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ALUMINUM BASE ALLOY

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4 Claims. (Cl. 148—32.5)

This application is a continuation-in-part of our co-pending patent application Serial No. 304,677, filed August 26, 1963, and now abandoned.

This invention relates to aluminum base alloys suitable for making wrought structural members, and it is more particularly concerned with those alloys which contain zinc and magnesium as the principal added elements in respect to the amounts present in the alloys.

Aluminum base alloys of the type just referred to have been known for many years. When worked, solution heat treated and age hardened, they develop high tensile and yield strengths, especially if a small amount of copper is included in the composition. Although the attainment of a high strength is advantageous in many instances, the alloys may be deficient in other respects, such as resistance to stress corrosion, weldability and notch toughness. We have discovered that within relatively narrow limits zinc, magnesium and other elements unite to produce an alloy which, in the absence of copper (except as an impurity), possesses a unique combination of properties.

It is one of the objects of our invention to provide a strong aluminum base alloy which in the age hardened condition is also resistant to stress corrosion cracking. Another object is to provide an alloy which can be readily welded. Still another object is to provide an alloy product which is free from segregation of relatively insoluble constituents. Still another object is to provide an alloy, which, particularly in the solution heat treated and age hardened condition, has a high notch toughness. These and other objects and advantages will become apparent from the following description and examples.

We have found that the combination consisting essentially of 3.5 to 8% zinc, 0.75 to 4.3% magnesium, 0.05 to 0.75% manganese, 0.06 to 0.30% chromium, 0.06 to 30% zirconium and 0.01 to 0.15% titanium with aluminum yields an alloy which is free from segregation, if the proper portions of high melting elements are employed, and which when worked and age hardened has unexpectedly high properties. The foregoing percentage values refer to percent by weight of the several elements. In particular, the alloys so produced possess a high strength, a high resistance to stress corrosion cracking, a high notch toughness at low temperatures and an excellent weldability. The combination of these properties and their high values which characterize our alloys are not found in the alloys which are devoid of the high melting point elements manganese, chromium, zirconium and titanium.

In respect to impurities, the alloys should be free from copper, that is, the alloys should contain not more than 0.1% of this element. Iron should not exceed 0.4% and silicon should not exceed 0.35%, the total iron plus silicon preferably not exceeding 0.6%.

The wrought products made from the alloys should be free from segregation of the relatively insoluble high melting point elements manganese, chromium, zirconium and titanium. This means that these elements and any constituents they form with aluminum or with each other or both should be in a finely divided condition and be uniformly dispersed, as compared to coarse particles many times the size of the fine particles which may be

non-uniformly distributed throughout the alloy products. Freedom from segregation serves to improve the properties referred to above. To assure such freedom from segregation the high melting point elements should be employed in amounts within the above-described ranges therefor such that the sum of

percent chromium × percent zirconium + 1.23 × percent titanium + 0.19 × percent manganese

does not exceed 0.6%, and preferably does not exceed 0.5%. This means that all of these four elements cannot be used at one time in the maximum amounts stated above. It will be appreciated that if the alloys are free from segregation in their initial form, that freedom will persist during subsequent working operations and thermal treatments.

The zinc and magnesium components are soluble in solid aluminum and they are chief contributors to strength when the alloy is age hardened. If less than the minimum amounts are employed, the strength suffers while if the maximum quantities are exceeded, fabrication and corrosion problems are encountered. The zinc content should, in any case, exceed the magnesium content of the alloy. For example, these components may desirably be present in such proportions as 4% zinc and 2% magnesium or 7% zinc and 1% magnesium. The term "age hardened" as used herein refers to both spontaneous aging at room temperature and to a low temperature treatment applied to an alloy where a substantial amount of the zinc and magnesium is in a state of solid solution before age hardening is started, as more particularly described below.

