



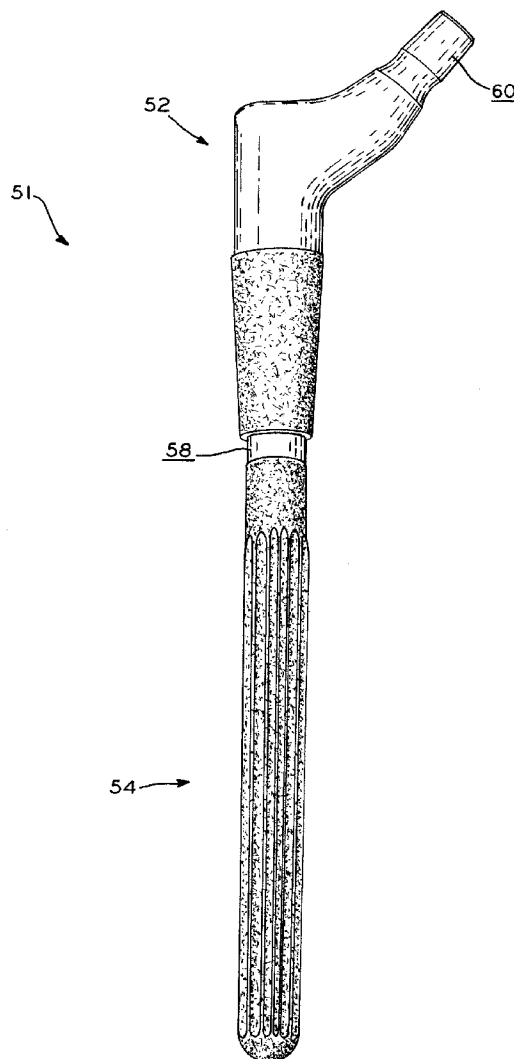
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Bhambri(10) **Pub. No.: US 2010/0051141 A1**(43) **Pub. Date: Mar. 4, 2010**(54) **METHOD FOR ENHANCING FRETTING
FATIGUE RESISTANCE OF ALLOYS****Related U.S. Application Data**(60) Provisional application No. 61/093,595, filed on Sep.
2, 2008.(75) Inventor: **Sushil K. Bhambri**, Warsaw, IN
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FORT WAYNE, IN 46802 (US)****ABSTRACT**

A method for increasing the fretting fatigue resistance of an alloy by prehardened a surface of the alloy followed by laser shock peening the prehardened surface. In one exemplary embodiment, an orthopedic prosthesis is formed from a titanium alloy and subjected to surface nitriding followed by laser shock peening. By nitriding the titanium alloy, the hardness of the alloy's surface is increased. Then, by subjecting the nitrided surface of the alloy to laser shock peening, the fretting fatigue of the nitrided surface may be increased by more than 100%.

(73) Assignee: **ZIMMER, INC.**, Warsaw, IN (US)(21) Appl. No.: **12/552,870**(22) Filed: **Sep. 2, 2009**

