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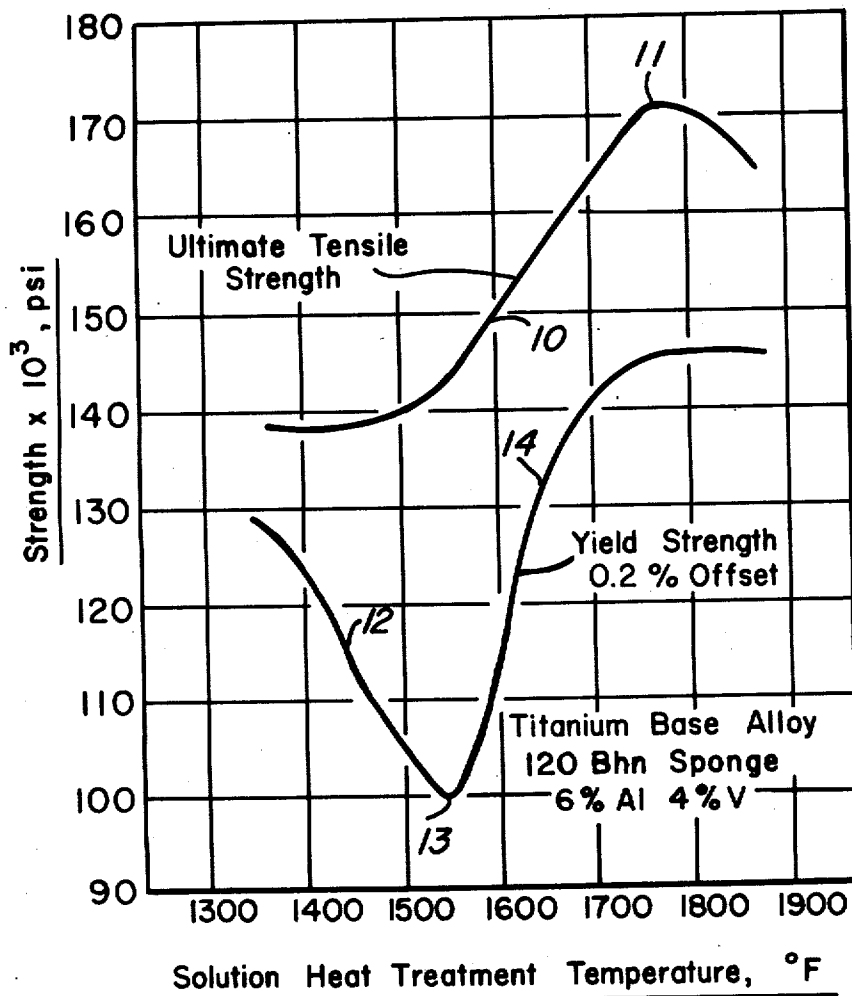


Fig. 1

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HEAT TREATING TITANIUM-BASE ALLOY PRODUCTS

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This invention relates to the heat treatment of titanium alloy products and particularly thin section products.

Titanium alloy bar, sheet and strip products as produced, for instance, by rolling ingots or billets to desired thin section, are often employed to fabricate specific articles by additional forming processes, particularly cold forming. In order to be readily formed by bending, pressing, stretching, cupping, spinning or other fabrication methods, such products must be relatively soft and ductile, and also possess good ultimate tensile strength so that the required deformation can be readily obtained without splitting or other mechanical failures. At the same time it is often desired that the finished formed product show high strength characteristics, which are apparently incongruent with the easy forming properties required for fabrication. Previously obtainable titanium alloy products, if produced so as to be readily formable, have not been strong enough in fabricated form even after the best heretofore known heat treatment; or if produced with actual or potential high strength characteristics have been too hard and strong for proper formability.

It is therefore an object of this invention to provide a titanium alloy thin section product having improved forming properties. Another object of this invention is to provide a titanium alloy thin section product having improved forming properties and which can be subsequently treated so as to possess high strength characteristics. A still further object of this invention is to provide an improved method for heat treating titanium alloy products. These and other objects of this invention will be apparent from the following detailed description thereof.

This invention, in its broadest aspects, contemplates heat treating of a thin section product, such as for instance bar, rod, wire, sheet or strip, manufactured from a titanium base alloy of the alpha-beta type by rolling, forging, drawing, extrusion, or other conventional methods, and developing superior forming properties in such product by application of a solution heat treatment, within a certain restricted, critical temperature range, followed by a rapid cooling. In this condition the material may readily be fabricated by forming, particularly cold forming. After forming, the product may be subjected to an aging heat treatment to develop high strength characteristics and other desirable mechanical properties.

