Nov. 10, 1964 M. B. VORDAHL 3,156,590

AGE HARDENED TITANIUM BASE ALLOYS AND PRODUCTION THEREOF

Filed April 4, 1960

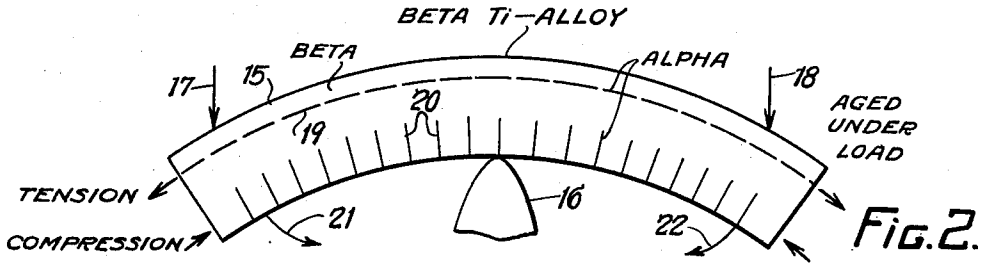


FIG. 2.

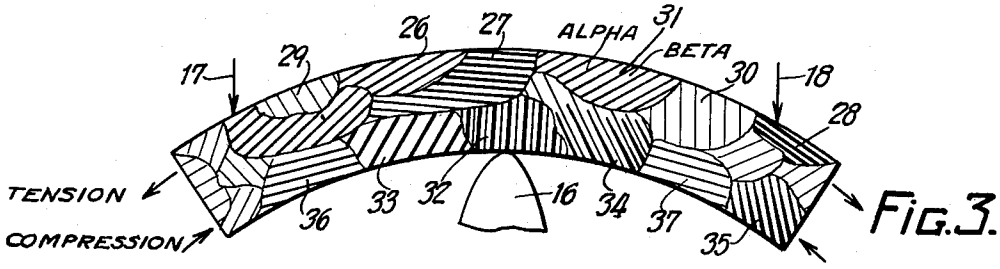


FIG. 3.

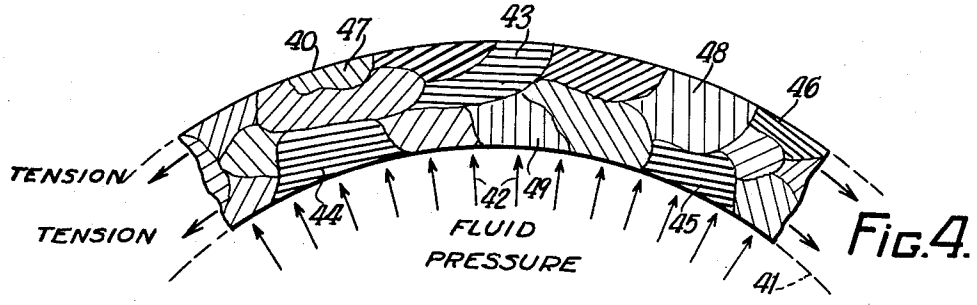


FIG. 4.

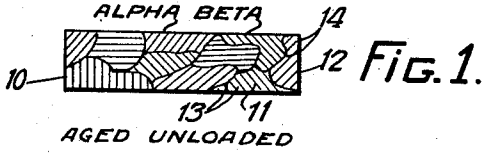


FIG. 1.

INVENTOR.
MILTON B. VORDAHL.
BY
Ward, Neal, Haselton, Orme & McElhannon
ATTORNEYS.

United States Patent Office 3,156,590 Patented Nov. 10, 1964

3,156,590

AGE HARDENED TITANIUM BASE ALLOYS AND PRODUCTION THEREOF

Milton B. Vordahl, Beaver, Pa., assignor to Crucible Steel Company of America, Pittsburgh, Pa., a corporation of New Jersey

Filed Apr. 4, 1960, Ser. No. 19,741
8 Claims. (Cl. 148—12.7)

This invention pertains basically to methods of age hardening titanium base alloys of the age hardenable type for imparting thereto a preferred orientation of alpha-nuclei precipitation, and to the so aged hardened alloy.

The invention also pertains in one of its important applications to methods of age hardening articles made of age hardenable titanium base alloys for imparting maximum strength in a given direction thereof together with good ductility in tension or bending, and also to the resulting age hardened articles.