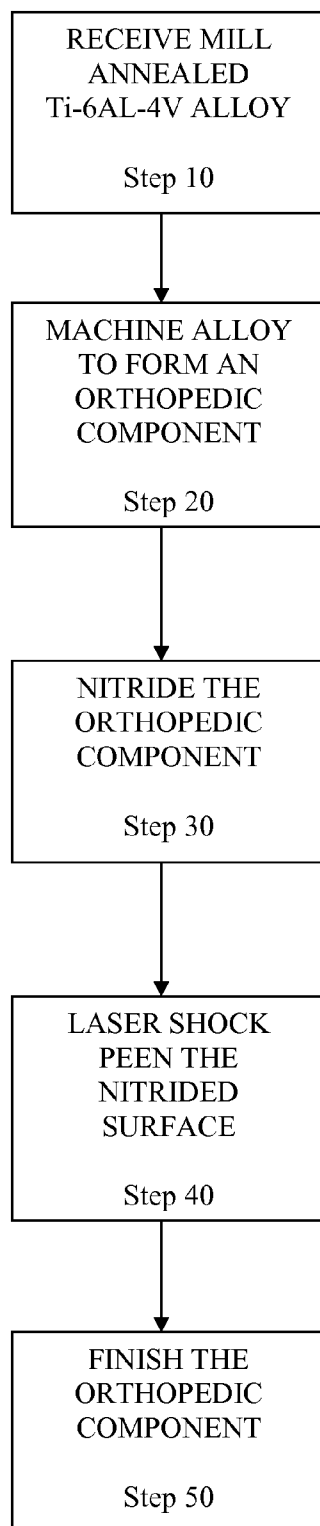


Fig. 1

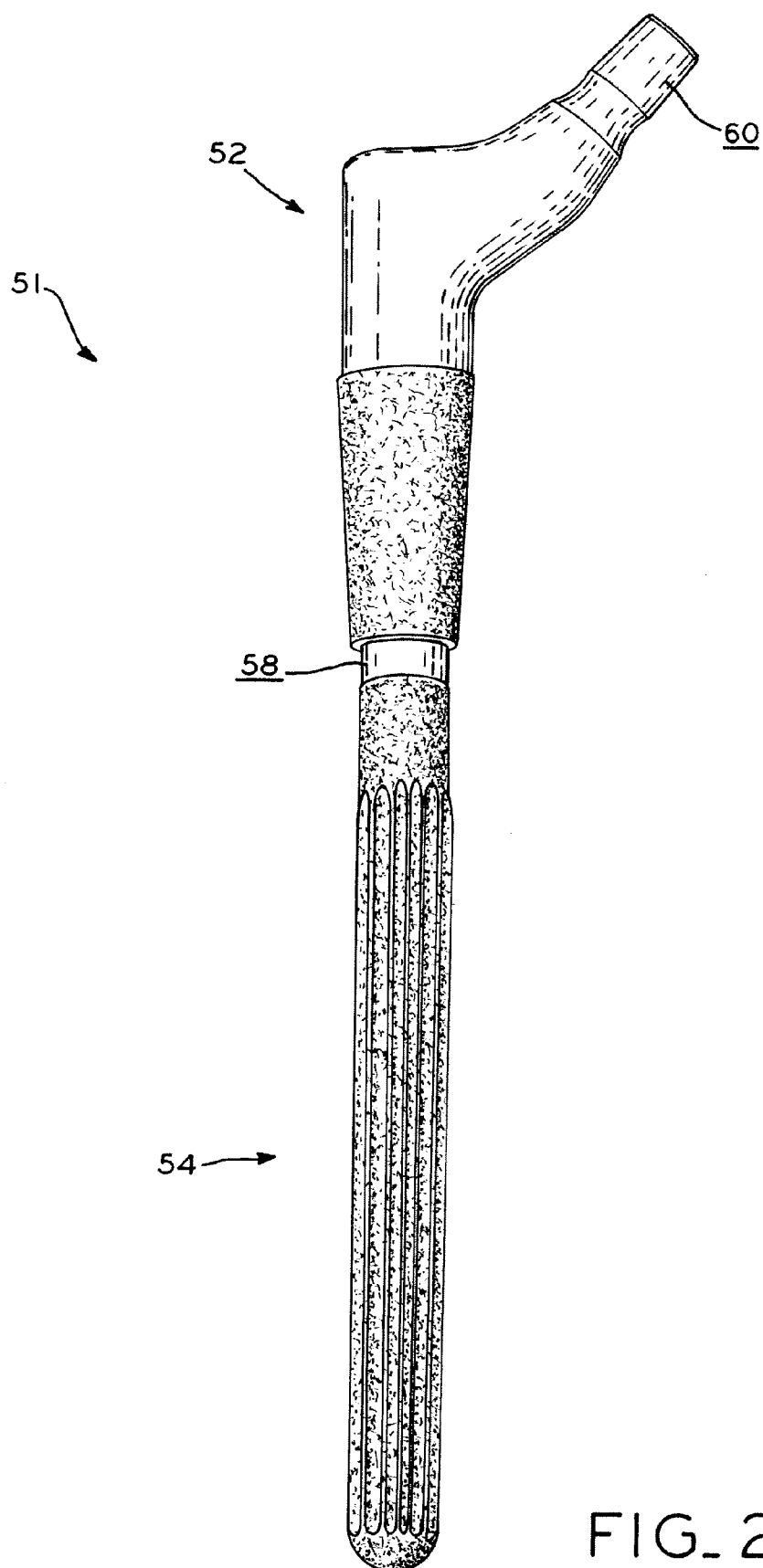


FIG. 2

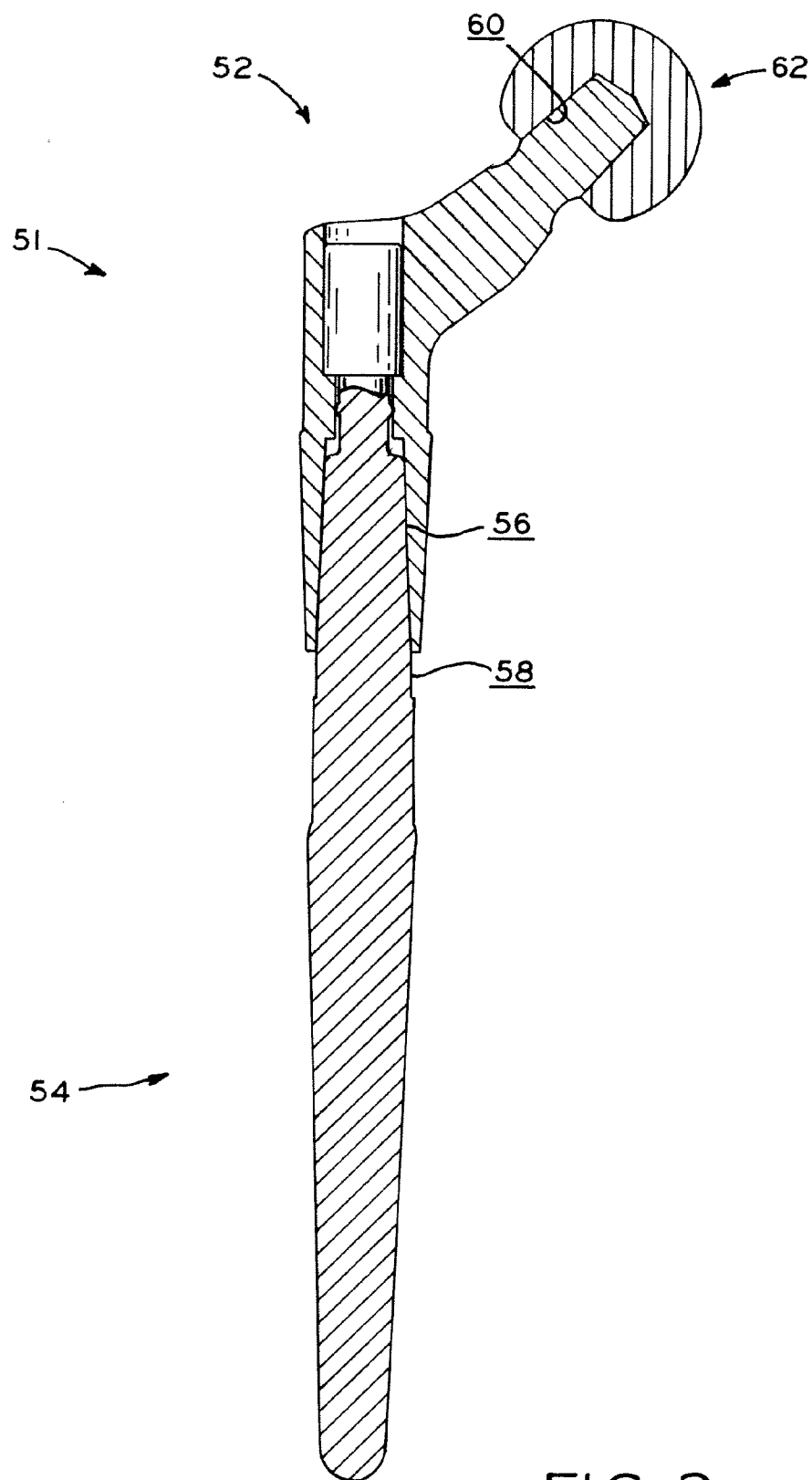


FIG. 3

METHOD FOR ENHANCING FRETTING FATIGUE RESISTANCE OF ALLOYS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under Title 35 U.S.C. §119(e) of U.S. Provisional Patent Application Ser. No. 61/093,595, entitled METHOD FOR ENHANCING FRETTING FATIGUE RESISTANCE OF ALLOYS, filed on Sep. 2, 2008, the entire disclosure of which is expressly incorporated by reference herein.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The present invention relates to methods for enhancing the fretting fatigue resistance of alloys and, particularly, methods of enhancing the fretting fatigue of alloys by the laser shock peening of prehardened surfaces.

[0004] 2. Description of the Related Art

[0005] Orthopedic prostheses are used to replace and/or repair damaged or diseased bone in a patient's body. To construct an orthopedic prosthesis, titanium alloys, such as Ti-6Al-4V, may be used which incorporate the superior strength to weight ratio of titanium. Additionally, some prostheses are manufactured to be modular, i.e., a number of smaller pieces are individually manufactured and then connected together to form a complete prosthesis. For example, a femoral component of a hip prosthesis may be comprised of a separate diaphyseal portion, metaphyseal portion, and ball-shaped head portion that are connected together via Morse tapers. The connections between these independent components of the prosthesis allow for micro-motion, i.e., extremely small relative surface displacement that occurs in the presence of loading, between the individual components. As a result, fretting fatigue may occur within the titanium alloy which can shorten the useful life of the prosthesis.

[0006] In order to increase the hardness of these alloys and, correspondingly, to increase their fretting fatigue resistance, alloys used in orthopedic components have been laser shock peened. In laser shock peening, a laser beam is directed at the surface of the alloy to induce deep compressive residual stresses in the material. Specifically, the surfaces to be laser shock peened are first coated with a layer of paint or another ablation material. The surfaces are then positioned beneath a curtain of flowing water and subjected to the repetitive firing of a high energy laser beam.

[0007] As the laser beam passes through the water, it contacts the paint or other ablation material coating the surfaces of the alloy. As a result, the material is ablated by the laser light and transformed into plasma. This transformation results in the generation of shockwaves that are directed toward the alloy's surface by the curtain of flowing water, which also washes away the ablated surface material. As a result of the shockwaves contacting the surface of the alloy, compressive stress is introduced into the alloy. This provides the alloy with a hardened surface and also slightly increases the fretting fatigue resistance of the alloy. Specifically, laser shock peening of an alloy, such as Ti-6Al-4V, results in an approximately 50% increase in the alloy's hardness. As a

result of the increased hardness, the alloy exhibits an approximately 30% increase in its resistance to fretting fatigue.

