Dec. 7, 1965 E. R. BAUGH ET AL 3,222,227

HEAT TREATMENT AND EXTRUSION OF ALUMINUM ALLOY

Original Filed May 13, 1960 5 Sheets-Sheet 1

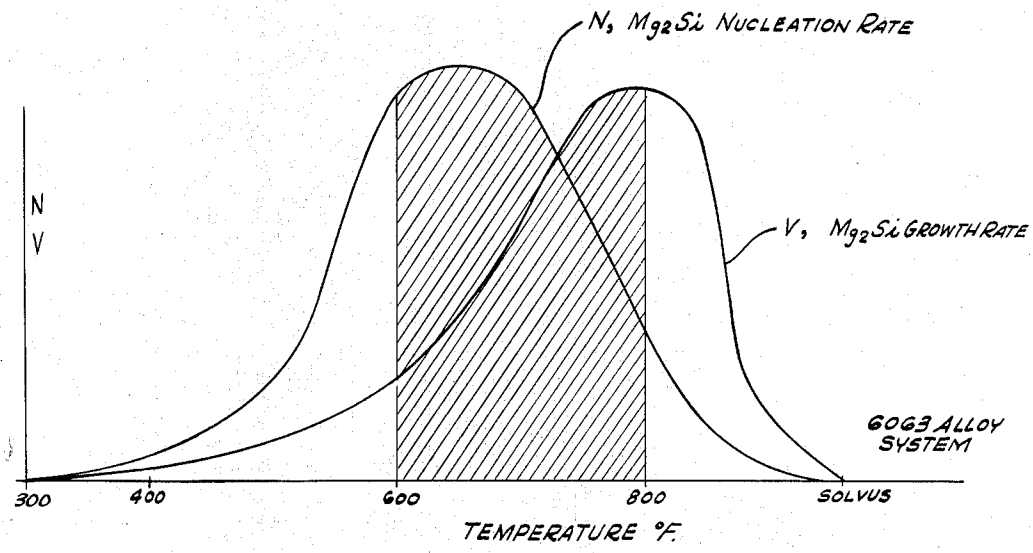

Fig. 1

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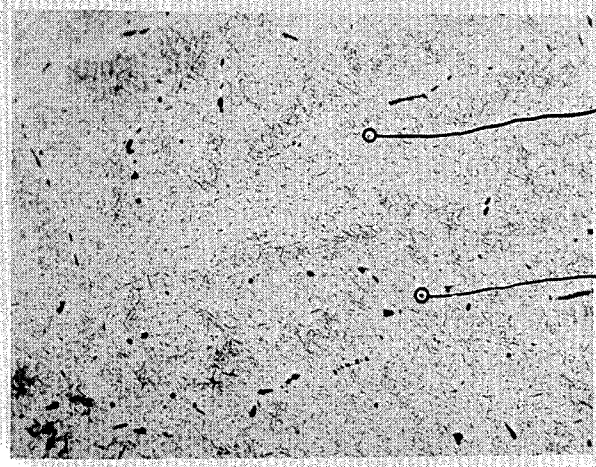

fig. 2

BILLET (500 X HF ETCHED)
COOLING CYCLE: 300/600/50

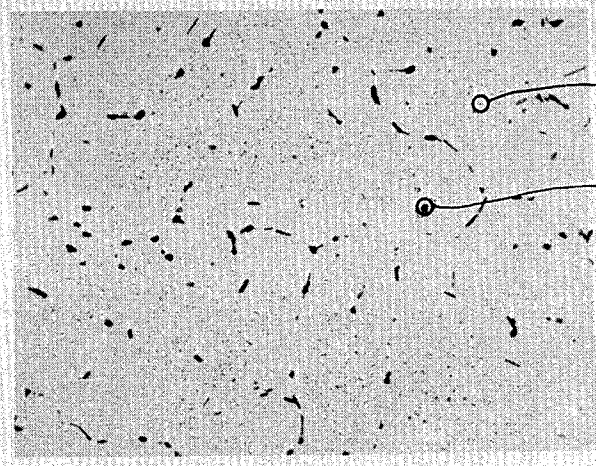

fig. 3

BILLET (500 X HF ETCHED)
COOLING CYCLE: 200/800/50

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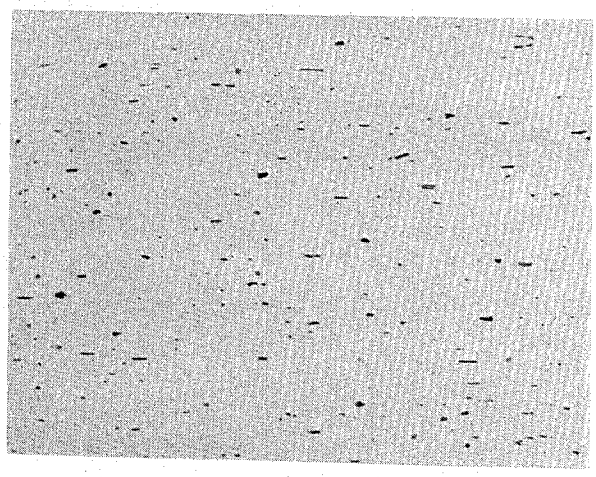

Fig. 4

AGED EXTRUSION (500X-HF ETCHED)
BILLET COOLING CYCLE: 300/600/50

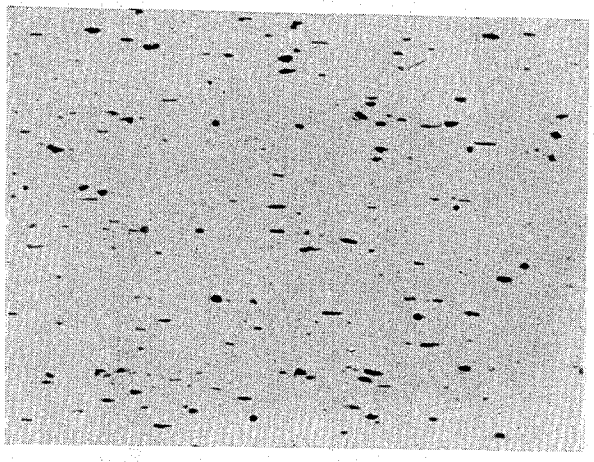

Fig. 5

AGED EXTRUSION (500X-HF ETCHED)
BILLET COOLING CYCLE: 200/800/50

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HEAT TREATMENT AND EXTRUSION OF ALUMINUM ALLOY

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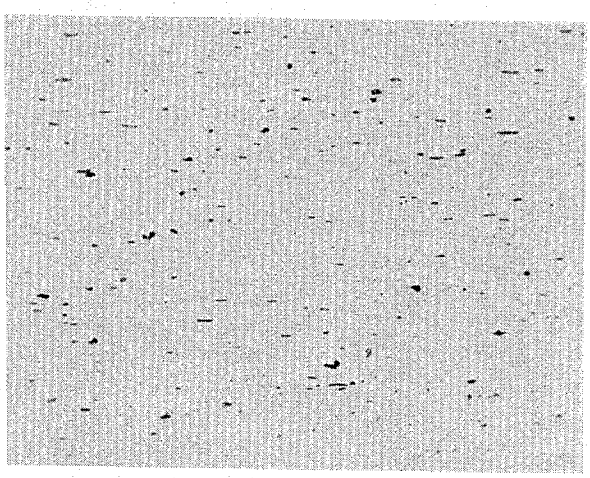

Fig. 6

AGED EXTRUSION (500X-HF ETCHED)
BILLET COOLING CYCLE: 200/ROOM TEMP.