The term "solution heat treatment," as employed herein, is intended to refer, as is generally accepted in this art, to a heat treatment at relatively high temperature to produce a partial solution of the alpha phase and transformation to beta. The rapid cooling (quenching) from this temperature retains at room temperatures substantially the amount and type of beta phase so formed. The "aging heat treatment" is a generally lower temperature, longer time treatment which normally stabilizes the alloy, which often improves the mechanical properties to some degree, but in the practice of this invention has a surprisingly significant and important effect in substantially raising the low yield strength previously obtained by the particular solution heat treatment employed.

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A clearer understanding of this invention may be obtained by reference to the annexed drawing in which Figure 1 illustrates a typical graph showing the ultimate tensile strength and yield strength (0.2% offset) obtained by solution heat treating at various temperatures and quenching, bar of titanium base alloy useful in the practice of this invention. As is apparent, the ultimate tensile strength curve shown at 10 slopes upward with increase in strength as the heat treating temperature is raised to a peak at 11 after which the curve drops. A very careful investigation of the heat treatment response with respect to yield strength, with determinations made at small increments of temperature difference reveals, however, that at the lower end of the yield strength curve, the curve slopes downward as at 12 reaching a low minimum point at 13, then slopes upwardly as at 14.

Discovery of this phenomenon is of the utmost significance. In the as-rolled condition the rod sample used for the tests of Figure 1 showed a yield strength to tensile strength (YS/TS) ratio of about 0.95. When solution heat treated at a temperature of about 1750° F., this ratio is about 0.85 and both yield and tensile strengths are higher. When heat treated at the temperature of minimum yield point 13, however, tensile strength of 141,000 and the yield strength 99,700 produces the YS/TS ratio of .71 and the wide difference between the yield and tensile strength values are apparent. The low YS/TS ratio provides the heretofore unobtainable combination of properties which include the extremely low yield strength to permit easy plastic deformation under minimum load, and a relatively high ultimate tensile strength to prevent fracture, splitting or rupture of the material during such deformation. Another important feature is the favorable response of alloy products produced according to this invention to a subsequent aging heat treatment. The low YS/TS ratio provides excellent forming characteristics, but in addition, after forming, treatment for from 1 to 48 hours at temperatures from 700° F. to 1200° F. substantially improves the ultimate tensile strength, and increases the yield strength tremendously. After this aging treatment a relatively high, more or less normal, YS/TS ratio is produced and the fabricated article is thus provided with most favorable strength characteristics for useful application. The following table shows the strength properties of the alloy of Figure 1 before and after the treatments described.

TABLE I

	Yield Strength, p. s. i.	Ult. Tensile Strength, p. s. i.
As rolled rod.....	143,000	149,000
	YS/TS=0.95	
Solution heat treated for 1 hour at 1,800° F. and water quenched.	99,700	141,000
	YS/TS=0.71	
Cold formed to shape—Aged for 24 hours at 900° F. followed by air cooling.	155,000	165,000
	YS/TS=0.94	

Titanium base alloys suitable for the practice of this invention are of the alpha-beta type, that is at normal temperatures they are composed of mixed alpha and beta type crystal structure. Essential characteristics of such alloys are:

1. They must contain aluminum generally within the range of from about 0.5% to about 8%. Less than .5% aluminum will not provide sufficient solution heat treatment effect at a temperature far enough removed from the beta transus to avoid grain growth and other undesirable effects. More than 8% aluminum will raise the strength level of the alloy too high with accompanying danger of embrittlement.

2. They must contain a beta stabilizing element or elements generally within the range of from about 2% to

10%. Beta stabilizers which may be employed include molybdenum, vanadium, manganese, chromium and iron. These may be employed singly or in combination. Molybdenum and vanadium employed individually or in combination are particularly advantageous. Less than 2% beta stabilizer will not provide the required amount of beta phase in the alloy while more than 10% will provide no appreciable gain in desirable properties and since these elements are all heavier than titanium, they will tend to increase the density of the alloy and partially destroy one of the principal advantages of titanium. Incidental impurities and other elements may be present in the alloys in amounts which do not significantly affect the character or properties thereof. The principal elements present will generally include oxygen, nitrogen, hydrogen, carbon and these should not total more than 0.5%.

