(12) UK Patent Application (19) GB (11) 2 418 384 (13) A

(43) Date of A Publication 29.03.2006

(21) Application No: **0519611.8**

(22) Date of Filing: **26.09.2005**

(30) Priority Data:
(31) **10953203** (32) **28.09.2004** (33) **US**

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(51) INT CL:
C21D 1/09 (2006.01)

(52) UK CL (Edition X):
B3V V211

(56) Documents Cited:
FR 002714320 A
US 5827378 A
US 4937421 A

(58) Field of Search:
UK CL (Edition X) **B3V**
INT CL^7 **C21D**
Other:

(54) Abstract Title: **Generation of high strength metal through formation of nanocrystalline structure by laser peening**

(57) A method of processing a metal piece comprises a number of steps. One step comprises directing a laser beam onto the metal piece for laser peening the metal piece. Another step comprises causing relative movement between the laser beam and the metal piece. Another step comprises providing a tamping material between the laser beam and the metal piece. Another step comprises continuing the laser peening to induce rapid strain and substantial strain in the metal piece and inducing the formation of nanocrystalline structure in the metal piece.

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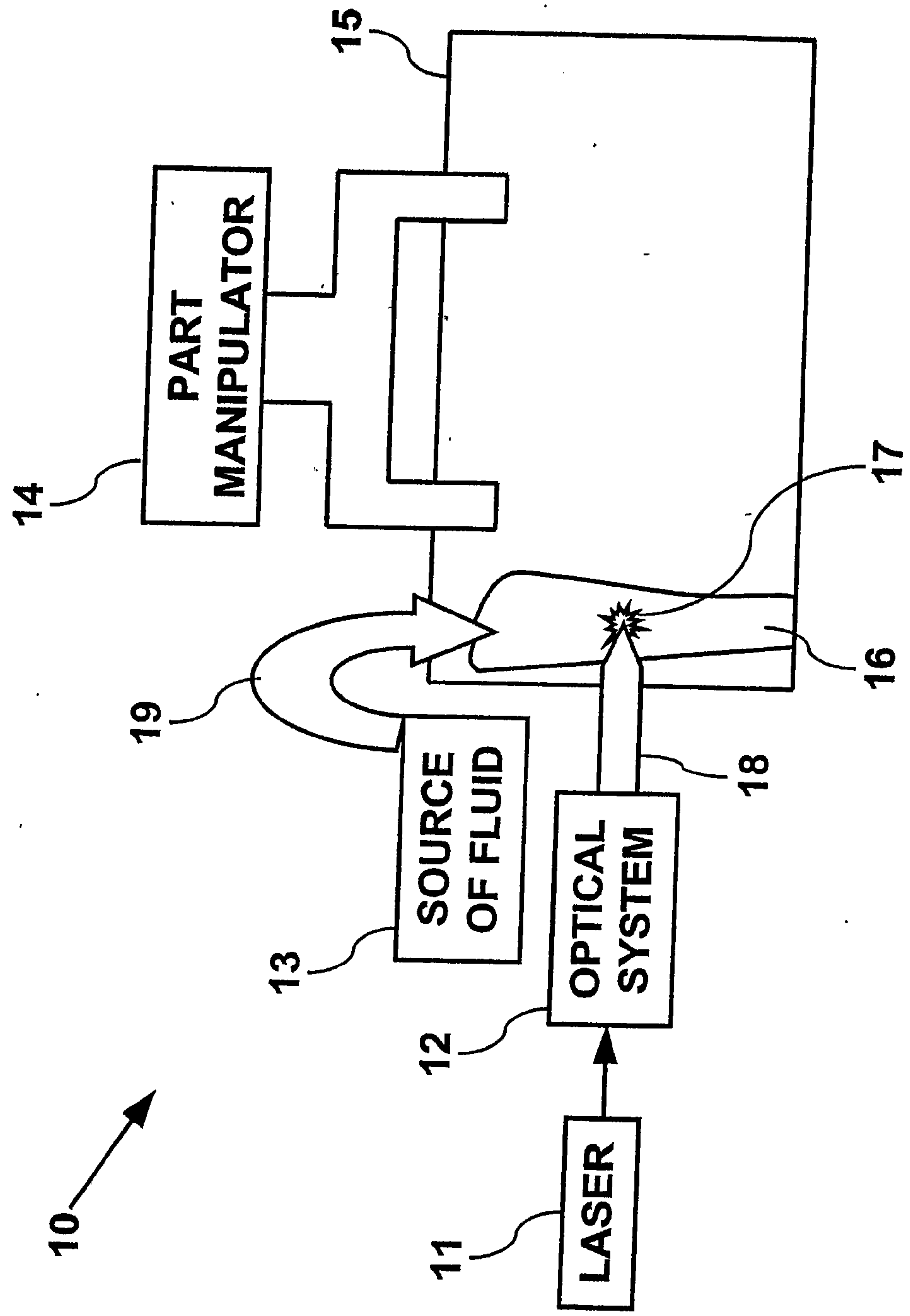
PART MANIPULATOR
SOURCE OF FLUID
OPTICAL SYSTEM
LASER
10
11
12
13
14
15
16
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18
19

