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METHOD OF HOT WORKING AN ALUMINUM BASE ALLOY AND PRODUCT THEREOF

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Fig. 1

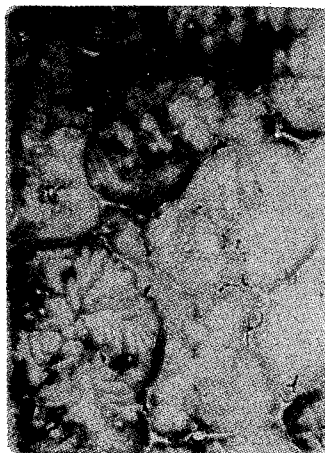


Fig. 2

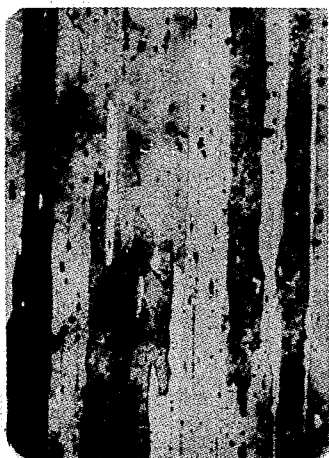


Fig. 3

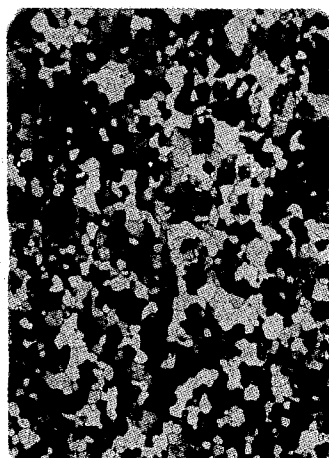


Fig. 4

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METHOD OF HOT WORKING AN ALUMINUM
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This invention relates to the working of aluminum base alloys, and it is especially concerned with the hot working of those alloys which can be hardened by precipitation after a solution heat treatment. The term "aluminum base alloys" as herein employed refers to those alloys which contain at least 75 per cent aluminum.

Aluminum and many aluminum base alloys are readily adapted to being shaped by a variety of both hot and cold metal working processes because of the inherent ductility of aluminum. The hot working process is generally carried out by rolling, pressing, forging, or extruding the metal at temperatures above 650° F. By whatever method of hot working that is employed, the metal is usually plastically deformed without setting up any substantial work-hardening strains in the metal. In the case where the extrusion method is employed, there is usually but one hot working operation, and hence it is adapted to the production of articles which have uniform cross-sectional dimensions over their entire length, such as moldings. In this process, the heated solid metal, in the form of an ingot or worked billet, is suitably confined in a chamber and then forced out, under pressure, through a small opening, known as the die orifice, at one end of the chamber, to produce elongated bodies of indefinite length and often of complex cross-sectional contour. Alloys containing manganese, or its equivalent, and one or more of such elements as copper, magnesium, zinc, silicon, and the like in amounts which will cause precipitation hardening often exhibit a characteristic elongated grain structure, as well as a preferred orientation of the crystals, when extruded or otherwise hot worked. Frequently there is also a variation in the grain size across the cross-section of an extruded article.

Extruded articles are sometimes not straight as they issue from the extrusion die, and it is therefore necessary to straighten them by a slight stretching. It not infrequently happens that even though the articles are stretched they still exhibit a slightly bowed condition which is objectionable. The bowed condition in the stretched article appears to be related to the variation in the grain size of the extruded product as well as to the degree of preferred orientation of the grains because it has been found that those articles which possess a uniform, equiaxed, small grain size do not become bowed after having been straightened. While the foregoing characteristics are particularly evident in the case of articles made by the extrusion process,

they are also found more or less in products made by other hot working processes.

To prepare the alloys for hot working it is usually necessary to heat them to a temperature slightly above that at which the working is to be done in order to allow for any cooling which may occur during the transfer from the furnace to the metal working machine. Furthermore, the hot working temperature varies with the type of working operation, whether it is rolling, forging, pressing, extruding, etc., and it will also vary with the composition of the alloy being treated. For example, in extruding aluminum base alloys containing 3 to 7 per cent copper, 0.1 to 1.5 per cent manganese, 0.1 to 2 per cent magnesium, and 0.25 to 1 per cent silicon, it is a common practice to heat the stock to between 750 and 800° F. and extrude it at 700 to 750° F. If, on the other hand, the alloys are to be rolled, they are first heated to about 900° F. and then hot rolled at 850° F.

