March 15, 1955 M. B. VORDAHL 2,704,251

TITANIUM-BASE MANGANESE ALLOY

Filed Dec. 10, 1949 2 Sheets-Sheet 1

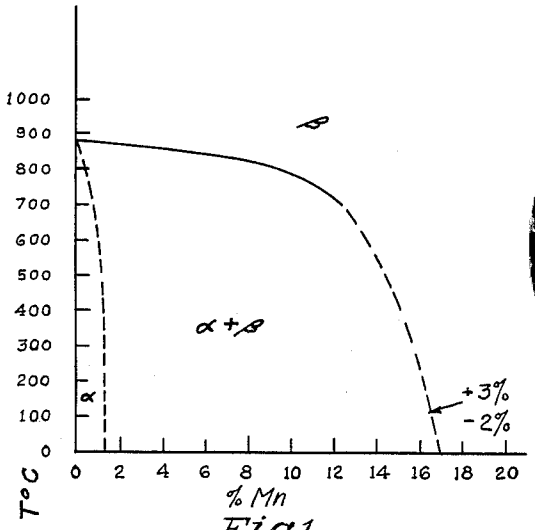



Fig. 1



Fig. 2

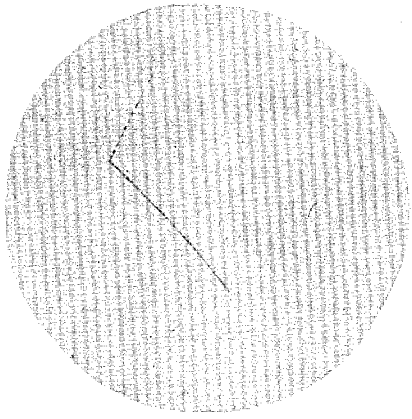


Fig. 3

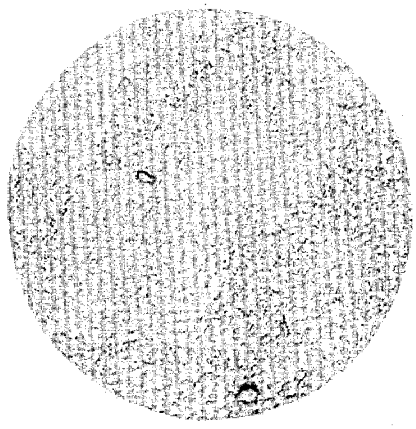


Fig. 4

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TITANIUM-BASE MANGANESE ALLOY

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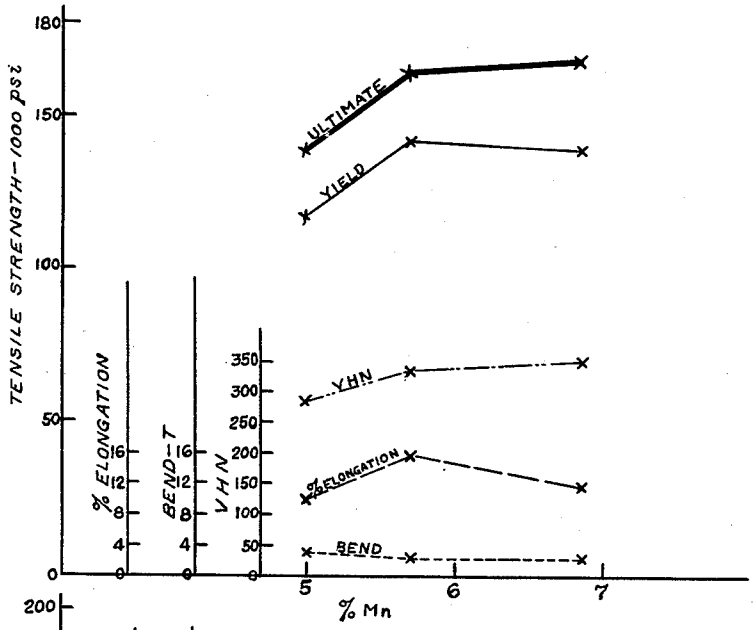