FIG. 1

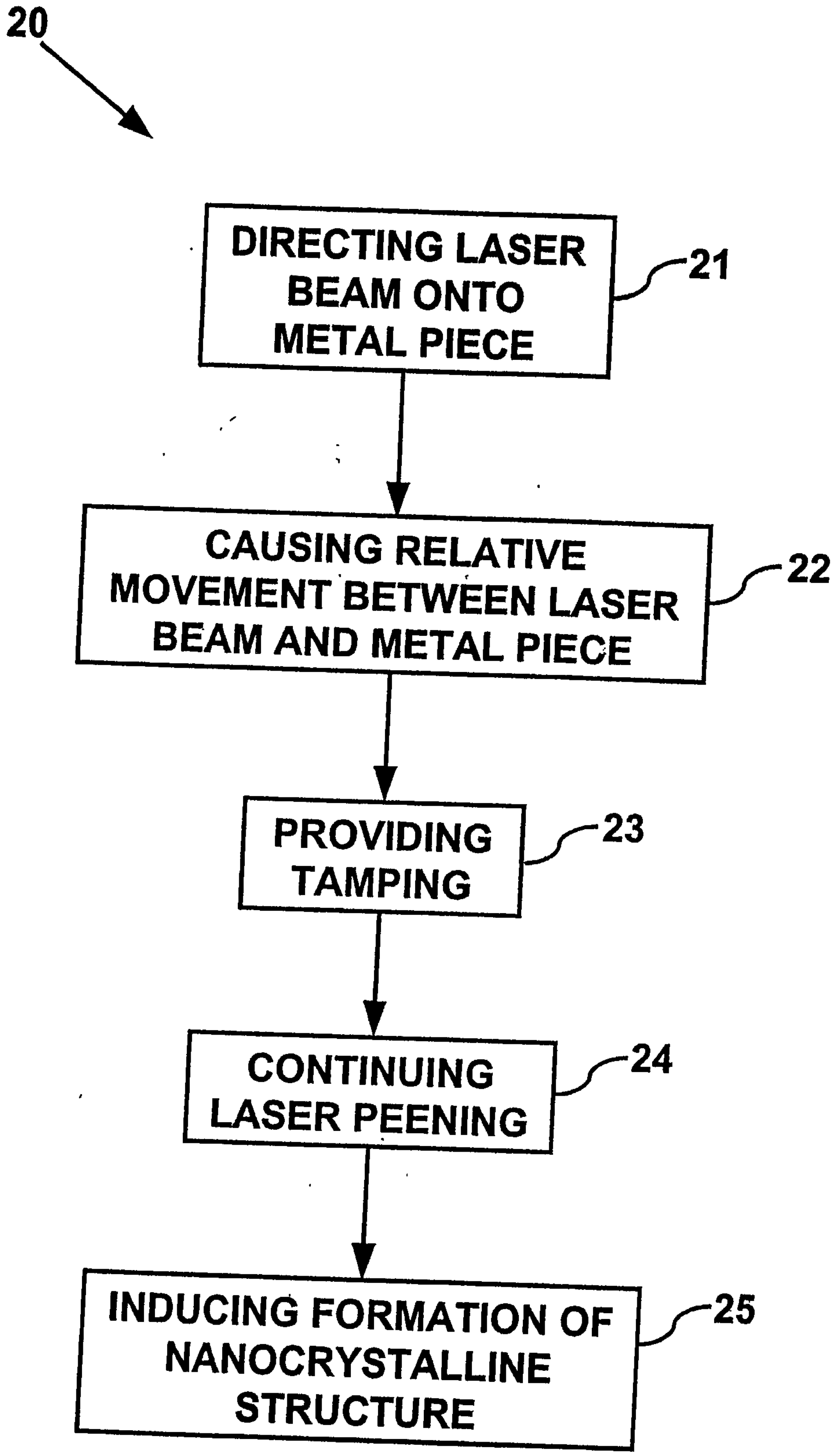
20
DIRECTING LASER BEAM ONTO METAL PIECE
21
CAUSING RELATIVE MOVEMENT BETWEEN LASER BEAM AND METAL PIECE
22
PROVIDING TAMPING
23
CONTINUING LASER PEENING
24
INDUCING FORMATION OF NANOCRYSTALLINE STRUCTURE
25

