

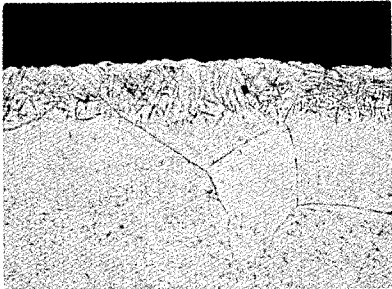
Sept. 15, 1959

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2,903,785

METHOD OF HOT WORKING TITANIUM

Filed Feb. 11, 1957



12-BRITTLE OXIDE-CONTAINING LAYER

10-TITANIUM BASE ALLOY

Fig. 1

BRITTLE OXIDE-CONTAINING LAYER-14

TITANIUM BASE ALLOY-10

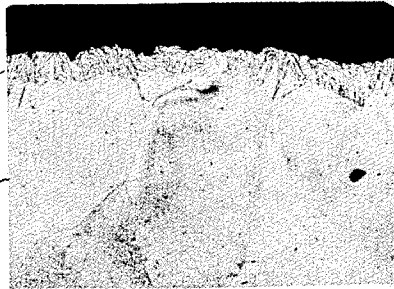


Fig. 2

16-ALUMINUM COATING

10-TITANIUM BASE ALLOY

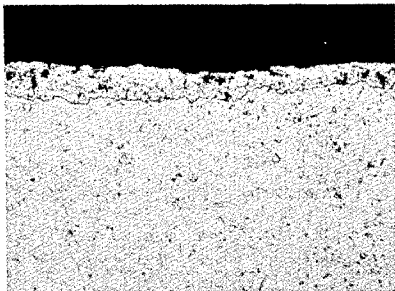


Fig. 3

TITANIUM-ALUMINUM ALLOY LAYER-18

TITANIUM BASE ALLOY-10

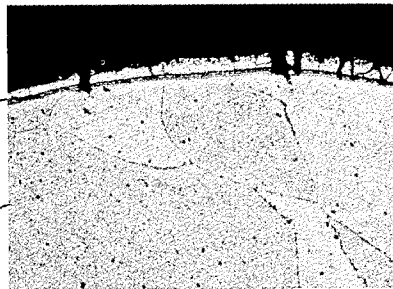


Fig. 4

20

10-TITANIUM BASE ALLOY

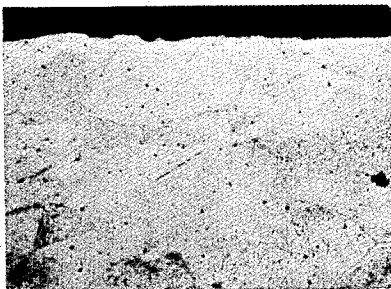


Fig. 5

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2,903,785

METHOD OF HOT WORKING TITANIUM

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Application February 11, 1957, Serial No. 639,408

11 Claims. (Cl. 29—156.8)

This invention pertains to a method of hot working titanium and more particularly to a process for forging titanium without forming a brittle surface layer containing absorbed oxygen and nitrogen.

In the manufacture of various titanium and titanium base alloy articles, such as turbine blades for gas turbine engines, it is frequently desirable to forge these articles in order to obtain certain desirable physical properties. It has been found that during the heating cycles employed in such forging or other hot working operations oxygen and nitrogen are absorbed at the surface of the titanium. The formation of a hard oxygen- and nitrogen-contaminated surface layer during heating operations materially reduces the machinability of the titanium article.

Moreover, the diffusion of oxygen and nitrogen into titanium results in severe embrittlement of the titanium article because oxygen and nitrogen form stable compounds with the titanium. As a result, it has heretofore been the practice to forge titanium parts, such as compressor blades, to dimensions considerably larger than those of the finished part so that the contaminated subsurface layer, formed during heating and forging in air, may be machined away. Although this layer is hard and abrasive and causes rapid wear of machine tools, it is necessary to remove it in order that the physical properties of the finished blade will not be detrimentally affected by the aforementioned brittle compounds.