It will be recognized that no one alloy or type of alloy will necessarily be best for all applications, and that certain mechanical properties can often be developed to a high degree at the expense of others.

Products composed of alloys containing beta stabilizers within the lower portion of the range, that is from 2% up to about 6%, for example, 6% Al, 4% V; 4% Al, 3% Mo, 1% V and 6.5% Al, 3% Mo, 1% V; when solution heat treated according to this invention will show yield to tensile strength ratios from 0.5 to 0.75. Such products, after aging treatment, will show excellent strength, ductility and elevated temperature properties. Products composed of alloys containing beta stabilizers within the upper portion of the range, that is from 6% to 10%, for example, 2% Al, 4% Mo, 2% V; 2% Al, 4% Mo, 4% V; and 4% Al, 6% Mo, 4% V, when solution heat treated according to this invention will show exceptionally low yield to tensile strength ratios generally between 0.25 and 0.6. Such products, after aging treatment, will show good room temperature properties but will not be adapted for elevated temperature service due to the tendency toward instability imparted by the high proportion of beta phase.

The solution heat treating temperature employed to obtain the low yield to tensile strength ratio, according to this invention, appears to be principally dependent on the amount of aluminum present in the alloy. The optimum temperature varies directly with the aluminum content, but is also affected by the amount of the interstitials, oxygen and nitrogen and possibly carbon present, and, in addition, by the percentage of vanadium in the beta stabilizing elements present in the alloy.

Since the analytical determination of the interstitial elements is long, tedious and often of doubtful accuracy, the gross effect of their presence is most often determined and measured by the hardness of the titanium sponge from which the alloy is made. Obviously introduction of such elements into the alloy other than by their presence in the sponge will result in the equivalent effect on the optimum solution heat treating temperature and should be considered accordingly. An alloy made from 160 Bhn. sponge, for example, will have an optimum solution heat treating temperature about 20° F. higher than one made from 140 Bhn. sponge, and an alloy made from 120 Bhn. sponge will have such temperature about 20° F. lower than the 140 Bhn. sponge alloy. Higher or lower Bhn. sponge will affect the critical solution heat treating temperature of the alloy by raising or lowering this temperature about 1° F. for each Bhn. point that the sponge from which the alloy is made, is higher or lower than 140.

Vanadium appears to affect the critical solution heat treating temperature in a different manner or to a different extent than other beta stabilizing elements. An alloy containing 100% vanadium as the beta stabilizer will have a critical solution heat treating temperature about 50° F. lower than an alloy whose beta stabilizing component is 50% vanadium, and in an alloy containing no vanadium this temperature will be raised 50° F. with intermediate proportions in direct ratio. Therefore, higher or lower percentages of vanadium in the beta stabilizing

component of the alloy will affect the critical solution heat treating temperature by lowering or raising this temperature 1° F. for each percent that the vanadium content of the beta stabilizing elements is respectively above or below 50%.

For practical operation of the process of this invention the range within which the low YS/TS ratio effect may be obtained, may be calculated as follows:

$$\text{Temperature range } ^\circ\text{F.} = 1350 \text{ to } 1450 \text{ plus } 37.5 \text{ multiplied by the percent Al}$$

For example an alloy containing 6% aluminum plus beta stabilizer should be solution heat treated at a temperature between $1350 + 37.5 \times 6 = 1575^\circ\text{F.}$ and

$$1450 + 37.5 \times 6 = 1675^\circ\text{F.,}$$

assuming that the alloy contained the interstitials oxygen, nitrogen and carbon in amounts corresponding to that which would be present in 140 Bhn. titanium sponge and also that the vanadium content of the beta stabilizers in the alloy was about 50%. If the alloy was made from 160 Bhn. sponge and the beta stabilizer content was composed of 3% molybdenum and 2% vanadium, the $1575^\circ\text{--}1675^\circ\text{F.}$ temperature range would have to be corrected. Since the 160 Bhn. would be 20 points higher than 140, an addition of 20° F. must be made and since the vanadium would amount to 40% of the total beta stabilizers, or 10% less than 50%, 10° F. must be added. The corrected range would then be $1615^\circ\text{ to } 1715^\circ\text{F.}$

It will be appreciated that the combined effect of the various types and amounts of beta stabilizers and impurity elements cannot be precisely predicted; the range calculated from the formula will provide an adequate and effective practical guide.