FIG. 2

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GENERATION OF HIGH STRENGTH METAL THROUGH FORMATION OF NANOCRYSTALLINE STRUCTURE BY LASER PEENING

(0001) The United States Government has rights in this invention pursuant to Contract No. W-7405-ENG-48 between the United States Department of Energy and the University of California for the operation of Lawrence Livermore National Laboratory.

BACKGROUND

Field of Endeavor

(0002) The present invention relates to the generation of high strength metal and more particularly to the generation of high strength metal by laser peening.

State of Technology

(0003) United States Patent No. 6,258,185 for methods of forming steel issued July 10, 2001 to Daniel J. Branagan and Joseph V. Burch provides the following state of technology information: "Steel is a metallic alloy which can have exceptional strength characteristics, and which, accordingly, is commonly utilized in structures where strength is required or advantageous. Steel can be utilized in, for example, the skeletal supports of building structures, tools, engine components, and protective shielding of modern armaments. The composition of steel varies depending on the application of the alloy. For purposes of interpreting this disclosure and the claims that follow, "steel" is defined as any iron-based alloy in which no other single element (besides iron) is present in excess of 30 weight percent, and for which the iron content amounts to, at least, 55 weight percent, and carbon is limited to a maximum of 2 weight percent. In addition to iron, steel alloys can incorporate, for example, manganese, nickel, chromium, molybdenum, and/or vanadium. Steel alloys can also incorporate carbon, silicon, phosphorus and/or sulfur. However, phosphorus, carbon, sulfur and silicon can be detrimental to overall steel quality if present in quantities greater than a few percent. Accordingly, steel typically contains small amounts of phosphorus, carbon, sulfur and silicon. Steel comprises regular arrangements of atoms, with the periodic stacking arrangements forming 3-dimensional lattices which define the internal structure of the steel. The internal structure (sometimes called "microstructure") of conventional steel alloys is always metallic and polycrystalline (consisting of many crystalline grains). Steel is typically formed by cooling a molten alloy. The rate of cooling will determine whether the alloy cools to form an internal structure that predominately comprises crystalline grains, or, in rare cases, a structure which is predominately amorphous (a so-called metallic glass). Generally, it is found that if the cooling proceeds slowly (i.e., at a rate less than about 10^4 K/s), large grain sizes occur, while if the cooling proceeds rapidly (i.e., at a rate greater than or equal to about 10^4 K/s) microcrystalline internal grain structures are formed, or, in specific rare cases amorphous metallic glasses are formed. The particular composition of the molten alloy generally determines whether the alloy solidifies to form microcrystalline grain structures or an amorphous glass when the alloy is cooled rapidly. Also, it is noted that particular alloy compositions have recently been discovered which can lead to microscopic grain formation, or metallic glass formation, at relatively low cooling rates (cooling rates on the order of 10 K/s), but such alloy compositions are, to date, bulk metallic glasses that are not steels. Both microcrystalline grain internal structures and metallic glass internal structures can have properties which are desirable in particular applications for steel. In some applications, the amorphous character of metallic glass can provide desired properties. For instance, some glasses can have exceptionally high strength and hardness. In other applications, the particular properties of microcrystalline grain structures are preferred. Frequently, if the properties of a grain structure are preferred, such properties will be improved by decreasing the grain size. For instance, desired properties of microcrystalline grains (i.e, grains having a size on the order of 10^{-6} meters) can frequently be improved by reducing the grain size to that of nanocrystalline grains (i.e., grains having a size on the order of 10^{-9} meters). It is generally more problematic to form grains of nanocrystalline grain size than it is to form grains of microcrystalline grain size. Accordingly, it is desirable to develop improved methods for forming nanocrystalline grain size steel materials. Further, as it is frequently desired to have metallic glass structures, it is desirable to develop methods of forming metallic glasses."

