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METHOD OF ROLLING TITANIUM SHEETS

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The invention relates to titanium sheets, and more particularly to methods or procedures for rolling titanium to form light gauge hot rolled sheets having sizes and thicknesses comparable to sheet steel, say for example, 36" x 96" x .020".

Titanium in the form of ore in the earth's crust is relatively abundant, and its potential uses in pure metallic form, due to its mechanical, physical and chemical properties—particularly its lightness in weight, its strength, and its corrosion resistance—are manifold.

Titanium has been used widely for many years in the form of ferro-titanium or ferrocobalt-titanium as a deoxidizing material in the manufacture of basic steel, because of its high affinity for both oxygen and nitrogen. It also has been used as an alloying agent in steel and aluminum.

However, little actual experience has been had and little use has been made of pure metallic titanium because of the present high cost of reducing the metal from ore to metallic form. As a result, only extremely small quantities of pure metallic titanium have been processed in an experimental manner to form small titanium bars and short, narrow sheet thickness sections for test purposes. Some titanium is said to have been hot rolled into heavy gauge sheet on the same equipment as used for stainless steel, but such procedure is laborious and costly and does not provide light gauge, hot rolled titanium sheet material finished in sizes and gauges comparable to sheet steel for use in pressing, stamping, drawing or otherwise forming large sheet titanium components, parts or devices.

Pure titanium ingots have only been available in weights ranging from 40 to 650 pounds and round in shape, being produced either by arc or induction melting of sponge titanium. Sponge titanium is produced by separating the iron and titanium from ilmenite (iron-titanium ore) to form titanium oxide which is converted to titanium tetrachloride. The latter, when reduced with molten magnesium, forms sponge titanium and magnesium tetrachloride.

The problem of rolling pure titanium into large size, thin gauge hot rolled sheets from such available ingots is complicated by the small size and weight of such ingots, their round shape, the affinity which titanium has for oxygen when heated which may produce undesirable surface oxides or scale, and the inherent stiffness of titanium when rolled to sheet form which prevents it from being satisfactorily doubled upon itself. An approach to the problem is further complicated by the belief of those who have investigated the properties of titanium that the material could not be heated to a high enough temperature for obtaining those reductions in hot rolling which are necessary to produce large

size, light gauge, titanium sheets without damaging the material.

Another factor complicating the problem is the relatively high heat conductivity of pure titanium which results in rapid cooling of the heated material during rolling. This rapid cooling characteristic, in addition to the relatively low temperatures believed to be required for avoiding damage to the material, has indicated that great difficulties would be encountered in obtaining desired reductions and uniformity of gauge in attempting to hot roll large size, light gauge, titanium sheets.

Notwithstanding these difficulties, we approached the problem from the standpoint of proper controls of rapid heating, rapid and extensive reductions, and surface protection against heat loss and excessive oxidation, and discovered that pure titanium sheets could be economically and satisfactorily rolled in sizes, for example, of 36" x 95" x .020" to 36" x 96" x .014", with satisfactory surfaces, free from mill marks, and with uniform gauge.

Accordingly, it is an object of the present invention to provide a method or procedure of rolling pure titanium into large size, thin gauge sheets of the order of 36" x 96" x .020" to 36" x 96" x .014".

Furthermore, it is an object of the present invention to provide a method or procedure of hot rolling pure titanium to light gauge sheet form with relatively high rolling temperatures without damaging the material.

Also, it is an object of the present invention to provide a method or procedure of hot rolling pure titanium sheets to light gauges, utilizing certain usual sheet rolling steps of matching and doubling without attendant difficulties due to the inherent stiffness of rolled titanium.

Furthermore, it is an object of the present invention to provide a method or procedure of hot rolling pure titanium to sheet form while protecting the material during final stages of reduction from rapid loss of heat and from excessive oxidation.

Also, it is an object of the present invention to provide a new method or procedure by which pure titanium sheets may be hot rolled economically with existing modern sheet mill equipment.

It is a further object of the present invention to advance the art by providing an economical method or procedure for the successful production of large size, light gauge, ductile, pure titanium sheets while avoiding difficulties heretofore believed to be so inherently associated with titanium as to prevent the economical and satisfactory production of such sheets.