SUMMARY

[0008] The present invention provides a method for increasing the fretting fatigue resistance of an alloy by pre-hardening a surface of the alloy followed by laser shock peening the prehardened surface. In one exemplary embodiment, an orthopedic prosthesis is formed from a titanium alloy and subjected to surface nitriding followed by laser shock peening. By nitriding the titanium alloy, the hardness of the alloy is increased to a depth of as much as 0.02 μ m below the surface. Then, by subjecting the nitrided surface of the alloy to laser shock peening, the fretting fatigue of the surface may be increased by more than 100%.

[0009] Advantageously, by combining laser shock peening with nitriding, the resistance of the surface to fretting fatigue is substantially increased when compared to the increase in the resistance to fretting fatigue that would have been expected by a person of ordinary skill in the art with laser shock peening alone. Specifically, it is believed by persons of ordinary skill in the art that improvements in an alloy's fretting fatigue resistance is a direct result of an increase in the alloy's hardness. For example, laser shock peening the surface of a non-hardened alloy results in an increase in the alloy's hardness of approximately 50% and, correspondingly, the alloy exhibits an increased resistance to fretting fatigue of approximately 30%. Based on this and other observations, the improved fretting fatigue resistance of an alloy's surface is, as indicated above, believed by those of ordinary skill in the art to be a by-product of the increased hardness of the alloy's surface.

[0010] However, when laser shock peening is performed on a previously hardened surface, the alloy's hardness is increased by another 50%, while the alloy's resistance to fretting fatigue unexpectedly increases by as much as 150%. Moreover, the increase in the alloy's resistance to fretting fatigue cannot be directly correlated to the increase in the hardness of the nitrided alloy after laser shock peening, as it is only improved by approximately 50% as compared to the nitrided alloy. Thus, the proportional relationship that those of ordinary skill in the art believe exists between the increase in the hardness of an alloy's surface and the increase in the fretting fatigue resistance of the alloy's surface has been disproved for a prehardened surface of an alloy that is subjected to laser shock peening. Furthermore, this increase in the alloy's resistance to fretting fatigue is substantially greater than the 30% increase that results from laser shock peening alone.

[0011] Advantageously, improving by 100% or more the fretting fatigue resistance of the surface of an orthopedic implant allows the orthopedic implant to withstand loads in excess of twice of the anticipated loading requirements during use, which are typically three times the patient's body weight. As a result, the size of the orthopedic component may be decreased. Additionally, the design of the orthopedic components may also be altered, as less material may be needed in certain positions to bear the same loads as traditional implants. Furthermore, by laser shock peening a previously hardened, e.g., nitrided, surface, only selected sections of a prosthesis, as opposed to the entirety of a prosthesis, may be subjected to the desired surface modification. As a result, the prosthesis may be produced for a substantially lower cost than a prosthesis that is laser shock peened in its entirety.

[0012] In one form thereof, the present invention provides a method of enhancing the fretting fatigue resistance of an alloy, including the steps of: forming an orthopedic component from an alloy, wherein the alloy has a melting point; nitriding at least a portion of the orthopedic component to form a nitrided surface, the nitrided surface having a first fretting fatigue strength; and laser shock peening at least a portion of the nitrided surface of the orthopedic component to form a laser shock peened surface, wherein the laser shock peened surface has a second fretting fatigue strength.

[0013] In another form thereof, the present invention provides a method of enhancing the fretting fatigue resistance of an alloy, including the steps of: forming a modular orthopedic component from an alloy having a melting point, the modular orthopedic component including: a first component defining a male tapered surface; and a second component defining a female tapered surface, the male tapered surface of the first component configured to form a taper lock with the female tapered surface of the second component; nitriding at least one of the male tapered surface of the first component and the female tapered surface of the second component to form a nitrided surface, the nitrided surface having a first fretting fatigue; and laser shock peening at least a portion of the nitrided surface to form a laser shock peened surface, wherein the laser shock peened surface has a second fretting fatigued strength.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention itself will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

[0015] FIG. 1 is a flow chart depicting an exemplary method of performing the present invention; and

[0016] FIG. 2 is a perspective view of an exemplary, modular orthopedic component in the form of a hip stem; and

[0017] FIG. 3 is a cross-sectional view of the hip stem of FIG. 2 further depicting a femoral head secured thereto.

[0018] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates a preferred embodiment of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION

[0019] The present invention provides a method for enhancing the fretting fatigue of an alloy by subjecting the alloy to surface hardening followed by laser shock peening. Although the present invention is described in detail below and in the following Example with specific reference to Ti-6Al-4V, the present invention is more generally applicable to titanium alloys and the teachings of the present invention may be utilized in conjunction with alpha/beta or beta titanium alloys such as Ti-6Al—Nb alloy, Ti-15Mo beta titanium alloy, and other biocompatible alloys, such as Co—Cr—Mo alloys, that can be surface hardened in a similar manner as Ti-6Al-4V.

