Aug. 13, 1968 L. D. BYLUND 3,397,044

ALUMINUM-IRON ARTICLES AND ALLOYS

Filed Aug. 11, 1967 2 Sheets-Sheet 1

FIG. 1.

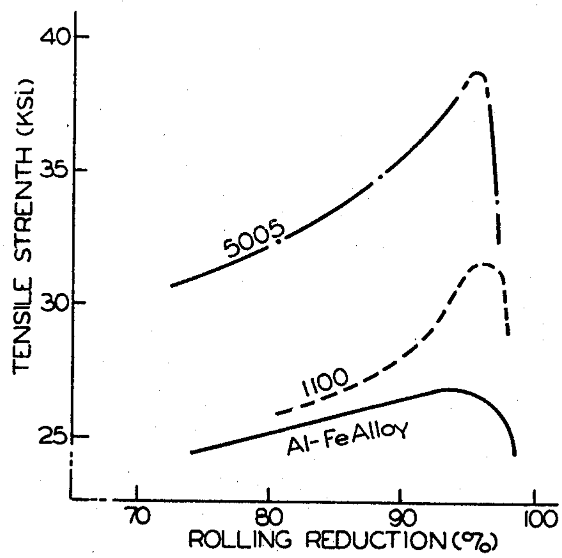

FIG. 2.

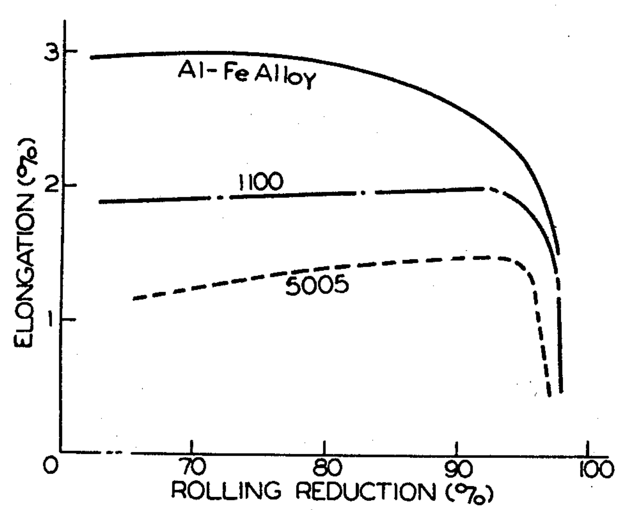

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FIG. 3

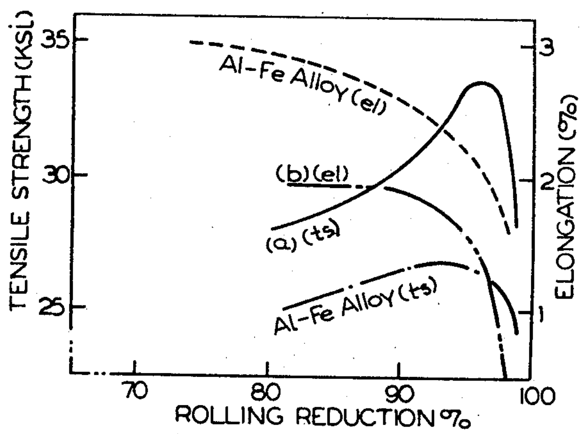
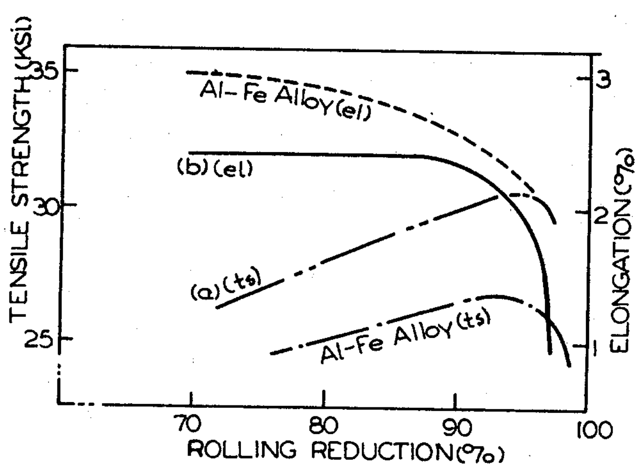


FIG. 4



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United States Patent Office

3,397,044
Patented Aug. 13, 1968

3,397,044

ALUMINUM-IRON ARTICLES AND ALLOYS

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Continuation-in-part of application Ser. No. 573,776, Aug. 8, 1966. This application Aug. 11, 1967, Ser. No. 660,132

26 Claims. (Cl. 29—183)

ABSTRACT OF THE DISCLOSURE

Aluminum foil and other wrought articles including drawn and ironed can bodies are produced from aluminum baes alloys containing up to about 2.5% iron, having a low work hardening rate above 75% reduction and sufficient ductility at high cold work levels to permit cold working to the extent of at least 90% without the necessity of annealing or stress relieving. Also provided are novel aluminum base alloys containing iron and at least one additional alloying element such as 0.1–2.5% magnesium or 0.1–1.5% manganese. A preferred can alloy includes about 0.75–1.2% iron, about 0.1–1.0% magnesium and about 0.25–0.8% manganese.

