00	18.71	57.41
1687	2.58	2.64	4.39	8.53	3.32	0.79	0.69	1.55	10.80	18.65	60.60
1691	2.08	2.25	2.69	8.09	3.08	0.60	0.64	0.54	7.13	18.40	62.73
1698	2.71	2.89	3.67	7.05	2.88	0.59	0.61	2.23	8.68	19.10	53.99
1699	2.78	1.97	3.57	6.91	3.19	1.07	0.98	3.57	10.46	18.58	58.01

Table 7: Machinability Results of Products Extruded from 18" Diameter Billet									
	4"x6" Rec Bar					8" Diameter			
Alloy	Long Drill	Short Drill	0.250 Drill	End Mill - Long	End Mill Short	OD Turn	Drill	ID Turn	Groove
1717	9.28	9.53	78.27	17.86	16.86	19.13	5.57	11.89	0.27

[0028] The grain structure developed in these extruded products was unrecrystalized with minimal to no peripheral coarse grain (PCG). Peripheral coarse grain is a thin band of coarse recrystallized grains that appear on the outer perimeter of a profile with an otherwise unrecrystalized grain structure. A typical example of the grain structure in the 2" diameter rod product can be seen in FIG. 2.

[0029] Samples were also anodized to compare the performance to that of typical 6061 material. The overall anodize were quite good and in line with the performance that can be expected from 6061 when it is being anodized. The anodize performance compared to 6061 material can be seen in FIG. 3.

[0030] Overall this demonstrates these compositions ability to achieve excellent mechanical property and machinability while maintain good anodizing performance with an unrecrystalized grain structure with minimal PCG.

Example 3:

[0031] The compositions shown in the table below were cast and extruded as per the previous example with some of the compositions being produced in 12" (305 mm) and some being produced in 18" (457 mm).

Table 8: Compositions of Alloys Studied in Example 3									
Alloy	**Diameter**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**	**Ti**
1771	12"	1.30	0.45	0.30	0.60	1.21	0.52	0.16	0.02
1772	12"	0.89	0.48	0.29	0.58	0.90	0.49	0.16	0.02
1773	12"	1.09	0.46	0.30	0.60	1.04	0.50	0.17	0.02
1774	18"	1.10	0.44	0.29	0.59	1.05	0.51	0.17	0.02

[0032] The amount of scrap utilized in each charge when producing these compositions was tracked and the percentage breakdown of scrap vs. prime in each charge is included in the following table.

Table 9: Charge Makeup for Casts Complete in Example 3		
Alloy	**% Scrap in Charge**	**% Prime in Charge**
1771	97.14	2.86
1772	100.00	0.00
1773	100.00	0.00
1774	100.00	0.00

[0033] Again, as per the previous example, this material was homogenized at 950 - 1060 °F (510 - 571 °C) for 2 - 10 hours. The billets were preheated to 800 °F - 1000 °F (427 - 538 °C) and the 12" diameter billets were extruded into 1" (25.3 mm) and 2" (50.6 mm) diameter rod as well as 2"x3" (50.6 mm x 76.2 mm) rectangular bar while the 18" diameter billets were extruded into 8" (203 mm) diameter rod as well as 4"x6" (102 mm x 152 mm) rectangular bar. The material was quenched and aged with the same practices that were utilized in the previous example.

[0034] The mechanical properties and machinability performance of this material as again evaluated through the same test methods as the previous example. The results of the testing were in line with the previous material performance over the range of sizes and compositions evaluated. These results are detailed in the following tables.

Table 10: Mechanical Properties of Products Extruded from 12" Diameter Billets									
	Avg. YTS [ksi]			**Avg. UTS [ksi]**			**Avg. Elong.**		
Alloy	**1"**	**2"**	**2"x3"**	**1"**	**2"**	**2"x3"**	**1"**	**2"**	**2"x3"**
1771	53.43	54.35	51.70	56.60	57.55	55.03	11.18	11.78	12.03
1772	52.81	50.51	49.80	56.49	54.49	54.33	12.09	12.36	11.65
1773	52.68	53.88	51.70	56.28	57.08	55.50	11.55	12.75	10.73