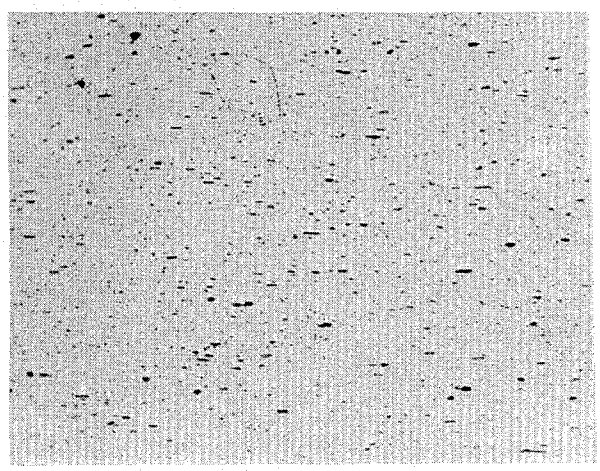

Fig. 7

AGED EXTRUSION (500X-HF ETCHED)
BILLET COOLING CYCLE: 300/800/600

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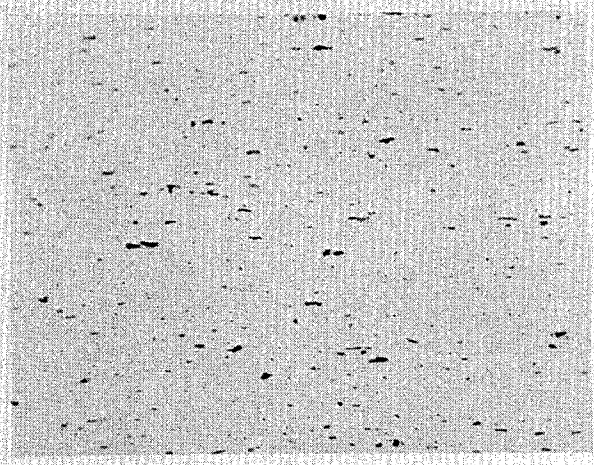

Fig. 8

AGED EXTRUSION (500X-HF ETCHED)
BILLET COOLING CYCLE: 300/ROOM TEMP.

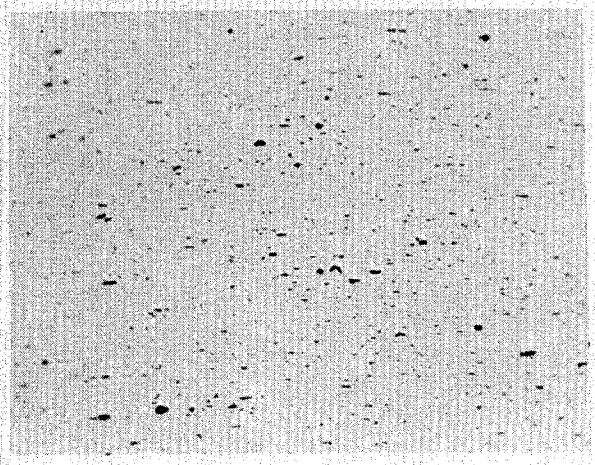

Fig. 9

AGED EXTRUSION (500X-HF ETCHED)
BILLET COOLING CYCLE: WATER QUENCH/400/50

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HEAT TREATMENT AND EXTRUSION OF ALUMINUM ALLOY

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Continuation of application Ser. No. 28,814, May 13, 1960. This application Mar. 13, 1964, Ser. No. 351,760

20 Claims. (Cl. 148—11.5)

This application is a continuation of our application Serial No. 28,814, filed May 13, 1960, now abandoned, for "Heat Treatment and Extrusion of Aluminum Alloy."

The invention relates to an improved process for facilitating the extrusion of an aluminum alloy of the precipitation hardenable type and to the billet product produced thereby. More particularly, the invention is concerned primarily with alloys in which the principal hardening constituents are magnesium and silicon, which may be present in the form of magnesium silicide (Mg_2Si).

In an aluminum extrusion plant, the aluminum is fed to the extrusion equipment in the form of cast billets of a convenient size, which are first heated to a proper temperature high enough for extrusion, and are then forced through the extrusion die to form an elongated part of a predetermined cross-section. At some time prior to the mentioned heating step, the billet may be homogenized, by maintaining the billet at a relatively high homogenizing temperature for an extended period of time which places the hardening constituents in solution in the aluminum. This homogenizing step may be performed by the prime producer of the aluminum billets, with the billets then being sold to an extrusion plant in homogenized condition.

A major object of the present invention is to provide a new type of heat treating procedure which will so precondition an aluminum alloy billet of the above discussed character as to allow the ultimate extrusion process to be performed at a considerably lower temperature than has heretofore been possible, and will do so without adversely affecting the mechanical properties of the final extruded product, and further results in a novel billet microstructure having novel characteristics. A reduction in the temperature of extrusion allows the aluminum to be extruded at a considerably increased speed, to thereby increase the productive capacity of a particular piece of extruding equipment.

In the past, it has been necessary to maintain the aluminum alloy at a temperature considerably higher than would otherwise be desired during extrusion, since a reduction in the temperature during extrusion drastically and adversely affected the mechanical properties (tensile strength and ultimate strength) of the final product. When a billet is pretreated by the process of the present invention, on the other hand, it is possible to perform the extrusion process at any temperature which is high enough to give the alloy sufficient fluidity to allow it to be forced through the extrusion die with the extrusion pressures normally used today, and yet in spite of this relatively low temperature of extrusion the ultimate product has mechanical properties and a surface finish which are at least as good as those heretofore attainable only at higher extrusion temperatures.

These and other objects of the invention will become more clearly understood with reference to the accompanying drawing and photomicrographs, wherein:

FIGURE 1 is a graph covering, in relative fashion, the nucleation rate and growth rate curves for Mg_2Si in a 6063 alloy system plotted against temperature;

FIGURE 2 is a photomicrograph of a cross-section of a billet microstructure enlarged 500×, the billet having been processed in accordance with the teachings of this invention;

FIGURE 3 is a photomicrograph of a cross-section of a billet microstructure enlarged 500×, the billet having been processed in a manner generally equivalent to that followed by the prior art;

FIGURE 4 is a photomicrograph of a cross-section of a T6 aged extrusion microstructure in 500× enlargement, the billet microstructure of which is shown in FIGURE 2;

FIGURE 5 is a photomicrograph of a cross-section of a T6 aged extrusion microstructure in 500× enlargement, the billet microstructure of which is shown in FIGURE 3; and

FIGURES 6 through 9 are photomicrographs of cross-sections of T6 aged extrusion microstructures, all in 500× enlargement, the extrusions having been pretreated in their billet stage, in accordance with the teachings of this invention.