Table 2, which follows, shows the results of solution heat treatment, according to this invention, of a wide variety of products, all made from alloys containing 140 Bhn. sponge except where noted.

The precise minimum point on the yield strength curve for any alloy may, of course, be readily determined. Samples of the alloy are heat treated at various temperatures, water quenched, and tested in a tensile machine and the ultimate tensile strengths and yield strengths obtained are plotted to obtain curves similar to those shown in Figure 1. The slope of the yield strength curve is relatively steep on either side of the minimum point; therefore to obtain the lowest possible yield strength to tensile strength ratio it is desirable to heat treat at a temperature at or close to the minimum point, and for best results not more than 50° F. above or below. For practical commercial operation a solution heat treating temperature may be selected by reference to amount of aluminum, vanadium and interstitials in the alloy employed as explained hereinbefore. For most effective treatment, the best temperature within the general or calculated range may be actually determined and the advantages of this invention realized to the fullest extent.

The time required at solution heat treating temperature will depend to a large extent on the thickness of the product being tested. It is necessary that the time of treatment be long enough so that all the material is raised to the desired temperature. In the case of thin sheet and strip, this may be accomplished in 15 seconds and generally not more than 1/2 hour, depending on conditions such as type of furnace and rapidity of heating. Electrical resistance heating of individual sheets and strips makes possible raising these to the desired temperature in a very short time, often less than a minute, while furnace treatment requires time for the heat to be conducted throughout the material and will take appreciably longer. For thicker plate and rods or bars the treatment time may have to be extended to 1-2 hours to insure adequate soaking. In the case of coiled strip, obviously sufficient time at temperature must be given to make sure that even the innermost portions of the coil are adequately heated.

TABLE 2

No.	Product	Alloy Composition	Solution Heat Treatment	Ultimate Tensile Strength	Yield Strength, 0.2% Offset	YS/TS Ratio	Elong. in 1", percent	Red. in Area, percent
1	1/2" x 1/2" bar.	0.75Al, 4Mo, 4V	1,450° F., 1 hr. WQ	112,000	60,000	.53	15	45
2	.040" sheet	1Al, 4Mo, 4V	1,450° F., 1/2 hr. WQ	116,000	61,000	.52	9	
3	.045" sheet	2Al, 4Mo, 4V	1,450° F., 1/2 hr. WQ	136,900	60,500	.44	17.5	
4	1" x 1" bar	2Al, 4Mo, 2V	1,480° F., 2 hrs. WQ	132,000	70,000	.53	20.0	50
5	.040" sheet	2Al, 4Mn	1,500° F., 1/2 hr. WQ	149,000	89,000	.60	16	
6	.040" sheet	2Al, 1Fe, 4V	1,500° F., 1/2 hr. WQ	128,000	76,000	.60	17	
7	.040" sheet	2Al, 2Zr, 4Mo, 4V	1,450° F., 1/2 hr. WQ	120,000	58,000	.48	12	
8	1 1/2" x 1 1/2" bar.	4Al, 3Mo, 1V	1,550° F., 1 hr. WQ	144,900	84,000	.58	21.5	52.9
9	1/2" round	4Al, 3Mo	1,580° F., 1/2 hr. WQ	158,600	117,000	.74	20	43.7
10	.040" sheet	4Al, 2.5Fe	1,600° F., 1/2 hr. WQ	151,000	106,000	.70	15	
11	1/2" x 1/2" bar.	4Al, 6Mo, 4V	1,550° F., 1 hr. WQ	151,000	51,000	.33	20	53
12	1/2" round	5Al, 1.6Fe, 1.4Cr, 1.2Mo (120 Bhn Sponge)	1,615° F., 1 hr. WQ	168,500	90,500	.53	18	37
13	1/2" round	5Al, 1.6Fe, 1.4Cr, 1.2Mo (140 Bhn Sponge)	1,635° F., 1 hr. WQ	187,000	102,400	.54	14	16
14	1/2" round	5Al, 1.6Fe, 1.4Cr, 1.2Mo (160 Bhn Sponge)	1,650° F., 1 hr. WQ	188,100	108,500	.58	9	7
15	1/2" x 1/2" bar.	6Al, 4V (120 Bhn Sponge)	1,550° F., 1 hr. WQ	145,000	103,000	.71	26	51
16	.040" sheet	6Al, 3Mo, 1Fe	1,650° F., 1/2 hr. WQ	147,000	77,000	.52	6.5	
17	.040" sheet	6Al, 3Mo, 2Mn	1,675° F., 1/2 hr. WQ	120,000	65,000	.54	4	
18	1/2" round	6.5Al, 3Mo, 1V (120 Bhn Sponge)	1,600° F., 1 hr. WQ	152,000	104,000	.68	21	47
19	1" x 1" bar	7Al, 3Mo	1,675° F., 2 hrs. WQ	163,600	111,000	.68	19	34
20	1/2" round	8Al, 1Mo, 1Mn	1,725° F., 1 hr. WQ	165,000	107,000	.65	19	32
21	1/2" x 1/2" bar.	8Al, 4Mo, 4V	1,725° F., 1 hr. WQ	178,000	45,000	.25	14	19
22	1 1/2" x 1 1/2" bar.	8Al, 6Cr	1,700° F., 1 hr. WQ	160,000	105,000	.66	14	38