Accordingly, a principal object of this invention is to provide a procedure by which titanium and titanium base alloy articles may be hot worked without forming a contaminated surface layer of hard, brittle oxygen-nitrogen compounds. A further object of the invention is to provide a method of protecting titanium and titanium alloy articles during forging at elevated temperatures in such a manner as to reduce the amount of machining subsequently required and to permit forging to closer dimensions.

These and other objects are attained in accordance with the present invention by a process involving applying a protective coating of aluminum on the titanium article to be forged or otherwise hot worked before it is heated to working temperature, thus preventing the formation of embrittling oxygen- and nitrogen-containing compounds during the forging operation. Not only is the protective nature of the aluminum coating retained during multiple heating and forging, but this coating does not interfere with the flow of titanium during the hot working operation.

Other objects and advantages of this invention will more fully appear from the following detailed description, reference being made to the accompanying drawing in which:

Figure 1 is a photomicrographic sectional view of a titanium base alloy, showing the metallographic structure of the alloy near its surface after it has been heated several times to an elevated temperature;

Figure 2 is a photomicrographic sectional view of the

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titanium base alloy shown in Figure 1 after it has been hot forged;

Figure 3 is a photomicrographic sectional view of a titanium base alloy having the same composition as the alloy shown in Figures 1 and 2 but which has been coated with aluminum in accordance with the present invention;

Figure 4 is a photomicrographic sectional view of the aluminum coated titanium base alloy shown in Figure 3 after it has been heated several times to the same temperature and in the same manner as the uncoated alloy of Figure 1; and

Figure 5 is a photomicrographic sectional view of the aluminum coated titanium base alloy shown in Figure 4 after it has been subjected to the same heating and hot forging procedure as the uncoated alloy shown in Figure 2.

In accordance with the invention, the titanium or titanium base alloy article to be hot worked is provided with a thin surface layer of aluminum or aluminum alloy. A satisfactory method of providing such a coating is described and claimed in co-pending patent application S.N. 287,039, filed on May 9, 1952, in the name of Dean K. Hanink and owned by the assignee of the present invention.

It will be understood that, by "aluminum base alloys," as hereinafter used, it is meant those aluminum alloys, including pure aluminum, which in general contain at least approximately 80% aluminum. Hence, it will also be understood that the terms "aluminum" and "aluminum base alloy," as used herein, are interchangeable and are not intended to restrict any phase of the invention to only one of these groups. Similarly, the terminology "titanium base alloy" or "titanium base metal" is meant to include pure titanium and all alloys thereof in which titanium constitutes at least 80% of the alloy.

The surfaces of the titanium article to be hot worked are preferably cleaned in any suitable manner prior to the aluminum coating operation. More consistent and uniform results are obtained if mechanical cleaning means, such as grit blasting, sand blasting, hydroblasting or vapor blasting, is employed. Other suitable cleaning treatments, such as etching by appropriate fluxes, may be used if desired. This preliminary cleaning treatment, although recommended as a preferred step in the procedure, is not necessary in all instances.

After cleaning the surfaces of the titanium or titanium base alloy to be hot worked, it is immersed in a molten or fused salt bath before being coated with aluminum. We have found it preferable to pass the unheated titanium base metal part directly through a relatively thin layer of the fused salt floating on top of molten aluminum or aluminum base alloy. The cold titanium base metal, in passing through the salt flux, which is activated by the aluminum, will become coated with a layer of the flux. This procedure eliminates the tendency to build up an uneven salt layer which is thicker on large sections and thinner on small sections of the titanium article. The adhering salt layer normally will solidify on the titanium, but it will remelt after sufficient time of contact with the molten aluminum or aluminum alloy bath underneath the fused salt layer.

It is preferable to immerse the titanium or titanium base alloy article in the molten aluminum coating metal immediately after it has contacted the salt bath and before the latter has remelted on the titanium alloy part. An excellent coating of aluminum on titanium base alloy may be obtained by this method because the aluminum contacts the titanium alloy immediately after the salt is removed from the surface, and hence there is no opportunity for titanium oxides to form. On the other hand, if the titanium metal article is permitted to remain in contact with molten salt for too long a period of time some titani-

um oxides are almost immediately formed by absorbing oxygen from the salt, and the resultant aluminum coating is not uniform. Hence, depending principally on the section size of the titanium article, immersion periods in the salt flux of one to four seconds are normally used. In the case of very large titanium articles, however, the salt immersion period may be as long as one minute or so, provided the salt does not remelt to any appreciable extent while the titanium is immersed therein. Only one furnace is required if this process is used, and a salt layer having a thickness of approximately one to two inches is usually satisfactory.