The age hardenable titanium base alloys as a class are those containing one or more of the beta promoters in appropriate amounts such as to produce a mixed alpha-beta or all-beta structure on quenching from the all-beta or high in the alpha-beta temperature field. The age hardening effect is in general enhanced by additions of one or more of the alpha promoters.

The most important age hardenable titanium base alloys are those containing one or more of the beta-isomorphous or sluggishly eutectoid beta promoters molybdenum, vanadium, columbium, tantalum, chromium, manganese, tungsten and iron in amounts ranging from about 2% up to 50% for the isomorphous beta promoters molybdenum, vanadium, columbium and tantalum, or up to about 20% for the sluggishly eutectoid beta promoters chromium and tungsten, or up to about 10% manganese, or 7% iron or any combinations of these. The rapidly eutectoid beta promoters copper, nickel and cobalt may be present up to about 5%, and silicon or beryllium not over about 2%, as otherwise the ductility even in the annealed condition is unduly low. One or more of the alpha promoters may be present in amounts up to about 23% for tin, 18% for antimony, 10% for aluminum, 20% for silver, 15% for indium, 40% for zirconium. The interstitials may be present in total amount of about 0.3% with up to 0.3% carbon and 0.2% for oxygen and/or nitrogen. Ordinarily these age hardenable alloys will contain 1 to 10% aluminum or 1 to 23% tin or both, tin being substitutable for aluminum on a 3:1 weight ratio basis.

As solution treated at an appropriate temperature in the all-beta or high in the alpha-beta temperature field and cooled thence with sufficient rapidity, these age hardenable titanium base alloys have a mixed alpha-beta or all-beta structure depending on the composition. On subsequent aging at about 500–1000° F., these alloys age harden by transformation of beta-to-alpha, i.e., by precipitation of alpha-nuclei along preferred planes of the beta crystals.

Within each beta grain the interfaces between the alpha and beta components tend to be regions of weakness, because they tend to be regions of strain and because of concentration of the interstitials carbon, oxygen and nitrogen thereat. Hence it is desirable to suppress or minimize alpha-nuclei precipitation along interfaces which are disposed normal or substantially normal to the direction of major tension stress in use of articles made therefrom, and to maximize such precipitation along interfaces which are disposed in said direction or substantially so, thus in effect to produce a preferred direction of orientation of such interfaces.

It is a primary object of the present invention to provide an age hardening process such as to impart the aforesaid preferred orientation of said interfaces in the direction of the major tension stress to which articles made of the age hardenable alloys in question are subjected in use, thereby to enhance the strength and ductility of such articles in said direction.

In accordance with the basic concept of the invention, these objectives are achieved by tensioning the article throughout its sectional area in the direction of said major tension stress in use, and age hardening the same while thus tensioned. This causes the alpha-nuclei to precipitate out to a maximum extent during the aging treatment along planes having the preferred orientation in the direction of said tensioning stress and to minimize precipitation along planes normal to said direction.

The reason for this appears to be that the alpha precipitate occupies less space than the beta from which it was transformed, so that the alpha tends to precipitate out along planes which are parallel to the direction of applied tensile stress, thus to minimize the overall strain produced by the applied load, as appears to be confirmed by the tests discussed below with reference to the annexed drawings wherein,

FIG. 1 illustrates the aged microstructure of a bar of an age hardenable titanium base alloy which has been aged in unloaded or unstrained condition.

FIG. 2 illustrates schematically the planes along which the alpha nuclei tend to precipitate in a bar of the aforesaid alloy as aged while subjected to an applied bending load; while FIG. 3 shows the actual aged microstructure of this bar.

FIG. 4 shows by way of contrast the aged microstructure of a segment of a pressure vessel which during aging has been tensioned throughout its sectional area by fluid pressure within the vessel.

Referring to FIG. 1, if a bar **10** of an age hardenable titanium base alloy such as Ti-13V-11Cr-3Al (B120VCA) is solution treated at, for example, 1400° F., water quenched and aged at 750° F. for several hours, its microstructure will be found to consist of beta grains, such as the irregular grains **11**, **12**, having alpha nuclei precipitated along substantially parallel planes of each, as at **13**, **14**, the planes **13** of grain **11** being randomly oriented with respect to the planes **14** and grain **12**, the white areas of each grain being the beta phase. It will be observed that in FIG. 1 alpha has precipitated out with substantially uniform intensity on the precipitation planes of all grains with no preference for any orientation or direction as compared to any other, relative to the bar.

