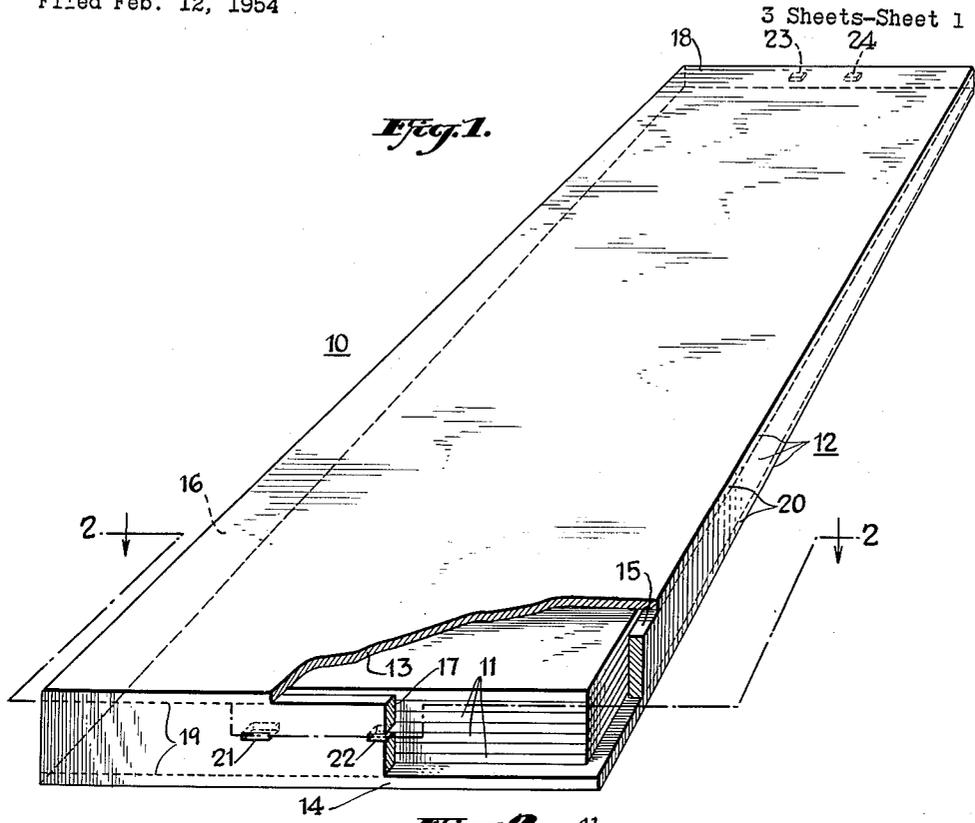


May 30, 1961

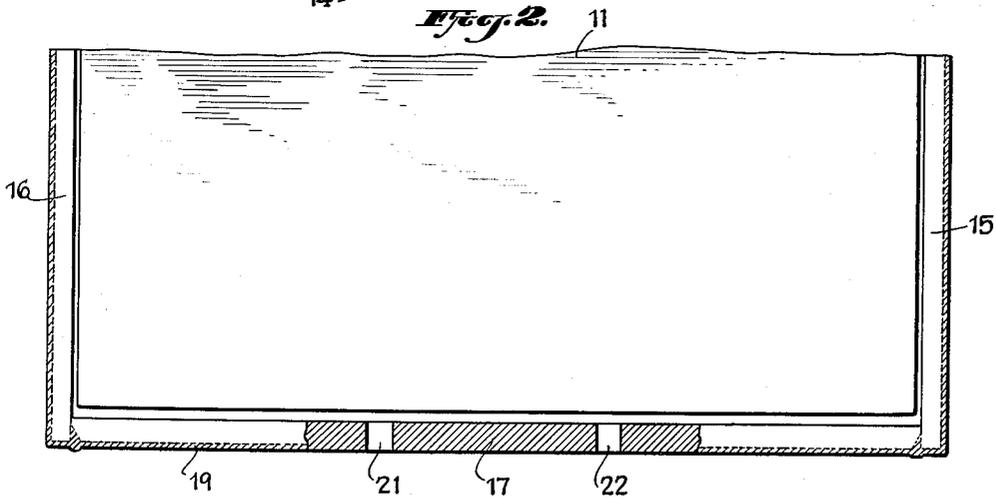
J. E. NORDHEIM ET AL  
PACK ROLLING

2,985,945

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*Fig. 1.*



*Fig. 2.*

