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METHOD FOR PRODUCING FLAT-ROLLED PRODUCT

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ABSTRACT OF THE DISCLOSURE

This invention relates to an improved method for producing titanium and high-alpha, titanium-base alloys in continuous strip form. Specifically, the invention is in the practice of heating said metal, prior to each cold reduction, or prior to achieving cold reduction on the order of at least 50%, to a temperature below the recrystallization temperature of the metal. The metal may be cold reduced while at said elevated temperature; or, alternately, it may be cooled to room temperature and then cold reduced. The invention provides an improved flat-rolled product, particularly with respect to directionality and formability.

If titanium or titanium-base alloys are subjected to continuous reduction in one direction, there will be major differences in the mechanical properties as measured longitudinal and transverse with respect to the rolling direction. These inconsistent mechanical properties, of course, affect the quality of any final products. Because of the problem of directionality, it is common practice to cross-roll titanium sheet material on a hand mill. In this manner, unidirectional rolling is avoided as is the attendant problem of directionality. This practice is, however, more laborious and time consuming than processing in the form of continuous strip by unidirectional rolling. In addition, with hand sheet rolling, gauge control and good surface finish are more difficult to achieve.

In an effort to overcome the problem of directionality resulting from strip-rolling of titanium and titanium alloys, various techniques have been attempted. One of these techniques comprises annealing the material in strip form prior to each cold-reduction operation at a temperature above or near the beta-transus temperature of the metal. Although this technique does have a beneficial effect with respect to directionality, it results in the production of striations that develop upon tensile straining of the material during the forming operations incident to the production of final products.

Another approach for alleviating directionality in strip production is to use heavy cold reductions (above about 30% reduction) with conventional intermediate anneals or long-time, high-temperature box anneals. The long thermal treatments, and the associated difficulties, render the box annealing practice expensive and time consuming. In addition, the beneficial results of the conventional intermediate annealing and heavy reduction practice are at best sporadic in alleviating directionality. With typical rolling equipment, heavy cold reductions without intermediate softening treatment are difficult to achieve.

It is accordingly a primary object of the present invention to provide a method for producing titanium and high-alpha, titanium-base alloys in continuous strip or band form with improved properties and at a lower cost than with conventional practice.

It is a further object of the invention to provide a low-cost, efficient method for producing titanium and high-alpha, titanium-base alloys in continuous band form with improved directional properties.

It is another object of the invention to provide a

method for producing titanium and high-alpha, titanium-base alloys in continuous strip form that are characterized by improved formability after cold reduction.

It is still another object of the invention to provide a method for producing titanium and high-alpha, titanium-base alloys in continuous strip form without the necessity of annealing prior to each cold reduction operation and without requiring heavy cold reductions at each operation.

These and other objects of the invention as well as a complete understanding thereof may be obtained from the following description and specific examples.

Broadly, the method of the invention embodies rolling metal, which may be titanium or high-alpha, titanium-base alloys, from an intermediate gauge which may typically be the hot-band gauge, to a final gauge by one or usually more reduction operations. A total reduction of at least 50% without recrystallization of the metal is essential to the invention. Preferably, this heavy reduction is accomplished by heating the metal to an elevated temperature below its recrystallization temperature and rolling at this temperature. Heavy reductions can much more readily be accomplished at suitable elevated temperatures than at room temperature. The lower temperature limit for this warm rolling operation is about 300° F. The upper temperature limit is typically 1200° F., but may be as high as 1600° F. for some highly alloyed compositions. It is important that this temperature be chosen so that no substantial recrystallization occurs during the rolling operation. Alternatively, the heavy reduction can be accomplished by a series of cold reductions with intermediate softening heat treatments at temperatures below the recrystallization temperature. These heat treatments can be carried out at temperatures from about 400° F. to 1200° F., or up to 1600° F. for highly-alloyed grades. The practice described differs substantially from conventional intermediate annealing, in which the metal is heated to temperatures above the recrystallization temperature. In other words in the practice of the invention the metal must be prevented from undergoing what is typically referred to as an intermediate annealing treatment in conjunction with the multiple cold-reduction operations. In the preferred practice of the invention, the metal in continuous band form will be reduced to final gauge by plurality of reduction operations and intermediate heating in accordance with the invention. If desired, however, production of final gauges need not be achieved by this practice.