In general, the results of this invention are attained by a method which is designed to very effectively retain or lock at least a portion of the hardening constituents in solution in the billet at the end of the homogenization procedure, and which does so in a manner such that these constituents then appear to remain in solution or, if precipitated, are mainly present in a small or very fine readily redissolvable precipitate form, even after the billet has cooled to ambient temperature. In particular, it is believed that most of the magnesium and silicon is retained in solution or as a fine readily redissolvable precipitate, by cooling or quenching the billet after homogenization more rapidly than is conventional in the art, with the rate of cooling being especially high as the temperature of the billet decreases through a critical precipitation range that we have found to exist.

To now commence a rather thorough discussion of the complete process through which an aluminum alloy treated in accordance with the invention passes up to the time of actual extrusion, the first step is of course the casting of the billet, which initial casting is performed by the prime producer of the alloy, usually at a temperature of about 1400° F. As mentioned, the invention is concerned primarily with alloys in which the principal precipitation hardening constituents are magnesium and silicon, normally considered to be present mainly as magnesium silicide (Mg_2Si). Even more specifically, we are especially concerned with the particular alloy which is designated alloy No. 6063 under the Aluminum Association four digit designation system. This alloy contains between .2 percent and .6 percent silicon and between .45 percent and .9 percent magnesium, with other impurities being present in not more than the following maximum amounts:

	Percent
Iron	.35
Copper	.10
Manganese	.10
Chromium	.10
Zinc	.10
Titanium	.10
Others (total)	.15

After the billet has been cast, it may be allowed to cool, and is then homogenized to force most of the magnesium and silicon into solution in the aluminum crystals of the billet. Such homogenization is effected by heating the billet to a proper homogenizing temperature for the alloy, specifically a temperature between about 990° F. and 1100° F., and maintaining the billet at that temperature long enough to make certain that most of the magnesium and silicon, and preferably substantially all of it, is in fact placed in solution. Desirably, the billet is maintained at the homogenizing temperature for at least about four hours, and for best results at least about five to six hours.

As mentioned above, a very critical portion of the present invention relates to the rate at which the billet is cooled or quenched after the homogenizing period. More particularly, it is theorized that the billet must be cooled after homogenization fast enough to assure retention in solution of a large portion of the magnesium and silicon, preferably most of it, and to assure that any precipitate that is formed is mainly present in the form of small or very fine readily redissolvable precipitate of Mg_2Si.

It should be understood at the outset that the prior art either taught a slow, retarded, or normal cooling in still air, as in Beck U.S. Patent No. 2,381,714, or Fritzlen U.S. Patent No. 2,249,353, or taught that the extrusion should be performed *immediately* after a partial quench of the billet to the temperature of extrusion (as in Murphy U.S. Patent No. 3,019,144, Nock U.S. Patent No. 1,926,057, Bobbs U.S. Patent No. 2,614,053, or Deutsch U.S. Patent No. 2,249,349). In conventional commercial practice, a billet load is cooled at an average rate of 50° F.–75° F. from homogenization down to about 150° F. The application of a high rate of cooling to a billet, from at, or within several hundred degrees of, its homogenization temperature, thus represents a complete departure from orthodox practice, and yields totally unexpected and surprising results with respect to the mechanical properties of the subsequent aged extrusion.

The theoretical basis underlying the use of high rates of cooling of the billet after homogenization, and its effect on the subsequent extrusion process, will now be discussed in some detail.

In order to attempt to fully understand the basis for the invention described and claimed herein, the rate at which Mg_2Si nucleates and grows in a 6063 alloy system has been explored. As a result, it has been found that the nucleation rate, and growth rate, curves for the 6063 alloy system are represented in approximate relationship by the curves shown in FIGURE 1. The nucleation rate curve and the growth rate curve are here plotted as a function of temperature based on experimental and theoretical considerations. Values for the nucleation and growth rate curves are set out in relative terms rather than in absolute values.

The term "nucleation" refers to the first appearance of particles of a new phase (in this case, Mg_2Si nuclei) while the term "growth" refers to the rate of increase in size of the new particles.

The driving force to produce nucleation of the Mg_2Si precipitate phase is the change in thermodynamic free energy which results from formation of the precipitate. Thermodynamically, a system tends to seek the state which has minimum free energy. At the solvus temperature (the solvus temperature is the minimum temperature at which all of the magnesium and silicon will remain in solution and varies between 800° and 950° F., depending on the amounts of Mg_2Si in the alloy), the free energy of the system is the same whether the Mg_2Si is dissolved in the solid solution matrix or exists as a separate phase. As the system is super-cooled below the solvus temperature, however, the free energy is lower for the condition where Mg_2Si is present as a separate phase than for the condition where it is in solution. This free energy difference, ΔF, becomes greater the further the system is super-cooled below the solvus temperature, i.e., the driving force to produce precipitation of Mg_2Si becomes greater with greater amounts of super-cooling. Thus, the rate at which material is precipitated from the solid solution should and does increase as the temperature is decreased from the solvus. The process of nucleation also involves a positive change in free energy due to the surface energy of the precipitated particle in the system, which change in free energy is in turn a function of particle radius. The net resultant free energy change reaches a maximum for a critical particle radius which in turn decreases as the temperature decreases.

Thus, as the temperature decreases, the free energy driving force causes an increase in the mass of material tending to precipitate; and at the same time once the critical size for the nucleus is reached, a greater number of nuclei form per unit mass of precipitate at the lower temperatures and the nucleation rate ascends sharply.

An activation energy is additionally required to establish a cluster of magnesium and silicon atoms large enough to form a Mg_2Si nucleus. This activation energy is supplied by statistical fluctuations in local thermal energy. As the temperature is decreased, eventually these fluctuations fail to reach the activation energy level and at this temperature the nucleation rate drops rapidly to zero for all practical purposes.

The effect of temperature on the nucleation rate is shown schematically in FIGURE 1, the nucleation rate having a zero value at the solvus, increasing rapidly to a maximum on the order of 600° F. to 650° F., and then decreasing rapidly because of lowered atomic mobility.

The driving force for Mg_2Si growth also involves the change in free energy in the system and the driving force therefore increases as the temperature drops below the solvus temperature. However, in addition, the rate at which the new particle can grow is controlled by diffusion considerations.

The rate of diffusion is dependent on atomic mobility and concentration gradient, which is the driving force for diffusion. Atomic mobility is high at elevated temperature. The concentration gradient near a growing particle is low at elevated temperature (near the solvus) and high at lower temperatures when atomic mobility is at a low level. The rate of growth therefore reaches a maximum at an intermediate temperature. This is shown schematically in FIGURE 1 where the separate contributions of diffusion and concentration gradient have been combined into the growth rate curve as a function of temperature.

The growth rate curve and the nucleation rate curve are similar in shape, each showing a maximum at an intermediate temperature. However, in the 6063 alloy systems, the maximum for the growth rate curve is displaced to higher temperatures by diffusion considerations while the maximum of the nucleation rate curve is displaced to lower temperatures by the critical particle size consideration. Thus, if a system is held at a temperature only moderately below the solvus temperature, e.g., 850° F., the nucleation rate tends to be low while the growth rate is relatively high. This results in few but fairly large precipitate particles. By contrast, if an alloy system is held at a temperature substantially below the solvus temperature (say, in the range 600 to 650° F.) the nucleation rate will be quite high while the growth rate is relatively low. This results in a large number of nucleated particles of a size very much less than observed at the higher temperature.