After solution heat treatment, the alloy product is rapidly cooled, preferably by water quenching. This is necessary to retain at room temperature the alpha-beta structure present at the critical heat treating temperature. Obviously thick section products cannot be effectively quenched because the heat cannot be extracted quickly enough from the central portions, and a non-uniform structure will result. In order, therefore, to obtain retention of the proper structure at normal temperatures the products must, according to this invention, be of sufficiently thin cross section to permit rapid and uniform quenching throughout. The limits of thickness will vary somewhat depending on shape, size and other conditions, but in general strip, sheet, plate and similar products up to about one inch in thickness, and bars, rods and such shapes with a minimum diameter of up to about two inches can be adequately quenched and are considered of thin section in the practice of this invention.

It will be appreciated that in commercial operation there may be some delay in quenching due to handling the alloy products from the heat treating furnaces into the quenching tanks or equivalent apparatus. If this delay is such that the material cools appreciably before quenching, an appropriately higher furnace temperature should be employed to compensate for the intermediate cooling so that the products are quenched from the proper temperature according to this invention.

After the titanium base alloy product is heat treated and quenched, it is in condition for forming. The forming operation may be carried out by suitable apparatus or process depending on the nature of the particular change in shape desired and the configuration of the fabricated article, and may involve rolling, bending, cupping, spinning, stretching, drawing, dimpling, pressing, etc. Since the titanium alloy at this stage is characterized by relatively low yield strength and relatively high tensile strength, it may readily be formed cold into a variety of shapes employing any, or several, of numerous forming operations known in the art without fracture, splitting, cracking or other failure.

The formed product is then ready for aging treatment and this is accomplished by heating at comparatively low temperature, between 700° and 1200° F., for a period of from about one to about 48 hours followed by air cooling. The higher temperatures within the range noted may

be employed for shorter times, and if the lower aging temperatures are necessary or desirable, somewhat longer time at such temperatures are generally required for equivalent effect. Temperatures below 700° F. will require inordinately long times for proper aging effect and temperatures above 1200° F. will affect the composition and structure of the alloy too drastically.

As an example of the general effects of aging for various times at various temperatures the following table shows the physical properties of a sample of one-half inch square bar solution heat treated at 1550° F. followed by water quenching and which was then aged according to this invention.

TABLE 3

[Ti-4Al-3Mo-1V alloy bar (1/2" square) solution heat treated for 1 hr. at 1,550° F., water quenched and aged.]

[Forged to 1/2" sq. bar at 1,650° F.]