Table 11: Mechanical Properties of Products Extruded from 18" Diameter Billets						
	Avg. YTS [ksi]		Avg. UTS [ksi]		Avg. Elong.	
Alloy	4"x6"	8"	4"x6"	8"	4"x6"	8"
1774	48.70	48.38	53.35	53.05	9.78	9.35

Table 12: Machinability Results of Products Extruded from 12" Diameter Billets											
	1" Diameter				2" Diameter				2"x3" Rec Bar		
Alloy	Drill	Cutoff	Turn	Form	Drill	Cutoff	Turn	Form	Drill	Mill	0.25" Mill
1771	4.93	3.31	7.56	10.28	3.08	1.25	1.03	2.22	5.23	14.00	29.28
1772	2.99	2.33	7.21	5.39	2.29	0.70	0.38	2.47	3.94	13.84	23.39
1773	3.42	2.82	7.95	7.12	3.09	0.74	0.74	2.24	5.22	13.85	26.17

Table 13: Machinability Results of Products Extruded from 18" Diameter Billets									
	4"x6" Rec Bar					8" Diameter			
Alloy	Long Drill	Short Drill	0.250 Drill	End Mill - Long	End Mill Short	OD Turn	Drill	ID Turn	Groove
1774	5.00	5.14	29.53	15.56	14.87	21.71	4.94	15.73	0.09

[0035] All casts in this evaluation were produced with scrap making up more than 90% of the charge showing that these properties can be achieved while using high levels of scrap material in the production process.

Example 4:

[0036] Rolling ingots were produced in 23"x46" (584 mm x 1168 mm) using conventional direct chill casting methods. The compositions for the ingots are included in Table 14.

Table 14: Compositions of Alloys Studied in Example 4								
Alloy	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
1781	0.90	0.41	0.28	0.56	0.88	0.47	0.15	0.02
1789	1.09	0.37	0.35	0.54	0.99	0.48	0.12	0.02
1791	1.31	0.44	0.30	0.59	1.21	0.53	0.16	0.02

[0037] These ingots were then homogenized at 950 - 1060 °F (510 - 571 °C) before being rolled into 1" (25.3 mm) thick plate. After rolling the plates were solution heat treat between 950 - 1150 °F (510 - 621 °C) before being quenched. Finally, the plates were aged at 250 - 375 °F for 6 - 20 hours.

[0038] After completion of aging tensile samples were taken from the plates and the results of the mechanical property testing can be seen in the following table.

Table 15: Mechanical Properties of Plate Products Produced in Example 4			
	Avg. YTS [ksi]	Avg. UTS [ksi]	Avg. Elong.
Alloy	LT Orientation	LT Orientation	LT Orientation
1781	50.30	53.10	9.60
1789	48.90	52.80	8.40

(continued)

Table 15: Mechanical Properties of Plate Products Produced in Example 4			
	Avg. YTS [ksi]	Avg. UTS [ksi]	Avg. Elong.
Alloy	LT Orientation	LT Orientation	LT Orientation
1791	46.60	50.50	11.70

[0039] This example demonstrates that these compositions are capable of achieving the same mechanical properties when produced in a rolled product as compared to an extruded product.

[0040] 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.

Claims

1. A 6xxx series aluminum alloy having a composition comprising, (by weight %):

0.5-1.5% Si;
0.1-0.7% Cu;
0.5-1.5% Mg;
0.3-1.2% Zn;
0.05-0.35% Cr;
≤0.8% Fe;
≤0.8% Mn;
≤0.15% Zr;
≤0.15% Ti;

with other elements restricted as unavoidable impurities limited to ≤0.05% each and ≤0.15% total with the balance being aluminum.

2. The 6xxx series aluminum alloy of claim 1 comprising,

0.8-1.4% Si;
0.1-0.7% Cu;
0.8-1.4% Mg;
0.3-1.1% Zn;
0.05-0.30% Cr;
≤0.6% Fe;
≤0.8% Mn;
≤0.15% Zr;
≤0.15% Ti.

3. The 6xxx series aluminum alloy of claim 1 or claim 2 including greater than 75% scrap.

4. The 6xxx series aluminum alloy of claim 1 or claim 2 including greater than 90% scrap.

5. An extruded, forged or rolled product manufactured from the 6xxx series aluminum alloy of any one of claims 1-4 having a yield tensile strength greater than 295 MPa (42.8 ksi).