The molten salt bath must be one capable of dissolving aluminum and titanium oxides. Accordingly, we have found that a highly satisfactory salt bath is one comprising, by weight, 37% to 57% potassium chloride (KCl), 25% to 45% sodium chloride (NaCl), 8% to 20% cryolite (Na_3AlF_6), and 0.5% to 12% aluminum fluoride (AlF_3). A salt flux consisting essentially of 47% by weight of potassium chloride, 35% by weight of sodium chloride, 12% by weight of cryolite, and 6% by weight of aluminum fluoride is a specific example of this salt bath which provides excellent results.

The flux composition usually preferred is one which will become molten when heated to a temperature of approximately 1200° F. or somewhat lower. The above specific salt bath has a melting point of approximately 1180° F. and, if desired, a small amount of lithium chloride may be added to the salt to lower the melting point thereof. For example, the addition of about 20% lithium chloride lowers the melting point of this composition to approximately 1075° F. During operation the temperature of the fused salt bath is maintained somewhat above the melting point of the aluminum or aluminum base alloy, a temperature within the approximate range of 1200° F. to 1400° F. usually being satisfactory. In general, however, a temperature between 1250° F. and 1350° F. is preferred.

While in the foregoing examples the double salt Na_3AlF_6 (cryolite) is included in the bath, it should be understood that an equivalent amount of this component may be supplied in the form of the single salts, sodium fluoride and aluminum fluoride. However, we have found that it is desirable to provide an excess of AlF_3 over that of the cryolite ratio in order to obtain the desired results.

Titanium or titanium base alloys of any shape can be coated with pure aluminum or aluminum base alloys by the foregoing procedure and, if desired, the process may be a continuous one.

The molten metal coating bath may be pure aluminum or an aluminum base alloy and, as hereinbefore indicated, this alloy preferably should contain approximately 80% or more aluminum. An aluminum base alloy which is particularly advantageous to use is one composed of approximately 5% to 15% silicon and the balance aluminum. This alloy has a relatively low melting temperature, i.e., eutectic at 12% silicon, and has high fluidity. Effective drainage of excess coating metal is obtained because of this high fluidity, particularly when protected from air during cooling by the salt flux layer. Specific examples of other appropriate aluminum base alloys include an alloy composed of 4% copper and the balance aluminum, an alloy composed of approximately 7% tin or 7% silicon and 93% aluminum, and an alloy containing 5% to 20% zinc and the balance substantially all aluminum. These specific examples are referred to merely for purposes of illustration and not of limitation.

It is preferred that the temperature of the aluminum or aluminum base alloy coating bath be maintained at a temperature between about 1250° F. and 1350° F. Temperatures within the approximate range of 1200° F. to 1400° F. are suitable, however, for the aluminum base alloys. Pure aluminum melts at approximately 1218° F., and consequently, when employing pure aluminum as the

coating metal, aluminum and salt bath temperatures of at least 1218° F. must be used. The upper temperature which should be employed with pure aluminum as the coating metal is also approximately 1400° F. Higher temperatures result in excessive solution of titanium in the aluminum.

After passing through the fused salt flux and into the the molten aluminum or aluminum base alloy bath, the coated titanium or titanium base alloy part is permitted to remain in the coating bath until at least its surface reaches the melting point of the coating metal. The time of immersion in the molten aluminum or aluminum base alloy bath may vary from as little as a few seconds up to several minutes, depending on the section size and on the degree of complication of recesses, etc., in the parts being processed. However, inasmuch as titanium and titanium base alloys are generally not readily soluble in aluminum and aluminum base alloys and do not form a low melting eutectic at the titanium and aluminum interface, they may be retained in the molten aluminum for considerable periods of time, if it is found convenient to do so. In general, however, it is preferable to remove the titanium article from the coating metal bath when it reaches a temperature of about 1300° F. The aluminum-coated article is then withdrawn from the coating bath through the molten salt layer.