This application is a continuation-in-part of copending application Ser. No. 573,776, filed Aug. 8, 1966, now abandoned, which in turn is a continuation-in-part of application Ser. No. 379,782, filed July 2, 1964, now abandoned.

The invention concerns an aluminum alloy especially suited for producing high strength, light gage wrought products including foil and cans and it also concerns a method of improving the rollability of aluminum for producing such products.

Metal foil is widely used today in both unsupported and laminated form for various applications such as packaging materials and the like. Aluminum alloys 1100 or 1235 or 1145 have been employed for this purpose, but there is an existing need for higher strength foil products. Of the stronger aluminum alloys previously known, most are unsuited to the requirements of packaging materials, particularly the need for a reasonable elongation characteristic and related physical properties in foil gages.

In addition to metal foil products, aluminum alloys have been employed to fabricate drawn and ironed cans. Conventional aluminum alloys include, for instance, 3004, which contains 1.0–1.5% manganese and 0.8–1.3% magnesium as the principal alloying elements, and which develops strength in fabricated form as a result of solid solution strengthening and work hardening. The ductility of alloy 3004 progressively deteriorates at high cold work levels, however, and resort is taken to various thermal treatments in making rolled sheet stock therefrom for forming into cans, and preparatory to such forming operations. Thus, for example, it is conventional practice to hot roll an ingot of 3004 alloy to a thickness of about 0.105″ followed by annealing and then by successive cold rolling reductions, typically with at least one intermediate annealing step, to provide sheet stock having a thickness of about 0.02″, after which a final stress relieving treatment is given prior to forming a drawn and ironed can.

The trend toward cans made of a higher strength alloy apparently is due to expanded use of aluminum cans for carbonated beverages which produce considerable internal pressure, thus necessitating a can construction capable of withstanding a test pressure of at least 90 p.s.i. There are disadvantages to employing increased amounts of alloying element, however, not the least of which is greater cost and increased fabrication difficulties.

On the other hand, alloys of aluminum ordinarily are susceptible to work-hardening to some extent, so that strengthening of the alloy in finished form can be effected by cold working, either in the can forming operation or in preparation of light-gage can stock suitable for forming. When producing a drawn and ironed can from about 0.02″ stock, moreover, with the final wall thickness to be about 0.007″ for example, it is readily apparent that a reduction of about 65% is involved. If the metal is too hard at the outset, the forming operation will render it unworkable and result in tool wear or excessive earring, or may even make it impossible to produce a satisfactory product. That is why stress relieving or other thermal treatment has conventionally preceded can making and other severe forming operations.

PRODUCTION OF ALUMINOUS METAL PRODUCTS SUCH AS FOIL

In accordance with the present invention for the production of foil, it has been found that a carefully controlled addition of iron in a commercial purity aluminum base provides an alloy having the desired characteristics; and it has also been found that a limitation of the copper content in such aluminum-iron alloys is also beneficial. This is an unexpected and surprising result for several reasons. To begin with, the addition of iron beyond a small fraction of a percent (for purposes of grain refinement) is ordinarily considered undesirable as promoting brittleness; and particularly in alloys composed almost entirely of aluminum, it would not be expected that the use of iron as the principal alloying addition would result in a material suitable for the heavy rolling reductions incident to producing light gage sheet or foil. Additionally, one type of alloy commonly utilized for foil production typically contains about 0.10–0.20% copper for achieving desired properties of the foil in its annealed condition. Thus, the addition of iron and the restriction of copper in foil alloys of aluminum is contrary to prior practices in this regard.

Aluminum-iron alloys suitable for purposes of the invention in the production of foil and other wrought articles include essentially binary systems containing from 0.6% to about 2.5% iron, by weight, and about .05–1.0% total of incidental elements ordinarily present as impurities in commercial grade aluminum of about 99% purity. Such alloys are conveniently produced by adding the necessary additional quantity of iron to ordinary reduction cell aluminum containing such incidental impurities as silicon, iron, copper, manganese, magnesium, chromium, nickel, zinc and titanium. Thus, the alloys may contain, in addition to iron as the principal alloying element by weight, up to about 1% total of silicon and incidental elements not exceeding 0.25% each, preferably within the limits of about .05–0.3% silicon, up to about 0.10% zinc, not more than 0.10% copper (most preferably a maximum of .05% copper), the others exclusive of iron preferably not exceeding about .05% each and about 0.15% total. In this regard, for example, the alloy for foil products may contain at least about 0.75% total of iron and silicon (preferably about 1%) and have an iron-to-silicon ratio of at least 5:1.

