HOT FORMING OF TITANIUM AND TITANIUM ALLOYS

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ABSTRACT

A method for bulk deformation of titanium and titanium alloys employing elevated temperatures for the billet and the dies. The method permits single step forging from a billet or preform to a final shape without the necessity of further machining.

11 Claims, 1 Drawing Figure
HOT FORMING OF TITANIUM AND TITANIUM ALLOYS

The present invention relates to the forming of titanium and titanium alloys. More particularly it relates to an improved method for the bulk plastic deformation of titanium and titanium alloys utilizing elevated deforming temperatures in dies that are heated to or close to the workpiece temperature.

Titanium and titanium alloys are becoming popular in the design of structures requiring a high strength-to-weight ratio. As used herein titanium alloys are defined to mean the structural alloys of titanium. Typical alloy compositions of this class normally include additions of aluminum and may also contain additions of one or more alloying agents such as zirconium, molybdenum, vanadium, silicon, chromium, manganes and iron. Whenever used herein after the term “titanium alloys” is understood to also include industrially pure titanium. Titanium alloys find particular application in the field of aircraft and missile design, though other applications are continually being found where the advantageous properties of titanium alloys are beneficial. While it is already known that several important end uses exist for titanium alloys, there remains serious difficulty in the bulk deformation of these materials to their final shape for an intended use. As used herein the term “bulk deformation” means the forming of a finished product from an ingot, billet, slug or preform as opposed to bending or drawing sheet material.

A commercial forming process for titanium alloys should permit economical forming of the alloy into a desired shape while retaining desirable physical properties. Inherently such a process must retain in the alloy the microcrystalline structure necessary for attaining high strength-to-weight ratio. The chief difficulty in the known processes for the bulk deformation of titanium alloys has been in overcoming the very high compressive yield strength of titanium alloys which makes them extremely difficult to form into thin-forged webs and ribs and other configurations requiring extensive flow of material in the die.

The problem is complicated by the lack of availability of die materials suitable for forming materials having yield strengths in excess of 150,000 p.s.i., which is typical of titanium alloys. To limit the loading of the die and assure filling of the cavity, commercial bulk deformation of titanium alloys is presently accomplished by multistep forging employing a series of progressive dies, each set of which produces part of the required deformation. The several dies must be designed and fabricated to perform the forging in steps beginning with the initial billet and ending with a finished product. The workpiece must be transferred to successive dies as many as five or six times to reach its final shape. The cost is high in terms of die cost and time expended. The manufacture for an already expensive metal. Die materials for present commercial forming methods are usually selected from the so-called hot-working die steels which possess adequate strength only at temperatures of 1,000°F or below. For this reason forging proceeds with a substantial temperature gradient between the titanium alloy and the die, and cooing of the workpiece limits the deformation that can be attained in a single operation.

It is an object of the present invention to provide a method for deforming titanium and titanium alloys. It is a further object of the present invention to provide an improved method of forging titanium and titanium alloys. These and other objects of the invention are more particularly set forth in the following detailed description and in the drawing which is a plot of compressive yield strength as a function of temperature and press speed for several alloys.

The present invention relates to a method of forming titanium alloys at elevated temperatures. The process is performed by heating the workpiece to a temperature above 1,400°F and heating the dies to the same or a slightly lower temperature. For simplicity, this process will be referred to herein as isothermal forming. The speed of the press is selected at from 0 to about 100 inches per minute depending on the alloy composition and the forming temperature. Titanium alloys are strain rate sensitive materials. That is, for any substantial deformation at elevated temperatures, the yield strength of the alloy is dependent on the rate of deformation. The higher the rate of deformation, the higher the yield strength. For the particular alloy employed, the temperature and press speed are selected so that the resultant yield strength does not exceed approximately one-third of the yield strength of the die material at the same temperature. A strength differential of this magnitude assures that the die material will not deform even when complex workpiece configurations are to be formed. It is by a proper selection of the above-named parameters that bulk deformation of titanium alloys is possible by isothermal forming, using a single die of commercially available material. The particular temperature selected and the particular press speed employed is keyed to the properties of the specific alloy being formed. The difficulty of forming is a function of the particular alloy being worked with industrially pure titanium at the easiest end of the spectrum and extending to the alloys most difficult to work, such as Ti-8Al-1Mo-1V.

As stated above titanium alloys exhibit a sensitivity to strain rate wherein the yield strength increases with strain rate. The drawing shows this property for three typical titanium alloys at several temperatures and pressing rates. The curves illustrate to a limited extent the variety of strain rate sensitivity exhibited by different alloys of titanium. The curves are labeled in inches per minute of press travel rather than actual strain rate because in forming complex shapes the strain rate varies throughout the forging. The values used to plot the curves were obtained by axially compressing alloy cylinders 1 inch in diameter and 2 inches long. The values plotted are for the compressive yield strengths at which plastic deformation begins.