The combination of manganese, chromium, zirconium and titanium in the alloys containing zinc and magnesium within the ranges mentioned above also improves the resistance to stress corrosion cracking, notch toughness, and minimizes the occurrence of cracks where the alloys are being fusion welded. Alloys without the four high melting point elements do not have the resistance to corrosion that is generally required nor do they possess high notch toughness, especially at low temperatures. The alloys are especially sensitive to the presence or absence of zirconium, where the other three elements are present, in respect to improved weldability, i.e. freedom from cracks in or adjacent to the weld bead, when a filler metal is used which also contains zinc and magnesium as the chief added alloy components. Filler metal compositions especially suited for use with the alloys described herein are described and claimed in the co-pending patent application of Dudas and Collins, Serial No. 306,622. The presence of zirconium in the alloys being welded is especially effective in eliminating cracks in or adjacent to the weld deposit under those conditions. The amount of zirconium which is effective for this purpose, as well as the other purposes named above, is small, less than 0.06% failing to have any significant effect while more than 0.30% introduces problems of segregation.

The manganese, chromium and titanium components are also important in obtaining a good welded joint and in obtaining improved resistance to corrosion and stress corrosion cracking.

As mentioned above, wrought alloys of this type develop their highest strength following a solution heat treatment and age hardening. Solution heat treatment can be effected by heating at a temperature between 700 and 970° F. for a sufficient length of time to bring about solution of the zinc and magnesium, for example, ½ to 24 hours depending upon the mass of material being treated, the temperature and other well-known factors. To retain a substantial portion of the dissolved elements in a state of solution the alloys are cooled to room tem-

perature or slightly above that temperature by quenching in a suitable medium. The alloys can be cooled relatively rapidly or slowly and for this reason they are considered to have a low quench sensitivity which is an important operational advantage.

The resistance to stress corrosion cracking is, however, affected by the thermal treatments, the maximum resistance being achieved through a sequence of thermal treatment steps being achieved through a sequence of thermal treatment steps as described and claimed in our copending patent application Serial No. 276,156. Where structures made from these alloys are not exposed to stress corroding conditions, or the conditions are relatively mild, the alloy products can be given a conventional single step age hardening treatment. The artificial age hardening treatment in any case consists of heating the alloys containing the zinc and magnesium in solid solution to a temperature between 200 and 320° F. and holding them within that range for a total period of 10 to 48 hours whereupon the alloys are cooled to room temperature. However, if the wrought products of these alloys have received a solution heat treatment and are quenched, they may be allowed to age harden at room temperature. Although the thermal treatments are important in developing strength, resistance to corrosion and other properties, the presence of the relatively insoluble elements manganese, chromium, zirconium and titanium are also important, for in their absence the desired properties are not attained.

In addition to possessing the properties mentioned above the thermally treated alloys are highly resistant to impact such as encountered in ballistic plate. It has been found that ballistic members made of these alloys, when solution heat treated and age hardened, are more resistant to impact than members made of a conventional alloy composed of aluminum, 4.5% magnesium, 0.45% manganese and 0.1% chromium. It has been observed, for example, that a higher protection is obtained on a weight basis than with the aforesaid conventional alloy.

A property, known as notch toughness, is another measure of resistance to impact. The notch toughness of our alloys in the age hardened condition is significantly higher than that of some of the present commercial high strength alloys, particularly at sub-zero temperatures. The test used to determine notch toughness is described in the Bulletin of the American Society for Testing Materials for January 1960, pages 29 to 40 and February 1960, pages 17 to 28. The tensile strength is determined on notched specimens at the desired temperature and the values compared to those of unnotched specimens, the result being expressed in a ratio of the former to that of the latter.

The alloys which have been described can be melted and cast according to normal practices. For those that are to be made into wrought products any of the conventional metal working processes can be used such as rolling, forging, extrusion, drawing and the like.

The advantages of our invention are illustrated by the following test data.

The tensile properties and notch toughness of alloys, with and without zirconium, are shown from the following tests at room temperature and at −320° F. The composition of the alloys is given in Table I below.