It is an object of my invention to provide a method for producing hot worked precipitation hardenable aluminum base alloy articles having a small, uniform grain size over the entire cross sectional area, and to improve the properties of the alloy associated with such a grain structure. A particular object is to provide a method for eliminating the elongated grain structure often found in extruded aluminum base alloys containing manganese or its equivalent. A further object is to provide a method for minimizing the bowing or distortion in articles which have been straightened after hot working.

My invention is predicated upon the discovery that by heating precipitation hardenable aluminum base alloy billets or ingots to much higher temperature than have heretofore been deemed to be a safe practice, preparatory to hot working, followed by cooling to substantially the normal hot working temperature, a change is effected in the internal structure of the alloy such that when it is hot worked in the normal manner, an equi-axed, randomly oriented grain structure is produced. To achieve this result the aluminum base alloy body should be heated to a temperature above that at which there is incipient fusion of the lowest melting constituent in the alloy, which temperature, in any case, should exceed 1000° F. All of the alloys to which this high temperature thermal treatment applies contain at least one structural constituent which has a definite melting point below that of aluminum. Low melting point constituents of this character are technically known as eutectics.

The fusion of the low melting point constituent does not of itself appear to promote the formation of an equi-axed grain structure, but it is indicative of the temperature to which the alloy must be heated to produce the desired effect in the hot worked product. Heating these alloys to such a high temperature has been carefully avoided heretofore because of the belief that incipient fusion of this character is always deleterious to the properties of the finished article. For the sake of convenience, the term "super-heating" will hereafter be employed to describe the practice of heating the billets or ingots up to a temperature above 1000° F. To be effective, the temperature of the super-heating treatment must exceed 1000° F., as stated hereinabove; and in the case of alloys which contain no constituents which melt below 1000° F., but one that fuses above this temperature, it is necessary that its temperature of fusion be exceeded in order to attain an equi-axed grain structure in the hot worked material. However, in no case should the super-heating temperature exceed 1200° F., since to do so would cause an excessive softening of the alloy to the point where it is difficult to handle.

The super-heating treatment should extend over a period of from ½ to 20 hours at the desired temperature, the actual time of treatment for a given alloy composition being dependent upon the mass of material being treated. The duration of the heating should be long enough, in any case, to cause a disappearance of substantially all undissolved particles of the readily soluble constituents within the grains, i. e., copper, magnesium, silicon, etc., as well as a marked reduction in the depth of color of the cored dendrites where a cast body, such as an ingot, is being treated. The cored dendritic structure just referred to is characteristic of nearly all cast aluminum base alloys, and the difference in density of color within a grain indicates a variation in the solid solution concentration within the grains. The effect of the super-heating treatment upon cored dendrites may be seen in the accompanying figures, which are described more specifically hereinbelow. Although the effect of the high temperature treatment upon low solubility constituents, such as manganese, chromium, and the like, may not be immediately visible, it nevertheless appears that the thermal treatment produces a change in the structural distribution of these materials in a manner which affects the grain size of a hot worked article.

When the body of metal has been super-heated for the requisite time, it is then removed from the furnace and allowed to cool to the desired hot working temperature range which, for the extrusion of the super-heated aluminum-copper-manganese-magnesium-silicon alloys referred to above, is usually about 750° to 800° F.

If the body of metal is to be hot worked by other methods, it may be necessary to use a higher working temperature. Although some manner of cooling is required to bring the super-heated body to the hot working temperature range, I find that the results obtained by allowing the heated body to cool in air to the desired temperature are superior to those obtained where a more drastic cooling is employed. It is possible, for example, to cool an ingot as slowly as 10° F. per hour from the super-heating temperature to the temperature at which hot working is to be done, and yet retain the benefits of the super-heating treatment. A cooling

from the super-heating to the hot working temperature, in any event, forms an essential step in the preparation of the body for hot working inasmuch as no hot working can be satisfactorily done at a temperature as high as that at which the body has been super-heated. The heated body should not be drastically chilled as is the practice in the treatment of aluminum base alloys which have just undergone a solution heat treatment for the purpose of increasing their strength. Since the cooling should occur less rapidly than by quenching in water, the cooling is herein referred to as a retarded or a slow cooling.