At times there may be a tendency to form a thicker but uniform coating of aluminum or aluminum alloy than desired. Excess molten coating material can be further drained off by passing the coated titanium base alloy article slowly through the molten salt during removal from the baths. Alternatively, this draining of excess coating metal may be accomplished by holding the coated part in the fused salt for a short period of time after it has been withdrawn from the coating bath. The coated titanium base alloy article, after removal, or as it is being removed from the aluminum or aluminum alloy bath, also may be rapidly vibrated or rotated or treated in other equivalent manner in order to remove excess molten or mushy coating metal. Similarly, the coated surfaces of the article may be air blasted to remove any excess coating metal without detriment to the aluminum coating.

The coated titanium or titanium base alloy article is then cooled or permitted to cool. Water or other quenching media may be employed for this purpose. The excess flux may be removed by washing, for example, or the coated titanium base metal article may be passed through rollers to remove the flux. Cleaning of the aluminum-coated article can follow accepted commercial methods for aluminum parts.

Following the aluminum coating operation, the titanium articles forged at a temperature between 1200° F. and 1950° F. An initial forging temperature of 1550° F. to 1750° F. is frequently preferred in order to obtain the desired grain size and metallurgical structure in typical titanium alloys. In general, however, it is desirable to begin the forging at as high a temperature as feasible. Accordingly, for large articles an initial forging temperature of 1950° F. is typical, the part being forged until the temperature has dropped to the range between 1300° F. and 1600° F. Normally optimum metallurgical properties are obtained when titanium is finish forged at a temperature of 1200° F. to 1300° F. In the case of large articles, however, it is necessary to complete the forging at a higher temperature because these articles require greater forging pressures. Since, as indicated above, it is advantageous to finish forge smaller parts at a temperature of 1200° F. to 1300° F., the initial forging temperatures of such parts generally are between 1300° F. and 1600° F. These temperatures are typical of one-blow forging procedures, for example.

The time the coated titanium metal article is in the furnace prior to forging depends, of course, on the temperature of the furnace. These articles are generally heated in a slightly oxidizing atmosphere, such as a

typical gas-fired furnace in which the atmosphere contains approximately 2% to 4% oxygen. In the case of uncoated titanium this type of oxidizing atmosphere is employed to avoid hydrogen pick up. In the present instance, however, wherein the titanium part is protected by an aluminum coating, the titanium part is protected under these conditions against both oxidation and hydrogen pick up.

When the titanium base metal article has been coated by the method hereinbefore described, it is provided with an overlay which essentially has the same composition as the coating metal, and little or no alloying has occurred between the aluminum and the titanium. The thickness of this original aluminum coating is usually about 0.0015 inch to 0.002 inch, although it may vary in thickness between approximately 0.0005 inch and 0.003 inch and still be satisfactory. When the coated titanium article is reheated for forging or other hot working operations, however, a titanium-aluminum alloy is formed on the surface of the titanium article. These re-heating temperatures are normally above the melting point of the aluminum, which penetrates the titanium, thereby forming a titanium-aluminum alloy and substantially eliminating free aluminum on the surface of the titanium article.

The protective titanium-aluminum layer thus formed appears to completely stop off surface reactions of titanium with oxygen and nitrogen at forging temperatures. Similar benefits are also provided during other hot working operations, such as extrusion and hot rolling processes. Although the thickness of this layer usually does not exceed approximately 0.002 inch, it possesses excellent ductility and adherence during hot working operations. In many instances it is capable of retaining its protective characteristics throughout a number of reheating and forging operations. A titanium-aluminum alloy layer having a thickness of about 0.0015 inch to 0.002 inch is normally preferred, while in some instances this layer may be as thin as 0.0005 inch. If any of this thin layer remains after forging, it may be removed by normal machining operations or, if no machining is required, by sand blasting.

The protection the aluminum coating on the titanium article provides during heating in the furnace is especially important because the time the titanium article is in the furnace is much longer than the actual forging time. Since it is normal to heat titanium to be forged approximately one hour per inch of cross-section thickness, it may be in the furnace one to two hours. On the other hand, typical forging operations are completed in only a few seconds, and there is little time for any detrimental oxidation to occur. The amount of oxide penetration, of course, is dependent upon time as well as temperature.

