A method for assembling metal shells, including: (a) providing a first shell made of a titanium fire-resistant alloy with a shape similar to a final shape thereof and having first and second opposite surfaces, the second surface including raised portions acting as anchoring points between shells; (b) providing at least one second shell made of a titanium alloy and having first and second opposite surfaces; (c) placing the first surface of the second shell on the second surface of the first shell; (d) heating the second shell to a temperature higher than a second temperature; (e) deforming the second shell at the second temperature on the first shell, such that the first surface of the second shell matches the second surface of the first shell, the second shell thus being secured to the first shell; and (f) cooling an assembly of the first and second shells to ambient temperature.
METHOD FOR ASSEMBLING A TITANIUM SHELL WITH A TITANIUM FIRE RESISTANT ALLOY SHELL

FIELD OF THE INVENTION

[0001] The present invention relates to a method of assembling metal shells.

BACKGROUND OF THE INVENTION

[0002] Certain parts are made of titanium alloy because of the special properties of such alloys, in particular mechanical strength, ability to withstand high temperatures, and corrosion resistance for density that is less than that of steel or that of other alloys such as alloys based on nickel or based on cobalt.

[0003] This applies in particular to aviation parts, e.g., parts of turbine engines such as high pressure compressor casings. Under such circumstances, the titanium part is in the form of a shell.

[0004] In the description below, the term “shell” is used to designate a part for which one of its three dimensions (its thickness) in three-dimensional space is small (at least five times smaller) than its other two dimensions (its length and its width) perpendicular to its thickness. The term “shell” thus covers a plate, a tube, a collar, or a casing.

[0005] The term “titanium” is used below to mean an alloy in which titanium is the majority element.

[0006] Such a titanium part must be capable of withstanding titanium fire, i.e., a catastrophic fire to which titanium can be subjected in the event of a sudden rise in temperature.

[0007] Various solutions are presently in use for preventing the titanium of a part that is used in a high temperature environment from catching fire. All of such solutions consist in fastening a part made of some other alloy (i.e., an alloy other than a titanium alloy) on the part made of titanium, the part made of some other alloy being positioned so as to be exposed to the highest temperatures and serving to form a shield between those high temperatures and the titanium part.

[0008] One solution consists in using bushings to fasten a shell made of some other alloy (steel, a superalloy based on nickel or cobalt, or some other alloy) on the surface of the titanium part that is exposed to the highest temperatures.

[0009] Another solution consists in hot-rolling a blank made of another alloy together with a blank made of titanium.

[0010] Yet another solution consists in pressing a shell made of some other alloy against a titanium shell, by hydraulic pressing or by explosive pressing.

[0011] Nevertheless, all of those solutions present drawbacks.

[0012] Firstly, it is difficult to control the exact position of the interface between the part made of titanium and the part made of some other alloy.

[0013] Furthermore, depending on implementation tolerances, on machining tolerances, and on machining strategies, the thickness of one or the other of the parts is not always optimized. For example, it is often impossible for the interface to follow the final shape all over the part as closely as possible to its design dimensions when the shape of the titanium part is three-dimensional.

[0014] It can also be impossible to ensure that the thickness ratio between the two materials lies within tolerances.

[0015] Furthermore, when one of the above-mentioned methods is used, the shear or separation strength between the part made of titanium and the part made of another alloy is quite low. Such shear strength is particularly low when there is a large difference between the coefficients of thermal expansion of titanium and of the other alloy.

[0016] Each of the above methods is expensive because of the complexity and the number of steps in the method, and because of the need to machine an assembly made up of the titanium part and the part of another alloy after they have been assembled together in order to ensure that the assembly has the required final dimensions.

Object and Summary of the Invention

[0017] The present invention seeks to remedy those drawbacks.

[0018] The invention seeks to provide a method of assembling metal shells together that enables a titanium shell to be assembled with a titanium fire resistant alloy shell in a manner that is effective, with excellent bonding between them, and at reduced cost.