In accordance with the invention, the aforesaid aluminum-iron alloys have been found to exhibit a particularly desirable rolling characteristic, chiefly as a result of their unexpectedly low work-hardening rates in the region of 90% reduction. This makes possible the rolling of foil in wider widths and at substantially heavier reduction under comparable mill conditions; and the resulting lower work-hardened properties enable the production of an excellent foil which is tough and ductile even in exceedingly light gages.

The maximum amount of iron in the alloy for purposes of the invention is determined by such factors as formation of massive primary crystals of an iron-aluminum intermetallic compound (e.g., $FeAl_3$) during casting, resulting in casting defects or excessively reduced ductility for rolling purposes; and increasing iron content eventually leads to deterioration of corrosion resistance in the resulting wrought products. Furthermore, the higher the iron content the more difficult it becomes to utilize recycled scrap (recovered in making or fabricating the alloy) for the production of other alloys in which the iron content has to be controlled, thus rendering the alloys of higher iron content less attractive as a practical matter.

In accordance with a preferred practice of the invention, light gage sheet or foil is produced from an alloy consisting essentially of aluminum, silicon and about 0.75–1.2% iron, with no more than .05% copper and up to about 0.25% silicon (preferably about .05–0.15%). This may be accomplished conveniently by adding iron to commercial purity aluminum of the requisite silicon and copper analysis, preferably containing no more than .05% each, 0.15% total, of the aforesaid incidental impurities such as zinc and manganese.

The improved characteristics of the alloy are exhibited in the accompanying drawings, in which:

FIGS. 1 and 2 are graphical representations of data showing physical properties (tensile strength and elongation, respectively) of an Al-Fe alloy in accordance with the invention, compared with standard commercial alloys 5005 and 1100 at various rolling reductions;

FIG. 3 is a composite plot of the same properties shown in FIGS. 1 and 2, showing the effect of making a small addition of iron to an alloy of aluminum containing a fractional percentage of magnesium; and

FIG. 4 is a similar composite plot showing the effects of increased copper content in an alloy otherwise similar to the preferred alloy of the present invention.

The reference alloys fall within the following percentage composition limits:

5005

Si	0.40 max.
Fe	0.7 max.
Cu	0.20 max.
Mn	0.20 max.
Mg	0.50–1.1.
Cr	0.10 max.
Zn	0.25 max.
Others	.05 max. each, 0.15 max. total.
Al	Balance.

1100

Si+Fe	1.0 max.
Cu	0.20 max.
Mn	0.05 max.
Zn	0.10 max.
Others	.05 max. each, 0.15 max. total.
Al (99.00 min.)	Balance.

The following examples are illustrative of the invention, but are not to be regarded as limiting.

Example 1

The aluminum-iron alloy for which the data of FIGS. 1 and 2 were determined had the percentage composition: 0.08 Si, 0.87 Fe, 0.02 Cu, 0.013 Mn, 0.02 Zn, balance aluminum.

It can be seen from inspection of FIG. 1 that the work-hardening curve for 5005 alloy typically rises at a progressively increasing rate toward a peak beyond 90% reduction, as is the case with 1100 alloy to a lesser extent. On the other hand, a surprising difference is exhibited by the aluminum-iron alloy, which actually has a substantially constant work-hardening rate as the critical heavy reductions are approached. This flattening of the curve is particularly advantageous, of course, where cold rolling to foil gages is to be accomplished.

FIG. 2, on the other hand, indicates a further beneficial result obtained with the alloy of this application. The elongation characteristic is considerably better than that of conventional 1100 and 5005 alloys. This property renders the alloy itself better adapted to foil manufacturing operations and also makes the resulting foil product superior for packaging uses, in which increased strength would be ineffective if coupled with appreciable loss of elongation.

Other properties are presented in Table 1, showing that tensile and Mullen bursting strength of foil made from the aluminum-iron alloy are comparable to those of conventional material, whereas the elongation is somewhat better. The alloy is also readily cast and hot rolled. It is apparent, therefore, that the special alloy has characteristics peculiarly suited for its intended use.

TABLE 1.—LIGHT GAGE ANNEALED PROPERTIES

Alloy and Gage	Tensile Strength (p.s.i.)	Percent Elong. (6″)	Mullen Test (p.s.i.)
Al-Fe alloy:			
.00096″	11,900	7.0	26.0
.00083″	11,900	6.3	21.4
.00064″	11,300	4.4	13.0
.00038″	10,400	3.2	6.0
1100 type alloy:			
.001″	11,500	6.0	27.0
.0007″	11,000	4.0	16.0
.00035″	10,000	2.5	6.0

Referring now to FIG. 3, a comparison is presented between the same Al-Fe alloy characterized in FIGS. 1 and 2, and a closely similar alloy further containing 0.28% mg. The work-hardening (tensile) curve a of the latter alloy is still inferior and much like that of ordinary 1100 alloy (although approaching the performance of 5005 alloy which has a somewhat greater addition of magnesium as its principal alloying element). The characteristic elongation curve b likewise is less desirable than that of the Al-Fe alloy.