Heat Treatment	Ult. Tensile Strength, p. s. i.	Yield Strength, p. s. i. (0.2% Offset)	Elong., Percent in 1"	Red. in Area, Percent
Solution Heat Treated, 1,550° F. (1 hr.) WQ	144,900	98,800	18	47.1
Aged:				
700° F. (2 hrs.) AC	161,000	144,200	17	43.5
700° F. (4 hrs.) AC	177,500	161,500	11	36.1
700° F. (8 hrs.) AC	166,000	147,000	13	55.4
700° F. (24 hrs.) AC	178,800	161,600	9	33.7
800° F. (2 hrs.) AC	174,700	155,000	15	41.0
800° F. (4 hrs.) AC	177,200	150,000	10	32.8
800° F. (8 hrs.) AC	187,700	150,300	13	35.1
800° F. (24 hrs.) AC	176,000	143,800	11	30.2
900° F. (2 hrs.) AC	178,400	146,700	11	32.1
900° F. (4 hrs.) AC	175,500	147,800	12.5	34.5
900° F. (8 hrs.) AC	177,200	154,300	14	34.1
900° F. (24 hrs.) AC	171,000	151,200	14	34.0
1,000° F. (2 hrs.) AC	175,000	147,500	11	39.8
1,000° F. (4 hrs.) AC	166,200	157,700	15	43.2
1,000° F. (8 hrs.) AC	161,800	151,500	15	39.3
1,000° F. (24 hrs.) AC	155,500	148,500	17	32.5
1,200° F. (2 hrs.) AC	153,000	147,000	18	38.2
1,200° F. (4 hrs.) AC	151,500	146,000	18	41.7
1,200° F. (8 hrs.) AC	149,300	145,700	19	43.2
1,200° F. (24 hrs.) AC	145,000	143,400	20	49.4

1 Flaw in gage length.

WQ—water quenched; AC—air cooled.

Aging for 24 hours at 1000° F. will, for all practical

purposes, produce a stable alloy composition although the aging time may, if desired and without deleterious effect, be extended to 48 hours. After such aging treatment the product may be placed in service up to the limit of its applicability, generally not higher than about 800° F., without further change in its physical properties. Aging at lower temperatures, for instance, 800° F. or 900° F., or for shorter periods of time, will generally produce higher strength products as shown by the data in Table 3. While such aged products should not be employed in elevated temperature service, their excellent strength and ductility make them very valuable for specific room temperature applications. The following table illustrates the properties obtained on solution heated and quenched products from Table 1 after heat treating at 1000° F. for 24 hours, with some random examples of treatment also at 900° F.

TABLE 4

No.	Aging Treatment	Ult. Tensile Strength, p. s. l.	Yield Strength, p. s. l. (0.2% Offset)	Elong., Percent in 1"	Red. in Area, Percent
1.....	1,000° F., 24 hrs.	152,000	134,000	19	43
2.....	900° F., 24 hrs.	174,000	161,000	3	-----
3.....	1,000° F., 24 hrs.	142,000	132,000	8	-----
4.....	1,000° F., 24 hrs.	154,000	142,000	7	-----
5.....	1,000° F., 24 hrs.	146,000	141,000	10	21
6.....	900° F., 24 hrs.	151,000	129,000	6.5	-----
7.....	1,000° F., 24 hrs.	129,000	121,000	12	-----
8.....	900° F., 24 hrs.	138,000	121,000	10	-----
9.....	1,000° F., 24 hrs.	123,000	118,000	12	-----
10.....	1,000° F., 24 hrs.	156,000	148,000	4	10
11.....	1,000° F., 24 hrs.	162,000	148,700	18.5	-----
12.....	1,000° F., 24 hrs.	177,000	158,000	12	-----
13.....	900° F., 24 hrs.	157,000	134,000	2	-----
14.....	1,000° F., 24 hrs.	140,000	130,000	2.5	-----
15.....	1,000° F., 24 hrs.	170,000	167,000	14	36
16.....	1,000° F., 24 hrs.	177,500	159,000	12	31
17.....	1,000° F., 24 hrs.	149,000	147,000	20	52
18.....	900° F., 24 hrs.	190,000	171,000	2	-----
19.....	1,000° F., 24 hrs.	180,000	164,000	3	-----
20.....	1,000° F., 24 hrs.	183,000	167,000	4	-----
21.....	1,000° F., 24 hrs.	157,000	151,000	18	40
22.....	1,000° F., 24 hrs.	187,000	165,000	12	23
23.....	1,000° F., 24 hrs.	178,000	177,000	10	14
24.....	1,000° F., 24 hrs.	247,000	210,000	4	4
25.....	1,000° F., 24 hrs.	175,000	170,000	8	26

It will be noted that the yield strength to tensile strength ratios after aging are all 0.85 or above with most of them above 0.9 compared to the range of .25 to .74 after solution heat treatment.

The work performed on the material during the forming operation will affect to some degree its mechanical properties at this stage. All titanium alloys, in common with those of other metals, work harden and this generally results in increasing tensile strength and reduction of ductility.