In the case of turbine or compressor blades formed of titanium, we have found it desirable to initially gather stock for the fastener section in a resistance upsetting machine. In such an apparatus the upset is free formed, i.e., it is unconfined by dies. The geometric configuration of the upset is governed by the speed of the upset ram, the resistance heat cycle, and the location and speed of movement of the electrical contact shoe. The time required for the upset operation usually is approximately 20 to 30 seconds and the temperature developed during the period ranges from about 1500° F. to 1600° F. Immediately following upsetting, the upset head is subjected to a mechanical press die coining operation.

The turbine blade may be forged with a drop hammer in a multi-cavity die, a four-cavity die having been found to be convenient. With a die of this type the first cavity can be used to pre-shape the fastener section and the second cavity can be employed primarily to flatten the blade section. Subsequent cavities may be designated for semi-coining and coining operations. Although only one or two hammer blows per cavity is all that is required, the entire blade section should be uniformly worked during coining. After the coining opera-

tion the blade may be immediately hot trimmed. In this manner the total elapsed time between removal of the part from the furnace and completion of the forging averages only approximately nine or ten seconds. Titanium turbine blades or articles of similar size normally are heated in the furnace prior to the forging operation for about 10 to 30 minutes.

Titanium base alloys which may be processed in accordance with our invention include the commercially available alloys containing appreciable amounts of chromium. Typical examples of these alloys are those having the following compositions:

	Percent
Chromium -----	3.00
Iron -----	1.50
Oxygen -----	0.50
Nitrogen -----	0.04
Tungsten -----	maximum-- 0.08
Carbon -----	0.02
Balance substantially all titanium.	

	Percent
Chromium -----	2.70
Iron -----	1.30
Oxygen -----	0.25
Nitrogen -----	0.02
Carbon -----	0.02
Tungsten -----	maximum-- 0.04
Balance substantially all titanium.	

Other titanium base alloys suitable for use in carrying out the invention include an alloy of 4% aluminum, 4% manganese and the balance substantially all titanium and an alloy of 3% aluminum, 5% chromium and the balance titanium plus incidental impurities such as carbon, nitrogen, oxygen, hydrogen and tungsten. In each instance these impurities normally would not exceed approximately 1% of the alloy.

Similarly, as hereinbefore indicated, our process is adapted for use in hot working pure or "commercially pure" titanium with aluminum or an aluminum base alloy. A typical example of this latter type of titanium alloy is one consisting essentially of 0.10% iron, 0.02% nitrogen, carbon not in excess of 0.04%, tungsten not in excess of 0.04%, traces of oxygen, and the balance substantially all titanium. We have found that, in general, the alloys containing the lower percentages of titanium may be more easily coated by our process than those having a very high titanium content.

Referring more particularly to the drawing, the photomicrograph of Figure 1 shows the surface condition of a titanium base alloy article 10 which has been subjected to three twenty-minute periods to heating at 1800° F. under an air atmosphere, the article being cooled to near room temperature between each heating operation. The particular alloy employed consists essentially of 3% aluminum, 5% chromium and the balance titanium plus incidental impurities. The brittle surface layer 12, which is formed principally of titanium compounds containing appreciable amounts of oxygen and nitrogen, is clearly shown in this figure. These compounds are produced because oxygen is soluble in titanium and does not merely form TiO₂ on the surface of titanium. Hence oxide penetration occurs with an appreciable amount of solid solubility and the titanium phase relationship is changed. Oxygen reacts primarily with the titanium to stabilize the alpha phase, resulting in the harder and more brittle compounds. We have found that the thickness of the surface layer of these compounds generally ranges from about 0.002 inch to 0.01 inch.

After a titanium base alloy of the type shown in Figure 1 has been heated for three twenty-minute periods at 1800° F. in an air atmosphere and subjected to a number of hot working blows, its surface still has a

thin layer 14 of stabilized, hard, brittle compounds of the aforementioned type, as shown in Figure 2.