The term "precipitation range," as used herein and in the claims, is the temperature range from at, or near, the solvus temperature down to the point where for practical purposes large nuclei no longer form, i.e., from between about 800° F. to about 400° F. By reference to the hatched area under the nucleation and growth curves, it will be seen that the greatest nucleation and growth activity occurs between about 800° F. to about 600° F. This will clearly be appreciated also from the test data set out hereafter. Since the bulk of precipitation and growth takes place in the range from about 800° F. down to about 600° F., the "precipitation range" is also properly defined within these narrower limits, and is therefore also used in this narrower sense in the specification and in the claims.

We will further define large precipitate particles as those precipitate particles readily visible in the optical microscope, i.e., those particles of greater than about 0.3 micron diameter and up to about 5 microns or larger; and small or fine particles are defined herein as those

of about 0.3 micron down to submicroscopic sizes, perhaps 0.01 micron or less.

If a material is cooled through the precipitation range, then during the dwell time at each temperature step within the range, nucleation will occur at a rate corresponding to the appropriate temperature position on the nucleation curve. Growth of existing nuclei will occur at rates corresponding to the appropriate temperature position on the growth curve. If the cooling rate is conventional, e.g., 50–75° F./hr. through the precipitation range, a precipitate population representative of all parts of the precipitation range will result. That is, there will be an appreciable number of particles which nucleate in the higher-temperatured portion of the precipitation range (these are believed to be large nuclei) and which will then grow at high growth rates to particles of substantial size. There will also be particles precipitated in the lower end of the precipitation range (smaller nucleus size) which do not grow substantially after nucleation because of the low growth rate in this part of the precipitation range.

If the 6063 alloy system is cooled at a sufficiently rapid rate during its passage through the precipitation range, appreciable nucleation does not have time to occur in any part of the precipitation range and therefore most of the Mg_2Si would be, and is, retained in supersaturated solid solution. At the preferred rates of cooling, i.e., from about 300° F./hr. to 600° F./hr. in the precipitation range, some nuclei are formed in passing through the precipitation range. However, when the cooling rate is this rapid, most of these nuclei will be formed near the lower end of the precipitation range, which means a small initial nucleus size and only slight growth subsequent to nucleation. Thus, most of the precipitate which does exist under these conditions is in an extremely fine particle size. If such an alloy system is then rapidly reheated, as is the practice prior to extrusion, it is found that a temperature is soon reached where these fine particles are below the critical size required for continued existence, and they will then redissolve.

It is found that the changes in the properties of 6063 alloy, e.g., strength, hardness, electrical conductivity, and microstructure, are all related to the precipitation process of nucleation and growth. Particle size and concentration of particles appear to exert a profound influence. Thus, the preferred extrusion billet is one which after reheating rapidly, extruding, and quenching, produces an extrusion with most of the Mg_2Si in supersaturated solution. This will result if, before reheating, all of the Mg_2Si is in supersaturated solution in the billet, or, alternatively, if only small Mg_2Si precipitate particles are present in the billet. These small particles redissolve rapidly on reheating above the temperature at which the particle size is unstable. By contrast, if large Mg_2Si particles are present, these do not become unstable until reaching a higher temperature and the rate of solution is appreciably slower. As a result, some of the Mg_2Si will probably remain out of solution as large particles throughout the extrusion schedule.

The Mg_2Si precipitate particles which have a pronounced effect on hardness and tensile properties of the final aged product are those in the small or submicroscopic range. The degree of strengthening of the alloy depends on the number of particles and also on their size. Thus, maximum strengthening depends on having as much as possible of the Mg_2Si in solution in the quenched extrusion, and then aging at a temperature producing maximum nucleation and only moderate growth rates. It is found that large particles which have survived the extrusion procedure do not contribute to the strengthening.

In summary, then, it is seen that the growth curve rises rapidly from solvus reaching a peak near 800° F., and then decreases fairly rapidly to 600° F. Nucleation, in large amounts, however, commences only near 800° F., and attains a high rate between about 600–700° F. Thus, the nucleation and growth rates, taken as a composite, are highest in the range between about 800° F. and about 600° F. and then slow considerably although the nucleation rate is still quite high at 600° F. (It is also to be noted that the rate of cooling between solvus and 800° F. will have some effect on the resulting crystal formation since the relatively few crystals formed will nevertheless be in a rapidly ascending portion of the growth curve.)

As mentioned, it appears to be most desirable to obtain a small Mg_2Si precipitate upon cooling the billet to room temperature. This can be attained by cooling the billet load by means such as forced air as it passes through the precipitation range, the rate of cooling required being substantially in excess of that obtained by cooling of the billet load in still ambient air. In numerical terms, a cooling rate of 300° F. will assure the benefits of this invention although it is found that rates of about 200° F./hr. through the precipitation range will give good results if the cooling rate above 800° F. is kept above 200° F./hr. One could also attempt to retain all the Mg_2Si in solution, e.g., by water quenching the billet, but this does not seem to be required for the reason that the small Mg_2Si precipitate produced by rapidly cooling the billet through the precipitation range is rapidly redissolved as it is reheated and passed through the extrusion die.

The billet microstructures shown in FIGURES 2 and 3 illustrate the effects of fast and slow cooling rates, respectively, during the precipitation range. FIGURE 2 is a photomicrograph of a cross-section of a billet made in accordance with this invention, and which was cooled at an average rate of 300° F./hr. from homogenization temperature to 600° F. and 50° F./hr. thereafter (designated for brevity herein as a 300/600/50 cooling cycle). This photomicrograph was etched with HF and enlarged 500× in accordance with standard practice (as were all the photomicrographs mentioned herein) to reveal the Mg_2Si precipitate. The large amount of fine precipitate and the few large particles will be noted. The majority of the Mg_2Si precipitated is in the form of small precipitate, i.e., under about 0.3 micron in diameter, and is, we believe, a novel extrusion billet microstructure.

Compare FIGURE 3, which is a photomicrograph of a cross-section of a billet (enlarged 500×, HF etched) cooled in a manner equivalent to cooling in still air, i.e., the average rate of cooling being below 75° F./hr. over the entire cooling range. The exact cooling cycle followed was a 200° F./hr. rate from homogenizing temperature to 800° F., and 50° F./hr. thereafter (200/800/50). In FIGURE 3, the coarseness of the precipitate is very apparent. The precipitate formed in large particles which grew with the slow cooling rate. Some fine particles were also produced in the lowest part of the precipitation range.

As an illustration of the difference in microstructure and mechanical properties of aged extrusions processed by this invention, i.e., by following a high rate of cooling in the precipitation range, and the comparatively very low rate of cooling of the prior art, reference should be had to FIGURES 4 and 5. FIGURES 4 and 5 are photomicrographs of the aged extrusions processed in accordance with this invention, and in accordance with the still air cooling cycle of the prior art, respectively. In FIGURE 4, the fineness of the precipitate relative to that of FIGURE 5 is readily apparent.

The microstructures shown in FIGURES 4 and 5 are cross-sections of extrusions enlarged 500× and HF etched to show Mg_2Si precipitate. The extrusions of FIGURES 4 and 5 were produced from the billets described with reference to FIGURES 2 and 3, i.e., employing a fast cool of 300/600/50 and a slow cool of 200/800/50, respectively. The extrusions were then aged to T6 temper.