The cold forming operation, as regards the type and details thereof, intermediate between solution heat treatment and aging, in and of itself form no part of this invention and may be conducted in any manner and to produce any result desired at this stage. It is significant that the over-all heat treatment of this invention involves a two step heat treatment; first the solution heat treatment to provide in the material properties which ideally adapt it for cold forming and second a subsequent aging heat treatment to develop an excellent combination of mechanical properties in the formed product.

To demonstrate the general range and character of the modification of properties during forming, a section of .043" sheet made from a titanium base alloy containing 4% Al, 3% Mo, and 1% V was solution heat treated at 1580° F. for one-half hour, water quenched and then rolled cold to provide a thickness reduction of 5% and 10%. This amount of cold working generally corresponds to that provided by industrial forming operations. After cold forming, the specimens were aged for periods from 2 to 48 hours at 800° F. and 1000° F. The mechanical properties obtained are tabulated in Table 5 below.

TABLE 5

[Ti-4Al-3Mo-1V alloy sheet solution heat treated at 1580° F. for one-half hour, water quenched, cold worked and aged at 800° F. and 1000° F.]

Aging Temp., °F.	Aging Time, Hrs.	Ult. Tensile Strength, p. s. l.	Yield Strength p. s. l. (0.2 Percent Offset)	Elong. Percent in 2"
0% Cold Work:				
Solution Treated.....				
800.....	2	153,800	101,800	6.5
800.....	8	176,100	161,300	6.0
800.....	24	191,000	172,600	-----
800.....	48	175,300	169,700	-----
1,000.....	2	188,600	164,600	10.5
1,000.....	8	178,400	166,300	2.0
1,000.....	24	161,800	154,900	5.0
1,000.....	48	155,000	149,600	3.5
5% Cold Work:				
As Cold Worked.....				
800.....	2	162,300	124,200	12.0
800.....	8	183,500	171,900	0.5
800.....	24	195,200	172,300	7.0
800.....	48	148,800	-----	-----
1,000.....	2	200,300	171,100	7.5
1,000.....	8	191,300	165,900	7.5
1,000.....	24	169,200	153,000	10.5
1,000.....	48	165,300	152,200	11.0
10% Cold Work:				
As Cold Worked.....				
800.....	2	166,500	133,900	11.5
800.....	8	190,100	163,300	6.0
800.....	24	208,000	176,000	3.5
800.....	48	207,200	179,200	5.0
1,000.....	2	196,400	169,100	6.0
1,000.....	8	196,800	171,700	-----
1,000.....	24	167,000	153,100	9.0
1,000.....	48	166,100	154,400	11.5
1,000.....	48	175,300	160,400	12.0

It will be appreciated by those skilled in the art that the yield to ultimate tensile strength ratios shown are illustrative and may vary slightly from the values shown when determined under different conditions. The determination of ultimate tensile and yield strength of different specimens of the same material may produce results which vary within some limits since such mechanical testing is never wholly precise, and differences in specimen treatment and preparation may introduce additional variables. Therefore, it is to be understood that the yield to tensile strength ratios of various products may fall within the ranges specified and are not to be considered as limited for any alloy or type of product to the specific values shown in the tables.

Titanium alloy products are generally produced in the form of rods, bars, plate, sheet, strip, wire, etc. in which form they are sold to fabricators. It is a particular advantage of this invention that thin section products of this type may be produced, solution heat treated and quenched to develop the low YS/TS ratio and this intermediate product sold to fabricators in this condition. Yield strength to tensile strength ratios of 0.75 or below will provide advantageous formability and ratios within the range of 0.75 to 0.25 are readily obtained according to this invention. The fabricator receives material ideally suited for mechanical working, particularly cold forming, and after the desired article is shaped or formed a simple aging treatment develops excellent over-all mechanical properties including a normally high yield strength to tensile strength ratio, high strength and good ductility.

Certain titanium base alloy compositions have been disclosed in this application for the purpose of illustrating the practice of the invention claimed herein. Those containing from 1% to 5% aluminum, and over 6% and up to 10%, in the aggregate, of molybdenum and vanadium are more particularly described and claimed in our copending application Ser. No. 567,720, filed Feb. 27, 1956.

It is to be understood that the solution heat treatment and quenching herein described does not at this stage produce the best apparently desirable over-all combination of mechanical properties. Heretofore heat treating temperatures have been selected to give the highest strength properties, both yield and ultimate tensile strength being considered, in combination with good ductility. A later

aging treatment has been proposed to stabilize and slightly improve, in some cases, the properties obtained by solution treatment. In contradistinction to this procedure the present invention contemplates solution heat treatment within a narrow critical temperature range to provide low yield strength and without particular regard to other properties. The subsequent aging treatment under these conditions has a significant and radical effect, raising the strength level and providing an over-all combination of mechanical properties often equal or better than those obtained by what would have been heretofore considered the best solution and aging heat treatment.

