This invention relates to the conversion of aluminum alloy ingots to sheet form and, more particularly, to the production of aluminum alloy sheets characterized by fine and uniform grain size.

The finer and more uniform the grain size of aluminum sheet, the greater is the formability of the sheet. The grain size and its uniformity depend on many factors, including the particle size and distribution of the so-called non-primary phases present in the aluminum alloy. These non-primary phases are practically insoluble, are only partially soluble or are not readily soluble in the aluminum alloy at elevated temperatures, and generally they consist of intermetallic compounds of iron and manganese. However, despite the relative insolubility of these non-primary phases, they tend to be retained in supersaturated solid solution in aluminum ingots produced by the direct chill casting process where rapid cooling and solidification of the ingots are an essential part of the process. In subsequent conventional processing of the ingot to sheet, which involves homogenization (soaking the ingot at a temperature close to the solidus temperature of the alloy) followed by hot rolling, cold rolling and annealing of the sheet, partial precipitation of the non-primary constituents takes place and phase changes occur which bring the constituent system closer to equilibrium conditions. Conventional treatment to effect this result often requires soaking the ingot for twelve hours or more and then air-cooling the ingot at a rate between 200°F and 400°F per hour or furnace cooling the ingot at a rate of approximately 50°F per hour.

I have now found that a significant improvement in grain size and uniformity of grain size of aluminum alloy sheet can be achieved by interrelated control of the thermal aspects of the homogenizing, hot rolling and annealing of the aluminum sheet. Specifically, I have found that by shortening the soaking time, by cooling the soaked ingot more slowly to a temperature close to the hot rolling temperature, and by subsequent controlled hot rolling and annealing procedures I am able to induce the proper precipitation of the non-primary phases so as to produce a uniformly fine grained product. Pursuant to the present invention, homogenization of the aluminum alloy ingot is carried out at a soaking temperature close to but below the solidus temperature of the alloy for a period not in excess of about 10 hours, the soaked ingot is then controllably cooled at a maximum rate of less than about 50°F per hour to a temperature not in excess of about 100°F above the initial hot rolling temperature. The conditioned ingot is then hot-rolled at a temperature not in excess of about 100°F above the annealing temperature of the alloy, cold rolled as before, and annealed at a temperature appropriate for the alloy.

During the soaking period while the aluminum alloy ingot is maintained at an elevated temperature, the non-primary phases are progressively dissolved and phase changes take place in those phases which remain undissolved. I have found that if soaking is carried out for over 10 hours the grain structure and micro-structure are changed to such an extent as to adversely affect the final grain size in the rolled sheet obtained from such an ingot. In practicing the present invention, however, the soaking period is limited to a maximum of about 8 to 10 hours and preferably is limited to a maximum of about 6 hours. A soaking period of about 4 hours presently appears to be satisfactory for conventional aluminum alloys such, for example, as 3003, 3004 and 3005.

The soaking temperature which is used in practicing the invention is the same as that heretofore used. This temperature is generally close to, but below, the solidus temperature of the alloy being treated. Soaking temperatures usually are within the range of 850°F to 1170°F depending on the alloy and are chosen to be between about 10°F and 100°F below the solidus temperature of the alloy under treatment. By way of example, the solidus temperature of 3003, 3004 and 3005 aluminum alloys are 1190°F, 1165°F and 1175°F, respectively, and the preferred soaking or homogenization temperature for these alloys is between about 1100°F and 1150°F.

The soaked ingot is cooled at a slow rate, pursuant to the invention, in order to prepare the ingot for hot rolling, the cooling operation being carried out in a suitable furnace or other temperature-controlled chamber in air or in any other conventional atmosphere.

The slow cooling rate employed promotes maximum precipitation of the non-primary phases and thus insures minimum retention of these phases in solid solution. The slow cooling rate also appears to produce the precipitated phases in a particle size range that resists re-solution during subsequent thermal treatment while the metal is being hot rolled and/or annealed. In addition, the particle size and particle distribution obtained by slow cooling is very effective in acting as a grain refiner during the recrystallization which takes place during annealing. The slow cooling rate used in the practice of the invention is less than 50°F per hour and is generally within the range of about 15°F to 35°F per hour. A cooling rate of about 25°F per hour is generally satisfactory for all conventional aluminum alloys, including those mentioned herein before.

Inasmuch as the slow cooling of the soaked ingot is used to obtain maximum precipitation of the non-primary phases of the alloy ingot, it is advantageous to slow cool the soaked ingot to a temperature close to the initial hot rolling temperature. Cooling to a temperature not in excess of about 100°F above the hot rolling temperature has been found to be satisfactory. For example, if the initial hot rolling temperature is between about 800°F and 850°F as is usually the case with 3003, 3004 and 3005 aluminum alloys, the ingot is advantageously slowly cooled to a temperature of about 900°F.