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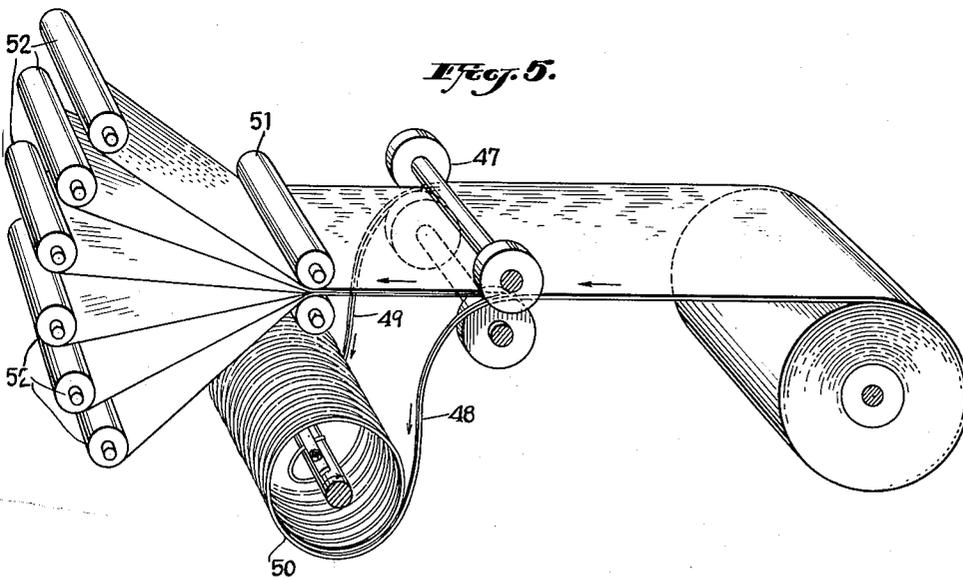
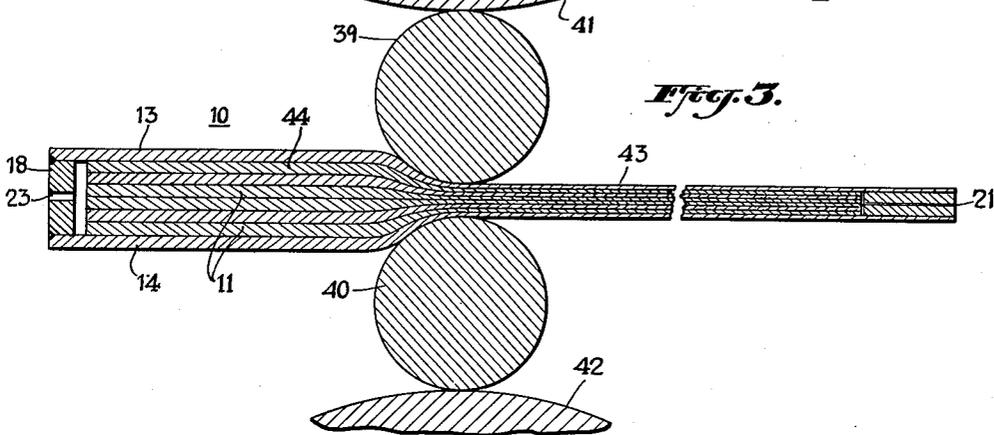
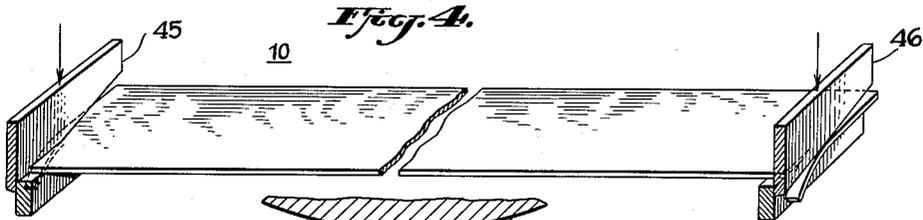
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3 Sheets-Sheet 2