Referring now to FIG. 2, if a bar **15** of FIG. 1 alloy, is flexed over a fulcrum **16** by loading the opposite ends, as indicated by the arrows **17**, **18**, and aged as thus loaded, the alpha nuclei will now tend to precipitate out in the upper portion of the bar which is under tension, along planes, as at **19**, which are parallel to the direction of the tensioning stress; and will tend to precipitate out in the lower portion of the bar which is under compression, along planes, as at **20**, which are normal to the direction of the compressive stress. The planes of precipitation are such in each instance as to reduce the volume of the metal in the direction in which it is being compressed by the applied load, on the assumption that the alpha phase occupies less space than the beta phase from which it is derived. The upper portion of the bar which is under tension in its longitudinal direction is of course under compression in the direction normal thereto, in accordance with the action above stated.

That the alpha precipitation does in fact occupy less space than the beta from which it was transformed, appears fully confirmed from the fact that with continuous aging, with or without the applied load, the bar **15** will actually curly permanently in the direction of the arrows **21**, **22**. This results from additional alpha nuclei precipi-

tating along the planes 19 and 20 resulting from the initial aging under stress.

It will be understood, of course, that FIG. 2 is a more or less idealized showing of what occurs during aging under the indicated stress. Actually, the planes along which the alpha nuclei precipitate in any given beta grain, are determined by the random orientation of the beta grain itself. Accordingly, in any given portion of the bar which is aged under tension, the alpha nuclei precipitation will be greatest in the beta grains, the precipitation planes of which are oriented in the direction of the tension stress and least in those grains the precipitation planes of which are oriented normal thereto, with progressive gradations therebetween for those grains the precipitation planes are angularly inclined in varying degree between these limiting positions. Conversely in any given portion of the bar 15 which is stressed under compression, the greatest alpha nuclei precipitation will occur in the beta grains thereof having their precipitation planes oriented normal to the direction of the compressive stress, with gradations therefrom as above indicated for the beta grains of said portion having precipitation planes oriented in varying angular inclinations with respect thereto.

This is illustrated in FIG. 3 for a tiny bar specimen of the alloy of FIGS. 1 and 2, and stressed as in FIG. 2, this specimen having dimensions comparable in magnitude to the size of the beta grains, such as 26, 27, etc. On the upper or tension side, the alpha nuclei precipitation planes of the beta grains 27 and 28 happen to be oriented substantially in the direction of the tension stress, and for grains 29 and 30, substantially normal thereto, and for grains 26 and 31 at intermediate angular inclinations therebetween. As shown, the alpha nuclei precipitation due to aging is greatest in grains 27 and 28, wherein the precipitation is along planes substantially parallel to the tension stress, and least in grains 29 and 30 the planes of which are substantially normal thereto, with intermediate effects for grains 26 and 31 having the intermediately inclined planes.

On the lower or compression side of the specimen, the precipitation is heaviest in grain 32, the precipitation planes of which are substantially normal to the direction of compressive stress, with gradation therefrom for the inclined plane grains 33–35, inc., and least for grains 36, 37, the planes of which are substantially parallel to the direction of compressive force.

Of course in a bar or other article of normal utilitarian dimensions, the beta grains will be extremely small in comparison and there will be an infinite number of them randomly oriented as to the alpha precipitation planes. Therefore, as the result of the aging treatment under the indicated stress, the alpha nuclei precipitation in the tensioned portion of the bar will be predominantly in the direction of the tensile stress, and will be predominantly in the direction normal thereto in the portion of the bar subjected to compressive stress. Hence the net over-all effect is substantially as indicated in FIG. 2.

Now as above stated, a bar aged in whole or in part under compressive stress, as in FIGS. 2 and 3, is quite brittle in bending and weak in tension, owing to the relatively large number of alpha-beta interfaces which are formed normal or substantially normal to the longitudinal direction of the bar in the portions aged under compression as at 20, FIG. 2, and 32, FIG. 3, due to the aforesaid selective mode alpha nuclei precipitation under stress. It will now be seen with further reference to FIGS. 2 and 3, that this embrittlement and weakness in tension would be eliminated if all portions of the bar were stressed under tension during the aging treatment, since then the alpha nuclei precipitation would then be predominantly along planes parallel to the direction of the tensioning stress, as at 19, FIG. 2, and 27, 28, FIG. 3, while precipitation along the planes normal thereto would be effectively suppressed.