(0004) United States Patent application No. 2003/0183306 for Selected processing for non-equilibrium light alloys and products by Franz Hehmann and Michael Weidemann, published October 2, 2003, provides the following state of technology information: "Aerospace applications require metallic materials with self-healing surface films to protect the interior, i.e., the bulk material when exposed to air (including rain independent on environmental particulars). None of the existing magnesium engineering alloys exhibit a surface passivation upon exposure to normal atmospheres containing saline species as it is known for titanium and aluminum alloys. For iron it is the allotropy which allows for passivation by equilibrium alloying austenitic and ferritic iron with chromium, for example. The absence of allotropy for aluminum, for example, results in deterioration of corrosion behavior of aluminum upon equilibrium alloying and this applies more seriously to magnesium alloys. Magnesium alloys yet represent the worst case among structural metals for aeronautical applications, since magnesium has not only no allotropy as titanium and iron, but Magnesium does also not develop a passive surface film on exposure to normal atmospheres as is evident for pure titanium and pure aluminum. None of the existing conventional magnesium alloys have yet shown pronounced passivation behavior by alloying as--by definition--becomes evident upon a significant decrease in corrosion rates compared to the pure metal. Hehmann et al. have shown 5 however, that significant passivation is possible by alloying the αMg solid solution with at least 17 wt. % Al in the supersaturated state. This type of passivation, however, was not obtainable unless very extreme conditions of rapid solidification from the melt were applied and it was therefore restricted to thin cross-sections and not obtainable by conventional ingot metallurgy. An engineering solution to this problem would provide the driving force to resolve many of the obstacles for the introduction of advanced light alloys, but the solution to this problem has not been recognized as a combined problem of the development of non-equilibrium new and/or established light alloys as well as of corresponding processes."

SUMMARY

(0005) Features and advantages of the present invention will become apparent from the following description. Applicants are providing this description, which includes drawings and examples of specific embodiments, to give a broad representation of the invention. Various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this description and by practice of the invention. The scope of the invention is not intended to be limited to the particular forms disclosed and the invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

(0006) The present invention provides a method of processing a metal piece. The method comprises a number of steps. One step comprises directing a laser beam onto the metal piece for laser peening the metal piece. Another step comprises causing relative movement between the laser beam and the metal piece. Another step comprises providing a tamping material between the laser beam and the metal piece. Another step comprises continuing the laser peening to induce rapid strain and substantial strain in the metal piece and inducing the formation of nanocrystalline structure in the metal piece.

(0007) The present invention has many uses, including the following uses. Industrial production of ultra-high strength nano-ferrite nano-carbide steels and other alloys. Processing of high carbon steel components to achieve desired ultra-high strength in specific areas. Production of ultra-high strength steels and other alloys for weapons applications. Industrial production of ultra-high strength nano-ferrite nano-carbide Fe-C steel alloys. Industrial production of ultra-high strength alloys. Processing of high carbon steel components to achieve desired ultra-high strength in specific areas. Production of steels possessing high strain-rate superplasticity (HSRS) at high temperature. Production of steels possessing low temperature superplasticity.

(0008) The invention is susceptible to modifications and alternative forms. Specific embodiments are shown by way of example. It is to be understood that the invention is not limited to the particular forms disclosed. The invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

(0009) The accompanying drawings, which are incorporated into and constitute a part of the specification, illustrate specific embodiments of the invention and, together with the general description of the invention given above, and the detailed description of the specific embodiments, serve to explain the principles of the invention.