The microstructure of FIGURE 5 has a relatively large number of large particles compared to the Mg_2Si precipitate of FIGURE 4. Furthermore, by comparing the microstructures of FIGURES 2 and 4, it is seen that the relatively few coarse particles of Mg_2Si changed in shape only during extrusion, and the fact that very little fine precipitate is visible in FIGURE 4 indicates that substantially all of the fine precipitate in FIGURE 2 redissolved during reheating and/or extrusion.

The mechanical properties, upon extrusion and aging of the 300/600/50 cooled billet of FIGURES 2 and 4 were excellent; the mechanical properties, upon identical extrusion and aging procedures of the 200/800/50 cooled billet of FIGURES 3 and 5, were poor. Table I sets forth the data.

TABLE I

Billet cooling cycle	Die temperature, ° F.	Exit temp. from die, ° F.	T6 tensile strength, p.s.i.	T6 yield strength, p.s.i.	Elong., percent in 2"	Hardness (Rockwell)
200/800/50	850	930	18,130	12,030	16.0	30
300/600/50	850	930	32,500	27,300	12.5	77
Specification requirements			30,000	25,000		

The differences in mechanical properties of the T6 aged extrusions caused by the rapid cooling through the precipitation range are striking.

It will also be realized that if the extrusion die temperature had been substantially less than 850° F., acceptable mechanical properties could still have been obtained with the 300/600/50 billet. In order to clearly illustrate the net reduction in extrusion temperature obtainable by the process of the present invention, the following tests were conducted.

66 billets of 6063 alloy which were 5.125 inches in diameter and 20 inches long and having a composition of 0.44% Si, 0.17% Fe, 0.01% Zn, 0.63% Mg, and the balance aluminum, were randomly divided into two groups of 33 billets each, said groups being designated "Group A" and "Group B."

Group A and Group B were both solution heated by holding at 1070° F. for 6 hours in a Lindberg Electric Tempering Furnace. The metal temperatures were sensed by a thermocouple buried 3 inches into the end of the center billet in each group and measured by a Leeds & Northrup eight-point recorder.

Group A, comprising a load of 33 billets, was cooled to 400° F. in two hours by forced air, followed by cooling to room temperature by normal air cooling at a rate of about 45° F. The average rate of cooling in the 800° F.–600° F. portion of the precipitation range was about 400° F./hr., and the average cooling rate between 800° F. and 400° F. was about 267° F. Group B, comprising a load of 33 billets, was cooled at a rate of about 50° F. per hour, which approximates the average cooling rate generally used in the prior art for cooling 6063 extrusion billets (this rate attained by leaving the load of billets to cool in still ambient air). About 15 hours' time is required to cool a load of such billets from about 1000° F. to about 150° F.

The billets from both Groups A and B were heated to extrusion reheat temperature in a single stage, 3-zone, Magnethermic induction heater which is rated at 2500 lb. per hour and operated on 440 volt, 3-phase, 60 cycle power.

The billets of both Groups A and B were extruded in a 1250 ton Loewy Hydropress having a 5-inch container, through a die having a cross-section of hollow-shape with a typical wall thickness of 0.062 inch. The billet material was extruded from a two-hole porthole type die having an extrusion ratio of 53:1, which is the ratio of the cross-sectional area of the press container, in square inches, to the cross-sectional area of the die opening, in square inches. The extruded shape had a factor of 28 which is the perimeter of the extrusion, in inches, divided by the weight per lineal foot, in pounds, of the extrusion.

Results of tests

(A) Billet reheat temperature in ° F. vs. breakout pressure in p.s.i.

Reheat temperature	Breakout pressure	
	Group A	Group B
900	2,400	2,140
800	2,600	2,270
700	2,950	2,400

(B) Maximum extrusion speed in feed per minute vs. reheat temperature in ° F. to produce an acceptable surface finish (maximum press speed was 182 feet per minute).

Reheat temperature	Speed	
	Group A	Group B
900	182	133
800	182	99
700	182	155
Average	182	129

(C) Average yield strength of extruded shape (T6 temper*) in p.s.i. vs. reheat temperature in ° F.

Reheat temperature	Yield strength	
	Group A	Group B
900	27,500	27,300
800	27,400	21,700
700	28,300	19,200

(D) Average tensile strength of extruded shape (T6 temper*) in p.s.i. vs. reheat temperature in ° F.

Reheat temperature	Tensile strength	
	Group A	Group B
900	31,700	31,800
800	32,000	26,900
700	33,400	24,800

*T6 temper here used means air quenching of the extruded material to room temperature and thereafter aged 3 hours at 390° F.

(E) Average elongation in percent in 2 inches of extruded shape (T6 temper*) vs. reheat temperature in ° F.

Reheat temperature	Elongation	
	Group A	Group B
900	10	10
800	10	10
700	10	11

(F) Average hardness (in Webster B hardness units) of extruded shape vs. reheat temperature in ° F.

Reheat temperature	Hardness			
	Group A		Group B	
	T4 [1]	T6 [2]	T4 [1]	T6 [2]
900	4	12	4	12
800	4	13	1	11
700	5	13	0	9

[1] T4 temper means air quenching to room temperature.
[2] T6 temperature here used means air quenching of the extruded material to room temperature and thereafter aged 3 hours at 390° F.

The specification requirement for extrusions of 6063 alloy calls for a T6 tensile strength and a T6 yield strength of 30,000 p.s.i. and 25,000 p.s.i., respectively. The specification requirements were easily met by following the billet cooling process of our invention even when the extrusion temperature was 700° F. This should be compared with results obtained by following the billet cooling process of the prior art, and subsequent extrusion processing at 700° F., 800° F. and 900° F. Only at 900° F. did the prior art cooled billet meet specification requirements; at 700° F. and 800° F. a completely unacceptable extrusion resulted.

As is clearly shown by the test data, the billet produced by this invention is vastly superior to the prior art billet in terms of its ability to be extruded at substantially lower temperatures while at the same time producing an extrusion possessing mechanical properties equal to or superior to those obtained by utilizing the prior art billet. Further, it will be seen that the billets of the present invention can be extruded at substantially greater speeds and the extruded shapes have an equal or better finish.

The ability to extrude an alloy at a materially lower temperature with consistently good mechanical properties and surface finish carries with it other very material advantages such as reduction in "pickup" by the extrusion die, reduction in "washout" or "tearing" of the extruded shape, and increased press capacity by virtue of the fact that it takes less time to heat the billets of the present invention to the extrusion temperature since a lower extrusion temperature is used.

The above tests thus clearly demonstrate that the process of treating an extrusion billet, in accordance with the process of our invention, is productive of a superior billet possessing characteristics permitting material reduction in extrusion temperature, while at the same time producing an extruded shape having mechanical properties which are equal to or better than those attained in an extrusion resulting from use of the prior art billet wherein the heat treatment involved relatively slow cooling of the billet from the homogenizing temperature. Further, the reduced extrusion temperature makes possible a substantial increase in extrusion speed over conventional practice and thereby results in an extruded shape having equal or better surface finish than the prior art billets.