In like manner, FIG. 4 shows a direct comparison between the novel Al-Fe foil alloy and one which had the analysis 0.07 Si, 0.81 Fe, 0.15 Cu, 0.02 Zn, balance aluminum. The deleterious effect in the latter alloy of additional copper is apparent by consideration of the location of tensile curve a and elongation curve b, again with reference to the corresponding characteristics of the same Al-Fe alloy as represented in FIGS. 1 and 2.

The foregoing comparisons shown graphically in FIGS. 3 and 4 emphasize the criticality of iron and copper content in relation to other constituents in alloys made according to the invention.

Further examples of the practice of the invention are the following:

Example 2

(a) An ingot measuring approximately 16″ x 50″ x 160″ was produced in an alloy having the aforesaid composition (i.e., 0.08 Si, 0.87 Fe, 0.02 Cu, 0.013 Mn, 0.02 Zn, balance aluminum), and the ingot was scalped, heated to about 950–1,000° F. and hot rolled to a thickness of about 0.125″, and then cold rolled in a 3-stand mill to .023″ gage. Employing conventional foil rolling practices, the .023″ strip was coil annealed (700° F.) for about six hours, cold rolled into foil in successive passes from 0.23″ to .0099″, to .0062″, .0030″, .0011″, .00062″ and, finally in a doubling pass (two thicknesses) to about .00029″. The foil was dry annealed in coil form

(775° F.) for about 10–11 hours. The foil exhibited the following properties at various stages, as indicated below:

Gage	Tensile Strength (p.s.i.)	Percent Elongation
.023" (annealed)	12,500	29.8
.0099"	21,700	3.5
.0062"	23,100	2.8
.0030"	24,900	2.0
.0011"	26,300	1.6
.00062"	25,400	2.8
.00029"	24,400	1.4
After final anneal (about .0003" gage)	9,000	2.5

(b) In like manner, an additional sample of the annealed .023" strip was cold rolled successively to 0.12", .0056", .0033", .0017" and, finally, in a doubling pass (two thicknesses) to .0007". The resulting foil was slick annealed (525–550° F. for about two hours). The foil properties at various stages are indicated below:

Gage	Tensile Strength (p.s.i.)	Percent Elongation
.023" (annealed)	13,900	33.8
.012"	20,800	1.6
.0056"	24,800	2.6
.0033"	26,200	2.9
.0017"	26,500	3.1
.0007"	25,200	1.3
After final anneal (.0007")	11,700	5.5

It is readily apparent from the foregoing data that in both instances the alloy exhibited a very low work hardening rate at heavy cold working reductions.

Example 3

The alloy of Example 2 responded so well to conventional processing that it was decided to try a modified practice, omitting any annealing of the 0.23" cold rolled strip prior to the foil rolling operation.

A 20" x 66" x 93" ingot was prepared having a composition 0.07 Si, 0.80 Fe, 0.01 Cu, balance substantially aluminum (Mn, Mg, Cu, Ni, Zn, Ti less than .02 inch). This was reduced to a hot line gage of about 0.100", annealed at 750–800° F. for about two hours, cold rolled in two passes to .023" and then directly rolled into foil in successive cold rolling reductions to .0109", .0077", .0033", .0014" and .00065". The work hardening curve was found to be substantially flat and no difficulty was found in the cold rolling operations. The foil was annealed at 525–550° F. The foil was found to have the following properties at the various stages:

Gage	Tensile Strength (p.s.i.)	Percent Elongation
.023" (unannealed)	23,800	4.0
.0109"	24,900	3.6
.0077"	25,500	4.0
.0033"	26,100	5.0
.0014"	25,700	4.2
.00065"	24,700	2.9
After final anneal [1] (about .00065")	11,500	5.0

[1] Mullen bursting strength 16.5 p.s.i.

Example 4

The alloy of Example 3 responded so well that it was decided to try a further simplified practice, omitting annealing of both the hot line gage and the .023" cold rolled strip. A 20" x 66" x 193" ingot was prepared having the composition 0.08 Si, 0.84 Fe, 0.03 Cu, balance substantially aluminum (Mn, Mg, Cu, Ni, Zn, Ti less than .02 inch). This was reduced to a hot line gage of about 0.100", cold rolled in two passes to .023", and then directly rolled into foil in successive cold rolling reductions to .012", .0077", .0038", .0014" and .00073". The work hardening curve was found to be substantially flat, and no difficulty was encountered in the cold rolling operations. The .00073" foil was annealed at 525–550° F. for about 2 hours. The foil was found to have the following properties at the various stages indicated.