FIG. 1 illustrates one embodiment of a system the generation of high strength metal through the formation of nanocrystalline structure by laser peening.

FIG. 2 illustrates one embodiment of a method for the generation of high strength metal through the formation of nanocrystalline structure by laser peening.

DETAILED DESCRIPTION OF THE INVENTION

(0010) Referring now to the following detailed description, the drawing figures, and to incorporated materials, detailed information about the invention is provided including the description of specific embodiments. The detailed description serves to explain the principles of the invention. The invention is susceptible to modifications and alternative forms. The invention is not limited to the particular forms disclosed. The invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

(0011) Referring to FIG. 1, one embodiment of a system is illustrated for the generation of high strength metal through the formation of nanocrystalline structure by laser peening. The system is designated generally by the reference numeral 10. The system 10 uses laser peening in creating high strength steel and other alloys through the creation of nanocrystalline structure (NS). Favorable conditions to create NS include a large strain and a high strain rate.

(0012) In the system 10, a laser 11 and optical system 12 direct a laser beam 18 onto a metal work piece 15. The metal piece 15 can be in the form of plate, sheet, or other configurations. The work piece 15 can be held stationary and the laser beam 18 moved or the work piece 15 can be moved by a part manipulator 14 with the laser beam 18 stationary. A source of fluid 13 directs a fluid stream 19 onto the work piece 15.

(0013) The system 10 uses laser peening with one or multiple layers of peening applied to the metal piece 15 so as to induce rapid strain and substantial strain to induce the formation of nanocrystalline structure. Formation of nanocrystalline structure (grain size smaller than 100 nm) in eutectoid steel and other metal alloys by severe plastic deformation has been of keen interest over the past decade. Various severe plastic deformation (SPD) methods including ball drop, ball milling, high pressure torsion, ultrasonic shot peening and air blast shot peening have been employed to produce nanocrystalline materials. Nanostructuring has been used to improve the mechanical properties of bulk metals and alloys. According to the current theories of strengthening of Fe-C steels refinement of ferrite grain size and of the carbide particle size promotes essential rise of strengthening. Moreover, microcrystalline materials can demonstrate high strain-rate superplasticity (HSRS) state at high temperature. Super high mechanical properties could be expected when extrapolating this tendency to nanocrystalline structures. Traditional deformation methods (elongation, compression, ruling, draft, etc.) are effective only on thin samples (e.g., wires).

(0014) Nanocrystalline solids, in which the grain size is in the nanometer range, often have technologically interesting properties such as increased hardness. Nanocrystalline metals can now be produced in several ways resulting in a polycrystalline metal with the grains randomly oriented. The hardness and yield strength of the material typically increase with decreasing grain size according to the relation known as the Hall-Petch effect. At the smallest grain sizes the opposite effect is sometimes reported. This is explained as follows. Most of the plastic deformation occurs in the grain boundaries in the form of a large number of small "sliding" events, in which only a few atoms (or sometimes a few tens of atoms) move with respect to each other. Occasionally a partial dislocation is nucleated at a grain boundary and moves through a grain. Such events are responsible for a minor part of the total deformation, but in the absence of diffusion they are required to allow for deformations of the grains as they slide past each other. As the grain size is reduced, a larger fraction of the atoms belongs to the grain boundaries, and grain boundary sliding becomes easier. This leads to a softening of the material as the grain size is reduced. This so-called reverse Hall-Petch effect has been observed experimentally.

(0015) The laser 11 and optical system 12 can be various laser systems. A specific laser system that can be used for the laser 11 and optic system 12 can be a Nd:glass laser with outputs approximately 20 J per pulse at 18 to 25 ns pulse duration directed onto the surface of the metal piece 15 at an irradiance of 200 J/cm2 and a power density of 10 GW/cm2. These parameters can be varied according to the reaction of the particular work piece 15 being treated. The surface of the work piece 15 can be covered with an ablation/absorption layer such as PVC tape, aluminum tape or paint. Multiple layers of peening can be applied until the work piece achieves the desired nanocrystalline structure and strength.