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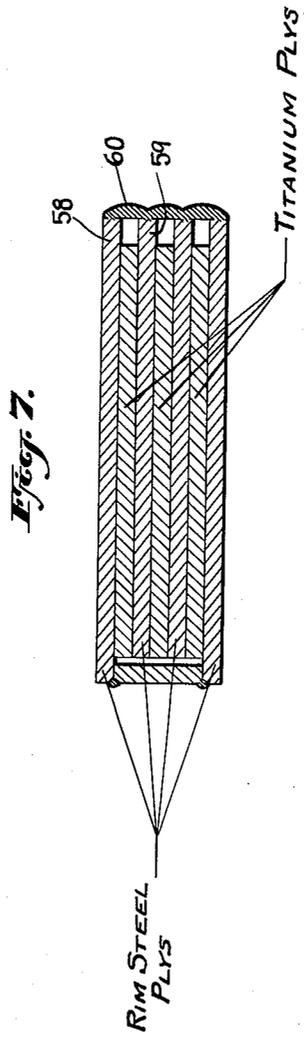
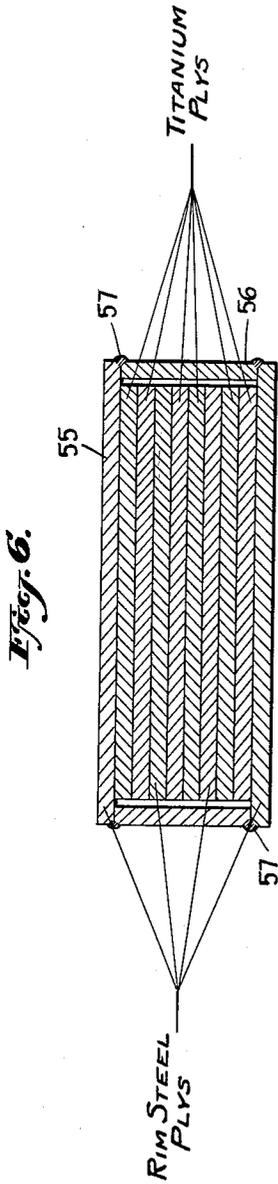
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3 Sheets-Sheet 3



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2,985,945

**PACK ROLLING**

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2 Claims. (Cl. 29—19)

This invention pertains to the multi-ply rolling of difficultly rollable metals down to extremely thin gauges on the order of 0.003 to 0.04 inch, or more or less as required. The invention pertains more especially to methods and assemblies for so rolling metals which are highly reactive chemically like titanium, zirconium and their alloys, and under conditions substantially free from atmospheric contamination and scaling.

The relatively inactive difficultly rollable metals like stainless steel, silicon electrical steel, etc. cannot be hot rolled by conventional rolling procedures to gauges much under about 0.10 inch as limited by the minimum setting of the mill screw-downs to avoid injury to the rolls. Further hot reductions by simple doubling or matching expedients are inapplicable as applied to difficultly rollable metals of this character. Hence cold rolling must be resorted to for further reducing the gauge, and this necessitates repeated passages through the rolls accompanied by frequent intermediate anneals. Also as the finer gauges are approached increasingly high roll pressures are required necessitating the use of mills especially constructed to exert usually heavy roll pressures, such as the Sendzimir or equivalent types.

In the rolling of metals which are highly reactive chemically, like those above mentioned, further difficulties are encountered. Such metals in addition to being inherently difficult to roll, are also subject to a high degree of embrittling contamination by atmospheric gases, such as oxygen, nitrogen, hydrogen, etc., at hot rolling temperatures, and are, moreover subject to excessive scaling under atmospheric conditions at such temperatures by reason of their high chemical reactivity. As a consequence it has been necessary in the hot rolling of such metals as heretofore practiced, to roll at relatively low temperatures in the range of about 900°-1800° F., which is considerably below the temperature range of about 1900°-2300° F. at which less chemically reactive metals, such as the ferrous base metals and alloys, may be successfully hot rolled. This relatively low temperature required for the hot reduction by rolling of metals like titanium, zirconium, etc. necessitates the employment of heavy roll pressures and repeated heatings and passages through the rolls for hot reducing the gauge by conventional rolling procedures.