TABLE I.—PERCENT COMPOSITION OF ALLOYS

Alloy	Percent Zn	Percent Mg	Percent Mn	Percent Cr	Percent Ti	Percent Zr	Percent Cu	Percent Fe	Percent Si
A	4.10	2.24	0.22	0.12	0.01	----------	0.04	0.17	0.10
B	4.15	1.92	0.22	0.11	0.01	0.12	0.03	0.18	0.08
C	4.32	2.51	0.28	0.16	0.02	----------	0.03	0.17	0.08
D	4.18	2.67	0.26	0.16	0.02	0.14	0.03	0.16	0.08

Alloys A and B were cast and rolled to sheet 0.063 inch in thickness in conventional manner. Samples of the sheet were solution heat treated 1 hour at 860° F., quenched in cold water and age hardened by heating at 250° F. for 48 hours. Tensile properties and notch tensile strength were determined at 75 and −320° F. with the following results at a theoretical stress concentration factor of 17.

TABLE II.—TENSILE PROPERTIES AND NOTCH STRENGTH OF SHEET SPECIMENS

Alloy	Temp., ° F.	Tensile Properties		Percent Elongation	Notch Tensile Strength, p.s.i.	Ratio	
		Tensile Strength, p.s.i.	Yield Strength, p.s.i.			Notch T.S./ Unnotched T.S.	Notch T.S./ Unnotched Y.S.
A	75	65,200	58,600	10.5	63,800	0.98	1.09
A	−320	83,900	70,400	15.0	59,000	0.68	0.81
B	75	64,300	58,800	11.0	63,900	0.99	1.09
B	−320	83,800	70,100	15.5	72,200	0.86	1.03

Alloys C and D were cast and rolled to plate 1½ inch in thickness, solution heat treated, quenched and aged at the same temperatures and for the same length of time as the preceding sheet specimens. Transverse specimens were cut from the plate and tensile and notch properties determined as above with a theoretical stress concentration factor of 12. The results are given in Table III.

TABLE III.—TENSILE PROPERTIES AND NOTCH STRENGTH OF PLATE SPECIMENS

Alloy	Temp., ° F.	Tensile Properties		Percent Elongation	Notch Tensile Strength, p.s.i.	Ratio	
		Tensile Strength, p.s.i.	Yield Strength, p.s.i.			Notch T.S./ Tensile T.S.	Notch T.S./ Tensile Y.S.
C	75	68,100	60,000	13.0	89,400	1.31	1.49
C	−320	86,100	71,800	13.0	75,800	0.88	1.06
D	75	67,200	59,100	13.5	90,800	1.35	1.54
D	−320	85,600	70,800	13.0	84,400	0.98	1.19

The benefit of zirconium upon the ratio of notch strength to tensile strength, i.e. notch toughness, at a very low temperature is at once apparent. This effect of zirconium in combination with the other insoluble elements, manganese, chromium and titanium is unique and unexpected as far as we know.

The resistance to stress corrosion cracking of an alloy containing the four insoluble elements and one without zirconium is to be seen in the following examples. Two alloys were employed which had the composition appearing in Table IV.

TABLE IV.—PERCENT COMPOSITION OF ALLOYS

Alloy	Percent Zn	Percent Mg	Percent Mn	Percent Cr	Percent Zr	Percent Ti
E	4.14	2.26	0.30	0.10		0.02
F	4.19	2.26	0.27	0.11	0.22	0.02

The alloys were cast and rolled to sheet 0.064 inch in thickness according to usual practice. Sections cut from the sheet were solution heat treated 1 hour at 860° F., quenched in cold water, and age hardened 48 hours at 250° F. Test specimens were stressed to 75% of the yield strength of the alloys and exposed to the well-known alternate immersion test in an aqueous solution of 3½% NaCl. All of the specimens of alloy E failed within 33 days whereas all of the specimens of alloy F remained intact. The improvement gained by the presence of zirconium is clearly evident.