Finally, it is an object of the present invention to satisfy the existing need for large size,

light gauge, ductile, hot rolled, titanium sheets, to solve problems existing in the manufacture of the same, to eliminate difficulties believed to be inherent in this field, and to obtain the foregoing advantages and desiderata in a simple, economical, and effective manner.

These and other objects and advantages apparent to those skilled in the art from the following description and claims may be obtained, the stated results achieved, and the described difficulties overcome by the discoveries, methods, steps, operations and procedures which comprise the present invention, the nature of which is set forth in the following general statement, preferred procedural embodiments of which—illustrative of the best mode in which applicants have contemplated applying the principles—are set forth in the following description, and which are particularly and distinctly pointed out and set forth in the appended claims forming part hereof.

The nature of the discoveries and improvements in methods of rolling titanium sheets may be stated in general terms as preferably including the steps of providing pure titanium sheet bar as by forging or rolling the same from titanium ingots; conditioning the surfaces of the sheet bar; repeatedly heating and elongating the same by single-ply rolling to heavy gauge sheet form; matching, reheating and rolling such sheets in pairs to further reduce and elongate the same; sandwiching such titanium sheets between basic steel sheets; and reheating and rolling such sandwich packs to desired gauge preferably accompanied by doubling.

By way of example, the improved methods and procedures of the present invention may be understood by reference to examples hereinafter described in detail. Three round, 40-pound, arc-melted, pure titanium ingots, $5\frac{1}{4}$ " in diameter and 12" long and containing up to 99.24% titanium and .36% carbon, after being surface conditioned in the same manner as other metal ingots to remove scale and surface imperfections by turning, grinding, etc., were heated in a reducing atmosphere in a gas-fired furnace to approximately 1700° F. to 1800° F. metal temperature, and forged on a drop hammer to flatten the same. After the first forging operation, the surfaces of the blanks were reconditioned with chipping hammers and grinding wheels in a usual manner, and the blanks were reheated, further hammer forged, again reheated, and finally hammer forged to provide from each ingot one rectangular sheet bar approximately $\frac{3}{4}$ " thick by 12" wide by 28" long.

One round, 100-pound, induction-melted, pure titanium ingot, 8" in diameter and $14\frac{1}{2}$ " long, and containing 98.57% titanium, .66% carbon, .22% iron, and .06% nitrogen, was similarly surface conditioned to remove scale and surface imperfections, and then heated in a reducing atmosphere to approximately 1750° F. to 1850° F. metal temperature, forged on a drop hammer, reheated, and further forged to form a 5" x 5" x 26" slab. This slab was then cut in two to form two blanks 5" x 5" x 13", and one blank was subjected to three heating and forging steps to form a sheet bar $\frac{3}{4}$ " x 12" x 34", and the second blank was subjected to two heating and forging operations to reduce the same to a sheet bar of similar size.

The five sheet bars thus forged from the 40# and 100# ingots were then surface conditioned by shot blasting and grinding over all, the ends thereof where not square being machined to provide square ends.

Example 40-1

One of the 40# ingot sheet bars was heated in a continuous bar heating furnace under a reducing atmosphere to 1520° F. metal temperature and given six passes on a 3-high hot mill to elongate the 12" width of the slab to 43", with a finishing speed of about 225 feet per minute. The piece was then reheated to 1580° F. and given two passes on the 3-high mill to elongate the same to about 57 inches. The piece was then heated in a continuous pack heating furnace under a reducing atmosphere with the furnace temperature maintained at approximately 1480° F. to approximately 1350° F. metal temperature and given two single-ply passes on a 2-high hot sheet mill to elongate the piece to 74" long by .115" thick, finishing at a speed of about 225 feet per minute.

The sheet was then sheared in half, matched in a pair, and the pair heated in the continuous pack furnace to 1350° F. and given four passes on the 2-high hot mill to 74" x .059". The pack was then reheated and hot-doubled without rolling and again reheated to 1350° F., and given four passes on the 2-high hot mill, producing four sheets in the pack each .029" thick. The doubled end of the pack containing the four sheets was sheared away, and the four sheets matched with two ordinary or basic steel sheets of approximately the same size and gauge in a sandwich with the four titanium sheets in the center and one basic steel sheet above and another below the four titanium sheets. This sandwich pack was heated in a continuous pack furnace to 1350° F. and given two passes on the 2-high hot mill to .023" gauge, then hot-doubled, reheated, and given two passes on the 2-high mill. The eight titanium and four steel sheets in the pack were then separated, the gauge of the eight titanium sheets therein being from .013" to .014". The finishing temperature of the titanium sheets in the pack was approximately 1100° F. to 1150° F.

