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ALUMINUM-HIGH SILICON ALLOYS

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The invention relates to a method of preparing aluminum alloys exhibiting superior wear resistance and to the alloys formed by such method.

It is well known that silicon improves the wear resistance of aluminum, particularly when the resulting alloy is hypereutectic i.e., contains above about 12 percent by weight of silicon. However, as the silicon content is increased above 12 percent, the primary silicon particles which separate during solidification of the molten alloy tend to grow into large acicular shapes that segregate and seriously impair ductility of the metal in cast form. This problem has been partially overcome by the addition of phosphorus which prevents silicon particles forming in the cast metal from growing to an excessively large particle size. However, while phosphorus additions are effective in so influencing the size of silicon particles in aluminum containing up to about 25 percent silicon, still higher silicon levels cause extreme brittleness, segregation, and casting problems, even though phosphorus is added. Since large silicon concentrations are latently capable of increasing the wear resistance and reducing the co-efficient of thermal expansion of aluminum alloys, it is highly desirable to find a method of preparing aluminum alloys containing more than about 25 percent by weight of silicon while avoiding their normally unfavorable properties.

It has now been discovered that aluminum alloys containing from about 26 to 45 percent by weight of silicon are brought into a highly usable form of metal exhibiting desirably high wear resistance, low thermal expansivity and other desirable properties upon transforming the alloy from a body of molten metal above its liquidus temperature into finely dispersed droplets and rapidly solidifying the same, whereby fine particulate aluminum-silicon alloy is formed, heating the fine particulate alloy to a temperature of about 800° F., and consolidating the heated particles under pressure with or without subsequent working.

The alloy of the invention contains from about 26 to 45 percent by weight of silicon and the balance substantially aluminum. Preferably the alloy contains from about 30 to 35 percent by weight of silicon. Such quantities of silicon far exceed the solid solubility of silicon in aluminum and the silicon separates as a brittle second phase having a volume in the range of about 27 to about 50 percent, based on the total volume of the alloy. Preferably the total volume of brittle second phase or phases is in the range of about 33 to 40 percent.

As a critical aspect of the invention, the particles of second phase silicon must be limited in size, by quenching, i. e., rapid cooling of the alloy, to a longest dimension not greater than 1×10^{-3} inch. Longest dimensions run as small as 1×10^{-5} inch and finer with particles having a longest limension about 1×10^{-4} inch predominating.

If desired, the alloy may be further improved or modified for specific uses by the addition of no more than

about 10 percent by weight of one or more of such metals as magnesium, copper, manganese, nickel, chromium, iron and titanium. In any event, the addition of such elements, singly or in compatible combination, is limited to quantities yielding a total amount of brittle second phase, in the alloy, including precipitated silicon, of less than about 50 percent by volume of the alloys. The term compatible combination refers to a combination of two or more additive metals which enhances the properties of the aluminum-silicon alloy in a useful manner and wherein the presence of each metal, in the combination, does not materially detract from the benefit of adding the remainder of the combination.

While phosphorus may be added, it is not at all essential, its normal modifying effect diminishing with the size of the frozen droplets produced directly from the molten metal. The alloy without deliberate phosphorus addition would normally contain less than about 0.005 percent by weight of phosphorus.

The alloy may be prepared in a standard manner by melting together aluminum and silicon and any other desired metal additions. If desired, the modifying metals may be added in the form of pre-alloys with aluminum or silicon.

The alloy, while in molten form, and at a temperature above its liquidus temperature is converted into fine droplets in any suitable manner. A convenient method of forming the droplets consists of jet atomizing in which a continuous stream of molten metal is intercepted by a high velocity jet of an inert gas. The jet of gas not only disperses the molten metal into fine droplets but facilitates cooling and solidification of the droplets into solid particles.

If desired, particles may be prepared in other ways, as by wheel atomizing in which the stream of molten metal is directed onto the surface of a spinning wheel or rotor within an enclosed zone containing a substantially inert atmosphere. If atomizing equipment is not available it is also possible to carry out splat casting in which a fine stream or spray of droplets of the molten metal is simply projected against a cold metal surface causing the stream or spray to form highly irregularly shaped droplets which cool promptly into relatively coarse non-spherical articles. Air may be used in jet or wheel atomizing if irregular shaped atomized particles are desired.

The particulate metal, however formed, is pre-heated to consolidation temperatures, generally in the range of 800 to 1,000° F. Consolidation is carried out in any desired manner as by compacting, extruding, or rolling directly into sheet. Extrusion is generally carried out at a speed in the range of 2 to 20 feet per minute, but in any event, lower than the speed at which hot shorting occurs. If desired, the consolidated metal may be used as consolidated, or further formed or shaped as by pressing, rolling, forging or impact extruding.

The alloy prepared in the foregoing manner contains small size silicon particles within the grain structure of the metal, and the metal exhibits superior wear resistance, low thermal expansivity, and surprisingly good mechanical properties, e.g., high tensile strength, high hardness, and appreciable ductility.