On the other hand, a titanium base alloy article having the same composition but which has been provided with an aluminum surface coating 16, as shown in Figure 3, is protected against the formation of a brittle layer of oxygen- and nitrogen-containing compounds during the heating and hot working operations. Such an article, after being heated for three twenty-minute periods at 1800° F. in an air atmosphere, is shown in Figure 4. A layer 18 of several phases of titanium-aluminum alloy has been formed, but there is no layer of brittle oxygen- and nitrogen-containing compounds. When such an article is subsequently subjected to forging in the same manner as the specimen shown in Figure 2, its surface 20 normally will contain remnants of titanium-aluminum alloy. The microstructure of such a heated and forged titanium article, which is shown in Figure 5, otherwise is substantially the same as the original alloy before heating.

Each of the specimens shown in the photomicrographs of Figures 1 through 5 was prepared by using an etchant consisting, by volume, of 2% hydrofluoric acid, 12% nitric acid, 46% glycerine and 30% water. All of the photomicrographs are at 500 magnifications.

It will be seen from Figure 5 that most of the titanium-aluminum alloy has been removed during the forging operation. Accordingly, where hot working is of a severe nature, it may be desirable to apply a new coating of aluminum before each successive reheat. This results from the fact that the titanium-aluminum alloy layer is destroyed when severe deformation causes a large amount of relative movement between the coated titanium workpiece and the die. Generally, however, contamination of the titanium article due to air exposure after the coating has been disrupted by the first few hammer blows is negligible because of the very short exposure time and the rapid cooling rate of the finished forging.

As indicated above, moreover, the protection offered by the aluminum coating is usually retained during forging operations involving processing procedures requiring multiple heatings. The particular thermal cycles normally employed do not affect this protection. Since the titanium-aluminum layer is substantially removed and there are no stabilized high oxygen and nitrogen content compounds beneath this layer, the forged titanium base article is as readily machinable as the original alloy.

When commercially pure titanium sheet material was subjected to bend tests, sheets which had been provided with the titanium-aluminum alloy protective layer in the above-described manner exhibited excellent ductility after exposure to air or hydrogen atmospheres and elevated temperatures between 1100° F. and 1600° F. On the other hand, all uncoated sheets of similar commercially pure titanium which were exposed to temperatures in excess of 1100° F. had extremely poor ductility. None of the protected titanium sheets fractured or spalled after being bent 180°, while the uncoated sheets fractured after being bent only 2° to 5°.

Metallographic examination of the protected titanium sheets revealed that these sheets had not absorbed oxygen, nitrogen or hydrogen and that hard compounds had not formed during exposure to the aforementioned atmospheric and elevated temperature conditions. The unprotected sheets in each instance contained hard compounds due to the absorption of oxygen, nitrogen and/or hydrogen.

Compressor rotor wheels formed of titanium alloys were forged by the "slick mill" roll forging process using billets which had been provided with the protective titanium-aluminum layer and also using billets which had not been so protected. During forging of the unprotected billets difficulties were encountered with grain flow run-out and low ductility resulting in die locking and

poor metal flow during the forging process. With the billets provided with the protective titanium-aluminum alloy layer, on the other hand, the slick mill roll forging process produced satisfactory mechanical properties and grain flow characteristics in the titanium alloy forging. The protective layer acted as a lubricant or barrier to prevent seizing or welding of the titanium alloy workpiece to the die, as well as preventing the formation of oxygen- and nitrogen-containing interstitial compounds. These rotor wheels were free of such defects as voids, cracks and solid dense inclusions. Microexamination indicated that radial sections of these wheels had satisfactory grain flow characteristics with no evidence of run-out or die locking. Likewise, transverse sections from various areas showed a relatively homogeneous Widmanstätten structure throughout the forging. Tensile tests conducted on radial and chordal specimens from the web areas of the wheels revealed that they possessed uniform ductility and satisfactory strength. Each of these rotor wheels was formed of a titanium alloy consisting of 5.5% to 7% aluminum, 3.5% to 5% vanadium and the balance substantially all titanium except for very small amounts of carbon and nitrogen.

While this invention has been described by means of certain specific examples, it will be understood that various changes and modifications of these embodiments may be made within the scope of the invention as defined in the following claims.