During some of the later rolling steps on the 2-high hot mill, gas flames were impinged on the rolls in an attempt to keep the rolls as hot as possible to prevent cooling of the titanium sheets during rolling.

We discovered in carrying out the foregoing procedure in rolling titanium to sheets as thin as .013-.014" thick, that excellent metal surfaces resulted on the titanium sheets, with little oxide formed thereon and no mill marks, and the gauge of each sheet was substantially uniform throughout. We further discovered in separating the sheets in the pack that the titanium sheets did not stick to the basic steel sheets between which the titanium sheets were sandwiched, and that the titanium sheets did not stick to each other.

We also discovered that the lower heat conductivity of the steel sheets between which the titanium sheets were sandwiched held heat in the titanium sheets longer and enabled more elongation of the titanium sheets in the pack in one heating than could have otherwise been obtained. Furthermore, the relatively high rolling temperatures used in rolling the titanium sheets enabled the necessary elongation to take place required for producing titanium sheets as thin as .013-.014" thick.

Also, the sandwiching of the titanium sheets between the basic steel sheets, in the later stages of the heating and rolling operations, protected the surfaces of the titanium sheets from excessive oxidation or scaling even at the relatively high temperatures used.

Example 40-2

The second 40# ingot sheet bar was similarly heated in a continuous bar heating furnace under a reducing atmosphere to a 1580° F. metal temperature and given six passes on a 3-high hot mill to an elongation of 49", with a 225-feet-per-minute finishing speed. The piece was then taken to a continuous pack heating furnace where it was heated under a reducing atmosphere to approximately 1350° F. metal temperature and given two single-ply passes on a 2-high hot mill to an elongation of 73" and a thickness of .122", finishing at about 225 feet per minute. The sheet was sheared in half, matched in a pair, and the pair reheated to 1350° F. In the continuous pack furnace, and then given three passes on the 2-high hot mill to 64" x .061".

At this stage, one of the titanium sheets in the pack was cut up for tests, and the other titanium sheet was matched with and sandwiched between two basic steel sheets and reheated to 1350° F., and given three passes on the 2-high hot mill, finishing the titanium sheet at 18" x .040". The sheets in the pack were separated, producing one titanium sheet and two basic steel sheets.

Example 40-3

The third 40# ingot sheet bar was similarly heated in a continuous bar heating furnace under a reducing atmosphere to a 1520° F. metal temperature and given four passes on a 3-high hot mill to an elongation of 22", with a 225-feet-per-minute finishing speed. The piece was then reheated to 1550° F. and given two passes to an elongation of 40". The piece was then taken to a continuous pack heating furnace where it was heated under a reducing atmosphere to approximately 1350° F. metal temperature and given three single-ply passes on a 2-high hot mill to an elongation of 80" and a thickness of .119", finishing at about 225 feet per minute. The sheet was sheared in half, matched in a pair, and the pair reheated to 1350° F. in the continuous pack furnace and then given three passes on the 2-high hot mill to 62" x .053".

At this stage, one of the titanium sheets in the pack was sandwiched between two basic steel sheets and reheated to 1350° F. and given one pass on the 2-high hot mill and then hot-doubled, reheated, given two passes on the 2-high hot mill to .033" gauge, reheated to 1350° F., and given two further passes on the 2-high hot mill to 71" x .020". The sheets in this pack were separated, producing two 71" x .020" titanium sheets and four basic steel sheets.

The other titanium sheet from the 62" x .053" pair was similarly sandwiched between two basic steel sheets and reheated to 1350° F. and given two passes on the 2-high hot mill, then hot-doubled, reheated to 1350° F., and finished with four passes on the 2-high hot mill to 81" x .020", producing in the doubled pack two 81" x .020" titanium sheets and four basic steel sheets.