6. An extruded, forged or rolled product manufactured from the 6xxx series aluminum alloy of any one of claims 1-4 having a yield tensile strength greater than 320 MPa (46.4 ksi).

7. An extruded, rolled or forged product manufactured from the 6xxx series aluminum alloy of any one of claims 1-6 having excellent machinability performance as defined by achieving a B grade or better in the ASM machinability test.

8. An extruded, rolled or forged product manufactured from the 6xxx series aluminum alloy of any one of claims 1-7 having a thickness of 0.25- 10 inches.

9. An extruded, rolled or forged product manufactured from the 6xxx series aluminum alloy of claim 8 having a thickness of 1-10 inches.

10. A method of manufacturing the 6xxx series aluminum alloy of any one of claims 1-9 comprising,

a) casting using conventional direct chill casting methods;
b) homogenizing at 950 °F to 1060 °F (510 - 571 °C) for 2 to 10 hours;
c) preheating to 800 °F - 1000 °F (427 - 538 °C);
d) hot working by extrusion, forging or rolling;
e) water quenching;
f) optionally stretching for stress relief and straightening, and
g) artificially aging at a temperature between 250 - 375 °F for 6 - 20 hours.

11. A method of manufacturing the 6xxx series aluminum alloy of claim 10, wherein said hot working is extrusion.

12. A method of manufacturing the 6xxx series aluminum alloy of any one of claims 1-9 comprising,

a) casting using conventional direct chill casting methods;
b) optionally homogenizing at 950 °F to 1060 °F (510 - 571 °C) for 2 to 10 hours;
c) preheating to a rolling temperature of 600 °F - 1000 °F (316 - 538 °C);
d) hot rolling;
e) solution heat treatment at a temperature of 950^0F to 1070^0F,
f) quenching to room temperature,
g) optionally stretching for stress relief and straightening, and
h) artificially aging at a temperature between 250 - 375 °F for 6 - 20 hours.

13. A method of manufacturing the 6xxx series aluminum alloy of any one of claims 1-9 comprising,

a) casting using conventional direct chill casting methods;
b) homogenizing at 950 °F to 1060 °F (510 - 571 °C) for 2 to 10 hours;
c) preheating to an extrusion temperature of 450 °F - 1000 °F (232 - 538 °C) and then extruding;
d) optionally drawing the extrusions;
e) solution heat treatment at a temperature of 950^0F to 1070^0F,
f) quenching to room temperature,
g) optionally stretching for stress relief and straightening, and
h) artificially aging at a temperature between 250 - 375 °F for 6 - 20 hours.