[0020] As indicated above, Ti-6Al-4V is a titanium alloy used to manufacture orthopedic prosthesis and is readily available from numerous commercial sources. Referring to

FIG. 1, Ti-6Al-4V is received at Step 10 in mill annealed condition as stock material. In this condition, the Ti-6Al-4V has a fine grain alpha-beta microstructure in which the alpha phase has a hexagonal close packed crystal structure and the beta phase has a body centered cubic crystal structure. Once received, the Ti-6Al-4V alloy is, in one exemplary embodiment, machined at Step 20 into a preform orthopedic component. Specifically, a preformed orthopedic component is an orthopedic component that has a shape that is dimensioned to be substantially similar to the desired dimensions of a final orthopedic component. However, unlike a final orthopedic component, a preform orthopedic component may require machining or other modifications, however slight, before it is formed into a finished orthopedic component. In another exemplary embodiment, a final orthopedic component is formed at Step 20.

[0021] Referring to FIG. 2, an exemplary, finished orthopedic component is shown in the form of modular hip stem 51. Modular hip stem 51 includes metaphyseal or neck portion 52, which forms a first component of modular hip stem 51, and diaphyseal or stem portion 54, which forms a second component of modular hip stem 51. As shown in FIG. 3, neck portion 52 includes female tapered surface 56 that cooperates with male tapered surface 58 of stem portion 54 to form a Morse taper and secure the components together. While described and depicted herein with specific reference to neck portion 52 and stem portion 54 being joined by cooperation of female tapered surface 56 of neck portion 52 and male tapered surface 58 of stem portion 54, the tapered surfaces may be reversed, such that neck portion 52 and stem portion 54 are joined by cooperation of a male tapered surface of neck portion 52 and a female tapered surface of stem portion 54. In addition to female tapered surface 56, neck portion also includes male tapered surface 60. Male tapered surface 60 is configured to form a taper lock with a corresponding femoral head 62, as shown in FIG. 3.

[0022] Irrespective of whether a preform or final orthopedic component is formed at Step 20, the orthopedic component is then subjected to nitriding or nitridization at Step 30. Nitriding is a surface hardening heat treatment that introduces nitrogen into the surface of the Ti-6Al-4V alloy of the orthopedic component at a temperature substantially below both the melting point and beta-transus temperature of mill annealed Ti-6Al-4V. Generally, nitriding processes introduce nitrogen into the surface of the Ti-6Al-4V orthopedic component by heating the component in either a liquid salt bath including nitrogen bearing salts or in a gas stream containing cracked ammonia. In one exemplary embodiment, the orthopedic component is nitrided utilizing a gas method, such as known methods that use a box furnace or fluidized bed, for example. Alternatively, the nitriding process may be a liquid or plasma nitriding process. Additionally, any other known methods of nitriding, such as ion implantation, may be used.

[0023] As indicated above, nitriding is performed at a temperature below both the melting point and the beta-transus temperature of mill annealed Ti-6Al-4V. Specifically, the melting point for mill annealed Ti-6Al-4V is approximately between 2420° F. and 3020° F. and the beta-transus temperature is approximately between 1777° F. and 1813° F. In one exemplary embodiment, the nitriding is performed by heating the components in a vacuum oven to approximately 1100° F. in a nitrogen gas environment and holding the components at approximately 1100° F. for 8 hours. In another exemplary embodiment, the nitriding is performed by heating the com-

ponents in a vacuum oven to approximately 1050° F.±50° F. in a nitrogen gas environment and holding the components at approximately 1050° F.±50° F. for 8 hours. Additionally, the nitriding treatment may be conducted utilizing a Ti-Nidium® nitriding process. “Ti-Nidium” is a registered trademark of Zimmer, Inc. of Warsaw, Ind. Exemplary methods of performing nitriding processes, including the Ti-Nidium® nitriding process, are disclosed in U.S. Pat. No. 5,192,323 to Shetty et al, entitled METHOD OF SURFACE HARDENING ORTHOPEDIC IMPLANT DEVICES, issued on Mar. 9, 1993, the entire disclosure of which is expressly incorporated by reference herein.

[0024] By performing the nitriding at temperatures far below the melting point and the beta-transus temperatures of the mill annealed Ti-6Al-4V, no thermally induced change in the bulk microstructure of the Ti-6Al-4V occurs during nitriding. As a result of subjecting the orthopedic component to a nitriding process, both the surface hardness and the fretting fatigue resistance of the alloy forming the orthopedic component are improved. The surface hardness may improve 60-70% from the nitriding process and the fretting fatigue resistance of the material may increase by up to 10%. Additionally, the nitriding process may be performed on only a portion of the orthopedic component. For example, while all of the surfaces of hip stem **51**, shown in FIG. 2, may be nitrided, it is also envisioned that only portions of the surfaces of hip stem **51** may be nitrided. For example, one or both of tapered surfaces **56**, **58** of neck portion **52** and stem portion **54**, respectively, may be nitrided.