Example 100-A

One of the 100# ingot sheet bars was similarly heated in a continuous bar heating furnace under a reducing atmosphere to a 1680° F. metal temperature and given four passes on a 3-high hot mill to a 22" elongation, with a 225-feet-per-minute finishing speed. The piece was then reheated to 1480° F. and given four passes on the 3-high mill to an elongation of 46". The piece was then taken to a continuous pack heating

furnace where it was heated under a reducing atmosphere to approximately 1480° F. and given three single-ply passes on a 2-high hot mill to an elongation of 70" and a thickness of .118".

- 5 The sheet was sheared in half, matched in a pair, and the pair reheated to 1550° F. in a continuous pack furnace, and then given four passes on the 2-high hot mill to 62" x .070". These titanium sheets at this stage were so brittle with no ductility that no attempt was made to roll them further.

- 10 It was impossible at this time to determine accurately whether the higher heating temperatures or the higher carbon, iron, and nitrogen in the original induction melted ingot were responsible for these brittleness and lack of ductility characteristics.

Example 100-B

- 20 The second 100# ingot sheet bar was similarly heated in a continuous bar heating furnace under a reducing atmosphere to a 1550° F. metal temperature and given six passes on a 3-high hot mill to an elongation of 32", with a 225-feet-per-minute finishing speed. The piece was then reheated to 1500° F. and given four more passes on the 3-high mill to an elongation of 57". The piece was then taken to a continuous pack heating furnace where it was heated under a reducing atmosphere to approximately 1350° F. metal temperature and given three single-ply passes on a 2-high hot mill to an elongation of 75" and a thickness of .134". The sheet was sheared in half, matched in a pair, and the pair reheated to 1350° F. in the continuous pack furnace and then given five passes on the 2-high mill to 74" x .061".

- 30 Here again, the titanium sheets were so brittle and lacking in ductility that no further rolling was performed. Since these titanium sheets originated from the same ingot as the titanium sheets produced in Example 100-A, but were heated and rolled with temperatures and passes comparable to and on the same equipment as the sheets rolled in Examples 40-1, 40-2, and 40-3, it is believed that the higher carbon content in the 100# ingot was responsible for the brittleness and lack of ductility.

- 40 All of the sheets rolled from the 40# arc-melted ingots having low carbon contents, were ductile and could be welded.

- 45 Although very little scale or oxide was formed on the titanium sheets rolled in the sandwiched packs, yet the slight amount of scale that did form was very hard and tight but could be removed following heat treatment, including heating to 1300° F. and air cooling, by de-scaling in a molten sodium hydride bath followed by a nitric hydrofluoric acid brightening dip, and finishing with a flattening pass on a 2-high cold mill.

- 50 The titanium sheets rolled in the sandwiched packs tested 104 Rockwell B-Scale hardness, while the basic steel sheets in said packs tested 65-75 Rockwell B-Scale hardness.

- 55 In forging the titanium ingots to form sheet bar, the metal was heated to between 1700° F. and 1800° F. causing scaling which was removed from the forged pieces by the surface conditioning operations. However, the ability to heat the sheet bar to from 1520° F. to 1580° F., as in Examples 40-1, 40-2, and 40-3, and to as high as 1680° F. in Example 100-A, without damaging the material, was a totally unexpected result since those skilled in the art indicate that 1300°

F. is the top limit to which titanium can safely be heated for rolling.

As indicated in the examples, the higher heating took place in the continuous bar furnace for heating the sheet bar, and a somewhat lower metal temperature of about 1350° F. (also above the indicated safe 1300° F. temperature) was used in heating in the continuous pack furnace, excepting in Example 100-A where temperatures of 1480° F. to 1550° F. were used. However, these temperatures did not damage the material since the brittleness occurring in Example 100-A was because of the high carbon content of the titanium, rather than the high heating temperature.

We believe that it is possible to heat titanium to the temperature ranges set forth in the examples for hot rolling without damaging the material primarily because of the rapidity with which the material can be heated in continuous furnaces and of the rapidity with which the material was rolled on the 3-high and 2-high mills, finishing at speeds of 225 feet per minute. Since a reducing atmosphere was maintained in the continuous furnaces, little or no scaling occurred therein, and the rapid rolling accomplished the necessary reductions to obtain the thin gauge finished sheets of the order of .020" to .013" in thickness before any damage to the material could occur as a result of the initially high temperatures to which the material was heated for rolling.