Now in accordance with the basic concept of the present invention, we have devised a method for hot rolling difficultly rollable metals down to extremely thin gauges of the order aforesaid and by employment of conventional types of rolling mills such as 2-high and 4-high sheet or strip mills of standard construction. This we accomplish in accordance with the broadest concept of the invention by interposing one or more plies of the difficultly rollable metal between a pair of outer or facing plies of a dissimilar metal, such for example as mild steel, which is more easily rollable, and which serves to cushion the interposed ply or plies of difficultly rollable metal, and thus facilitate the reduction and accompanying elongation of such plies during passages between the reducing rolls.

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A modification of this basic concept comprises the interposition of additional plies of the dissimilar or cushioning metal between one or more intermediate plies of the difficultly rollable metal, as for example between alternate plies thereof, or between groups comprising several such plies. In this way the difficultly rollable metal plies are cushioned by the dissimilar metal not only by the facing plies of the latter but also by the interposed intermediate plies thereof whereby gauge reduction and accompanying elongation of the difficultly rollable metal plies is further assisted and facilitated.

Hot reduction of any of the stacked assemblages aforesaid may be affected by simply feeding the same between the reducing rolls. It is preferable, however, in order to prevent warping, skewing, crimping, etc., to integrate these assemblages prior to rolling, as for example by welding together along contiguous edges. In the preferred embodiment, however, the outer facing plies of the cushioning metal are extended longitudinally and laterally beyond the interposed plies for reception of side and end bars, which are welded to the outer plies, thus substantially to encase the inner plies in an outer metal sheath, consisting of the facing plies together with the interposed side and end bars.

For the hot reduction with assemblies or packs of this character of metals which are highly reactive chemically, like titanium, zirconium, etc., the outer sheath must substantially seal the inner titanium, zirconium, etc. plies against the outer atmosphere in order to prevent atmospheric contamination. To this end the welding of the side and end bars to the outer or facing plies of mild steel or the like, must extend around the entire peripheries thereof. However to permit escape of hot gases from the pack interior during rolling the end bars must be provided with one or more small vents or slots, as otherwise the pressure exerted by the heated gases on the interior will burst the assembly in the first passage through the rolls.

By employment of packs of this character which protect the inner plies against atmospheric contamination during rolling, the rolling temperature of the pack may be increased to the optimum for hot reducing any particular type of difficultly rollable metal. In the case of chemically reactive metals like titanium, zirconium, etc., the rolling temperature employed may thus be increased to a value approximately that at which less chemically reactive metals are conventionally rolled, such for example as the ferrous base metals. In this way rapid gauge reduction is facilitated.

The metal selected for the outer sheath is preferably of such character as to be easily gripped by the reducing rolls of the mill, namely, a metal that the reducing mills will "bite into" and thereby assist the gauge reduction of the pack during rolling. Also it is preferable that the metal selected for the outer sheath possess hot strength characteristics comparable to the metal of the inner plies, in order to assure that the inner plies will be reduced in gauge proportionately to the outer plies during the hot rolling reduction. As stated mild or low carbon steel, such as rim steel has been found generally suitable for the outer sheath, particularly as applied to the pack rolling of titanium or zirconium of commercial purity as well as the alloys thereof with other metals having comparable hot strength hardnesses. However, for pack rolling such alloys as possess considerably higher hot strength characteristics, for example the so called alpha-alloys containing alpha alloying additions like aluminum, or the mixed alpha-beta or beta-alloys containing alloying additions of such refractory metals as manganese, chromium, tungsten, molybdenum, etc., the outer sheath comprises a metal of comparable hot strength such as straight chrome steel and austenitic stainless steel and

such metals as Engraver Plate and as are sold under the trademarks "Max-el 2B and Max-el 3½, Max-el being a registered trademark of Crucible Steel Company of America. Woldman, "Engineering Alloys," published by the American Society for Metals, gives the following nominal compositions: Engraver Plate—0.35% C, balance Fe; Max-el 2B—0.4% C, 1% Mn, 0.2% Mo, balance Fe; Max-el 3½—0.5% C, 1.25% Mn, 0.6% Cr, 0.15% Mo, balance Fe.