Gage	Tensile Strength (p.s.i.)	Percent Elongation
.012"	31,200	4.4
.0077"	31,800	4.3
.0038"	32,300	4.3
.0014"	28,500	4.4
.00073"	31,500	2.1
After final anneal [1] (about .0007")	13,000	4.5

[1] Mullen bursting strength 18 p.s.i.

The somewhat higher tensile strength in the annealed condition compared to the preceding examples was due to the highly oriented structure resulting from the elimination of intermediate annealing. X-ray diffraction patterns showed that recrystallization was not completely effected by the final annealing treatment. This characteristic can be utilized to advantage in products requiring higher strength, such as containers (e.g. cans), fin stock (for heat exchangers), and laminated foil composites.

Example 5

Following the procedures of Example 4, similar results were obtained using hot line gages of .110" and .125", again without any intermediate thermal treatment.

Example 6

To explore the effect of even greater amounts of iron, additional runs were made with alloys A and B respectively containing 1.37 and 1.60% iron (each having .08 Si, with Cu, Mn, Mg and Zn less than .02 inch, balance essentially Al). Reroll coils of .023" sheet x 61½" width (weighing 22,258 lbs. and 12,628 lbs. respectively) were annealed and cold rolled into foil without further annealing. It was noted that the power needed in the hot mill was about 10% less than that required for rolling the 0.87% Fe alloy (cf. Example 2).

The foil exhibited the following properties at various stages, as indicated below:

Gage	Tensile Strength (p.s.i.)	Percent Elongation
Alloy A (1.37% Fe):		
.023" (annealed)	13,900	36.0
.0096"	23,500	4.3
.0072"	24,600	4.1
.0033"	25,300	3.8
.0014"	28,100	3.3
Alloy B (1.60% Fe):		
.023" (annealed)	14,900	40.2
.010"	23,800	3.7
.005"	26,200	3.6
.0034"	26,200	3.2
.0015"	25,800	2.9

The final annealed foil product had the following properties:

	Gage	T.S. (p.s.i.)	Percent El.	Mullen Bursting Strength (p.s.i.)
Alloy A (1.37% Fe)	0.00067	12,500	7.6	20.6
Alloy B (1.60% Fe)	0.00066	15,100	6.5	24.2

PRODUCTION OF CAN BODIES AND THE LIKE

In accordance with another aspect of the present invention for the production of articles such as drawn and ironed can bodies having a peripheral side wall and one end formed in a single piece, it has been found possible to eliminate thermal treatment of aluminous metal sheet at any thickness below about 0.100", while still providing sufficient ductility for rolling and forming operations which involve as much as 90% cold working and more. This is accomplished by carefully controlling the aluminous metal composition in relation to the fabricating practices applied thereto, particularly as regards the relationship between drawing and ironing operations and the cold rolling steps immediately preceding such operations.

In general, the practice of the invention concerns three principal considerations: (1) selection of aluminous metal on the basis of its ductility at high levels of cold work, so as to provide a starting material which has a low work-hardening rate above 75% reduction and sufficient ductility in work-hardened condition to permit cold working to the extent of at least 90% in one or more cold rolling passes without having to anneal or stress relieve the metal; (2) inclusion in the aluminous metal, in keeping with the above consideration, of sufficient alloying elements to meet the strength requirements of the finished article, including enough iron to keep the work-hardening rate low, and, particularly in making drawn and ironed cans, to minimize die pickup and achieve a desirable die polishing effect; and (3) control of the sheet rolling operation in relation to the work-hardening effect of subsequent forming operations.

In accordance with the invention, and in keeping with the foregoing considerations, it has been found that aluminous metal of various types may be subjected to a fabricating operation which involves the steps of:

(a) hot rolling the metal to a hot line gage suitable for single or multi-stand cold rolling, such as between about 0.100" and about 0.250";

(b) rolling the metal from hot line gage in one or more cold rolling passes into coilable sheet stock of a thickness on the order of 10–20% of the hot line gage;

(c) forming the cold rolled sheet into a finished article, such as by drawing and ironing to effect a further reduction of about 65% (the total cold working reduction from hot line gage being in excess of 90%);

(d) performing the cold rolling and forming operations without the use of a thermal treatment at any thickness of the metal below about 0.100", the metal being work-hardened in the course of such operations and still retaining sufficient ductility for finishing steps such as necking or flanging of can bodies.

It has also been discovered that the beneficial effects of relatively high iron content in the essentially binary aluminum-iron alloys previously mentioned, particularly in reducing the work hardening rate, are applicable with respect to alloys containing additional alloying elements such as magnesium, manganese, or both. Thus, novel aluminum base alloys provided in accordance with the present invention contain 0.75–2.5% iron, by weight, at least one additional alloying element from the group consisting of 0.1–2.5% magnesium and 0.1–1.5% manganese, up to about 1% total of silicon and incidental impurities, balance about 96.5 to 99% aluminum. The amount of iron included is controlled to provide an alloy having a low work-hardening rate above 75% reduction and sufficient ductility to permit cold working to the extent of at least 90% without the necessity of annealing or stress relieving the alloy in the course of such cold working.