The super-heating treatment is not only adapted to improve the grain structure of hot worked aluminum-copper-magnesium-manganese-silicon alloys of the kind referred to hereinabove, but it can also be used to improve the grain structure of other aluminum base alloys. I have found that the treatment herein described is particularly effective for those aluminum base alloys known as precipitation hardening alloys which undergo a solution heat treatment and precipitation or age hardening to produce a high strength material. These alloys, in general, contain from 0.1 to 12 per cent, but not more than a total of 25 per cent, of one or more elements or compounds which enter into solid solution with aluminum in substantial amounts at elevated temperatures, as well as forming eutectics with it. Elements such as copper, magnesium, zinc, and silicon, and compounds such as Mg_2Si and $MgZn_2$, are illustrative of these solid solution-forming components. The alloys to which this invention applies must also contain high melting point elements that are nearly insoluble in solid aluminum at the usual solution heat treating temperatures. These elements appear to exercise a considerable influence on the grain structure of the hot worked article, and this influence in turn can be modified by my high temperature treatment. The elements which exert such an influence are manganese, chromium, zirconium, tungsten, molybdenum, vanadium, titanium, uranium, iron, nickel, cobalt, beryllium, columbium and tantalum, and they are usually employed in amounts of from 0.05 to 1.5 or 2 per cent, the total amount in any case not exceeding about 3 per cent. The type of alloy which I have found to be particularly benefited by the super-heating treatment is one which contains from 3 to 7 per cent copper, 0.1 to 1.5 per cent manganese, with or without 0.1 to 2 per cent magnesium. Another type of alloy which I have found to be improved by my treatment is one that contains from 0.5 to 4 per cent each of magnesium and silicon, together with a small amount of manganese or chromium, or their equivalent.

As an example of the effect produced by treating alloys in the manner described hereinabove, reference is made to the accompanying figures which show the microstructure of the same alloy in both the cast and extruded conditions. The alloy, which is one that is widely used, had a nominal composition of 4 per cent copper, 0.5 per cent magnesium, 0.5 per cent manganese, and balance aluminum with impurities.

Fig. 1 is a photomicrograph, at 100 diameters, of an ingot designed for extrusion which was preheated in the normal manner;

Fig. 2 is a photomicrograph, at the same magnification, of a section of a similar ingot which was super-heated and cooled in accordance with my preferred practice;

Fig. 3 is a photomicrograph, at 100 diameters, of an extruded section from an ingot preheated in the normal manner, after the extruded section had received a conventional solution and precipitation hardening treatment; and

Fig. 4 is a photomicrograph, at the same magnification, of an extruded section made from a superheated and cooled ingot after the extruded section had received a conventional solution and precipitation hardening treatment.

The material which is represented by the accompanying figures was prepared by first melting it in the usual manner and casting it in ingot molds having a cylindrical cavity $4\frac{1}{2}$ inches in diameter and 22 inches in length. The ingots were removed from the mold and cooled to room temperature in accordance with the usual practice. One of the ingots was then given the customary preliminary thermal treatment of 8 hours at 905 to 935° F., removed from the furnace and cooled in air to room temperature, whereupon it was cut into two sections. Both sections were reheated to 800° F., the extrusion temperature, one piece being quenched from this temperature in order to show the structure of the material at that temperature, while the other section of the ingot was placed in a press and extruded in the conventional manner. The microstructure of a representative section of the reheated and quenched ingot is shown in Fig. 1, and the microstructure of the extruded product appears in Fig. 3. Two other ingots from the same lot, prepared as described above, were super-heated at 1075° F. for 3 hours, removed from the furnace and cooled in air to 800° F. in about 8 minutes. One of the ingots was then quenched in water to show the structure of the metal after such treatment. The other ingot was immediately placed in an extrusion press and extruded in the same manner as the previous extruded material. Figs. 2 and 4 show the microstructure of the super-heated ingot and extruded material, respectively. The microstructure in all cases was developed by polishing and etching with the standard HF—HCl—HNO₃ etching solution.