Hot rolling is carried out, pursuant to the invention, at the lowest practicable temperature so as to minimize re-solution of the precipitated non-primary phases. Such a temperature, I have found, is initially within about 150°F, and preferably not more than about 100°F, above the appropriate annealing temperature for the aluminum alloy being treated. The initial hot rolling temperature, of course, depends upon the alloy, and in the case of the 3003, 3004 and 3005 alloys, an initial temperature of about 800°F to 850°F, is presently preferred.

Following hot rolling, the sheet is cold rolled to final gage in the usual manner, the sheet being annealed following each series of cold rollings at the annealing temperature established for the alloy being treated. For example, the annealing temperature of 3003 aluminum alloy is between about 775°F to 850°F, and the annealing temperature of 3004 and 3005 aluminum alloys is between about 650 and 850°F, the higher temperatures within the aforesaid ranges being ordinarily preferred. The annealing of the rolled sheet pursuant to the invention not only effects re-crystallization of the aluminum
sheet but also continues the desired controlled precipitation of the non-primary phases previously described. The resulting homogenized hot rolled, cold rolled and annealed sheet is characterized by a uniform and very fine grain size.

The following examples are illustrative of treating schedules employed in accordance with the invention to produce rolled sheet from ingots of representative aluminum alloys obtained by conventional direct chill casting procedures:

**Example I**

A chill cast ingot of 3003 aluminum alloy was soaked for four hours at 1140°F., and the soaked ingot was then cooled at a rate of 25°F. per hour until it reached a temperature of 900°F. The initial hot rolling temperature of the ingot was 850°F. After 12 passes through the rolling mill the gauge of the alloy had been reduced to 0.270 inch, and the temperature of the sheet on completion of the hot rolling operation was 430°F. The sheet was then cold rolled to final gage of 0.020 inch with one interanneal and a final anneal. Both anneals were performed at a temperature of 820°F. with a 2 hour soak period. The resulting rolled sheet had a uniform and fine grain size.

**Example II**

An ingot of 3004 aluminum alloy obtained by conventional direct chill casting was soaked at 4 hours at a temperature of 1120°F. The homogenized ingot was cooled at a rate of 25°F. per hour to a temperature of 900°F. and then was subjected to a hot rolling operation at an initial temperature of 850°F. The sheet was then cold rolled to final gage with one interanneal and a final anneal. Both anneals were performed at a temperature of 750°F. with a 2 hour soak period. The resulting sheet had a fine and uniform grain size.

From the foregoing description of my new process for producing aluminum sheet of uniform fine grain, it will be seen that I have made an important contribution to the art to which my invention relates.

I claim:

1. A method for producing a uniformly fine grained sheet product from a chill cast ingot of an aluminum alloy in which there is present a non-primary manganese-containing phase and which is processed by homogenizing, hot rolling, cold rolling and annealing by means of the inter-related control of the thermal aspects of homogenizing, hot rolling and annealing so as to induce proper precipitation of the non-primary phase, said method comprising (a) homogenizing the ingot at a temperature just below the solidus temperature for the alloy for a period not in excess of about 10 hours, (b) slowly cooling the ingot at a rate less than 50°F. per hour to a temperature which is not in excess of 100°F. above the initial hot rolling temperature, (c) hot rolling at the lowest practical temperature, (d) cold rolling the resulting sheet to final gage, and (e) annealing following cold rolling at the annealing temperature of the aluminum sheet so as to continue the aforesaid phenomena of proper precipitation of the non-primary phase.

2. The method according to claim 1 in which the homogenizing of the ingot is carried out at a temperature between 10°F. and 100°F. below the solidus temperature of the alloy.

3. The method according to claim 1 in which the slow cooling of the homogenized ingot is carried out at a rate of between about 15°F. to 35°F. per hour.

4. The method according to claim 1 in which the hot rolling is carried out at an initial temperature of not more than 150°F. above the annealing temperature of the alloy.

5. The method according to claim 1 in which the homogenizing of the ingot is carried out at a temperature between 10°F. and 100°F. below the solidus temperature of the alloy for a period not in excess of about 6 hours, the slow cooling of the homogenized ingot is carried out at a rate of between 15°F. to 35°F. per hour, and the hot rolling is carried out at an initial temperature of not more than about 100°F. above the annealing temperature of the alloy.

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