In order to prevent the inner plies of the chemically reactive metals aforesaid from welding or bonding together during the hot rolling operation, they are preferably given initially, and prior to assembly in the pack, a low temperature continuous anneal, under atmospheric conditions, at a temperature for example of about 1100°–1200° F. thereby to provide the plates or sheets or such metal with surface coatings of a thin transparent oxide. This oxide coating thereafter serves as a separating agent to prevent bonding of the sheets during subsequent rolling. Alternatively or as an additional precaution to this end these sheets, prior to assembly in the pack, may be given a thin coating of dilute lime which likewise is an effective separating agent to prevent bonding during rolling. Other suitable separating media may be employed during assembly of the pack such as aluminum oxide, clay, etc.

In the ensuing disclosure, the invention will be described more in detail as applied to the multi-ply rolling of titanium sheets and plates, as an illustrative example, but it will be understood that the same principles are directly applicable to the rolling of other difficultly rollable metals or chemically reactive metals having equivalent characteristics.

Having thus described the invention in general terms, reference will now be had for a more detailed description, to the accompanying drawings wherein:

Figure 1 is a perspective view of a "pack" assembly in accordance with the preferred embodiment of the invention, this view having parts broken away to show the interior assembly.

Figure 2 is a partial longitudinal, sectional plan view taken substantially along 2—2 of Fig. 1, to illustrate the assembly of the side and end bars to the top and bottom plates comprising the outer sheath.

Figure 3 is a longitudinal section through the pack assembly during its passage through the reducing rolls of a 4-high mill, to illustrate the manner in which the pack as a whole is reduced in gauge by rolling.

Figure 4 is a perspective view illustrative of the end cropping of the pack assembly, subsequent to rolling, to shear off the end portions, including the end bars.

Figure 5 is a perspective view showing the longitudinal edge slitting of the pack subsequent to rolling, to shear off the longitudinal edge portions, including the side bars of the assembly, this view also illustrating the subsequent separation of the individual plies of the thus trimmed assembly, and the individual coiling thereof onto separate reels.

Figures 6 and 7 are diagrammatic showings in end elevation, with the end bars removed, of assemblages in accordance with the above discussed modification of the invention wherein additional plies of the easily rollable metal are interposed between alternate plies or groups of plies of the difficultly rollable metal.

Referring to the drawings and more particularly to Figs. 1 and 2, the "pack" or assembly shown generally at 10, comprises a series of superimposed sheets or plates 11 of for example a difficultly rollable, chemically reactive metal like titanium to be reduced in gauge by rolling. This stack of plates is housed within an outer enveloping sheath, shown generally at 12, consisting of top and bottom outer facing plates 13 and 14, together with side and end bars as at 15, 16 and 17, 18. It will be observed that the top and bottom plates 13, 14 of the outer sheath have lateral and longitudinal dimensions slightly in ex-

cess of those of the pack 11, thus to project beyond the pack both laterally and longitudinally. Within these projecting portions of the top and bottom plates, the side bars 15, 16 and the end bars 17, 18 are inserted, being welded to the top and bottom plates as at 19, 20, thus to seal the interior of the assembly against the outer atmosphere. However, as stated, the end bars 17, 18 are vented at spaced intervals by slots or drilled holes, as at 21–24 inc.

The top and bottom plates 13, 14 of the enveloping sheath are preferably made of a low carbon or mild steel, as it has been found that material of this character provides an effective gripping action by the rolls of the rolling mill during reduction. Furthermore, such material is relatively cheap and undergoes no troublesome scaling during heating for rolling, or during the rolling operation itself. It furthermore elongates well without tearing during rolling, being tough, ductile and easily forgeable. The side and end bars 15–18, inc., may likewise be made of low carbon steel for the same reasons and because easily rolled or drawn into the sectional configurations shown.

Figure 3 illustrates the reduction by rolling of the pack. In this operation a conventional 2-high or 4-high mill may be employed, that shown in the drawing being of the 4-high type, comprising vertically aligned reducing rolls 39, 40, of relatively small diameter and such as to bite easily into the pack, these reducing rolls being respectively backed up by backing up rolls 41, 42, of much larger diameter in accordance with conventional practice. During passage through the rolls, the assembly is reduced in gauge as illustrated by the reduced thickness 43 on the delivery side as compared to the greater gauge or thickness 44 on the entry side. During the passage through the reducing rolls, the heated gases within the assembly interior are forced to the entry side of the pack, and as the trailing end of the pack approaches the rolls, any excess of gas pressure within the interior as compared to the outer atmosphere escapes through the vent holes 23, 24 in the trailing end bar.