[0025] Once nitrided, the orthopedic component is laser shock peened at Step **40**. Specifically, at least a portion of the surface that was previously nitrided at Step **30** is subjected to laser shock peening. In one exemplary embodiment, the entirety of the surfaces nitrided at Step **30** is subjected to laser shock peening. In another exemplary embodiment, only a portion of the surfaces subjected to nitriding at Step **30** are subjected to laser shock peening at Step **40**. For example, if all of the surfaces of hip stem **51** are nitrided, only one or both of tapered surfaces **56**, **58** of neck portion **52** and stem portion **54**, respectively, may be subjected to laser shock peening.

[0026] As indicated above, in laser shock peening, a laser beam is directed at the surface of the alloy to induce deep compressive residual stresses in the material. Specifically, the surfaces to be laser shock peened are coated with a layer of paint or another ablation material. The surfaces are then positioned beneath a curtain of flowing water and subjected to the repetitive firing of a high energy laser beam. As the laser beam passes through the water, it contacts the paint or other ablation material coating the surfaces of the alloy. As a result, the material is ablated and is transformed into plasma. This transformation results in the generation of shockwaves radiating from the surfaces of the alloy. These shockwaves are redirected toward the alloy's surfaces by the curtain of flowing water, which also washes away the ablated surface material. As a result of the shockwaves contacting the surfaces of the alloy, compressive stress is introduced into the alloy.

[0027] As a result of subjecting the previously nitrided surface of the orthopedic component to laser shock peening, a slight improvement in the hardness of the surfaces of the orthopedic component is achieved. More importantly, an unexpectedly large improvement in fretting fatigue resistance is also achieved. Specifically, as indicated above, an increase in fretting fatigue resistance of an alloy is believed by persons of ordinary skill in the art to be directly proportional to an

increase in the hardness of the surface of an alloy. In fact, it is believed that the increased fretting fatigue resistance of a laser shock peened alloy is derived substantially entirely from the increased hardness of the alloy. However, by laser shock peening the previously nitriding surface of an orthopedic component, an unexpected improvement in fretting fatigue resistance may be achieved. For example, as set forth in the Example below, a nitrided and laser shock peened alloy may exhibit an improvement in fretting fatigue resistance that exceeds 100% when compared to an alloy that is only nitrided. In exemplary embodiments, the improvement in fretting fatigue resistance of a nitrided and laser shock peened alloy may be as great as 100%, 110%, 120%, 130%, 140%, or 150% as compared to an alloy that is only nitrided.

[0028] While the exact mechanism that results in the substantial and unexpected increase in fretting fatigue resistance is not specifically understood at present, the increased fretting fatigue resistance is thought to result from a compressive residual stress induced into the surface layer. Thus, it is thought that the laser shock peening induces greater compressive residual stress to a larger depth below the surface of the orthopedic component than is achieved without the prior surface hardening treatment. This increased residual stress may delay crack nucleation and early crack propagation, while offering a resistance to abrasion. Thus, this increase in the residual stresses may enhance the crack tolerance capacity, i.e., the ability of a material to accept crack formation without failure, increase the alloy's resistance to crack initiation, and increase the alloy's ability to arrest crack growth, all of which are indicative of the alloy's overall resistance to fretting fatigue failure.

[0029] Once the laser shock peening of the orthopedic component is completed at Step **40**, the orthopedic component may be formed into a finished orthopedic component at Step **50**. For example, if the orthopedic component is a preform, it may be subjected to additional machining and/or milling steps using a computer numerical control machine, i.e., a CNC machine, for example. Additionally, irrespective of whether the orthopedic component is a preform or a final orthopedic component, additional work, such as additional surface treatments and/or sterilization procedures, may be performed on the orthopedic component at Step **50** to render the orthopedic component suitable for implantation.

Example

[0030] The following non-limiting Example illustrates various features and characteristics of the present invention, which is not to be construed as limited thereto. The following abbreviations are used throughout the Example unless otherwise indicated.

TABLE 1

Abbreviations	
Abbreviation	Full Word
F	Fahrenheit
°	degree
Hz	Hertz
N	Newton
KHN10 g	Knoop Hardness
GW	gigawatt
cm	centimeter
Nd	Neodymium
Ti	Titanium

TABLE 1-continued

Abbreviations	
Abbreviation	Full Word
Al	Aluminum
V	Vanadium
kbar	kilobar

Fretting Fatigue Tests of Modular Components with Improved Surface

[0031] Wrought mill annealed Ti-6Al-4V ELI titanium alloy (ASTM F-136-02A) bar stock was obtained from Supra Alloys, Inc., of Camarillo, Calif. The alloy bar stock was formed into ten complete, modular hip stems each having a mid-stem Morse taper. The modular hip stems that were formed were similar to hip stems available in the ZMR® Hip System, commercially available from Zimmer, Inc., of Warsaw, Ind. “ZMR” is a registered trademark of Zimmer, Inc., of Warsaw, Ind. Each of the modular components that form the Morse taper, i.e., diaphyseal or stem components and metaphyseal or neck components, were subjected to thermal nitrogen diffusion surface hardening treatment, i.e., nitriding. Specifically, in order to nitride the male and female tapered sections of the modular components, the individual modular components were placed in a Model H 26 vacuum furnace, manufactured by Vacuum Furnace Systems Corporation of Souderton, Pa., and heated to approximately 1100° F. in a nitrogen gas environment. The components were held at approximately 1100° F. for 8 hours. The components were then allowed to cool and were removed from the vacuum furnace.