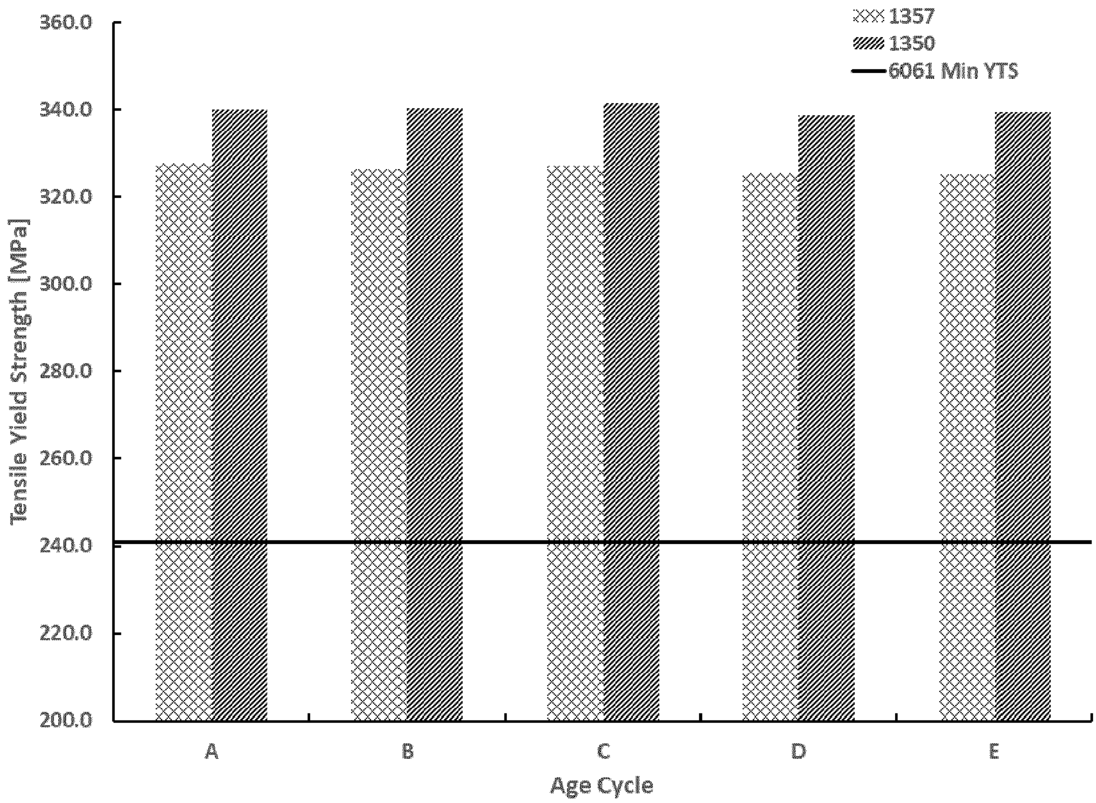
1357
1350
6061 Min YTS
360.0
340.0
320.0
300.0
280.0
260.0
240.0
220.0
200.0
Tensile Yield Strength [MPa]
A
B
C
D
E
Age Cycle