The solid lines represent commercial Ti-6Al-6V-2Sn alloy compressed at press speeds ranging from 0.6 to 50 inches per minute of head travel. This alloy is representative of a titanium alloy which can be worked at a wide variety of pressing speeds and virtually throughout the temperature range from about 1,400°F to about 1,950°F without excessive die pressures.

The dash lines represent commercial Ti-8Al-1Mo-1V alloy. The press speeds range only from 0.05 to 5.0 inches per minute, yet the strain rate sensitivity of this alloy is much more pronounced. Also, for this alloy the practical temperature range is at the upper end of the 1,400°F to 1,950°F temperature range. At a pressing speed of 5 inches per minute the yield strength ranges from 4,000 p.s.i. at 1,900°F up to 30,000 p.s.i. at 1,700°F. Ti-8Al-1Mo-1V represents alloys which are at the difficult to work end of the spectrum in the context of the present invention. These alloys should be deformed at temperatures above 1,700°F or at extremely low-strain rates, or both, depending on the die material employed. In addition, high pressing speeds such as 50 inches per minute appear to be impractical at any temperature for this alloy, and working this alloy below 1,700°F appears feasible only at pressing speeds of the order of about 0.1 inch per minute or less. Even the curve for 0.05 inches per minute displays a marked increase in stress between 1,750°F and 1,700°F.

The dot-dash lines represent Ti-6Al-4V alloy deformed at two press speeds. As can be seen this alloy remains relatively easy to work between 1,500°F and 1,800°F, so long as the pressing speed is low. When the pressing speed is raised to just 5 inches per minute, the stress-temperature relationship becomes similar to, if not as extreme as that of Ti-8Al-1Mo-1V alloy.

It should be pointed out that the data of the drawing present approximate figures for yield strength which is the stress at which plastic deformation begins. The forging pressures necessary to fill an intricate die with these alloys are considerably higher than the yield strength values illustrated. However, the relationship between the various alloys illustrated in the drawing holds approximately true for the respective final forging pressures. For this reason the yield strength of the titanium alloy as stated earlier should not be more than
0.2% Compressive Yield Strength of Die Materials—(k.s.i.)

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The present invention may be better understood by reference to the following specific examples which show the relationship of temperature and pressing speed.

EXAMPLE I
A scaled down airplane nosewheel was prepared from a preform of Ti-6Al-6V-2Sn. The preform was in the form of an annular ring having an outside diameter of 7.27 inches, an inside diameter of 2.40 inches and a thickness of 0.54 inches. The preform weighed 3.25 pounds and was coated with a glass lubricant prior to forming. The preform was heated in a furnace of 1,800°F. Suitable dies of IN 100 were inserted in a press and were heated to 1,800°F. by external induction heating coils surrounding the dies. The preform was inserted between the dies and was pressed at a pressing speed of 0.1 inches per minute to a final forging load of 250 tons. The forging was completed in a single step to form a finished nosewheel. The forging had a plan area of 37 square inches. The final forging pressure was 13,500 p.s.i.

EXAMPLE II
A preform having the same composition and dimensions as example I was heated to 1,700°F. and was inserted into the same set of dies which were also preheated to 1,700°F. Pressing was effected at 0.1 inches per minute. At this temperature a forging load of 300 tons was required to close the dies resulting in a final forging pressure of 16,200 p.s.i.

EXAMPLE III
A preform having the same composition and dimensions as example I was heated to 1,600°F. and was inserted into the same set of dies which were also preheated to 1,600°F. Pressing was again effected at 0.1 inches per minute. At this temperature a forging load of 350 tons was required to close the dies resulting in a final forging pressure of 18,900 p.s.i.

EXAMPLE IV
A pair of dies weighing 150 pounds each was formed of IN 100 to define a die cavity having an intricate form including corners, thin webs and flanges. A billet in the form of a rectangular block of Ti-6Al-6V-2Sn weighing 2.1 pounds and having dimensions of 2.75 inches by 3 inches by 1.52 inches was heated in a furnace to 1,800°F. The dies were also heated to 1,800°F. by induction heating coils surrounding the dies. The billet was coated with glass lubricant prior to forging, was inserted between the dies and was pressed at 1,800°F. at a press speed of 3 inches per minute. Pressing was continued at a constant speed until the die cavity closed at a forging load of 250 tons. Complete die filling was achieved. The plan area of the finished forging was 10.5 square inches giving a final forging pressure of 47,600 p.s.i. The final form of the forging was generally of a rectangular shape and included four sidewalks roughly one-fourth inch in thickness and 2/4 inches high with a central web spanning the rectangular opening approximately half the distance from the bottom to the top of the rectangular walls. The shape was designed for maximum material displacement during the forging operation.