We claim:

1. A method of forming a titanium base alloy article into a desired shape, said method comprising immersing the titanium base alloy article in a fused salt bath activated by aluminum in contact therewith, subsequently immersing said article in a molten bath of a coating metal selected from the class consisting of aluminum and aluminum base alloys, removing the resultant coated article from said coating bath, permitting said coating to solidify on said article, thereafter heating said coated article to a temperature between approximately 1200° F. and 1950° F., and finally hot working said article while at said temperature.

2. A method of hot working a titanium base metal article without forming compounds containing oxygen and nitrogen at the surface of said article, said method comprising coating said titanium base metal article with a metal containing at least 80% aluminum, thereafter heating said aluminum-coated article to a temperature between 1200° F. and 1950° F., and subsequently hot working said article while at said temperature.

3. A method of hot working a titanium base metal article into a desired shape without forming a brittle surface layer of oxygen- and nitrogen-containing compounds on said article, said method comprising applying an aluminum coating having a thickness of approximately 0.0005 inch to 0.003 inch to surfaces of said titanium base metal article by a hot dipping operation, thereafter heating said aluminum coated article to a temperature between 1200° F. and 1750° F. so as to form a thin layer of titanium-aluminum alloy at said surfaces, and subsequently subjecting said hot article to a multiplicity of hammer blows.

4. A method of hot forging a titanium base metal article without forming a contaminated surface layer of brittle compounds containing oxygen and nitrogen, said method comprising applying a thin coating of aluminum to the surfaces of said titanium base metal article, thereafter heating said coated article to a temperature between 1200° F. and 1950° F. to thereby form a layer of titanium-aluminum alloy at said surfaces, said titanium-aluminum alloy layer having a thickness between approximately 0.0005 inch and 0.002 inch, and subsequently forging said article to shape while at said temperature by subjecting said article to a multiplicity of hammer blows.

5. A method of forming a titanium base metal article

into a desired shape which comprises immersing said article in a fused salt bath comprising, by weight, approximately 37% to 57% KCl, 25% to 45% NaCl, 8% to 20% Na_3AlF_6 and 0.5% to 12% AlF_3 , said fused salt being activated by aluminum in contact therewith and being maintained at a temperature of about 1200° F. to 1400° F. while said titanium base metal article is immersed therein, subsequently immersing said article in a molten metal containing at least 80% aluminum, removing the coated article from said molten metal, subsequently heating said coated titanium base metal article to a temperature between 1200° F. and 1900° F. and forging said article to desired shape at said temperature.

6. A method of hot working a titanium base metal article without forming hard brittle compounds containing oxygen and nitrogen at surfaces of said article, said method comprising passing said titanium base metal article into and out of a coating metal bath containing at least 80% aluminum through a molten salt layer floating on said coating metal bath, said article being passed through said salt layer into said coating metal bath sufficiently quickly so that salt solidifies on said article and does not remelt until immersed in said coating metal bath, said molten salt layer being maintained at a temperature of approximately 1200° F. to 1400° F. while said titanium base metal article is passing therethrough, thereafter heating the resultant coated article to a temperature of about 1200° F. to 1900° F. to form a thin surface layer of titanium-aluminum alloy on said article, and subsequently hot working said article into a desired shape.

7. A method of hot working a titanium base metal article without forming hard brittle compounds containing oxygen and nitrogen at surfaces of said article, said method comprising passing said titanium base metal article into and out of a molten bath of a coating metal containing at least 80% aluminum through a molten salt layer floating on said molten coating metal bath, said article being passed through said salt layer into said coating metal bath sufficiently quickly so that salt solidifies on said article and does not remelt until immersed in said coating metal bath, said molten salt layer consisting essentially of 37% to 57% KCl, 25% to 45% by weight of NaCl, 8% to 20% by weight of Na_3AlF_6 , and 0.5% to 12% by weight of AlF_3 , said molten salt layer being maintained at a temperature of approximately 1200° F. to 1400° F. while said titanium base metal article is passing therethrough, thereafter heating the resultant coated article to a temperature between about 1200° F. and 1900° F. to form a surface layer of titanium-aluminum alloy having a thickness of approximately 0.0005 inch to 0.002 inch on said article, and subsequently hot working said article into the desired shape.