This is illustrated in FIG. 4, which shows a sector

40 of a pressure vessel 41, which is stressed throughout under tension by filling the interior with a fluid, such as air, under sufficient pressure thus to apply a bursting and tensioning type force to all parts of the vessel, as indicated by the arrows 42. The air pressure selected is such as substantially to exceed any compressive strain that might be present in portions of the vessel due to forming operations or mode of support. The vessel as thus tensioned under pressure is now aged, in consequence of which the alpha nuclei will precipitate predominantly in the beta grains, the precipitation planes of which are oriented substantially in the direction in which the wall or skin 40 of the vessel is being stressed under tension, as at 43–46, inc., whereas precipitation will be substantially suppressed in the beta grains having their precipitation planes oriented substantially normal to this direction, as at 47–49, inc., etc. Due to the preferred alpha nuclei orientation thus obtained, the aged material is far stronger and more ductile than that resulting from aging under the conditions illustrated in FIGS. 2 and 3.

As a practical application of this method, a gas pressure tank made of the aforesaid Ti-13V-11Cr-3Al alloy (B120VCA), may be pressurized with air under pressure such as to impart a skin tension to the vessel of about 10,000–20,000 p.s.i. Aging is effected by heating to about 800–900° F. and holding for an hour or so. Aging can then be completed without further pressurization, with resulting minimum formation of alpha-beta interfaces normal to the wall surface of the vessel.

What is claimed is:

1. A titanium base alloy having an aged alpha-plus-beta microstructure consisting at least in part of alpha nuclei disposed in a beta matrix and forming therewith interfaces which are predominantly oriented substantially parallel to one direction.

2. A titanium base alloy having an aged microstructure consisting at least in part of beta grains having alpha nuclei precipitated therein and forming therewith substantially parallel interfaces in each grain, said interfaces being randomly oriented from grain to grain and said nuclei being predominantly precipitated in the beta grains having alpha-beta interfaces which extend substantially parallel to a common direction.

3. An article made of a titanium base alloy having an aged alpha-plus-beta microstructure consisting at least in part of alpha nuclei dispersed in a beta matrix and forming therewith interfaces which extend predominantly substantially parallel to a given direction.

4. An article adapted in use to be tensioned in a preselected direction thereof and composed at least in part of a titanium base alloy having an aged alpha-plus-beta microstructure consisting of alpha nuclei dispersed in a beta matrix and forming therewith interfaces which extend predominantly substantially parallel to said preselected direction.

5. An article of bent surface configuration made of a titanium base alloy having an aged alpha-plus-beta microstructure consisting of alpha nuclei disposed in a beta matrix and forming therewith interfaces which are predominantly oriented substantially parallel to the surface configuration of said article.

6. A titanium base alloy having an age hardened alpha-plus-beta phase microstructure consisting of beta grains having alpha nuclei precipitated along substantially parallel planes in each grain, said nuclei being precipitated to a maximum extent along planes extending in a given direction and to progressively lesser extent along planes increasingly inclined to said direction and to a minimum extent in planes normal to said direction.

7. The method of age hardening an article made of an age hardenable titanium base alloy for imparting maximum strength and ductility in a given direction thereof, which comprises: tensioning said article throughout its sectional area in substantially only said direction with a

tension of about 10,000 to 20,000 p.s.i. and aging at elevated temperature while so tensioned.

8. The method of age hardening an article made of a titanium base alloy having a beta containing microstructure for imparting maximum strength in a given direction thereof, which consists in tensioning said article in substantially only said direction throughout its cross-sectional area with a tension of about 10,000 to 20,000 p.s.i. and aging at elevated temperature while so tensioned, thereby to precipitate alpha nuclei predominantly along preferred interface planes parallel to said direction.

References Cited in the file of this patent

UNITED STATES PATENTS

2,550,474	Harrington	Apr. 24, 1951
2,857,269	Vordahl	Oct. 21, 1958
2,974,076	Vordahl	Mar. 7, 1961

OTHER REFERENCES

Holden et al.: Journal of Metals, vol. 6, No. 2, Section 2, February 1954, pages 169–184.

Holden et al.: Transactions AIME, vol. 6, 1954.