In order to further illustrate the scope and variety of the cooling cycles falling within the invention, a series of billets were cooled at various rates starting from 200° F./hr. up to the water quench rate in the precipitation range. All billets were extruded at about the same extrusion temperature. The extrusions had excellent mechanical properties as set forth in Table II below:

TABLE II

Test No.	Cooling cycle	Tensile strength (p.s.i.)	Yield strength (p.s.i.)	T6 elong., percent in 2"	T6 hardness (Rockwell)
1	200° F./hr. to RT [1]	31,000	25,000	12.4	70
2	300/800/600	30,830	25,000	12.5	74
3	300/400/50	30,800	25,130	12.0	74
4	300° F./hr. to RT [1]	31,250	26,050	12.3	75
5	600/600/50	33,800	27,850	13.0	79
6	600/400/50	31,930	26,390	12.4	76
7	WQ [2]/600/50	32,450	26,650	12.0	76
8	WQ [2]/400/50	30,100	25,050	11.8	74

[1] RT—Room temperature. [2] WQ—Water quench.

Photomicrographs of extrustions of test Nos. 1, 2, 4 and 8 in Table II were taken, enlarged, and HF etched in accordance with standard techniques. These microstructures are shown in FIGURES 6, 7, 8 and 9, respectively. They all show substantially minor amounts of large Mg_2Si precipitate compared to the prior art microstructure type shown in FIGURE 5. In other words, the majority of Mg_2Si precipitate is present in the form of small or fine particles in the extrusion microstructure.

It also appears that the cooling rate must be high enough in the precipitation range so that the majority of any precipitate formed will be small enough (below about 0.3 micron) to redissolve upon subsequent reheating and/or extrusion, even at low extrusion temperatures, i.e., about 850° F. or below. A cooling rate averaging above 200° F./hr. in the precipitation range appears to give acceptable properties, but it is preferred to utilize at least a rate of 300° F. in order to assure the forming of a fine precipitate of the 0.3 micron or less size.

In order to further illustrate the importance of the cooling rate in the precipitation range, tests were performed wherein high rates of cooling of between 300° F./hr. and 600° F./hr. were employed above 800° F., and low rates were employed below 800° F. The results of these tests are set forth in Table III.

*T6 temper here used means air quenching of the extruded material to room temperature and thereafter aged 3 hours at 390° F.

TABLE III

Test No.	Cooling cycle	Tensile strength (p.s.i.)	Yield strength (p.s.i.)	Percent elong. in 2"	Hardness (Rockwell)
1	300/800/50	17,450	10,950	16.4	30
2	600/800/50	17,100	10,570	16.2	25
Comparison	300/600/50 (From Table I).	32,500	27,300	12.5	77
	600/600/50 (From Table II).	33,800	27,850	13.0	79

It will be noted that the additional amount of high rate cooling between 800° F. and 600° F. resulted in tremendous change in properties. The tensile values were increased by almost 100% and the yield strength by almost 300%. The hardness value also increased approximately 3-fold.

A homogenized billet subjected to a cooling rate of 100° F./hr., or less, during the precipitation range, extruded and T6 tempered, as aforedescribed, results in completely unacceptable tensile and yield strength properties (25,600 p.s.i., tensile strength, and 20,200 p.s.i., yield strength) whereas a cooling cycle of 100/800/600 gave very acceptable properties of 31,600 p.s.i. for tensile strength and 26,250 p.s.i. yield strength. This further illustrates the importance of a high rate of cooling during the precipitation range, and illustrates the relative unimportance of the cooling rate above 800° F., although it is desirable that the cooling rate be maintained at an average value of at least 100° F./hr. down to 800° F. because of the ascending nucleation rate.

The cooling of the billet from honogenizing temperature to 200° F., to ambient temperature (say under 100° F.) may be effected in any convenient manner, as by spraying water onto the billet, passing cooling air or other gas past the billet, or in certain instances immersing the billet in water or other liquid, through this last mentioned method is considered less desirable than the others.

After the billet has been cooled to a temperature under 200° F. in accordance with the above discussed procedudes, the hardening constituents are locked in solution or are present mainly in fine precipitate form in the billet, as explained previously, and otherwise are sufficiently stable to allow the billet to be stored at ambient temperature for long periods of time, shipped from one plant to another, or handled in virtually any desired manner, without destroying the condition of the billet, and its advantages for subsequent extrusion.

When the extruder desires to extrude the billet, it should for best results be brought up to extrusion temperature rather rapidly, as by induction heating which may heat the billet to the desired temperature within a period of less than ten minutes, and usually about one and one-half minutes. After being heated, the material of the billet is fed into the extrusion press, and is forced by the press at very high pressure through an extrusion die, to form an elongated product of predetermined cross section. Generally speaking, the billet may, by virtue of the unique type of heat treatment to which it has been subjected, be extruded at virtually any temperature at which the material of the billet can be forced by the press through the extrusion die with conventially used extrusion pressures. In the past, it has been necessary in most instances to extrude at temperatures between about 875° F. and 950° F., in order to assure satisfactory mechanical properties in the final extruded product. A billet treated in accordance with the present invention, on the other hand, can successfully be extruded at temperatures as low as 550 degrees F., and even though extruded at these low temperatures the ultimate product has tensile strength, ultimate strength, other mechanical properties, and a surface finish which are at least as good as the same properties heretofore attained at the mentioned relatively high extrusion temperatures. With conventional presses and billet sizes the preferred billet temperature just prior to extrusion in the process of the present invention is between about 550° F. and 850° F.

The extruded section is desirably quenched (usually by an air stream or water) as or soon after it leaves the extrusion die, typically at a rate of at least about 1000° F. per hour, and to a temperature at least as low as about 600° F. (the metal having normally been increased in temperature by the extrusion process).

To assure complete and adequate disclosture of the invention, the following specific examples are given of specific processes embodying the invention:

EXAMPLE 1

A billet formed of the previously mentioned aluminum alloy designated by the Aluminum Association as Alloy No. 6063 was heated in an oven to a temperature of 1025° F., and the entire thickness of the billet was maintained at that temperature continuously for a period of six hours. At the end of the six hours, the billet was removed from the oven, and large volumes of cooling air at ambient temperature (about 65° F.) were blown past the billet. Thermocouple temperature readings indicated that the air cooled the billet from the initial 1025° F. temperature to about 600° F. at an average rate of about 1300° F. per hour, and then cooled the billet from about 600° F. to 300° F. at an average rate of about 450° F. per hour. From 300° F. to 200° F., the cooling rate decreased progressively, but was at an average rate of approximately 300° F. per hour. After the billet had been cooled to about 75° F., it was heated by an induction heater, in a period of one and one-half minutes, to 500° F., and was then extruded at that temperature by an extrusion press, and quenched rapidly by a cool air stream as it left the extrusion die (quenching rate approximately 1800° F. per hour). The resultant product had very satisfactory mechanical properties and surface finish, meeting the standards which ordinarily require extrusion at a temperature near 900° F.

EXAMPLE 2

This example is the same as Example 1, except that the cooling from the homogenizing temperature was effected by spraying water onto the billet, with the cooling being at the very rapid average rate of 2200° F. per hour as the billet was cooled from 1025° F. to 200° F.