We believe further that it would be impossible to reduce the material to such thin sheet gauges without using the high rolling temperatures, without finishing at metal temperatures of the order of 1100° F. to 1150° F., and without sandwiching individual or multiple titanium sheets between basic steel sheets not only to protect the titanium sheet surfaces in the final rolling operations, but also to retain high heating temperatures during rolling.

Thus, the ultimate essence of the present invention lies in the fact that sheets of a metal dissimilar to titanium, such as basic steel sheets, are used to form a sandwich pack with the dissimilar metal sheets on the outside of the pack in completing the rolling of titanium sheets to form large size, thin gauge titanium sheets. These sandwich packs of the two dissimilar metal sheets may be repeatedly heated and rolled to desired gauge with the optimum number of passes as in Examples 40-1 and 40-3, or may be repeatedly heated and rolled accompanied by doubling as in Examples 40-1 and 40-3, or may be heated and rolled without doubling as in Example 40-2. Furthermore, one titanium sheet may be sandwiched between two sheets of a dissimilar metal as in Examples 40-2 and 40-3, or a plurality of titanium sheets may be sandwiched between a plurality of sheets of a dissimilar metal as in Example 40-1.

Accordingly, the present invention includes a discovery of a successful procedure which may be used for the economical manufacture of hot rolled titanium sheets of large size and thin gauge; provides a method of hot rolling pure titanium to light gauge sheet form with relatively high rolling temperatures without damaging the material; provides for the use of a doubling step in the manufacture of titanium sheets without difficulty from the inherent stiffness of rolled titanium; provides a method of protecting titanium sheets during the final stages of reduction from rapid heat loss and from oxidation or scaling; provides a procedure by which pure titanium

sheets may be hot rolled economically with existing modern sheet mill equipment; and provides a solution to existing problems and difficulties encountered in satisfying the need for large size, light gauge, ductile, hot rolled, titanium sheets in a simple, economical and effective manner.

The hot rolled titanium sheets made in the manner described may, after annealing and pickling, be cold rolled to lighter gauges in a usual manner to as much as 50% reduction when it is desired to obtain cold rolled titanium sheet material, or when it is desired to obtain titanium sheet material thinner than hot rolled titanium sheet material which may be made in accordance with the present invention.

In the foregoing description, certain terms have been used for brevity, clearness and understanding; but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such terms are utilized for descriptive purposes herein and not for the purpose of limitation and are intended to be broadly construed.

Moreover, the description of the improvements is by way of example, and the scope of the present invention is not limited to the exact details described nor to the specific examples set forth.

Having now described the features, discoveries and principles of the invention, the methods and procedures comprehended, the characteristics of the products produced thereby, and the advantageous, new and useful results obtained; the new and useful discoveries, methods, steps, operations, procedures and principles, and mechanical equivalents obvious to those skilled in the art, are set forth in the appended claims.

We claim:

1. The method of hot rolling thin gauge titanium sheets including the steps of heating and rolling intermediate gauge titanium sheets from sheet bar, sandwiching at least one intermediate gauge titanium sheet between two sheets of a dissimilar metal having a lower heat conductivity than titanium to form a sandwich pack, heating and rolling the pack to desired final titanium sheet gauge, and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the dissimilar metal sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

2. The method of hot rolling titanium sheets to a gauge as thin as .013", including the steps of heating and rolling intermediate gauge titanium sheets from sheet bar, sandwiching at least one intermediate gauge titanium sheet between two sheets of a dissimilar metal having a lower heat conductivity than titanium to form a sandwich pack, repeatedly heating the pack to about 1350° F. and rolling the pack to desired final titanium sheet gauge and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the dissimilar metal sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

3. The method of hot rolling thin gauge titanium sheets including the steps of rapidly heating titanium sheet bar to 1480° F. to 1680° F. and rapidly rolling the same by a plurality of passes to elongate and thin the metal, rapidly reheating the material to about 1350° F., and further rapidly rolling the same by single-ply passes to intermediate gauge; matching and rapidly heating and rolling the intermediate gauge material to further reduce the same; sandwiching at least one further reduced titanium

sheet between two sheets of a dissimilar metal having lower heat conductivity than titanium to form a sandwich pack; rapidly heating and rolling the pack to desired final titanium sheet gauge, and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the dissimilar metal sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