[0032] As compared to a non-nitrided surface, the resulting nitrided surfaces of the male tapered modular orthopedic component, prior to later laser shock peening, experienced an increase in hardness of approximately 400 KHN10 g on the Knoop Hardness Scale. Additionally, the nitriding technique used in the present testing has an insignificant effect on the fatigue strength of the alloy. Specifically, as disclosed in U.S. Pat. No. 5,192,323 to Shetty et al., which is expressly incorporated by reference herein above, a component nitrided using this technique experiences a 5%-10% decrease in fatigue strength as compared to a non-nitrided component. However, when analyzed in terms of debris generation, the fretting fatigue behavior of nitrided titanium alloy tapers has been reported to be slightly better than non-nitrided tapers when used in modular orthopedic components.

[0033] The nitrided modular components that included the male tapered sections were then sent to Lawrence Livermore National Laboratory in Livermore, Calif., to be subjected to laser shock peening. The male tapers of the modular components were laser shock peened twice with 10 GW/cm² of laser energy. Generally, as discussed above, in a laser shock peening process, an intense beam of laser light is generated using a Nd:glass slab laser system and is impinged onto a sacrificial ablating material layer, such as paint or adhesive backed aluminum tape. The laser light rapidly vaporizes a thin portion of the ablative layer and produces plasma confined by a thin laminar layer of water flowing over the surface of the ablating material. Expanding plasma generates shockwaves having a pressure of approximately 100 kbar that is directed toward the component by the flowing water. These shock-

waves create a plastic strain in the material resulting in the formation of a compressive residual stress field. Laser peening parameters are optimized by varying the laser pulse irradiance, the laser energy, the duration of the laser pulse, and the number of treatment layers.

[0034] Once complete, the male tapered modular components having the nitrided and laser shock peened male Morse taper section were taper locked to the female tapered modular components having only the nitrided female Morse taper section to form a mid-stem junction between the two components. The resulting hip stem assemblies were then subjected to fatigue testing. Specifically, the male modular components, i.e., the diaphyseal components, of the hip stem assemblies were potted in bone cement 0.25 inch below the mid-stem modular junction of the assemblies. The fatigue tests were conducted on specimens mounted in an anatomical orientation (150 medial/lateral, 100 anterior/posterior, and 120 anti-version) and in ambient conditions at a frequency of 10 Hz.

[0035] Specifically, load was applied vertically to the hip stem assemblies using a MTS servohydraulic test machine, commercially available from MTS Systems Corporation, of Minneapolis, Minn. The specimens were cyclically loaded in a sinusoidal waveform to 10,000,000 cycles or until fracture, whichever occurred first. At the completion of a test, the next specimen was tested at higher or lower load depending upon whether the previous specimen had fractured or survived 10,000,000 cycles. Thus, if a specimen survived the completion of a test, the next specimen was tested at a higher load. However, if a specimen fractured, the next specimen was tested at a lower load.

[0036] The resistance to fretting fatigue, i.e., fretting fatigue strength, was determined for each of the modular components having a nitrided and laser shock peened male taper by plotting a load vs. number of cycles curve on a semi-log scale. Additional fatigue tests were repeated on three more groups of specimens at varying loads that were laser shock peened at different times. The results of these tests are set forth in Tables 2-5 below.

TABLE 2

Fretting Fatigue Test of Nitrided, Laser Shock Peened Male Morse Tapers		
Specimen #	Load (N)	Cycles/Fracture
1	4003.6	10,000,000
2	4893.2	10,000,000
3	5782.9	10,000,000
4	7562.3	10,000,000
5	7562.3	1,959,009/Fracture

TABLE 3

Fretting Fatigue Test of Nitrided, Laser Shock Peened Male Morse Tapers		
Specimen #	Load (N)	Cycles/Fracture
1	4003.6	10,000,000
2	4893.2	10,000,000
3	5782.9	10,000,000
4	6227.8	10,000,000
5	7562.3	10,000,000

TABLE 4

Fretting Fatigue Test of Nitrided, Laser Shock Peened Male Morse Tapers		
Specimen #	Load (N)	Cycles/Fracture
1	7562.3	10,000,000
2	7562.3	10,000,000
3	7562.3	10,000,000
4	7562.3	10,000,000

TABLE 5

Fretting Fatigue Test of Nitrided, Laser Shock Peened Male Morse Tapers		
Specimen #	Load (N)	Cycles/Fracture
1	7562.3	10,000,000
2	7562.3	10,000,000
3	7562.3	10,000,000
4	7562.3	10,000,000
5	7562.3	6,609,228 metaphyseal component Fracture
6	7562.3	10,000,000
7	7562.3	10,000,000
8	7562.3	10,000,000
9	7562.3	251,351 metaphyseal component Fracture
10	7562.3	10,000,000