EXAMPLE V
A billet having the same dimensions and composition as that of example IV was heated to 1,700°F. and inserted between the same set of dies as in example IV. The dies were preheated to 1,700°F. and pressing was effected at 3 inches per minute to die closure. The resulting shape was identical to that of example IV and required a forging load of 325 tons resulting in a final forging pressure of 61,800 p.s.i.

EXAMPLE VI
A billet of the same composition and dimensions as in the example IV was heated to 1,800°F. and inserted into the same set of dies. The dies were preheated to 1,800°F. Pressing was effected at 0.1 inches per minute to die closure. The resulting shape was identical to that of example IV and required a forging load of 75 tons for die closure resulting in a final forging pressure of 14,300 p.s.i.

EXAMPLE VII
A larger set of dies defining a die cavity of the same shape as that of example IV and having scaled up dimensions was formed from IN 100. A billet of Ti-6Al-6V-2Sn in the form of a block having dimensions of 4.06 inches by 2.81 inches by 1.89 inches and weighing 3.6 pounds was heated to 1,800°F. The dies were also heated to 1,800°F. as in example IV. The billet was coated with glass lubricant and inserted between the dies. Pressing was effected at 3 inches per minute to die closure with a forging load of 350 tons required for die closure. The plan area of the final forged form was 15.5 square inches resulting in a final forging pressure of 45,200 p.s.i.

The foregoing examples illustrate the principle of the invention described and claimed herein. In examples I to III the only variable is the temperature and the effect on the forging pressure is evident. Examples IV and V show the effect of increased pressing speed at the temperatures illustrated in examples I and II. Example VI differs from example I only in the shape. The values for forging pressure are quite close indicating for given temperature and press speed the final forging pressure can be predicted regardless of the shape of the forging. Example VII is similar to example IV and illustrates that the forging pressure is not appreciably affected by the size of the forging.

While the present invention has been described with reference to a forging operation, it applies equally to the extrusion of titanium and titanium alloys. In the extrusion process the die is manufactured of superalloy and a billet of material is placed in a container and forced through the die. In the application of the present invention both the billet and the die are heated above 1,400°F. and are maintained at the desired temperature during the extrusion by conventional heating means compared to present processes of extrusion, pressures can be substantially reduced because much slower extrusion speeds can be selected in the absence of cooling thus taking advantage of the strain rate sensitivity of the alloy.

The present invention provides a new process for forming finished parts of titanium and titanium alloys either above or below the beta transus with a minimum of difficulty and process steps. The result is better products at a great savings in time and cost.

Various changes and modifications of the present invention will occur to those skilled in the art without deviating from the spirit or scope of the invention which features are defined in the following claims.

What is claimed is:
1. A method of forging titanium and titanium alloys comprising the steps of:
   a. without first preworking of a workpiece to change the grain size thereof having a workpiece to a temperature within the range of between about 1,400°F and about 1,950°F,
   b. heating a forging device to a temperature within the range of about 1,400°F and about 1,950°F,
   c. inserting said workpiece into said forging device exposed to the ambient atmosphere,
   d. forging in the ambient atmosphere said heated workpiece while maintaining said forging device and said workpiece within said temperature range, and
   e. controlling the forging speed such that the highest pressure exerted does not exceed the yield strength of said forging device at the temperature employed.
2. The method defined in claim 1 wherein said forging is accomplished at a substantially constant temperature.
3. The method defined in claim 1 wherein said forging is conducted in a superalloy die.
4. The method defined in claim 1 wherein said forging speed is selected so that the yield strength of the titanium alloy does not exceed one-third of the yield strength of the forging device.

5. The method defined in claim 1 wherein said forging is accomplished in a single step and produces a finished shape.

6. A method for forging complex three-dimensional shapes with strain rate sensitive titanium alloys comprising the steps of:
   without first preworking a billet to change the grain size thereof heating an alloy billet and heating a single set of forging dies to a temperature above 1,400°F,
   forging said alloy billet to fill completely a complex shaped three-dimensional die cavity to a finished shape in a single set of heated dies while maintaining said temperature, and maintaining a sufficiently low die speed that the final forging pressure does not exceed the yield strength of said set of dies.

7. The method defined in claim 6 wherein said final forging pressure does not exceed 100,000 p.s.i.

8. The method defined in claim 6 wherein the die speed does not exceed 10 inches per minute.

9. The method defined in claim 6 wherein the die speed varies from 0 to 10 inches per minute during the forging process.

10. The method defined in claim 6 including the further steps of coating said alloy billet with a material to prevent oxidation of the billet and to serve as a lubricant to prevent adhesion of the billet to the die and wherein said forging takes place in the ambient atmosphere.

11. The method defined in claim 10 wherein a thin coating comprised of glass and graphite is applied to said billet to provide the lubrication and to prevent oxidation without providing such an accumulation as would prevent complete filling of the complex shape of the die by the billet.