Fig. 5

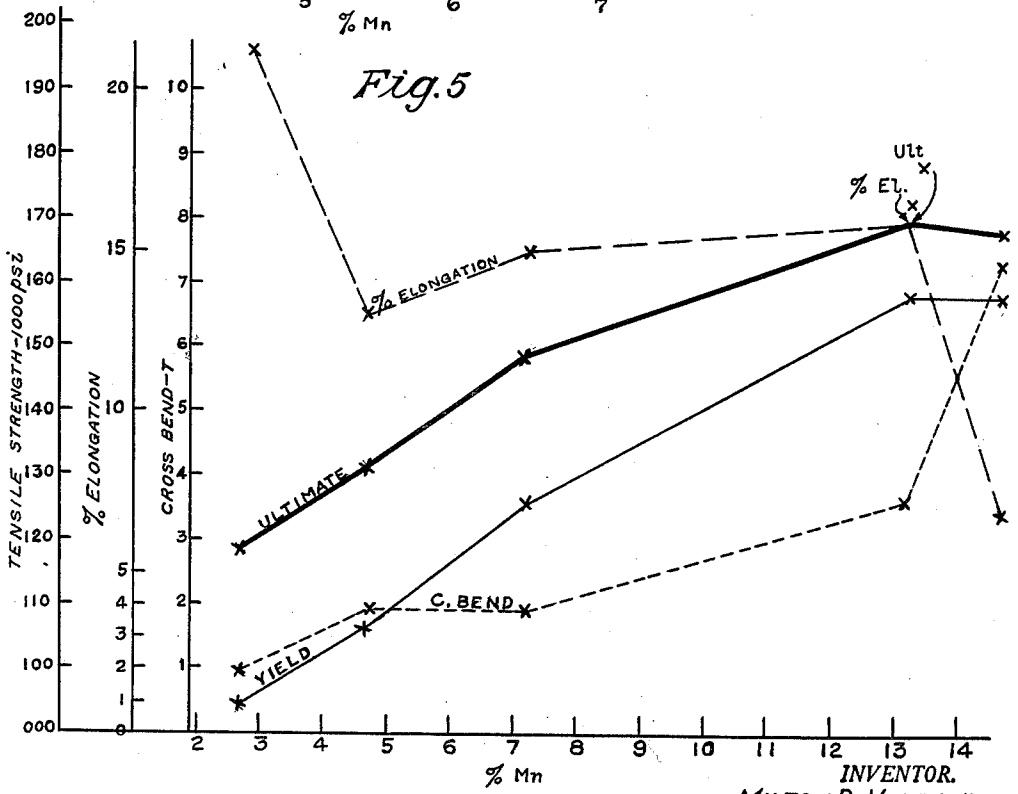



Fig. 6

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2,704,251

# TITANIUM-BASE MANGANESE ALLOY

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Application December 10, 1949, Serial No. 132,328

8 Claims. (Cl. 75—175.5)

This invention relates to alloys of titanium and manganese, and comprises the discovery of distinctive characteristics and properties of a group of such alloys containing manganese in proportions from about 6% to about 12%.

In the drawings:

Fig. 1 is a phase diagram of the titanium-rich-end of the binary-titanium-manganese system.

Fig. 2 is a photomicrograph of an alloy of commercial titanium with about 5% manganese, the alloy having been water-quenched from a temperature of 950° C.

Fig. 3 is a photomicrograph of an alloy of commercial titanium with about 5.7% manganese, the alloy having been water-quenched from a temperature of 950° C.

Fig. 4 is a photomicrograph of an alloy of commercial titanium with 6.8% manganese, the alloy having been water-quenched from a temperature of 700° C.

Fig. 5 is a graph showing the relationship of the hardness and tensile properties of certain alloys within the invention.

Fig. 6 is a graph illustrating the properties of a group of alloys within the invention as compared with other alloys.

The low temperature or alpha phase of substantially pure titanium, which has a close packed hexagonal structure, transforms at a temperature of about 885° C., to a beta phase, having a body-centered cubic structure. The presence of such contaminants as carbon, oxygen and nitrogen, in the proportions in which they are commonly found in commercial titanium, tends to raise the transformation temperature. However, the presence of some metals, such as iron, chromium, manganese and molybdenum, in increasing amounts, progressively lowers the beta transformation temperature and tends to stabilize the beta phase at normal temperature. A probable phase diagram of the titanium-rich-end of the titanium-manganese system is shown in Fig. 1, the broken lines representing boundaries which have not been experimentally established.

The present invention comprises the discovery of certain marked changes in structure and properties which take place in the alloys of titanium and manganese in the region between 5% and 6% manganese content, as compared with alloys of lower manganese content. The structural changes are well illustrated by comparison of an alloy containing 5% manganese with an alloy containing about 5.7% or a higher percentage of manganese, both alloys having been quenched from a temperature of about 950° C. The structure of the alloy of lower manganese content is illustrated in Fig. 2, and will be seen to be characterized by the presence of very numerous martensite-like needles of the alpha phase. An increase in the manganese content of as little as 0.7%, all other conditions remaining the same, results in a wholly different structure, as illustrated in Fig. 3. Martensitic needles are wholly absent. The structure as seen at 600 magnification consists entirely of relatively large beta grains, with no visible alpha.

The optimum properties of alloys containing 5.7% or more of manganese are best developed by extensive plastic deformation at a temperature within the two phase field, either with or without subsequent quenching from and stabilizing at two phase field temperatures. The structure of an alloy of commercial titanium with 6.8% manganese, the alloy having been extensively worked in the two phase field and water-quenched after heating for one hour at 700° C., is shown at 600 magnification in Fig. 4. It is seen to consist of very numerous small islands of alpha titanium well distributed in a matrix of beta titanium which is the predominant part of the composition. The larger dark bordered islands are carbides.