The effect of manganese, chromium, zirconium and titanium upon the tendency for weld beads to crack between structural members is illustrated in the following test which involved welding a ½ inch thick plate 10 inches in length to a 1 inch thick plate of the same length in the form of a T-joint. Welding was performed by the inert gas arc welding method wherein a filler rod was used to form a fillet on both sides of the junction of the ½ inch plate with the 1 inch plate. Two weld-formed in a single pass from one end of the plate to the other, and a second one on another specimen wherein the fillet formation was interrupted and then continued. Cracks generally occur longitudinally of the weld bead and the length of the crack is considered to indicate relative weldability of the structural or parent metal mem bers.

In the test a filler metal wire was used having the following composition: 3.90% magnesium, 2.00% zinc, 0.51% manganese, 0.10% chromium, 0.12% titanium, 0.14% iron and 0.10% silicon, the balance being aluing procedures were followed one in which the fillet was minum. Hot rolled plates were used in the as-rolled condition, the plates having the compositions stated in Table V.

TABLE V.—PERCENT COMPOSITION OF ALLOYS

Alloy	Percent Zn	Percent Mg	Percent Mn	Percent Cr	Percent Zr	Percent Ti	Percent Cu	Percent Fe	Percent Si
G	3.93	2.01						0.13	0.09
H	4.15	1.92	0.22	0.11	0.12	0.01	0.03	0.18	0.08

A pair of plates of alloy G were welded by each of the two welding procedures. Plates of alloy H were welded in the same manner. The length of cracks in the weld beads produced by the two methods was measured and an average value determined. It was found that in the case of alloy G the cracks extended over 49% of the total length of the weld bead whereas in the case of alloy H, the carcks amounted to only 3% of the total length of the weld beads. This is considered to show quite clearly the superior welding characteristics of the alloys of the invention.

Having thus described our invention and certain embodiments thereof, we claim:

1. A copper-free aluminum base alloy consisting essentially of aluminum, 3.5 to 8% zinc, 0.75 to 4.3% magnesium, wherein the zinc content always exceeds the magnesium content, 0.05 to 0.75% manganese, 0.06 to 0.30% chromium, 0.06 to 0.30% zirconium and 0.01 to 0.15% titanium, the iron impurity not exceeding 0.4% and the silicon impurity not exceeding 0.35%, said manganese, chromium, zirconium and titanium being employed in amounts within the foregoing ranges such that the sum of percent chromium+percent zirconium+1.23×percent titanium+0.19×percent manganese does not exceed 0.6%, said alloy being characterized by substantial freedom from segregation of said manganese, chromium, zirconium and titanium components.

2. An alloy according to claim 1 wherein the zinc content exceeds the magnesium content and the sum referred to does not exceed 0.5%.

3. An alloy according to claim 1 having an internal structure developed by age hardening at 200 to 320° F. for a total period of 10 to 48 hours.

4. An alloy according to claim 1 having an internal structure resulting from a solution heat treatment at 700 to 970° F., and age hardening at 200 to 320° F. for a total period of 10 to 48 hours.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,304,209 February 14, 1967

William A. Anderson et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 45, for "30%" read -- 0.30% --; column 2, line 7, for "chromium ×" read -- chromium + --; column 6, line 5, strike out "ing procedures were followed one in which the fillet was" and insert the same after "weld-" in line 48, column 5; column 6, line 25, for "carcks" read -- cracks --.

Signed and sealed this 17th day of October 1967.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

Dedication

3,304,209.—*William A. Anderson*, Verona, and *William D. Vernam*, New Kensington, Pa. ALUMINUM BASE ALLOY. Patent dated Feb. 14, 1967. Dedication filed Apr. 16, 1970, by the assignee, *Aluminum Company of America.*

Hereby dedicates the entire patent to the Public.

[*Official Gazette August 18, 1970.*]