4. The method of hot rolling thin gauge titanium sheets including the steps of rapidly heating titanium sheet bar to 1480° F. to 1680° F. and rapidly rolling the same by a plurality of passes to elongate and thin the metal, rapidly heating the material to about 1350° F. and further rapidly rolling the same by single-ply passes to intermediate gauge, matching and rapidly heating and rolling the intermediate gauge material to further reduce the same, sandwiching at least one further reduced titanium sheet between two basic steel sheets having a lower heat conductivity than titanium to form a sandwich pack, repeatedly heating the pack to 1350° F. and rolling the same accompanied by hot doubling to desired titanium sheet gauge, and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the steel sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

5. The method of hot rolling thin gauge titanium sheets including the steps of rapidly heating titanium sheet bar to 1480° F. to 1680° F. and rapidly rolling the same by a plurality of passes to elongate and thin the metal, rapidly heating the material to about 1350° F. and further rapidly rolling the same by single-ply passes to intermediate gauge, matching and rapidly heating and rolling the intermediate gauge material to further reduce the same, sandwiching a further reduced titanium sheet between two basic steel sheets having a lower heat conductivity than titanium to form a sandwich pack, reducing the pack to desired titanium sheet gauge by operations of heating to 1350° F. and rolling, and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the steel sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

6. The method set forth in claim 3 in which the matched intermediate gauge titanium material prior to sandwiching is heated to 1350° F., hot-doubled, reheated to 1350° F., rolled in doubled condition and sheared to remove the doubled end; and in which the four intermediate gauge titanium sheets thus produced are sandwiched between two basic steel sheets to form the sandwich pack.

7. The method set forth in claim 4 in which the matched intermediate gauge titanium material prior to sandwiching is heated to 1350° F., hot-doubled, reheated to 1350° F., rolled in doubled condition and sheared to remove the doubled end; in which the four intermediate gauge titanium sheets thus produced are sandwiched between the two basic steel sheets to form the sandwich pack; and in which the sandwich pack is heated to 1350° F., rolled by a plurality of passes, heated to 1350° F. and hot-doubled, reheated to 1350° F. and rolled by a plurality of passes to desired titanium sheet gauge.

8. The method set forth in claim 4 in which one intermediate gauge titanium sheet is sandwiched between two basic steel sheets to form the sandwich pack; and in which the sandwich pack

is heated to 1350° F., rolled, heated to 1350° F. and hot-doubled, reheated to 1350° F. and rolled by a plurality of passes to desired titanium sheet gauge.

9. The method set forth in claim 5 in which the sandwich pack of one titanium sheet and two basic steel sheets is heated to 1350° F. and rolled by a plurality of passes to desired final titanium sheet gauge.

10. The method of making hot rolled thin gauge titanium sheets from a titanium ingot including the steps of conditioning the ingot surfaces, repeatedly heating the ingot to 1700° F. to 1850° F. and forming the same to sheet bar size, conditioning the surfaces of the bar, repeatedly heating and rolling the sheet bar to intermediate gauge titanium sheets, sandwiching at least one intermediate gauge titanium sheet between two basic steel sheets having a lower heat conductivity than titanium to form a sandwich pack, heating and rolling the pack to desired final titanium sheet gauge, and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the steel sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

11. The method as set forth in claim 10 in which the sheet bar is rapidly heated to 1480° F. to 1680° F. and rapidly rolled by a plurality of passes to elongate and thin the same, then reheated to about 1350° F. and further rapidly rolled by single-ply passes to intermediate gauge, and then matched and rapidly heated and rolled; and in which the sandwich pack is rapidly heated to 1350° F. and rolled to desired final titanium sheet gauge.

12. The method of making hot rolled thin gauge titanium sheets from a titanium ingot including the steps of conditioning the ingot surfaces, repeatedly heating the ingot to 1700° F. to 1850° F. and working the same under pressure to form sheet bar, conditioning the surfaces of the sheet bar, repeatedly heating and rolling the sheet bar to intermediate gauge titanium sheets, sandwiching at least one intermediate gauge titanium sheet between two sheets of a dissimilar metal having a lower heat conductivity than titanium to form a sandwich pack, heating the pack to 1350° F. and rolling the same to desired titanium sheet gauge, and protecting the titanium sheet material from rapid heat loss and excessive oxidation by the dissimilar metal sheets during heating and rolling of the sandwich pack to final titanium sheet gauge.

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