Following the rolling operation, the ends of the pack are cropped by means of shears as at 45, 46, Fig. 4. The pack is then passed through a slitter, as at 47, Fig. 5, to trim off the lateral edges including the side bar portions 15, 16, the trimmed edges 48, 49 being reeled up as at 50. The thus trimmed pack passes thence between pinch rolls 51, and thereupon the superimposed plies are separated and separately wound onto individual coiling reels as at 52.

The preferred procedure for carrying out the invention is as follows: The individual titanium plates comprising the pack 11 are first produced in gauges of about 0.2–0.4" thick, preferably about 0.25", in conventional manner by first hot rolling an ingot on a breakdown or universal mill, with subsequent rolling on a "hot" reversing or tandem mill into plates of this gauge. The plates are then cleaned free of scale, surface imperfections, and oxides, as by caustic descaling, pickling, etc. The plates are then given a low temperature continuous anneal at about 1100–1200° F., to impart thereto surface coatings of a thin, transparent oxide which, as above stated, serves as a separating agent to prevent the plates from bonding or sticking together during the subsequent hot rolling operation. These plates are then assembled as at 11 in Fig. 1. Prior to this assembly, they may also be given a thin coating of dilute lime which also functions as a separator to prevent bonding during rolling. As part of this assembly, top and bottom plates 13, 14 of mild steel are also included, and the side and end bars 15–18, inc., inserted and welded to the top and bottom plates as above described, the end bars being provided with vent holes as explained. These cover plates 13 and 14 range in thickness from about ⅜" to ¾". The choice in thickness is determined by the minimum possible thickness of about 0.3 inch to which the pack may be hot

rolled owing to the minimum adjustments of the mill roll screw-down.

The composite assembly or pack is thereupon heated in a conventional slab heating furnace to a rolling temperature of about 1370° plus or minus about 25° F., and rolled in a conventional hot sheet or strip mill, such as a 2-high or 4-high hot mill in the manner illustrated in Fig. 3. This mill may be of tandem or reversing type, but in any event, hot rolls the assembly to the minimum gauge of about 0.3 inch aforesaid. The resulting strip pack is then annealed, either by box, open fire or continuous annealing. Following the annealing, it is cleaned, either by a dry method, such as by sand blasting or brushing, or by a wet method, as by acid pickling, or caustic descaling plus acid pickling. The pack may thereupon, if desired, be cold rolled on a conventional 2-high or 4-high "cold" rolling mill to a predetermined final gauge. In this cold rolling, the reduction can be approximately 10% to 60% as desired or required. To this end, ordinarily only about 1 to 3 cycles through the mill are necessary. After cold rolling, the pack is again annealed, either by box, open fire or continuous annealing. At this stage either of two alternative procedures may be employed for final finishing, or both procedures may be utilized to suit operating conditions. One procedure is to end crop and slit the pack and recoil the successive plies on multiple winding reels, winding each ply separately, as illustrated in Figs. 4 and 5. This separates the top and bottom steel plies from the inner plies of titanium or other reactive metal, and thus provides individual coils of the titanium plies. The other procedure is to end crop the pack, edge trim the same as illustrated in Figs. 4 and 5, and then cut to length to produce sheets, the plies being then separated by removing the top and bottom plies of steel and stacking the inner plies of titanium or other reactive metal.

The individual coils or sheets of titanium or other reactive metal obtained as above, may now be further cold reduced on conventional mills, to the extent of about 3% to 8% to develop the requisite surface finish, the strips or coils being then cut to length if desired. In either procedure the resulting sheets are given a final anneal as aforesaid and are then flattened or leveled by conventional procedures.

In a typical example illustrative of the invention a pack is built up of three plates of commercial purity titanium or titanium base alloy, each 0.25 inch thick. Top and bottom cover plates of rim steel each of  $\frac{3}{8}$  or  $\frac{3}{4}$  inch thickness are then applied. The choice in thickness is determined by the minimum possible finishing gauge of 0.30" of the pack and by the desired final gauge of the titanium plies. The width and length of the cover plates are always 2 inches in excess of the titanium plates to permit of insertion of  $\frac{3}{4} \times \frac{3}{4}$ " spacer bars plus a  $\frac{1}{4}$  inch empty space all around the interior. The overall dimensions are such as to give a maximum pack weight of about 850 pounds. The spacer bars are welded in place as above described, the end spacer bars being provided with several vent holes, each about  $\frac{1}{4}$ " diameter.