In accordance with this alloy aspect of the present invention, typical alloy systems are the following:

(a) essentially ternary Al-Fe-Mg alloys containing 0.1–2.5% magnesium and 0.75–2.5% iron, in approximately inverse proportions including alloys consisting essentially of about 0.75–1.2% iron, about 0.1–1.0% magnesium and up to about 0.25% silicon, by weight, balance aluminum and incidental impurities, as well as Al-Fe-Mg-Si alloys containing, for example, as much as 1% silicon in addition to the iron and magnesium;

(b) essentially ternary Al-Fe-Mn alloys containing 0.1–1.5% manganese and about 0.75–1.2% iron, preferably with a total iron and manganese content from about 1% to about 2% including alloys consisting essentially of about 0.75–1.2% iron, about 0.25–0.8% manganese and up to about 0.25% silicon, by weight, balance aluminum and incidental impurities, especially such of the latter alloys as contain about 1.5% total of iron and manganese; and

(c) essentially quaternary Al-Fe-Mg-Mn alloys containing both manganese and magnesium in addition to iron, including alloys consisting essentially of about 0.1–1.0% magnesium, about 0.25–0.8% manganese, about 0.75–1.2% iron and up to about 0.4% silicon, by weight, balance aluminum and incidental impurities.

In the above ternary and quaternary systems, the balance is commercial grade aluminum of at least 99% purity containing about 0.05 to 1 percent total of incidental elements ordinarily present as impurities. Ordinary commercial grade reduction cell aluminum as defined hereinbefore can effectively be used in the present invention.

Example 7

A typical and conventionally known technique for making drawn and ironed cans from aluminum alloy 3004 involves rolling to a hot line gage of about 0.105", cold rolling to .0275", annealing, cold rolling to .0195", stress relieving, then forming a can body. In contrast, due to the substantially zero work hardening rate of Al-Fe alloys at high work levels, the present invention makes possible a considerably simplified practice which involves hot rolling to about 0.125", cold rolling to .0195" without prior or intermediate annealing, then directly forming a can body without prior stress relieving; or, alternatively, where annealing of the 0.125" strip is considered desirable to minimize earring of the drawn can, it may be included while still omitting any subsequent thermal treatment in the course of cold rolling operations. Additional examples of producing can stock and the like are the following:

Example 8

Bottle cap material is commonly produced in aluminum alloy 3003–H12, by hot rolling to about 0.135", annealing, cold rolling to about .024", annealing again, cold rolling to .013", annealing for a third time, cold rolling in a third stage to .0095", and finally drawing into a cap. In accordance with the present invention, the procedure involves simply hot rolling an aluminum-iron type alloy to about 0.100", annealing, cold rolling all the way down to .008" without any intermediate thermal treatment, and drawing into a finished cap.

Example 9

(a) Using the same alloy as in Example 4, coil stock suitable for making cans and the like was produced by hot rolling the ingot to 0.100" reroll gage and cold rolling to .023" without prior or intermediate annealing. Then the strip was flat milled by cold rolling to .0195" and, without annealing or stress relieving, drawn into cans.

(b) In like manner, another run was made which included annealing the 0.100" reroll stock at 750° F. for about 2 hours prior to cold rolling.

Typical properties of the can stock and the resulting cans produced in the foregoing manner are tabulated below:

T.S.	Y.S.	Percent El.	Bulge Pressure (p.s.i.)	
			Before Coating	After Coating
(a) 30,100	25,800	4.0	94	90
(b) 23,900	20,500	3.3	78	--------

Example 10

Using the same ingot composition as in Example 9 (also Example 4), reroll stock was produced by hot rolling to 0.125" (rather than 0.100" as in the preceding example), followed by cold rolling in a three-stand mill to .023" (also without annealing). Then the strip was flat milled by cold rolling to .0195" and, without annealing or stress relieving, drawn into can bodies. Thus, essentially the only difference in the practice was increased hot line gage compared to Example 9(a). Typical properties obtained were as follows:

T.S.	Y.S.	Percent El.	Bulge Pressure (p.s.i.)	
			Before Coating	After Coating
27,000	23,500	3.5	85	85

Finally, as a general indication of the effective performance of Al-Fe alloys and the fabricating practices of the invention as applied thereto, the cold rolling of ordinary 1100 or 2S aluminum from a hot line gage of 0.125" typically requires a three-step reduction to .023" gage and also an annealing treatment at .023" or some other intermediate gage before proceeding to lighter foil gages. In contrast, aluminum-iron alloys of the character described correspondingly require only two cold rolling stages from 0.125" to .023" (and no annealing prior to further rolling into foil). Thus, heavier hot line gages can be handled effectively in multi-stand cold mills.