EXAMPLE 3

Same as Example 1, except that the billet was cooled more slowly, in the oven, and at the following rates:

From 1025 degrees F. to 800 degrees F., average cooling rate 120 degrees F. per hour.

From 800 degrees F. to 400 degrees F., average cooling rate 350 degrees F. per hour.

From 300 degrees F. to 200 degrees F., average cooling rate about 100 degrees F. per hour.

EXAMPLE 4

Same as Example 1, except that the billet was left in the oven during cooling. During the first hour and thirty-five minutes of the cooling period (after homogenization), the doors of the oven were kept closed while air was blown through the oven, and after that period both of the doors of the oven were opened while the fans were left on. The cooling rates were as follows:

From 1025 degrees F. to 800 degrees F., average cooling rate 140 degrees F. per hour.

From 800 degrees F. to 300 degrees F., average cooling rate 350 degrees F. per hour.

From 300 degrees F. to 200 degrees F., average cooling rate 150 degrees F. per hour.

EXAMPLE 5

Same as Example 1, except that the billet was left in the oven during cooling. For fifty minutes of the cooling period, the doors of the oven were kept closed, with the fans on, and thereafter the fans were turned off, with one pair of doors open (the oven having doors at opposite sides). The cooling rates were as follows:

From 1025 degrees F. to 900 degrees F., average cooling rate 140 degrees F. per hour.

From 900 degrees F. to 400 degrees F., average cooling rate 350 degrees F. per hour.

From 400 degrees F. to 200 degrees F., average cooling rate 100 degrees F. per hour.

All of the billets treated in accordance with the above discussed examples produced extrusions at 550 degrees F. and 600 degrees F. which were superior in mechanical properties and surface finish to those which could be produced at those temperatures without the heat treating process of the present invention.

EXAMPLE 6

A number of 6063 billets were heated for six hours at 1050 degrees F. and cooled at a rate of 300 degrees F., from homogenizing temperature, to 600 degrees F. by means of forced air, and thereafter were cooled at an average rate of 50 degrees F. per hour to room temperature (cooling cycle: 300/600/50). The billets were then extruded into a 2¾ inch wide solid extrusion approximately 0.065 inch thick (factor 23, 0.270 pound per cubic foot) at a temperature of about 850 degrees F. The extrusions had an exit temperature of about 930 degrees F.

The resulting extrusions were quenched at the die, and aged to T6 temper (six hours soak at 350 degrees F.). The average mechanical properties are set forth in Table I, and the billet and extrusion microstructures are shown in FIGURES 2 and 4, respectively.

EXAMPLE 7

The procedure of Example 6 was followed, except that a cooling rate of 200 degrees F. per hour was employed from homogenizing to room temperature. The mechanical properties are set forth in Table II, and the extrusion microstructure is shown in FIGURE 6.

In conclusion, it is important to note that the rate of cooling of the billet in the precipitation range is substantially greater than that taught by the prior art, and is sufficiently high to inhibit the growth of the majority of the precipitate formed, the net result being a precipitate formation primarily composed of particles that readily redissolve on reheating or extrusion of the billet because of their favorable size—at a lower extrusion temperature than is otherwise required. The size of such readily redissolvable particles is calculated to be about 0.3 micron in diameter or less. It is also important to note that the cooling rate required to bring about such ready dissolution may, in some instances, be as low as 200 degrees F. per hour during the precipitation range, depending upon conditions of cooling above 800 degrees F. and conditions during the extrusion, and that in order to assure the ready redissolution of the Mg_2Si upon reheating for extrusion, or during extrusion, a rate of 300 degrees F. per hour during the precipitation range is preferred.

From a practical point of view, an average rate of from about 300 degrees F. per hour to 600 degrees F. per hour from the homogenizing temperature down to the lower end of the precipitation range gives excellent results.

The prior art of pre-extrusion heat treatment of the billet does not appear to have recognized the significance of maintaining a high rate of cooling during the precipitation range in order to avoid the presence of large precipitate formation. The prior art billet cooling, e.g., 50–75 degrees F. per hour through the precipitation range, results in the production of coarse Mg_2Si precipitate which cannot readily redissolve upon reheating and extrusion. The amount of this coarse Mg_2Si is a significant deleterious factor inasmuch as the large precipitate does not contribute to the strength of the final aged extrusion.

While various heat treatment procedures for aluminum alloy homogenized billets have been described, it will be understood that these heat treatment procedures are merely illustrative of our invention. We intend to be bound only by the scope of the claims which follow.

We claim:

1. The process that comprises heating a load of extrusion billets, each formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said billets at a temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said billets from said temperature down to about 800° F. and further coling said billets at an average rate substantially in excess of that attained by cooling said billets in still ambient air from about 800° F. through the precipitation range.

2. The process of claim 1 wherein said average cooling rate of said billets is at least about 300° F. per hour through said precipitation range.

3. The process that comprises heating to a temperature between about 990° F. and 1100° F. an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said billet at said temperature for a period of at least about four hours and sufficient to place most of said hardening constituents in solution, then cooling said billet from said temperature down to about 800° F., further cooling said billet, at an average rate substantially in excess of that attained by cooling said billet in still ambient air, from about 800° F. through the precipitation range, whereby said billet is capable of extrusion at a temperature below about 875° F. and at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet cooled in still ambient air from 800° F. through said precipitation range and subsequently extruded at a temperature in excess of about 875° F.

4. A pretreatment process for billets that comprises heating, to a temperature between about 990° F. and 1100° F., a load of extrusion billets formed of precipitation hardenable aluminum alloy containing between about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as primary hardening constituents thereof, maintaining said billets at said temperature for a period sufficient to place most of said hardening constituents therein in solution, then cooling said billets from said temperature down to about 800° F., and further cooling said billets at an average rate substantially in excess of that attained by cooling said billets in still ambient air through the precipitation range, whereby said billets are capable of extrusion at a temperature below 850° F., at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a load of billets cooled in still ambient air through said precipitation range and extruded subsequently at a temperature in excess of 875° F.

5. A process for extrusion of billets which comprises heating, to a temperature between about 990° F. and 1100° F., a load of billets formed of precipitation hardenable aluminum alloy containing between about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as primary hardening constituents thereof, maintaining said billets at said temperature for a period sufficient to place most of said hardening

constituents therein in solution, then cooling said billets from said temperature down to about 800° F., and further cooling said billets at an average rate substantially in excess of that attained by cooling said billets in still ambient air through the precipitation range, subsequently reheating said billets to extrusion temperature, and then extruding the material of said heated billets to a predetermined shape.

6. The process that comprises heating an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said billet at a temperature for a period sufficient to place most of said hardening constituents in solution, then rapidly cooling said billet at a high average rate of cooling substantially in excess of that attained by cooling said billet in still ambient air whereby a majority of any magnesium silicide precipitate formed is present in a particle size diameter of less than about 0.3 micron.