In a typical practice of the invention, therefore, titanium or high-alpha alloys thereof would be hot rolled to an intermediate gauge from slab by unidirectional rolling at a temperature of, for example, 1625° F. The material is then given a short-time anneal at for example 1500° F. for about 10 or 15 minutes. The metal in continuous band form is next heated in accordance with the invention to a temperature of, for example, 800° F., but in any event substantially below the recrystallization temperature of the metal. The strip is then unidirectionally rolled to strip form at such elevated temperature. If the alternate practice of room-temperature rolling is to be used, the metal need not be heated prior to the first rolling operation. The heating operation to a temperature below the recrystallization temperature, e.g., 800° F., is repeated prior to each rolling operation with the preferred practice until a reduction to final gauge or at least a reduction of 50% is achieved. Finally, the strip is conventionally annealed at, for example, 1400° F. for five minutes or less at annealing temperature. It is understood that with this practice, and as will be shown in detail hereinafter, the formability of the material at room temperature as well as the directional properties are substantially improved over conventional practice and conventional materials, without re-

quiring intermediate annealing during cold reduction and without requiring heavy cold reductions at each reduction operation. It appears that the amount of reduction at each operation has no effect, so long as a total reduction of at least 50% is achieved prior to any recrystallization of the material. As mentioned hereinabove, in most instances it would be preferred to reduce the material to final gauge prior to further recrystallization. If desired, however, the strip could be reduced to an extent of at least 50% and then subjected to annealing. Thereafter, reduction to final gauge could be completed by conventional practice.

As a specific example of the practice of the invention, hot band of commercially pure titanium at a gauge of about 0.175 inch was heated to a temperature of 800° F. and rolled to final gauge at this temperature. Multiple reduction operations were used with the material being reheated to about 800° F. for each operation. After reduction to a final gauge of about 0.03 inch, the metal was subjected to a conventional final anneal at about 1400° F. for about four minutes. The properties of this material are reported in Table I. It may be noted particularly that the directionality of this material is markedly reduced with respect to that characterizing the conventional hot-band material also reported in Table I. This material (hot band) is the same hot band as subjected to the practice of the invention. It should be further noted that the formability, as evidenced by Olsen Cup Test height and tensile elongation, is also substantially improved over the hot-band material and material produced in accordance with conventional practice from the same hot band as also reported in Table I. This conventionally produced material was subjected to four cold-reduction operations with intermediate anneals at 1400° F. The improvement with respect to formability of the material produced in accordance with this invention over this conventionally processed material may be particularly noted with respect to the Olsen Cup Test height; the Olsen Cup Test height in inches for the conventional material is 0.297, whereas the material processed in accordance with the invention has an Olsen Cup Test height in inches of 0.390. The Olsen Cup Test is the most widely used test to evaluate the capability of a material to be formed into useful parts. Elongation in tensile testing is also significantly higher than obtained for conventionally processed material. This totally unexpected and significant improvement with respect to the room-temperature formability of the material, the additional improvement with respect to directionality,

TABLE 1

Sample No.	Condition	Test Direction	0.2% Offset Yield Strength (K s.i.)	UTS (K s.i.)	El. (percent)	T-L Yield Strength Directionality (K s.i.)	Olsen Cup Height (in.)	Striation Tendency	Grain Size
QT	Mill annealed hot band as received	T	89.7	100.5	27.5	18.80			
RT		T	88.7	100.5	27.5				
QL		L	70.6	93.6	25.5				
RL		L	70.4	93.6	26.5				
8 ATA	As received plus 4 cycles of 33% cold reduction and normal anneals (1,400 F.), final gage ~0.030 [1] (conventional process).	T	82.7	93.5	27.0	12.75	0.297	None, Lt. orange peel.	7
8 ATB		T	85.9	93.5	28.0				
8 ALA		L	70.4	89.0	26.5				
8 ALB		L	72.7	91.5	26.0				
18 TA	As received and warm rolled (800° F. entry temperature) to final gage (~0.030) normal final anneal.[2]	T	82.4	89.9	31.0	4.95	0.390	None	8-9
18 TB		T	80.4	89.4	31.0				
18 LA		L	76.6	94.1	28.0				
18 LB		L	76.3	94.2	29.0				

[1] Time in furnace geared to normal mill annealing line speeds.
[2] Material reheated, just to 800° F. between passes.

and the fact that such improvements are achieved without resort to expensive and time-consuming production practices represents a significant advance in the art of producing flat-rolled titanium and titanium alloy products. It should be understood that not only are the properties of the materials improved by the process of the invention but, in addition, the elimination of the conventional annealing between cold reduction operations represents a significant cost savings in the over-all operation.