Example 11

Coil stock suitable for making cans and the like was produced from an ingot having the composition 0.75 Fe, 0.58 Mn, 0.24 Mg, 0.15 Si, incidental impurities including 0.14 Cu, 0.06 Zn and 0.02 Ti, balance essentially aluminum, by hot rolling to 0.127" gage, annealing at 650° F. for two hours to minimize earring of the drawn can, cold rolling to 0.0193" and forming into cans without intermediate annealing or stress relieving.

Typical properties produced in the foregoing manner are tabulated below:

T.S.	Y.S.	Percent El.	Bulge Pressure (p.s.i.)	
			Before Coating	After Coating
33,400	31,400	3.0	94–98	92–95

Example 12

In like manner an ingot having the following composition: 0.73 Fe, 0.50 Mn, 0.30 Mg, 0.14 Si, incidental impurities including 0.09 Cu, 0.02 Zn, and 0.01 Ti, balance essentially aluminum, was hot rolled, annealed, cold rolled and formed into cans under the conditions set forth in Example 11. The resulting can stock and cans had the following properties:

T.S.	Y.S.	Percent El.	Gage	Bulge Pressure (p.s.i.)	
				Before Coating	After Coating
30,400	29,500	3	.0191	90–100	-----------

Example 13

An ingot having the following composition: 0.75 Fe, 0.48 Mn, 0.29 Mg and 0.14 Si, incidental impurities including 0.09 Cu, 0.02 Zn and 0.01 Ti, balance essentially aluminum, was treated in the manner set forth in Example 12 to produce can stock and drawn and ironed cans having the following properties:

T.S.	Y.S.	Percent El.	Gage	Bulge Pressure (p.s.i.)	
				Before Coating	After Coating
32,200	29,500	3	.0192	90–100	-----------

Example 14

An ingot was prepared having a composition 0.85 Fe, 0.5 Mn. the balance being essentially commercial grade aluminum having a purity of at least 99% with incidental impurities including Mg, Cu, Ni, Zn, Si and Ti, the total of which did not exceed 1%. Following the procedures set forth in Example 11, drawn and ironed cans of comparable characteristics are produced.

Example 15

The procedures of Example 11 are again employed using, however, an ingot having a composition 0.95 Fe, 1.0 Mg, the balance being essentially commercial grade aluminum having a purity of at least 99% with incidental impurities including Mn, Cu, Ni, Zn, Si and Ti, the total of which did not exceed 1%. The resulting drawn and ironed cans also exhibit favorable characteristics.

Examples 16–17

Again following the method outlined in Example 11, cans are produced from ingots of compositions tabulated below:

	Fe	Mn	Mg	Si
Example 16	0.9	0.5	0.8	----------
Example 17	0.9	----------	1.0	1.0

The balance of each of the above compositions is commercial grade aluminum of at least 99% purity having conventional incidental impurities, the total of which does not exceed 1%.

For purposes of clarity, the following terminology used in this application is explained below:

Hot rolling.—Rolling carried out at elevated temperatures, usually to convert the cast structure of an ingot to a wrought structure and to reduce the thickness of the resultant slab preparatory to cold rolling into strip of lighter gage. For aluminum and its alloys, the metal temperature during at least the first part of the hot rolling process is well above the recrystallization temperature, e.g. greater than 600° F. and usually 750° F.–1,000° F. or higher. The temperature usually drops as the hot rolling proceeds, with the final temperature often less than the recrystallization temperature, say 400°–500° F., so that cold work is effected. This cold work is called residual or equivalent cold work and is designated as an "E" factor.

Cold Rolling.—Rolling carried out at temperatures lower than the recrystallization temperature to decrease the thickness, and causing work hardening of the strip. The input metal temperature for cold rolling is usually room temperature or slightly higher.

Annealing.—A thermal treatment to effect softening of a cold worked structure by at least partial recrystallization or by relief of residual stresses.

While present preferred embodiments of the invention have been described, it will be apparent to those skilled in this art that the invention may be otherwise variously embodied and practiced within the scope of the following claims.

What is claimed is:

1. Aluminum foil composed of an alloy consisting essentially of aluminum, from 0.6% to about 2.5% iron, and about .05–0.3% silicon, by weight, with 0.05–1.0% total of silicon and incidental elements not exceeding 0.25% each from the group consisting of copper, manganese, magnesium, chromium, nickel, zinc and titanium, including not more than 0.10% copper; said alloy containing at least 0.75% total of iron and silicon, and having an iron-to-silicon ratio of at least 5:1.

2. Aluminum foil according to claim 1, in which said alloy includes up to about 0.25% silicon, a maximum of 0.10% zinc, the remainder of said incidental elements not exceeding about 0.05% each and about 0.15% total.