[0019] This object is achieved by the fact that the method comprises the following steps:

[0020] a) providing a first shell made of titanium fire resistant alloy in a shape close to its final shape, the first shell presenting a first face and a second face opposite from the first face, the second face presenting portions in relief that act as anchor points for anchoring the second shell on the first shell;

[0021] b) providing at least one second shell of titanium alloy, the second shell presenting a first face and a second face opposite from the first face;

[0022] c) placing the first face of the second shell on the second face of the first shell;

[0023] d) heating said second shell to a temperature higher than a second temperature T2;

[0024] e) deforming the second shell on the first shell at the second temperature T2, such that the first face of the second shell fits closely to the second face of the first shell, the second shell thus being secured to the first shell; and

[0025] f) cooling the assembly formed by the first shell and the second shell to ambient temperature.

[0026] By means of these provisions, the assembly constituted by the two metal shells assembled together by the method of the invention is not only capable of withstanding titanium fire, but also presents better dimensional accuracy, since the titanium alloy fits closely to the shell of titanium fire resistant alloy. Thus, less subsequent machining and in particular less machining of the titanium alloy is needed compared with prior art methods, and consequently the fabrication cost is smaller.

[0027] In addition, the assembly presents better shear resistance since, because of the deformation, the titanium alloy is better distributed in and around the portions in relief of the titanium fire resistant alloy shell, and fits more closely to its shape.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The invention can be well understood and its advantages appear better on reading the following detailed description of an implementation given by way of non-limiting example. The description refers to the accompanying drawings, in which:

[0029] FIG. 1A is a perspective view of a first shell and a second shell prior to being assembled together by a first implementation of the method of the invention;
FIG. 1B is a perspective view of a first shell and of a second shell after they have been assembled together by a first implementation of the method of the invention; [0031] FIG. 2 is a section view of the first shell and of the second shell on plane II-II of FIG. 1B; [0032] FIG. 3 is a perspective view of a first shell and of a second shell before being assembled together by a variant of the method of the invention; [0033] FIG. 4A is a perspective view of a first shell and of a second shell prior to being assembled together by a second implementation of the method of the invention; and [0034] FIG. 4B is a perspective view of a first shell and of a second shell after they have been assembled together by a second implementation of the method of the invention.

DETAILED DESCRIPTION

By flowing, the titanium alloy is suitable for fitting closely over these portions in relief, which can thus act as anchor points 19.

By way of example, these portions in relief are indentations in the second face 12 of the first shell 10. Alternatively, these portions in relief are protuberances. By way of example, these protuberances may be hook-shaped. These portions in relief may also be a mixture of indentations and of protuberances.

FIG. 2 is a section view of the first shell 10 and of the second shell 20 after they have been assembled together, this figure showing these portions in relief.

These anchor points 19 thus contribute to securing the first shell 10 and the second shell 20 together more firmly, and consequently they contribute to increasing the shear strength of the assembly constituted by these two shells.

A first implementation of the invention is described below, in which:

in step d), said first shell 10 is maintained at a temperature lower than the first temperature T1, the second temperature T2 being greater than the first temperature T1; and

in step e), the second shell 20 is deformed superplastically at the temperature T2 on said first shell 10.

Thus, in step d), the hottest point of the first shell 10 is at a temperature lower than the first temperature T1.

This first temperature T1 is advantageously a temperature at which the titanium fire resistant alloy deforms little and does not deform superplastically.

For example, at the first temperature T1, the deformation ratio of the titanium fire resistant alloy is less than 1% when T1 is less than 50°C, less than 3% when T1 is less than 600°C, or less than 10% when T1 is less than 950°C.

Advantageously, a calculation is performed beforehand to simulate the plastic deformation of the titanium alloy in order to assist in developing the fabrication range as a function of the final dimensions desired for the second shell 20.

For example, the first temperature T1 is less than 200°C.

For example, this first temperature T1 is equal to ambient temperature, so the first shell 10 then needs to be cooled during the superplastic deformation of the second shell 20.

By way of example, this cooling is obtained by causing a fluid at a temperature lower than the first temperature T1 to flow in a circuit inside the first shell 10 along its first face 11.

Thereafter, the second shell 20 is heated to a temperature higher than a second temperature T2, which is higher than the first temperature T1 (step d)), i.e. the coldest point of the second shell is at a temperature higher than the second temperature T2.

Advantageously, the titanium fire resistant alloy is selected so that its flow stresses at the first temperature T1 are clearly greater than those of the titanium alloy at the second temperature T2. The term “clearly greater” is used to mean at least twice.