FIG. 1

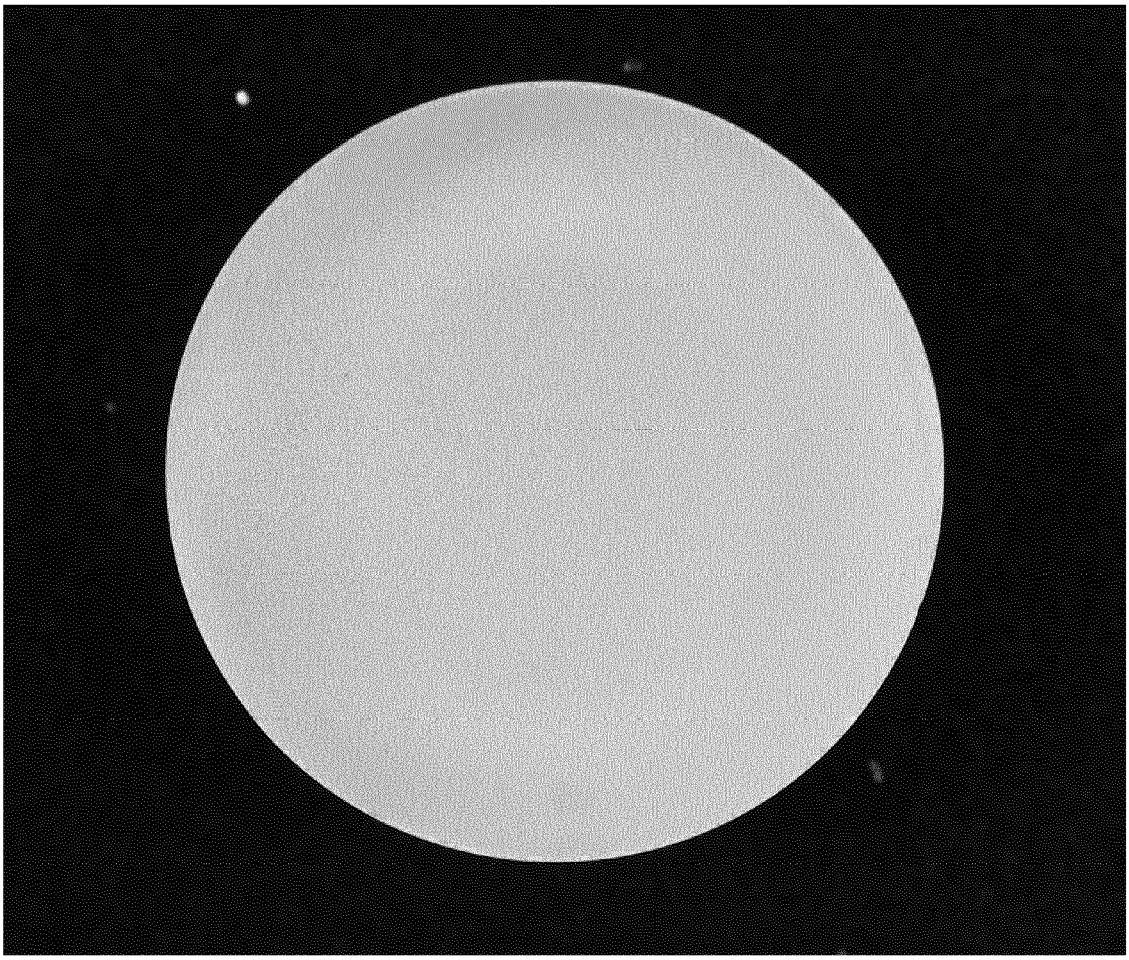

FIG. 2

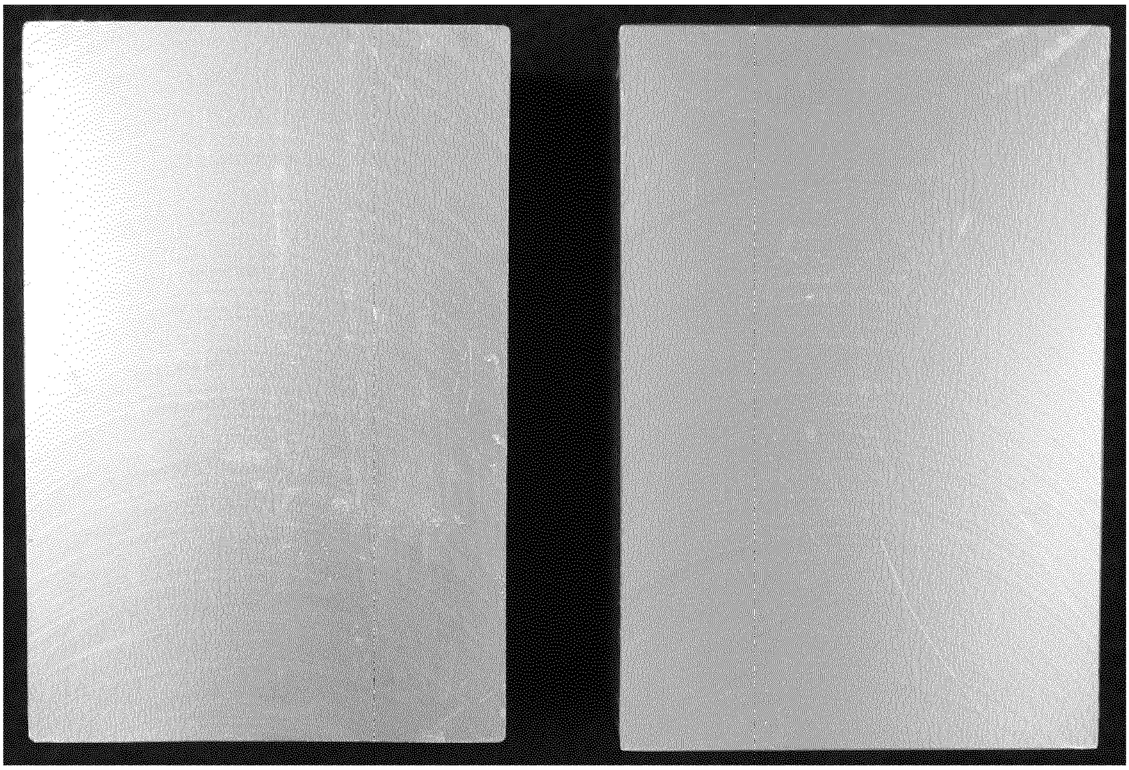

FIG. 3

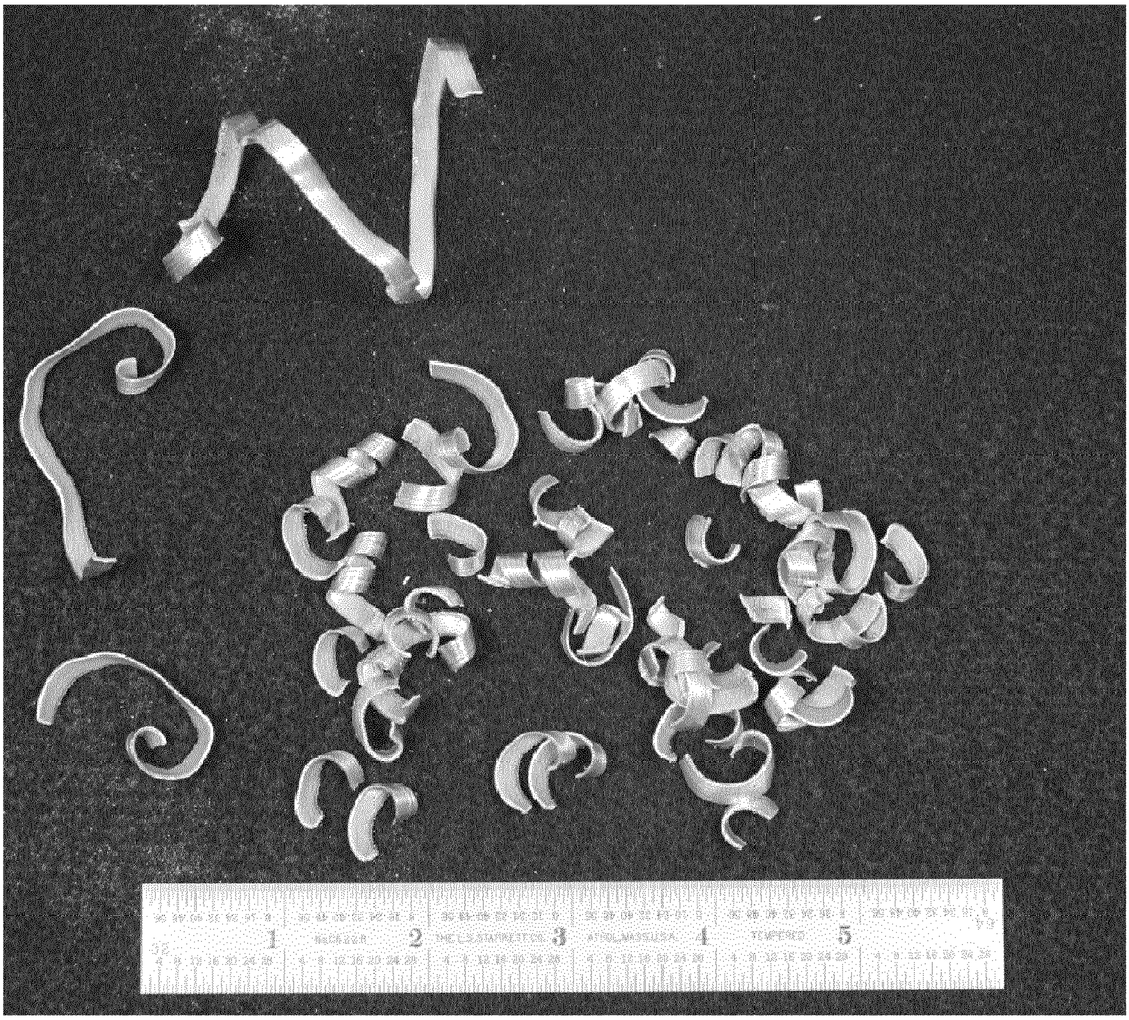

FIG. 4

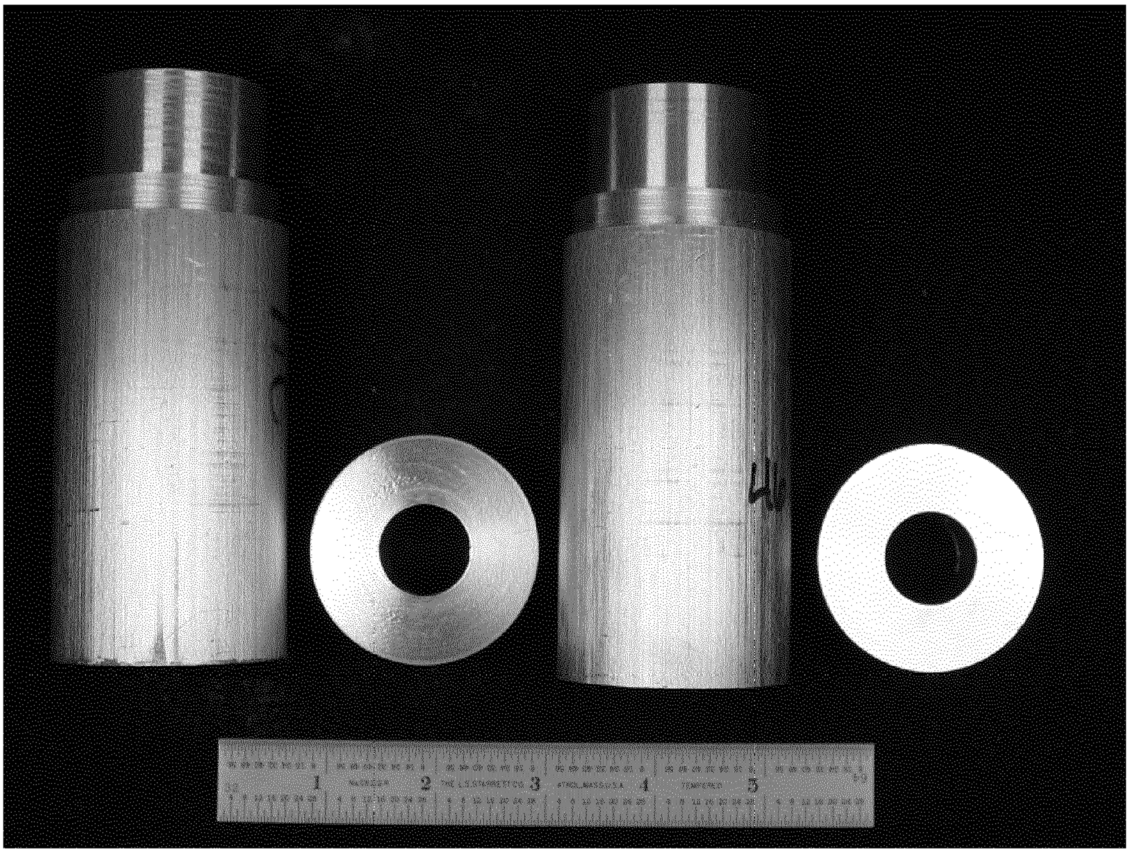

FIG. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 23 18 2059

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 0 826 072 B1 (KAISER ALUMINIUM CHEM CORP [US]) 2 July 2003 (2003-07-02) * Alloy No. 5; tables 6-7 * * paragraph [0018] - paragraph [0025] * * paragraph [0037] - paragraph [0046] * * claims 1-17 * -----	1-13	INV. C22C21/14 C22C21/08 B22D21/00 C22B21/00 C22C1/02 C22F1/05 C22C21/02
X A	CN 112 853 161 A (HENAN TAIHONG NEW MAT CO LTD) 28 May 2021 (2021-05-28) * paragraph [0021] * * Embodiment 5 * * Embodiments 7-8 * * claims 1-8 * -----	1-11,13 12	
X A	CN 112 853 176 A (HARBIN ZHONGFEI NEW TECH CO LTD) 28 May 2021 (2021-05-28) * Examples 1-2 * * claims 1-10 * -----	1-10,12 11,13	
X	ANONYMOUS: "International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys", THE ALUMINUM ASSOCIATION, 1 August 2018 (2018-08-01), pages 1-45, XP093027436, * 6019; page 11 * -----	1-4,7	TECHNICAL FIELDS SEARCHED (IPC) C22C B22D C22B C22F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	19 October 2023	Neibecker, Pascal

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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19-10-2023

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