[0037] Based on the results of the fretting fatigue strength testing, the mill annealed modular components having the male tapered sections that were hardened by nitriding and then laser shock peened had an average fretting fatigue strength of 7562 N. Specifically, of 17 samples that were tested at 7562.3 N, 3 of the samples failed before reaching the conclusion of the testing at 10,000,000 cycles for a failure rate of 18%. In contrast, referring to FIG. 6 below, the fretting fatigue strength of modular components having male tapered sections that were only hardened by nitriding averaged 3113 N. Specifically, of the 10 nitrided-only samples tested at 3113 N, 2 of samples fractured before reaching the conclusion of the testing at 10,000,000 cycles for a failure rate of 20%. This indicates that, at the mid-stem junction, the modular components having male tapered portions that were first hardened by nitriding and then laser shock peened had a fretting fatigue strength that was increased by approximately 143% over the modular components having male tapered portions that were only hardened by nitriding.

TABLE 6

Fretting Fatigue Test of Nitrogen Diffusion Surface Hardened Morse Tapers		
Specimen #	Load (N)	Cycles/Fracture
1	3113	682,866
2	3113	10,000,000
3	3113	545,021
4	3113	10,000,000
5	3113	10,000,000
6	3113	10,000,000
7	3113	10,000,000
8	3113	10,000,000
9	3113	10,000,000
10	3113	10,000,000

[0038] While this invention has been described as having a preferred design, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

What is claimed is:

1. A method of enhancing the fretting fatigue resistance of an alloy, comprising the steps of:
forming an orthopedic component from an alloy, wherein the alloy has a melting point;
nitriding at least a portion of the orthopedic component to form a nitrided surface, the nitrided surface having a first fretting fatigue strength; and
laser shock peening at least a portion of the nitrided surface of the orthopedic component to form a laser shock peened surface, wherein the laser shock peened surface has a second fretting fatigue strength.
2. The method of claim 1, wherein the second fretting fatigue strength is at least 100 percent greater than the first fretting fatigue strength.
3. The method of claim 1, wherein the second fretting fatigue strength is at least 120 percent greater than the first fretting fatigue strength.
4. The method of claim 1, wherein the second fretting fatigue strength is at least 140 percent greater than the first fretting fatigue strength.
5. The method of claim 1, further comprising the step of heating the orthopedic component to a nitriding temperature, wherein the step of nitriding the orthopedic component is performed at the nitriding temperature.
6. The method of claim 1, further comprising the step of heating the orthopedic component to a nitriding temperature, the nitriding temperature being less than the beta-transus temperature of the alloy, wherein the step of nitriding the orthopedic component is performed at the nitriding temperature.
7. The method of claim 1, wherein the forming step further comprises forming the orthopedic component from a titanium alloy.
8. The method of claim 7, wherein the titanium alloy is Ti-6Al-4V.
9. The method of claim 1, wherein the forming step further comprises forming the orthopedic component from Co—Cr—Mo.
10. A method of enhancing the fretting fatigue resistance of an alloy, comprising the steps of:
forming a modular orthopedic component from an alloy having a melting point, the modular orthopedic component comprising:
a first component defining a male tapered surface; and
a second component defining a female tapered surface, the male tapered surface of the first component configured to form a taper lock with the female tapered surface of the second component;
nitriding at least one of the male tapered surface of the first component and the female tapered surface of the second component to form a nitrided surface, the nitrided surface having a first fretting fatigue; and

laser shock peening at least a portion of the nitrided surface to form a laser shock peened surface, wherein the laser shock peened surface has a second fretting fatigued strength.

11. The method of claim **10**, wherein the first component defining a male tapered surface comprises a stem portion of a hip stem and the second component defining a female tapered portion comprises a neck portion of a hip stem.

12. The method of claim **10**, wherein the second fretting fatigue strength is at least 100 percent greater than the first fretting fatigue strength.

13. The method of claim **10**, wherein the second fretting fatigue strength is at least 120 percent greater than the first fretting fatigue strength.

14. The method of claim **10**, wherein the second fretting fatigue strength is at least 140 percent greater than the first fretting fatigue strength.

15. The method of claim **10**, wherein the nitriding step further comprises nitriding both the male tapered surface of the first component and the female tapered surface of the second component.

16. The method of claim **10**, wherein the nitriding step further comprises nitriding at least one of the male tapered surface of the first component and the female tapered surface of the second component at a nitriding temperature, the nitriding temperature being at least 1,000 degrees Fahrenheit and less than the melting point of the alloy.

17. The method of claim **10**, wherein the nitriding step further comprises nitriding at least one of the male tapered surface of the first component and the female tapered surface of the second component at a nitriding temperature that is less than the beta-transus temperature of the alloy.

18. The method of claim **10**, wherein the forming step further comprises forming the orthopedic component from a titanium alloy.

19. The method of claim **18**, wherein the titanium alloy is Ti-6Al-4V.

20. The method of claim **10**, wherein the forming step further comprises forming the orthopedic component from Co—Cr—Mo.

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