A number of aluminum-high silicon alloys were prepared according to the invention. In each case, part of the molten metal was jet atomized and part of the metal was cast into 3 inch diameter billets. The resulting atom-

ized pellets and the cast billets were respectively preheated to a temperature of 800 to 1,000° F. in the container of an extrusion press and extruded into ⅛ by 1¼ inch strip at a speed of about 10 feet per minute. In each case, the surface of the pellet extrusion was generally found to be smoother, on visual inspection, than that of the corresponding ingot extrusion. Silicon second phase particles, in the pellet extrusions, were found to have a longest dimension less than 0.001 inch and predominantly about 0.0001 inch. Test bars were cut from each of the extruded ⅛ by 1¼ inch strips and subjected to physical testing. The composition of the alloys and the test results are listed in Table I.

TABLE I

Run No.	Composition, weight percent[1]			Pellet Extrusion					Ingot Extrusion				
	Si	Ti	Fe	Percent E	TYS	TS	Hardness	Test Temp., ° F.	Percent E	TYS	TS	Hardness	Test Temp., ° F.
1	33			2	18	30	67	75	1	12	16	62	75
							42	400				37	400
							26	600				23	600
2	38				28	34	100	75			13	59	75
							67	400				39	400
							42	600				21	600
3	33	3		1	24	36				14	17		
4	33		2		20	31			1	13	19		
5	29	2.7	3.6	1	23	37	80	75	1	14	19	57	75
							53	400				64	400
							33	600				21	600

[1] Balance commercial purity aluminum.
PercentE=percent elongation in 2 inches.
TYS=tensile yield strength in 1,000's of pounds per square inch.
TS=ultimate tensile strength in 1,000's of pounds per square inch.
Hardness=Brinell hardness (500 grams load).

By way of illustration of the excellent wearing qualities of the present alloy, samples of three of the alloys described above in Table I and extruded according to the invention were subjected to a standard wear resistance test.

In each test, two samples, each 2 inches in length were cut from different parts of the same extruded strip, machined to produce a flat surface and rubbed back and forth over a hardened (62 Rockwell) steel block ground to a finish of 30 to 50 micro inches. Weights were attached to the top of each sample to produce a constant vertical load of 285 grams. Total cumulative weight loss of each sample was determined after each of five 100,000 cycle periods, as an indication of the wear resistance of the test alloy.

The compositions of the alloys tested and the results of the wear resistance tests are shown in Table II. The results show that these alloys exhibit expected high wear resistance in addition to the other superior properties described.

TABLE II

Run No.	Composition, weight percent[1]			Sample[2] No.	Wear resistance—total weight loss in milligrams after successive 100,000 cycle periods				
	Si	Ti	Fe		1	2	3	4	5
1	33			1	32.1	38.0	47.6	54.4	57.8
				2	15.6	17.2	20.3	23.5	24.6
2	38			1	6.2	6.6	11.8	14.4	14.6
				2	4.1	5.9	10.5	11.8	19.5
5	29	2.7	3.6	1	4.3	5.9	7.3	7.3	7.4
				2	18.5	30.2	35.0	36.6	40.7

[1] Balance commerial purity aluminum.
[2] Duplicate test samples were cut from different parts of same extruded strip.

The method and composition of the invention having been thus fully described various modifications thereof will at once be apparent to those skilled in the art and

scope thereof is to be considered limited only by the claims appended hereafter.

We claim:

1. The method of preparing a wear-resistant aluminum-silicon alloy which comprises,

providing an aluminum-silicon alloy in molten form at a temperature above its liquidus temperature, said alloy comprising from about 26 to 45 per cent by weight of silicon and the balance substantially aluminum,

dispersing said molten alloy into droplets,

quenching said droplets thereby to obtain solidified particulate alloy,

pre-heating said particulate alloy at a temperature in the range of about 800 to 1,000° F., and consolidating the so-heated particulate alloy.

2. The method as in claim **1** in which consolidation is carried out by extruding the alloy at a speed in the range of about 2 to 20 feet per minute.

3. The method as in claim **1** in which the molten alloy is dispersed into droplets by means of a gas jet.

4. The method as in claim **1** in which the alloy contains, in addition to aluminum and silicon, not more than 10 percent by weight of a modifying metal addition selected from the group consisting of magnesium, copper, manganese, nickel, chromium, titanium, iron and compatible combinations thereof.

5. An aluminum-silicon alloy which comprises from about 26 to 45 percent silicon and characterized by the presence of separated second phase silicon particles, substantially all said particles having a longest dimension less than about 0.001 inch.

6. The alloy as in claim **5** containing less than about 0.005 percent by weight of phosphorus.

7. The alloy as in claim 5 containing not more than 10 percent by weight of a modifying metal addition selected from the group consisting of magnesium, copper, manganese, nickel, chromium, titanium, iron, and compatible combinations thereof.

8. The alloy as in claim 5 containing from 30 to 35 percent by weight silicon.

9. The alloy as in claim 5 in extruded form.

References Cited

UNITED STATES PATENTS

3,147,110	9/1964	Foerster	75—226 X
3,226,267	12/1965	Foerster	75—148 X

FOREIGN PATENTS

563,616	8/1944	Great Britain.

OTHER REFERENCES

Dixon and Shelly: "Hypereutectic Aluminum-Silicon Alloys Produced by Powder Metallurgy Techniques," International Journal of Powder Metallurgy, vol. I, No. 4, October 1965, pp. 28–36.

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