The alloys of this invention are outstanding as compared with alloys of lower manganese content in their ratio of strength to ductility. Whereas strength is ordinarily gained only at the expense of ductility, the alloys of this invention show a greatly increased strength with little, if any, loss of ductility. This characteristic is illustrated in the graphs (Fig. 5) which show the properties of three commercial titanium alloys containing, respectively, 5%, 5.7%, and 6.8% manganese. Each alloy had been water-quenched after heating for one hour at 700° C., then stabilized for one hour at 500° C., but these temperatures and times are not critical. Between a manganese content of 5% and one of 5.7%, corresponding to change in structure above discussed, the hardness, yield strength and ultimate strength, all increase sharply. Elongation, instead of decreasing in proportion to the increase in strength, as it usually does, actually increases from under 10% to about 14%. Likewise, the bend ductility diminishes only slightly.[1] Further additions of manganese effect a more gradual increase in hardness and strength which may be accompanied by some loss in elongation and/or bend ductility, but the favorable ratio of strength to ductility, established in the region between 5% and 6% manganese, persists up to a manganese content of at least 13%.

Fig. 6 shows the properties of certain alloys within this invention as compared with other titanium-manganese alloys. These alloys, containing respectively 2.75%, 4.8%, 7.2%, 13.2% and 14.7% manganese, balance substantially all titanium, had been procured by cold-rolling to 0.025" with a 650° C. anneal between passes, and stabilized for one hour at 600° C. It will be seen that the strength of the low manganese alloys is low, and that when the manganese content is increased to 4.8%, the strength is materially increased, but the ductility drops sharply. Between 4.8% and 7.2% manganese, the strength continues to increase and the ductility curve is actually reversed, the 7.2% manganese alloy having greater elongation than the 4.8% manganese alloy, and at least as good bend ductility. From 7.2% to 13.2% manganese both yield and ultimate strength continue to increase, although less rapidly, elongation undergoes a further slight increase, and bend ductility becomes somewhat poorer but is still acceptable. Between 13.2% and 14.7%, there is a second critical point. With no material change in yield or ultimate strength, elongation drops and bend radius increases with extreme rapidity. It is thus established that the high ratio of ductility to strength, and the capacity for maintaining and even improving ductility while increasing strength, are peculiar to alloys containing manganese in proportions from about 5.7% to about 13%.

While the general utility of the alloys of this invention will be obvious from their properties, their suitability for sheet and structural parts of high speed aircraft and other elevated temperature uses warrants special mention. At temperatures up to say 450° C., they retain their normal strength to a far greater degree than aluminum and its alloys. In this respect, the present alloys more nearly resemble stainless steel, to which they are superior in their ratio of strength to weight. This characteristic, frequently indicated in the course of the extensive work leading to the present invention, is well exemplified by a titanium base alloy showing, by accurately controlled analysis, a manganese content of 7.6%. When quenched from 950° C., the Vickers hardness was about 360. Upon aging at 550° C., it passed a hardness peak after about one hour, and after 16 hours again showed a hardness of about 360, which remained substantially unchanged up to 90 hours at 550° C. Alloys containing less than

[1] The measurement of bend ductility is not standardized. The present applicant and his associates measure this property as the radius over which the specimen can be bent to an angle of 75° without cracking, the radius being expressed as a multiple of specimen thickness.

about 5% manganese show a substantial loss in strength under the same test conditions.

What is claimed is:

1. A thermally stable and ductile titanium base alloy in wrought form obtained by plastic deformation in the two-phase temperature range, said alloy consisting essentially of from about 6% to about 12% of manganese, said alloy having a minimum ultimate strength of about 130,000 p. s. i.

2. A thermally stable and ductile titanium base alloy in wrought form obtained by plastic deformation in the two-phase temperature range, said alloy consisting essentially of from about 6% to about 12% of manganese, said alloy being characterized by a dispersion of discrete parts of alpha titanium in a matrix of beta titanium.

3. A thermally stable and ductile titanium base alloy in wrought form obtained by plastic deformation in the two-phase temperature range, said alloy consisting essentially of from about 6% to about 12% manganese, said alloy having an ultimate strength of at least 130,000 p. s. i. and a tensile elongation of at least 10%.

4. A thermally stable and ductile titanium base alloy in wrought form obtained by plastic deformation in the two-phase temperature range, said alloy consisting essentially of from about 6% to about 12% of manganese, said alloy being characterized in having a beta-containing microstructure, and in undergoing no appreciable change in hardness on prolonged aging at temperatures up to about 550° C.

5. A thermally stable and ductile alloy consisting essentially of from about 6% to about 12% manganese, balance titanium, said alloy having a minimum ultimate strength of about 130,000 p. s. i.

6. A thermally stable and ductile alloy consisting essentially of from about 6% to about 12% manganese, balance titanium, said alloy being characterized by a dispersion of discrete parts of alpha titanium in a matrix of beta titanium.



7. A titanium base alloy consisting essentially of from about 6 to 12% manganese, characterized by high strength, ductility and thermal stability, and in having a minimum ultimate strength of about 130,000 p. s. i. and a minimum tensile elongation of about 10%.

8. A titanium base alloy consisting essentially of from about 6 to 12% manganese, said alloy having a microstructure comprising a dispersion of discrete parts of alpha titanium in a matrix of beta titanium, and being characterized by high strength, ductility and thermal stability, and in having a minimum tensile elongation of about 10%.

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