A comparison of Figs. 1 and 2 shows the effect of the high temperature treatment upon the ingot structure. It is apparent that the high temperature treatment has served to dissolve all of the particles of soluble constituents within the grains and has substantially equalized the solid solution concentration within the same grains. The treatment has not, of course, eliminated the coarse eutectic network and particles of fused low melting point eutectic which appear between the grains. The copious fine, dark precipitate which characterizes the normally heated ingot, as seen in Fig. 1, is completely absent in the super-heated material illustrated in Fig. 2 in spite of the cooling from 1075 F. to 800° F. Fig. 2 also shows that there has been a coalescence or agglomeration of all undissolved constituents, rather than a general distribution of them as occurs in Fig. 1. The peculiar light and dark areas within the grains in Fig. 2 are believed to be the result of the cooling from 1075 to 800° F., since ingots which have been quenched from the higher temperature do not have this appearance.

Portions from both lots of extruded material were given a conventional solution heat treatment at 940° F. and aged at room temperature in the normal manner, since that is the condition in which this material is commonly employed.

A thermal treatment of this character does not materially alter the grain size of the metal, since it does not cause a recrystallization of hot worked material. The differences between material extruded from the normally treated ingot and the super-heated ingot are evident in Figs. 3 and 4. The elongated grain structure seen in Fig. 3 is characteristic of extruded sections as heretofore produced, while the equi-axed grain structure seen in Fig. 4 is characteristic of hot worked material which has been super-heated.

As a further example of the benefit derived from the use of my invention of treating the above alloy, a comparison may be made between the strength of the above-described heat treated and aged extruded material. Test samples which were taken in a longitudinal direction, that is, parallel to the direction in which extrusion occurred, had the following average tensile properties.

Material	Tensile properties		
	Tensile strength	Yield strength	Elongation
	Lbs. per sq. in.	Lbs. per sq. in.	Percent
Normal.....	52,350	38,950	26
Super-heated.....	56,650	41,050	23.5

It has also been found that the transverse tensile properties of extruded material are improved by the super-heating treatment. Such an improvement is of particular value in cases where fittings are made from extruded stock.

Another example of the benefit to be gained from using the super-heating practice is found in the extrusion of an aluminum base alloy having a nominal composition of 1.3 per cent magnesium, 0.7 per cent silicon, 0.25 per cent chromium, balance aluminum with impurities. Cylindrical ingots $6\frac{1}{2}$ x 10 inches of this alloy are heated to a temperature of 1170° F. and held at that temperature for a period of 4 hours. The heated ingots are then removed from the furnace and allowed to cool to about 960° F. before being placed in an extrusion press. The extruded product had a fine equi-axed grain structure.

A difficulty sometimes encountered in the straightening of extruded articles is that where stretching is employed, a rippled or "orange peel" appearance develops on the surface of the article. For certain purposes, such an appearance is highly undesirable. I have found that the equi-axed extruded material produced in accordance with my invention is free from that defect when straightened by stretching.

Although I have described my invention with particular reference to the treatment of cast bodies, such as ingots, it is to be understood that it is also applicable to bodies which have been previously worked, since an equi-axed grain structure can also be produced in such bodies by my super-heating and cooling practice. Furthermore, it is to be understood that the hot working operation is not limited to extrusion, but may consist of such operations as rolling, pressing, or forging.

I claim:

1. The method of hot working an aluminum base alloy body which contains at least one eutectic-forming, solid solution-forming constituent in sufficient amount to produce a precipitation hardening alloy and at least one insoluble high melting point constituent, said method comprising

forming a body of said alloy, heating said body for more than $\frac{1}{2}$ hour at a temperature not less than 1000° F. and not over 1200° F., said temperature being also above the fusing point of the most easily fusible constituent of said alloy, and thereafter hot working said body of alloy.

2. The method of working an aluminum base alloy body which contains at least one eutectic-forming, solid solution-forming constituent in sufficient amount to produce a precipitation hardening alloy and at least one insoluble high melting point constituent, said method comprising forming a body of said alloy, heating said body for $\frac{1}{2}$ to 20 hours at a temperature between 1000 and 1200° F., said temperature being also above the fusing point of the most easily fusible constituent of said alloy, slowly cooling said body to the hot working temperature and thereafter hot working said body of alloy.