Thus, the fact that the first shell 10 deforms only very little while performing the method of the invention contributes to ensuring that an assembly made up of the first shell 10 and of the second shell 20 is obtained that is very close to its final dimensions and shape, thereby minimizing or avoiding subsequent machining of the assembly. Above-described steps c) and d) are performed in that order. Alternatively, it is
possible initially to maintain the first shell 10 at a temperature lower than the first temperature T1 and/or to heat the second shell 20 to a temperature higher than a second temperature T2, and then place the second shell 20 against the first shell 10. [0064] The second shell 20 is deformed superplastically at this second temperature T2 against the first shell 10 so that the first face 21 of the second shell 20 fits closely to the second face 12 of the first shell 10 (step e), as shown in FIG. 1B. [0065] The second shell 20 is thus secured to the first shell 10, in particular because of the portions in relief 19. The consequence of being secured in this way is that the two shells then form a single-piece unit. [0066] Thereafter the assembly made up of said first shell 10 and said second shell 20 is cooled to ambient temperature (step f). [0067] By way of example, the titanium second shell 20 is deformed superplastically by using one or more dies placed against the second face 22 of the second shell 20 and moved to deform the second shell 20 and press it against the first shell 10. [0068] The fact of deforming the second shell 20 in superplastic manner enables the second shell 20 to fit more closely to dies of any shape, thereby obtaining the desired distribution of thickness over the entire surface area of the second shell 20, and thus coming even closer to the desired dimensions. [0069] The superplastic range of titanium alloys is optimized when the microstructure is biphasic alpha and beta and when the grain size of the alloys is as small as possible. The second temperature T2 is thus ideally situated in a temperature range where both of those conditions apply. [0070] Thus, the second temperature T2 is lower than the boundary temperature Tb, which is the temperature above which the titanium alloy has a β microstructure. [0071] Thus, the second temperature T2 is then low enough to avoid any chemical reaction taking place at the interface between the titanium alloy and the titanium fire resistant alloy. Consequently, no weakening phase is formed at this interface, and the bonding between the first shell 10 and the second shell 20 is thus better. [0072] For example, for the TA6V titanium alloy, this boundary temperature Tb is equal to about 1050°C. [0073] The second temperature T2 must not be too low, since the lower the temperature at which the titanium is deformed, the more difficult it is to deform it (a more powerful press is needed). [0074] For example, the second temperature T2 is higher than 500°C. [0075] Advantageously, the second temperature T2 is higher than 700°C. [0076] Ideally, the second temperature T2 is about 900°C. [0077] Advantageously, the dies for deforming the second shell 20 are heated so that the titanium remains at the temperature T2 throughout its superplastic deformation. [0078] Tests performed by the inventors show that the deformation rate to be used for superplastically deforming the titanium preferably lies in the range 10⁻² per second (s⁻¹) to 10⁻³ s⁻¹. Ideally, this deformation rate is about 10⁻² s⁻¹. [0079] This superplastic deformation of the second shell 20 serves to optimize the pressing of the second shell 20 against the first face 12 of the first shell 10, even in the zones of the second face 12 that do not present any machining (such as holes), or zones in which the radius of curvature is small (i.e. relative to the thickness of the first shell 10). [0080] Advantageously, in use, the difference Δt between the coefficient of expansion of the titanium of the second shell 20 and the coefficient of expansion of the alloy of the first shell 10 is less than 3x10⁻⁶/°C. [0081] Thus, for a variation in external temperature of a given amplitude, the stresses generated at the interface between the two shells are smaller. Consequently, the shear strength of the assembly constituted by these two shells is greater. [0082] After superplastically deforming the second shell 20 (step e), it is possible under certain circumstances to perform heat treatment with machining in order to impart its final shape to the assembly constituted by the first shell 10 and the second shell 20. [0083] In a variant, and as shown in FIG. 3, prior to step c), the first face 11 of the first shell 10 rests against a core 30 with which it is in contact. [0084] The core 30 is substantially a close fit against the first face 11 of the first shell 10, and the surface of the core 30 in contact with the first face 11 presents a shape as close as possible to the final dimensions desired for the first shell 10. [0085] Thus, during the method of the invention, the deformation of the first shell 10 is minimized, since the first shell 10 is restricted in its deformation by the core 30. Consequently, the assembly constituted by the metal shells is even closer to the final shape desired for this assembly, and even less subsequent machining and in particular less machining of the titanium alloy is needed in comparison with prior art methods. This serves to further reduce fabrication costs. [0086] Advantageously, the core 30 is maintained at a temperature lower than the first temperature T1 so that it is easier to maintain the first shell 10 at this temperature lower than the first temperature T1 during the superplastic forging of the second shell 20, thereby imparting greater rigidity to the core 30. [0087] Advantageously, the core 30 possesses a heating and/or cooling system in order to be maintained at said temperature lower than the first temperature T1. For example, the core 30 possesses an internal system for circulating liquid. [0088] The second shell 20 is a single shell or an assembly of a plurality of shells. The first faces are the concave (respectively convex) faces of each of the shells, and the second faces are the convex (respectively concave) faces of each of the shells. [0089] In a particular configuration, the first shell 10 and the second shell 20 form a collar, e.g. of tubular or conical shape. The first faces are then the concave faces of each of the shells, and the second faces are the convex faces of each of the shells. [0090] Under such circumstances, prior to step a), the first shell 10 may be subjected to pre-rolling or pre-forming in order to be given the shape of a collar. [0091] There follows a description of a second implementation of the invention, in which: [0092] in step c), the shells 10 and 20 are placed in a hermetically sealed enclosure 80; [0093] in step d), the first shell 10 is heated to a temperature higher than the second temperature T2; and [0094] in step e), pressure is established inside the enclosure 80 that is high enough to deform the second shell 20 at the second temperature T2. [0095] As shown in FIG. 4A, the first face 21 of the second shell 20 is placed against the second face 12 of the first shell
10 (step c)), and these two shells are placed in a hermetically closed enclosure 80 that is filled with a fluid (a preferably inert gas, or a liquid).