7. In a method of preparing billets for extrusion, each of said billets being composed of a precipitation hardenable aluminum alloy containing between 0.2 percent and 0.6 percent silicon and 0.45 percent and 0.9 percent magnesium as primary soluble hardening constituents, an improved heat treatment for preconditioning said billets so as to allow the ultimate extrusion operation to be performed upon each billet at a substantially lower temperature than has been hitherto possible without adversely affecting the mechanical properties of the final extruded product, which comprises the steps of:

heating said billets to a homogenizing temperature in excess of about 990° F. for a sufficient period of time to place most of said magnesium and silicon in said billets in solution;

and rapidly cooling said billets at a high rate of cooling substantially in excess of that attained by the average rate of cooling of said billets in still air, as said billets pass through the precipitation range, said high rate of cooling being such that each of said billets, upon being reheated to a relatively low reheat temperature of between about 550° F. and about 850° F. is extrudable at such relatively low reheat temperature to produce an extrusion having tensile strength and ultimate strength properties that are at least equal to those attained in an extrusion produced from billets of said same aluminum alloy cooled at an average rate equivalent to that attained by cooling in still air and then reheated to a reheat temperature of about 875° F. for extrusion.

8. In a method of preparing billets for extrusion, each of said billets being composed of a precipitation hardenable aluminum alloy containing between 0.2 percent and 0.6 percent silicon and 0.45 percent and 0.9 percent magnesium as primary soluble hardening constituents, an improved heat treatment for preconditioning said billets so as to allow the ultimate extrusion operation to be performed upon each billet at a substantially lower temperature than has been hitherto possible without adversely affecting the mechanical properties of the final extruded product, which comprises the steps of:

heating said billets to a homogenizing temperature in excess of about 990° F. for a sufficient period of time to place most of said magnesium and silicon in said billets in solution;

and rapidly cooling said billets at an average rate of at least about 300° F. per hour, as said billets pass through the precipitation range.

9. In a method of preparing billets for extrusion, each of said billets being composed of a precipitation hardenable aluminum alloy containing between 0.2 percent and 0.6 percent silicon and 0.45 percent and 0.9 percent magnesium as primary soluble hardening constituents, an improved heat treatment for preconditioning said billets so as to allow the ultimate extrusion operation to be performed upon each billet at a substantially lower temperature than has been hitherto possible without adversely affecting the mechanical properties of the final extruded product, which comprises the steps of:

heating said billets to a homogenizing temperature in excess of about 990° F. for a sufficient period of time to place most of said magnesium and silicon in said billets in solution;

and rapidly cooling said billets at a high average rate of cooling substantially in excess of that attained by the average rate of cooling of said billets in still ambient air, as said billets pass through the precipitation range, a majority of any magnesium silicide precipitate formed being present in a particle size diameter such that it readily redissolves upon reheating of said billets between 550° F. and 850° F. and upon extrusion thereof at said reheated temperature.

10. The process that comprises heating an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said billet at a temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said billet from said temperature down to about 800° F., further cooling the billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F., whereby said billet is capable of extrusion at a temperature below about 875° F. and at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400 degrees F. and subsequently extruded at a temperature in excess of about 875° F., subsequently reheating said billet to extrusion temperature, and then extruding the material of said heated billet to a predetermined shape.

11. The process that comprises heating to a temperature between 990° F. and 1100° F. an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said billet at said temperature for a period of at least about four hours and sufficient to place most of said hardening constituents in solution, then cooling said billet from said temperature down to about 800° F., further cooling the billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F. whereby said billet is capable of extrusion at a temperature below about 875° F. and at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and subsequently extruded at a temperature in excess of about 875° F., subsequently reheating said billet to extrusion temperature, and then extruding the material of said heated billet to a predetermined shape.

12. The process as recited in claim 10, in which said extrusion temperature is between about 550° F. and 850° F.

13. The process of treating an extrusion billet that comprises heating an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said extrusion billet at a temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said extrusion billet from said temperature down to about 800° F., and further cooling the extrusion billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F. whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F.

14. The process of treating an extrusion billet that comprises heating an extrusion billet formed of precipitation hardenable aluminum alloy containing between

about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as its primary hardening constituents, maintaining said extrusion billet at a temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said extrusion billet from said temperature down to about 800° F., and further cooling the extrusion billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F. whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F.

15. The process that comprises heating to a temperature between about 990° F. and 1100° F., an extrusion billet formed of precipitation hardenable aluminum alloy containing between about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as its primary hardening constituents, maintaining said billet at said temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said billet from said temperature down to about 800° F., and further cooling the billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F., whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F., subsequently reheating said billet to extrusion temperature, and then extruding the material of said heated billet to a predetermined shape.

16. The process of treating an extrusion billet that comprises heating to a temperature between about 990° F. and 1100° F. an extrusion billet formed of precipitation hardenable aluminum alloy containing between about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as its primary hardening constituents, maintaining said billet at said temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said billet from said temperature down to about 800° F., and further cooling the billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F., whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F., subsequently rapidly reheating said billet by induction to extrusion temperature, and then extruding the material of said heated extrusion billet to a predetermined shape.

17. The process of treating an extrusion billet that comprises heating to a temperature between about 990° F. and 1100° F. an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said extrusion billet at said temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said extrusion billet from said temperature down to about 800° F., and further cooling the extrusion billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F., whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F.

18. The process of treating an extrusion billet that comprises heating to a temperature between about 990° F. and 1100° F. an extrusion billet formed of precipitation hardenable aluminum alloy containing between about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as its primary hardening constituents, maintaining said extrusion billet at said temperature for a period of at least four hours to place most of said hardening constituents in solution, then cooling the said extrusion billet from said temperature down to about 800° F., and further cooling the extrusion billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F., whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F.

19. The process of treating an extrusion billet that comprises heating an extrusion billet formed of precipitation hardenable aluminum alloy containing magnesium and silicon as its primary hardening constituents, maintaining said extrusion billet at a temperature for a period sufficient to place most of said hardening constituents in solution, then cooling said extrusion billet from said temperature down to about 800° F., and further cooling the extrusion billet at an average rate of at least about 300° F. per hour from about 800° F. to about 400° F., and at an average value of at least about 100° F. per hour from 400° F. to below 200° F., whereby said billet is capable of extrusion at a temperature below 850° F. at rates of speed and with resultant mechanical properties comparable to those of an extrusion formed from a billet slowly cooled from 800° F. to 400° F. and extruded subsequently at a temperature in excess of 875° F.

20. In an extrusion billet formed of precipitation hardenable aluminum alloy containing between about .45 percent and .9 percent magnesium and between about .2 percent and .6 percent silicon as its primary hardening constituents, the improvement in its metallurgical structure which comprises:

a majority of magnesium silicide precipitate particles present in the solid solution matrix of said aluminum alloy having a diameter of less than about 0.3 micron.

References Cited by the Examiner

UNITED STATES PATENTS

1,926,057	9/1933	Nock et al.	148—11.5
2,249,349	7/1941	Deutsch	148—11.5
2,249,353	7/1941	Fritzlen	148—12.7
2,381,714	8/1945	Beck	148—11.5
2,695,253	11/1954	Schaaber	148—159
3,019,144	1/1962	Murphy et al.	148—159 X
3,104,189	9/1963	Wagner	148—32.5

OTHER REFERENCES

Aluminum Industry, vol. 2, 1930, McGraw Hill, pp. 182–183.

Transactions of the American Society for Metals, vol. 42, 1950, pp. 357–375.

DAVID L. RECK, *Primary Examiner.*