8. A method of hot working a titanium base metal turbine or compressor blade without forming hard brittle compounds containing oxygen and nitrogen at surfaces of said blade, said method comprising passing said titanium base metal turbine blade into and out of a bath of molten metal containing at least 80% aluminum through a molten salt layer floating on said molten metal bath, said molten metal being at a temperature of about 1200° F. to 1400° F. while said blade is immersed therein, said turbine blade being passed through said salt layer into said metal bath sufficiently quickly so that salt solidifies on said blade and does not remelt until immersed in said molten metal bath, said molten salt layer being maintained at a temperature of approximately 1200° F. to 1400° F. while said turbine blade is passing therethrough, thereafter permitting the molten metal on surfaces of said blade to solidify into an overlay having a thickness of about 0.0005 inch to 0.002 inch, subsequently reheating the aluminum coated blade thus formed to a temperature of about 1200° F. to 1750° F. to provide a thin surface layer of titanium-aluminum on said article, and finally hot working said article into a desired

shape and removing any remaining titanium-aluminum alloy.

9. A method of hot working a titanium base alloy article without the formation of undesirable hard compounds containing oxygen and nitrogen at the surfaces of said article, said method comprising immersing said titanium base alloy article in a molten salt flux which is at a temperature of approximately 1200° F. to 1400° F. and floating on top of a molten bath of a coating metal containing at least 80% aluminum, said titanium base alloy article being immersed in said fused salt for an insufficient period of time to raise the temperature of said article to the temperature of said salt, subsequently lowering said article into said molten coating metal bath and retaining it therein until said article reaches a temperature above 1200° F. and salt which solidified on surfaces of said article remelts, thereafter removing the coated titanium base alloy article from said coating metal bath through said molten salt, subsequently heating said coated article to a temperature between 1200° F. and 1950° F. to form a thin surface layer of titanium-aluminum alloy on said article, forging said article to desired shape while at said temperature and removing any titanium-aluminum alloy which remains on said article.

10. A method of hot working a titanium base metal article without forming brittle oxygen- and nitrogen-containing compounds at surfaces of said article, said method comprising immersing the titanium base metal article in a fused salt bath comprising, by weight, approximately 37% to 57% KCl, 25% to 45% NaCl, 8% to 20% Na_3AlF_6 and 0.5% to 12% AlF_3 , said fused salt being at a temperature of approximately 1200° F. to 1400° F. and floating on top of a molten bath of a coating metal containing at least 80% aluminum, said titanium base metal article being retained in said fused salt for an insufficient period of time to raise the temperature of said article to the temperature of said salt, subsequently lowering said titanium base metal article into the molten coating metal bath and retaining it therein until said article reaches a temperature above 1200° F., thereafter removing the coated titanium base metal article from said coating metal bath through said fused salt and permitting a layer of said coating metal to solidify on surfaces of said article, said layer having a thickness of approximately 0.0005 inch to 0.003 inch, subsequently reheating said coated article to a temperature of about 1200° F. to 1950° F. and thereby forming a surface layer of titanium-aluminum alloy on said article, said titanium-aluminum alloy layer having a thickness between approximately 0.0005 inch and 0.003 inch, and thereafter hot working said article to the desired shape while at a temperature of about 1200° F. to 1950° F.

11. A method of forging a titanium base alloy turbine or compressor blade without forming a brittle layer of hard oxygen- and nitrogen-containing compounds at surfaces of said blade, said method comprising immersing said titanium base alloy turbine blade in a molten salt flux which is at a temperature of approximately 1200° F. to 1400° F. and floating on top of a molten bath of a coating metal containing at least 80% aluminum, subsequently lowering said turbine blade into said molten coating metal bath, said blade being passed through said salt flux sufficiently quickly so that salt which solidifies on said blade does not remelt until said blade is immersed in said coating metal bath, thereafter removing the coated turbine blade from said coating metal bath through said molten salt flux and permitting coating metal on surfaces of said blade to solidify thereon, subsequently heating said coated turbine blade in an air atmosphere to a temperature between about 1300° F. to 1750° F. to diffuse said coating into said titanium base alloy and from a surface layer of titanium-aluminum alloy, forging said heated blade for a few seconds to not more than 30 seconds, and

finally machining said article and removing any remaining titanium-aluminum alloy.

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