As mentioned hereinabove, an alternate practice of the invention embodies the use of heating to a temperature below the recrystallization temperature of the metal intermediate each rolling operation, with the metal strip being cooled to room temperature prior to each rolling operation. The properties of material processed in accordance with this alternate practice of the invention and comparative property data for conventionally processed material are reported in Table II.

TABLE II

Sample No.	Condition	Test Direction	0.2% Offset Yield Strength (K s.i.)	UTS (K s.i.)	El. (percent)	T-L Yield Strength Directionality (K s.i.)	Olsen Cup Height (in.)	Striation Tendency	Grain Size
QT	Mill annealed hot band as received	T	89.7	100.5	27.5	18.80			
RT		T	88.9	100.5	27.5				
QL		L	70.6	93.6	25.5				
RL		L	70.4	93.6	26.5				
8 ATA	As received plus 4 cycles of 33% cold reduction and normal anneals (1,400° F.), final gage ~0.030" [1] (conventional process).	T	82.7	93.5	27.0	12.75	0.297	None, lt. orange peel	7
8 ATB		T	85.9	93.5	28.0				
8 ALA		L	70.4	89.0	26.5				
8 ALB		L	72.7	91.5	26.0				
2 ATA	As received plus 6 cycles of 20% cold reduction and 7' at 800° F. anneals, 7' at 1400 F. final anneal., final gage ~0.030."	T	85.5	90.8	31.0	8.05	0.337	None	8-9
2 ATB		T	81.6	90.6	29.0				
2 ALA		L	75.6	94.0	32.0				
2 ALB		L	75.4	93.3	31.0				
4 ATA	As received plus 6 cycles of 20% cold reductions and 7' at 1,000° F. anneals, 7' at 1,400 F. final anneal., final gage~0.030".	T	82.5	94.5	28.0	9.05	0.331	do	8-5
4 ATB		T	84.7	92.6	29.5				
4 ALA		L	75.0	93.9	27.5				
4 ALB		L	74.1	94.0	29.5				
6 ATA	As received plus 6 cycles of 20% cold reductions and 7' at 1,400° F. anneals, 7' at 1,400 F. final anneal., final gage ~0.030."	T	86.1	101.8	24.0	16.30	0.295	None, orange peel.	4-5
6 ATB		T	85.6	100.5	24.0				
6 ALA		L	69.4	90.2	25.0				
6 ALB		L	69.7	90.3	24.5				
7 ATA	As received plus 5 cycles of 25% cold reductions and 7' at 1,000° F. anneals, 7' at 1400° F. final anneal., final gage ~0.030."	T	72.4	82.5	23.0	11.9	0.311	None, very lt. orange peel.	7
7 ATB		T	72.8	81.8	29.5				
7 ALA		L	60.5	78.0	25.0				
7 ALB		L	60.9	78.9	25.5				

[1] Time in furnace geared to normal mill annealing line speeds.

As shown in Table II, strip of commercially pure titanium, substantially the same as that used in the test reported in Table I, was subjected to both conventional treatment embodying cold reduction and intermediate annealing and to treatment in accordance with the present invention, wherein intermediate annealing and resulting recrystallization were replaced with intermediate heating at 800 or 1000° F. The material processed in accordance with the invention was cooled from the temperatures of 800 or 1000° F. to room temperature prior to each reduction operation. It should be noted from the Olsen Cup Test height data reported in Table II that the titanium strip material produced in accordance with the invention and subjected to intermediate heat treatment at 1000° F. between each of the rolling operations exhibited somewhat poorer formability than the material similarly processed with a heat treatment at 800° F., though formability is still improved as compared to conventional material. In particular, cold reductions of 25% per operation with intermediate anneals at 1000° F. resulted in poorer properties than obtained with 20% cold reductions. This is believed to result from the fact for the commercially pure titanium used in these tests, the temperature of 1000° F. combined with the heavier reductions resulted in some recrystallization prior to the completion of substantial cold reduction on the order of at least about 50%. These data, therefore, show the importance of minimizing and preferably substantially eliminating any recrystallization prior to the completion of at least 50% reduction, and preferably reduction to final gauge. In any event, however, the strip material produced in accordance with the present invention exhibited improved formability over conventionally produced material wherein intermediate anneals at 1400° F. were employed. Specifically, material produced in accordance with the invention with intermediate heating at 800° F. exhibited an Olsen Cup height in inches of 0.337; whereas, conventionally processed material having intermediate anneals at 1400° F. exhibited substantially less room-temperature formability as characterized by an Olsen Cup height in inches of 0.297.