This application is a continuation-in-part of Serial No. 513,752, filed June 7, 1955, by Harold D. Kessler et al. entitled "Heat Treating Titanium-Base Alloy Products," now abandoned.

We claim:

1. A method for solution heat treating a thin section product composed of an alloy consisting essentially of aluminum in amount from about 0.5 to about 8%, a beta stabilizer selected from the group consisting of chromium, iron, vanadium, molybdenum, manganese and combinations thereof in amount from about 2% to about 10%, and balance titanium with incidental impurities, which comprises heating said product for from about 15 seconds to about 2 hours at a temperature about that at which said alloy shows a minimum point on its yield strength, solution heat treating temperature curve, and rapidly quenching said product from said temperature thereby to provide as a characteristic thereof a yield strength to tensile strength ratio of between 0.25 and 0.75.

2. A method for solution heat treating a thin section product composed of an alloy consisting essentially of aluminum in amount from about 0.5 to about 8%, a beta stabilizer selected from the group consisting of chromium, iron, vanadium, molybdenum, manganese and combinations thereof in amount from about 2% to about 10%, and balance titanium with incidental impurities, which comprises heating said product for from about 15 seconds to about 2 hours at a temperature, in degrees F. within the range determined by the formula

$$1350 \text{ to } 1450 \text{ plus } 37.5 \text{ multiplied by the percent aluminum in the alloy}$$

said range being corrected by adding or subtracting 1° F. for each Brinell point of hardness that the titanium sponge content of the alloy is respectively above or below 140 and by adding or subtracting 1° F. for each percent that the vanadium content of the beta stabilizing portion of the alloy is respectively below or above 50%, and rapidly quenching said product from said temperature thereby to provide as a characteristic thereof a yield strength to tensile strength ratio of between 0.25 and 0.75.

3. A method for heat treating a thin section product

composed of an alloy consisting essentially of aluminum in amount from about 0.5% to about 8%, a beta stabilizer selected from the group consisting of chromium, iron, vanadium, molybdenum, manganese and combinations thereof in amount from about 2% to about 10%, and balance titanium with incidental impurities, which comprises heating said product for from about 15 seconds to about 2 hours at a temperature, in degrees F., within the range determined by the formula

$$1350 \text{ to } 1450 \text{ plus } 37.5 \text{ multiplied by the percent aluminum in the alloy}$$

said range being corrected by adding or subtracting 1° F. for each Brinell point of hardness that the titanium sponge content of the alloy is respectively above or below 140 and by adding or subtracting 1° F. for each percent that the vanadium content of the beta stabilizing portion of the alloy is respectively below or above 50%, rapidly quenching said product from said temperature thereby to provide as a characteristic thereof a yield strength to tensile strength ratio of between 0.25 and 0.75, and, after an intermediate forming operation, aging said product at for from 1 to 48 hours at a temperature between 700° F. and 1200° F.

4. A thin section product composed of an alloy consisting essentially of aluminum in amount from about 0.5% to about 8%, a beta stabilizer selected from the group consisting of chromium, iron, vanadium, molybdenum, manganese, and combinations thereof in amount from about 2% to about 10%, and balance titanium with incidental impurities, heat treated according to the method of claim 1, characterized by a yield strength to ultimate tensile strength ratio of between 0.25 and 0.75.

5. A thin section product composed of an alloy consisting essentially of aluminum in amount from about 0.5% to about 8%, a beta stabilizer selected from the group consisting of chromium, iron, vanadium, molybdenum, manganese, and combinations thereof in amount from about 2% to about 10%, and balance titanium with incidental impurities, heat treated according to the method of claim 2, characterized by a yield strength to ultimate tensile strength ratio of between 0.25 and 0.75.

References Cited in the file of this patent

UNITED STATES PATENTS

2,754,204 Jaffee et al. ----- July 10, 1956

FOREIGN PATENTS

1,094,616 France ----- Dec. 8, 1954

OTHER REFERENCES

"Investigation of Heat Treatment of Commercial Titanium Base Alloys," WADC Technical Report 53-26, April 1953, page 28.