The resulting integrated pack is heated in a furnace at temperatures of about 1370° plus or minus 25° F., for about one hour for each inch of thickness. It is then clogged down in one or two heatings each of about fifteen minutes duration at about 1370° F., until approximately 1 inch thick. The end holes are always left open. The breakdown is now reheated at about 1300° F. for fifteen minutes and rolled down to final gauge of about 0.3" in this one heat.

Each pack will produce six titanium or titanium base alloy sheets of 36 x 120 x 0.025 inches for a total finished weight of 120 pounds. Other sizes are in direct proportion.

It will be understood, of course, that much larger and heavier packs may similarly be made up and processed, ranging up to 2000 or 3000 pounds or heavier.

Referring to Figs. 6 and 7 in the modifications therein shown, the packs comprise one or more plies of the difficultly rollable metal such as titanium separated individually or in groups by interposed plies of a softer and more easily rollable cushioning metal, such as mild steel or the like. As in the previous embodiments the outer plies or cover plates are likewise of mild steel. In the Fig. 6 embodiment the plies of cushioning metal are interposed as shown between successive pairs of groups of the titanium plies; whereas in the Fig. 7 embodiment the cushioning metal plies alternate with the titanium plies.

The pack assembly may be integrated by assembling and welding side and end bars 55 and 56 between and to the cover plates, as at 57, Fig. 6, or the cushioning plies may project beyond the titanium plies, and the pack integrated by heliarc or otherwise welding only the cushioning plies 58 and 59 together, as at 60.

These embodiments result in greater uniformity in gauge of the innermost as compared to the outermost titanium or other difficultly rollable metal plies as a result of hot rolling especially of packs built up of a large number of plies of the difficultly rollable metal. The plies are prevented from sticking together in any of the various ways above indicated, as by initial surface oxidation, liming, or by interposition of other suitable separating media, such as chromium oxide, magnesium oxide, aluminum oxide, etc.

What is claimed is:

1. The method of pack rolling annealed plates which are each about 0.2 to 0.4 inches thick and of chemically highly reactive and difficultly rollable metal selected from the group consisting of titanium and zirconium of commercial purity and alloys thereof which comprises: applying a thin separating medium to the surfaces of each one of said difficultly rollable metal plates which medium is selected from the group consisting of transparent oxide formed by annealing said plates at a temperature of about 1100° to 1200° F. under atmospheric conditions, dilute lime, clay, aluminum oxide, chromium oxide, and magnesium oxide; assembling a plurality of the thus thinly coated said plates in superimposed relation; encasing the thus assembled said coated plates in an outer sheath to thereby form a pack that is open only at small holes at the ends of said pack which holes provide an escape for gases enclosed in said pack during the subsequent rolling thereof, said sheath being of a metal selected from the group consisting of mild steel, low carbon steel, and rim steel; heating said pack to a temperature of from about 1345° to 1395° F. for about an hour for each 1 inch of pack thickness; rolling said pack to a thickness not under 0.3 inch; annealing said pack; cleaning said pack by suitable means as by any one of sandblasting, brushing, acid pickling, and caustic descaling plus acid pickling; cold rolling said pack to obtain a reduction of from 10% to 60% of said 0.3 inch; again annealing said pack; end cropping and edge trimming said pack; separating the trimmed pack into its component sheets; further cold rolling the separated said sheets to effect a reduction of from 3% to 8% and to concurrently develop the requisite desired surface finish; annealing said separated sheets; and flattening said sheets.

2. A method as in claim 1 wherein said difficultly rollable metal is selected from the group consisting of alpha alloys, beta alloys, and alpha-beta alloys of titanium and zirconium, where said alpha alloys contain alpha alloying additions like aluminum and where said beta alloys contain additions of refractory metals as manganese, chromium, tungsten and molybdenum; and wherein said sheath comprises a metal such as straight chrome steel and austenitic stainless steel.

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