3. Aluminum foil according to claim 2, in which said alloy contains about 0.75–1.2% iron.

4. Aluminum foil according to claim 3, in which said alloy contains about 1% total of iron and silicon.

5. Aluminum foil made of an alloy consisting essentially of

(a) aluminum,

(b) from 0.6% to about 2.5% iron, by weight, and

(c) about .05–1.0% total of incidental impurities including no more than 0.10% copper;

the amount of iron being selected to provide substantially zero work hardening behavior; said alloy retaining sufficient ductility in work hardened condition to permit cold rolling from a hot line gage at least as thick as 0.100 inch to a final gage below .001 inch without the necessity of annealing or stress relieving at any intermediate thickness, and being adapted to conventional ingot casting and hot rolling practices preparatory to cold rolling; said foil being further characterized by its improved ductility and bursting strength.

6. Aluminum foil according to claim **5**, in which said alloy includes up to about 0.25% silicon and up to about 0.10% zinc; with copper, manganese, magnesium, chromium, nickel and titanium not exceeding about .05% each and about 0.15% total.

7. Aluminum foil according to claim **5**, in which said alloy contains about 0.75–1.2% iron.

8. An aluminous metal sheet product made of an aluminum base alloy containing iron as its principal alloying element by weight, said alloy consisting essentially of

(a) aluminum,

(b) from 0.6% to about 2.5% iron, by weight, and

(c) about .05–1.0% total of incidental elements ordinarily present as impurities in commercial grade aluminum of at least 99% purity;

said alloy having a low work hardening rate and sufficient ductility in work hardened condition to permit cold working to an extent of at least 90% without having to anneal or stress relieve the alloy in the course of such cold working, and being adapted to conventional ingot casting and hot rolling practices preparatory to cold working.

9. An article according to claim **8**, in which said alloy includes about .05–0.3% silicon and up to about 0.10% zinc; with copper, manganese, magnesium, chromium, nickel and titanium not exceeding about .05% each and about 0.15% total.

10. An article according to claim **8**, in the form of a can body.

11. An article according to claim **8**, in the form of a bottle cap.

12. An article according to claim **8**, in which said alloy contains more iron than silicon and more silicon than any other element except iron and aluminum.

13. An article according to claim **8**, comprising a can body having its peripheral side wall and one end formed integrally in one piece.

14. An article according to claim **8**, in the form of a drawn body.

15. An article according to claim **8**, in the form of coilable re-roll stock.

16. An article according to claim **9**, in which said alloy contains about 0.8% iron.

17. An article according to claim **9**, in which said alloy contains about 1.4% iron.

18. An article according to claim **9**, in which said alloy contains about 1.6% iron.

19. An aluminum base alloy consisting essentially of at least 96.5% aluminum, 0.75–2.5% iron, 0.1–2.5% magnesium and up to about 1.5% manganese, by weight with silicon and any incidental elements not exceeding 1% total; said alloy having a low work-hardening rate above 75% reduction and exhibiting sufficient ductility to permit cold working to the extent of at least 90% without the necessity of annealing or stress relieving the alloy in the course of such cold working.

20. An alloy according to claim **19**, including about 0.75–1.2% iron, about 0.1–1.0% magnesium and up to about 0.25% silicon, balance aluminum and incidental impurities.

21. An alloy according to claim **19**, including about 0.75–1.2% iron, about 0.25–0.8% manganese and up to about 0.25% silicon, balance aluminum and incidental impurities.

22. An alloy according to claim **21**, including about 1.5% total of iron and manganese.

23. An aluminum base alloy consisting essentially of aluminum, 0.75–2.5% iron, up to about 0.4% silicon and at least one additional alloying element from the group consisting of 0.1–2.5% magnesium and 0.1–1.5% manganese, by weight, with silicon and any incidental elements not exceeding 1% total, and the total amount of iron, silicon, magnesium, manganese and incidental elements not exceeding 3.5% of the alloy.

24. An alloy according to claim **23** having iron and manganese totaling from about 1% to about 2% of the alloy.

25. An alloy according to claim **23** including about 0.75–1.2% iron, about 0.25–0.8% manganese and about 0.1–1.0% magnesium.

26. A drawn and ironed can body having its peripheral side wall and one end formed integrally in one piece, said can body being adapted at its opposite end to be necked and flanged for attachment of a closure element without splitting said side wall, said can body being made of work-hardened aluminous metal composed of an alloy consisting essentially of aluminum, up to about 1 weight percent incidental impurities, a first alloying element consisting of iron, and at least one additional alloying element selected from the group consisting of magnesium, manganese and silicon, said alloying elements being present in amounts sufficient to provide an alloy having a low work-hardening rate above 75% reduction and exhibiting sufficient ductility to permit cold working to the extent of at least 90% without the necessity of annealing or stress relieving the alloy in the course of such cold working.

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