Thereafter, the first shell 10 and the second shell 20 are heated to a temperature higher than the temperature T2 and pressure is established inside the enclosure 80 that is high enough for the second shell 20 (and possibly also to a smaller extent the first shell 10) to deform at this second temperature T2 (hot isostatic compression).

Thus, the second shell 20 is deformed on the first shell 10 in such a manner that the first face 21 of the second shell 20 fits closely to the second face 12 of the first shell 10 (step c), as shown in FIG. 4B.

Advantageously, the titanium fire resistant alloy is selected so that the first shell 10 deforms only very little during the method of the invention, thereby contributing to obtaining an assembly formed by the first shell 10 and the second shell 20 that is as close as possible to its final dimensions and shape, and the distribution of thickness in the second shell 20 over its entire surface area is as desired. This minimizes or avoids any need for subsequent machining of the assembly.

The second temperature T2 is lower than the overheating or burning temperature of each of the materials constituting the two shells so as to avoid damaging the shells.

By way of example, the second temperature T2 is less than 1200°C.

The second shell 20 is thus secured to the first shell 10, in particular because of the portions in relief 19. As a consequence of being secured in this way, the two shells then form a single-piece unit.

The assembly constituted by the first shell 10 and the second shell 20 is then cooled to ambient temperature (step f).

Because of the deformation of the second shell 20, the second shell 20 is pressed against the second face 12 of the first shell 10 in optimum manner, even in zones of the second face 12 that present machining (such as holes) or that present a radius of curvature that it small (i.e. relative to the thickness of the first shell 10).

Advantageously, the assembly comprising the first shell 10 and the second shell 20 is covered in a metal sheath (e.g. made up of welded-together metal sheaths) prior to raising the pressure and the temperature inside the enclosure 80. The inside of the sheath is evacuated (to a pressure lower than atmospheric pressure).

Thus, the distribution of pressure on the two shells is made more uniform.

Advantageously, a layer of a material such as a thermal barrier (alloy based on Ni, Co, or Mo) or a mineral is placed at the interface between the first shell 10 and the second shell 20. By way of example, this layer is placed (e.g. deposited) on the first shell 10. This measure is particularly useful when the temperature T2 is higher than about 1000°C, in order to avoid forming weakening phases at the interface between the two shells.

This ensures that greater shear strength is obtained at the interface.

Tests performed by the inventors show that the deformation rate to be used for deforming the titanium preferably lies in the range $10^{-3}$ s$^{-1}$ to $10^{-5}$ s$^{-1}$. Ideally, this deformation rate is about $10^{-4}$ s$^{-1}$.