It may be seen from the above-reported specific examples that the practice of the invention provides advantages over the conventional production of flat-rolled titanium and titanium alloy products with respect to both time and cost savings during processing, and improved mechanical properties in the final cold-rolled products, particularly with respect to directionality and room-temperature formability. Specifically, by eliminating the necessity of conventional annealing between cold-rolling operations, the costly and time-consuming practice of pickling after each anneal and prior to cold rolling is avoided. The improvements in directionality and room-temperature formability permit fabricators of the material to utilize the same more economically in the manufacture of final products.

The practice of the invention finds utility with titanium and high-alpha, titanium-base alloys. The term high-alpha, titanium-base alloys, as used herein, means alloys having over 30% alpha. With alloys having less than about 30% alpha, the described practices of the invention are not considered beneficial with regard to the desired properties.

Although the invention has application to the production of titanium or high-alpha, titanium-base alloys in the form of flat-rolled products by any rolling technique, it finds its greatest advantage with the production of such material in the form of continuous strip or band. It is with the production of material by this operation that unidirectional rolling, and the adverse effects of directionality resulting therefrom, is impossible to avoid. As is well known, and as discussed hereinabove, continuous strip production provides greater economies with respect to

processing costs than does, for example, cross-rolling on a hand sheet mill. Consequently, the practice of the invention finds its preferred use in the production of flat-rolled products of titanium or high-alpha, titanium-base alloys with the unidirectional rolling of continuous strip or band material.

Although various embodiments of the invention have been described herein, it is obvious that other adaptations and modifications may be made by those skilled in the art without departing from the scope and spirit of the appended claims.

What is claimed is:

1. A method for producing flat-rolled products of metal selected from the group consisting of titanium and high-alpha, titanium-base alloys comprising hot-rolling said metal to an intermediate gauge, heating said metal in an intermediate gauge to a temperature substantially below the recrystallization temperature of said metal and thereafter rolling said metal to reduce the same at least 50% in the absence of further recrystallization.

2. The method of claim 1 wherein said metal in an intermediate gauge is heated to a temperature of at least about 300° F. but substantially below the recrystallization temperature.

3. The method of claim 1 wherein said metal in an intermediate gauge is heated to a temperature within the range of about 300 to 1200° F. but below the recrystallization temperature of said metal.

4. The method of claim 1 wherein said rolling is unidirectional.

5. A method for producing flat-rolled products of metal selected from the group consisting of titanium and high-alpha, titanium-base alloys comprising hot-rolling said metal to an intermediate hot-band gauge, rolling said metal from an intermediate gauge to reduce the same at least 50% in the absence of recrystallization during said rolling, said metal being at a temperature above about 300° F. but substantially below the recrystallization temperature of said metal during said rolling.

6. The method of claim 5 wherein said rolling to reduce said metal at least 50% is achieved by a plurality of rolling operations.

7. The method of claim 5 wherein said metal is at a temperature within the range of about 300 to 1200° F. but substantially below the recrystallization temperature of said metal during rolling.

8. A method for producing flat-rolled products of metal selected from the group consisting of titanium and high-alpha, titanium-base alloys comprising hot-rolling said metal to an intermediate hot-band gauge, heating said metal at an intermediate gauge to a temperature above about 400° F. but below the recrystallization temperature of said metal, cooling said metal, and thereafter rolling said cooled metal ot reduce the same at least 50% in the absence of further recrystallization, said reduction being achieved by a plurality of heating and rolling operations.

9. The method of claim 8 wherein said metal at an intermediate gauge is heated to a temperature within the range of about 400 to 1200° F. but below the recrystallization temperature of said metal.

10. A flat-rolled metal product produced by the method of claim 1.

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CHARLES W. LANHAM, Primary Examiner

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,496,755 Dated February 24, 1970

Inventor(s) John B. Guernsey et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

After the title, names of the inventors and their addresses, please change the assignee "Crucible Inc., a corporation of New Jersey" to --Crucible Inc., a corporation of Delaware--.

SIGNED AND
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AUG 18 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents

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