3. The method of hot working an aluminum base alloy body, said alloy containing from 0.1 to 12 per cent of at least one eutectic-forming, solid solution-forming constituent and from 0.05 to 2 per cent of at least one insoluble high melting point constituent, said alloy also being capable of being hardened by precipitation, said method comprising forming a body of said alloy, heating said body for $\frac{1}{2}$ to 20 hours at a temperature between 1000 and 1200° F., said temperature being also above the fusing point of the most easily fusible constituent of said alloy, slowly cooling said body to the hot working temperature and thereafter hot working said body of alloy.

4. The method of hot working a body of aluminum base alloy containing from 3 to 7 per cent copper, 0.1 to 2 per cent magnesium, 0.1 to 1.5 per cent manganese, and 0.25 to 1 per cent silicon, said method comprising forming a body of said alloy, heating said body for $\frac{1}{2}$ to 20 hours at a temperature between 1000 and 1200° F., slowly cooling said body to the hot working temperature, said temperature being not lower than 650° F. and thereafter hot working said body of alloy.

5. The method of working an aluminum base alloy body by the process in which pressure is exerted on the body in all directions except that in which the worked metal issues, said alloy containing from 0.1 to 12 per cent of at least one eutectic-forming, solid solution-forming constituent, and from 0.05 to 2 per cent of at least one insoluble high melting point constituent and capable of being precipitation hardened, said method comprising forming a body of said alloy, heating said body for more than $\frac{1}{2}$ hour at a temperature between 1000 and 1200° F., said temperature also being above the fusion point of the most easily fusible constituent of said alloy, slowly cooling said body to the working temperature of not less than 650° F., and thereafter hot working said body of alloy.

6. The method of working an aluminum base alloy body by the process in which pressure is exerted on the body in all directions except that in which the worked metal issues, said alloy containing from 3 to 7 per cent copper, 0.1 to 2

per cent magnesium, 0.1 to 1.5 per cent manganese, and 0.25 to 1 per cent silicon, said method comprising forming a body of said alloy, heating said body for $\frac{1}{2}$ to 20 hours at a temperature between 1000 and 1200° F., cooling said body in air to the working temperature of not less than 650° F., and thereafter hot working said body of alloy.

7. The method of working an aluminum base alloy body by the process in which pressure is exerted on the body in all directions except that in which the worked metal issues, said alloy containing from 0.5 to 4 per cent each of magnesium and silicon, and at least one insoluble high melting point constituent, said method comprising forming a body of said alloy, heating said body for $\frac{1}{2}$ to 20 hours at a temperature between 1000 and 1200° F., said temperature also being above the fusion point of the most easily fusible constituent of said alloy, slowly cooling said body to a hot working temperature above 650° F., and thereafter hot working said body of alloy.

8. The method of hot working an ingot of an aluminum base alloy capable of being precipitation hardened, and containing at least one eutectic-forming, solid solution-forming constituent, and at least one insoluble high melting point constituent, said method comprising casting an ingot of said alloy, heating said ingot for $\frac{1}{2}$ to 20 hours at a temperature between 1000 and 1200° F., said temperature also being above the fusion point of the most easily fusible constituent of said alloy, cooling the ingot to a temperature not lower than 650° F. and immediately thereafter hot working said ingot.

9. As an article of manufacture, a hot worked body of an aluminum base alloy containing at least one eutectic-forming, solid solution-forming constituent in sufficient amount to produce precipitation hardening and at least one substantially insoluble high melting point constituent, said hot worked body being characterized by an equiaxed grain structure resulting from superheating said body prior to hot working at a temperature between 1000 and 1200° F. but above the temperature of fusion of the lowest melting point constituent in said alloy, slowly cooling said body to the hot working temperature and thereafter hot working said body.

10. As an article of manufacture, a hot worked body of an aluminum base alloy containing from about 0.1 to 12 per cent of at least one eutectic-forming, solid solution-forming constituent and from 0.05 to 2 per cent of at least one substantially insoluble high melting point constituent, and capable of being precipitation hardened, said hot worked body being characterized by an equiaxed grain structure resulting from superheating said body prior to hot working at a temperature between 1000 and 1200° F. but above the temperature of fusion of the lowest melting point constituent in said alloy, slowly cooling said body to the hot working temperature, and thereafter hot working said body.

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