Advantageously, in use, the difference $\Delta \epsilon$ between the coefficient of expansion of the titanium of the second shell 20 and the coefficient of expansion of the alloy of the first shell 10 is less than $3 \times 10^{-6}$/°C.

Thus, for a variation in external temperature of a given amplitude, the stresses generated at the interface between the two shells are smaller. Consequently, the shear strength of the assembly constituted by these two shells is greater.

Advantageously, the second temperature T2 is less than the boundary temperature $T_b$, which is the temperature above which the titanium alloy has a β microstructure.

Below the boundary temperature $T_b$, there is the optimum range of superplasticity in titanium alloys where the microstructure is biphasic alpha and beta and the grain size of these alloys is as small as possible.

Thus, the second shell 20 is deformed in the superplastic deformation range of titanium and at a temperature that is low enough to avoid a chemical reaction taking place at the interface between the titanium alloy and the titanium fire resistant alloy. Consequently, no weakening phase is formed at the interface, and the bonding between the first shell 10 and the second shell 20 is therefore better.

By way of example, for the TA6V titanium alloy, this boundary temperature $T_b$ is equal to about 1050°C.

The second temperature T2 must not be too low, since the lower the titanium at which the titanium is deformed, the more difficult it is to deform (greater pressure is required).

For example, the second temperature T2 is higher than 500°C.

Advantageously, the second temperature T2 is higher than 700°C.

Ideally, the second temperature T2 is about 900°C.

After deforming the second shell 20 (step c)), it is possible in certain circumstances to perform heat treatment with machining in order to impart its final shape to the assembly constituted by the first shell 10 and the second shell 20.

The second shell 20 is a single shell or an assembly of a plurality of shells. The first faces are the concave (respectively convex) faces of each of the shells, and the second faces are the convex (respectively concave) faces of each of the shells.

In a particular configuration, the first shell 10 and the second shell 20 form a collar, e.g. of tubular or conical shape. The first faces are then the concave faces of each of the shells, and the second faces are the convex faces of each of the shells.

Under such circumstances, prior to step a), the first shell 10 may be subjected to pre-rolling or pre-forging in order to be given the shape of a collar.

A method of assembling metal shells, the method comprising:

a) providing a first shell made of titanium fire resistant alloy in a shape close to its final shape, the first shell including a first face and a second face opposite from the first face, the second face including portions in relief that act as anchor points for anchoring a second shell on the first shell;

b) providing at least one second shell of titanium alloy, the second shell including a first face and a second face opposite from the first face;

c) placing the first face of the second shell on the second face of the first shell;
d) heating the second shell to a temperature higher than a second temperature T2;
e) deforming the second shell on the first shell at the second temperature T2, such that the first face of the second shell fits closely to the second face of the first shell, the second shell thus being secured to the first shell; and
f) cooling an assembly formed by the first shell and the second shell to ambient temperature.

11. A method according to claim 10, wherein in d) the first shell is maintained at a temperature lower than a first temperature T1, the second temperature T2 being higher than the first temperature T1, and in e) the second shell is superplastically deformed at the second temperature T2 against the first shell.

12. A method according to claim 11, wherein the temperature T1 is less than 200°C.

13. A method according to claim 11, wherein prior to e), the first face of the first shell rests against a rigid core with which it is in contact.

14. A method according to claim 11, wherein the superplastic deformation of the titanium second shell is performed by using at least one die that is placed against the second face of the second shell and that is moved to deform the second shell and press it against the first shell.

15. A method according to claim 10, wherein in c) the shells are placed in a hermetically closed enclosure, in d) the first shell is heated to a temperature higher than the second temperature T2, and in e) a pressure is established in the enclosure that is high enough to deform the second shell at the second temperature T2.

16. A method according to claim 10, wherein the second temperature T2 is higher than 500°C.

17. A method according to claim 10, wherein the second temperature T2 is less than a temperature Tb, the temperature Tb being a temperature above which the titanium alloy has a β microstructure.

18. A method according to claim 10, wherein a difference Δα between the coefficient of expansion of the titanium of the second shell and the coefficient of expansion of the alloy of the first shell is less than 3×10⁻⁶°C.