(0016) The laser 11 and optic system 12, with its nanosecond pulse duration and controllable high peak pressure, creates these favorable conditions better than methods such as ball milling, high pressure torsion and ultrasonic or air blast shot peening. Because the laser 11 can process large areas of arbitrary surface geometry, this process can be used in an industrial processing format for flat plate material as well as in large geometry and complicated shaped components.

(0017) In the system 10, a source of fluid 13 can be a water nozzle with a laminar stream of water 19 that is applied at the metal surface of the work piece 15 at the point of the laser beam incidence 17. This water 16 acts as a tamping medium, increasing the effective pressure and thus the intensity of the developed shock wave. The laser beam 18 and water flow can be moved systematically over the work piece 15 being processed or the beam 18 can be held stationary and the metal work piece 15 moved. Combinations of these two can also be used to cover the entire area to be treated. Multiple layers of peening may require stripping and re-application of the absorption/ablation layer. In peening multiple layers, the spot positions of the individual beams are offset in successive applications. Entire bulk material can be treated in the manner or the laser can be applied to selected parts of metal components adding the strength where desired.

(0018) The near field output of the beam 18 from laser 11 is image relayed to the work piece 15 to be peened. In one embodiment, the front surface of the work piece 15 is coated with an ablative layer and a pressure confinement (tamping) layer of fluid 19 is flowed over the ablative layer. This layer, transparent to the laser light, confines the plasma pressure that develops and greatly increases the intensity of the shock wave that transmits into the metal.

(0019) In the process, laser light of typically 100 to 200 J/cm2 passes through a confining layer (typically 1 mm thickness of water) and is incident on an ablation layer (typically a plastic of a few hundred micron thickness) to create a high pressure shock wave. Although the laser pulse lasts for only 20 ns, the shock wave propagates through the blade at acoustic sound speed which is approximately 4000 meters per second for titanium 6-4 alloy. In order to travel a thickness of 1 mm to 2 mm requires 250 ns to 500 ns.

(0020) The system 10 can use a number of laser systems. For example the system can use laser systems such as the laser systems illustrated in United States Patents Nos. 5,689,363 and 6,198,069, the disclosures of which are incorporated herein by reference and which are attached hereto. One embodiment of the system 10 utilizes a laser 11 and optic system 12 such as that shown in United States Patents No. 5,689,363. This embodiment of the system 10 utilizes a long-pulse-width, narrow-bandwidth, solid state laser system. The laser system includes an oscillator/preamplifier comprising, e.g., a single frequency Nd:YLF laser oscillator or preamplifier. An oscillator/preamplifler produces a single frequency laser beam. The beam has a wavelength of 1054 nm, at 240 ns FWHM and typically 60 mJ of power. Upon exiting the oscillator/preamplifier, the beam is polarized horizontally. The beam maintains this polarization as it reflects from turning mirrors, passes through a Faraday isolator and negative lens, reflects from mirror, passes through a positive collimating lens, reflects from mirror and is masked by an input mask. A polarizing beamsplitter is oriented to transmit P-polarization, and thus, transmits a horizontally polarized beam. The beam conditioning optics include an anamorphic relay telescope and collimating lens which prepare the beam size to fit the required aperture of the amplifier. The beam reflects from mirrors and transmits through polarizing beamsplitter which is configured to transmit P-polarization and reflect S-polarization. The transmitter beam is relayed by 1:1 relay telescope to a two-pass optical axis using mirrors. The amplifier is place on axis with this two-pass optical axis. After passing through relay telescope again, the polarization of the beam is rotated 90.degree. by a quartz rotator to the vertical plane. The beam is then reflected by polarizing beamsplitter to be re-injected into the amplification system by polarizing beamsplitter.

(0021) After two more amplification passes, the polarization of beam is again rotated 90.degree allowing transmission through the beamsplitter, reflection from mirror and entrance into a Four-wave mixing SBS phase conjugator, which reverses the phase of beam. Upon reversal of direction, the horizontally polarized beam undergoes 4 more amplification passes and propagating through the polarizing beamsplitter, collimating lens, anamorphic relay telescope, conditioning optics, and Faraday isolator, the beam exits the system at the polarizing beamsplitter, which is configured to reflect S- polarization. A mirror directs the beam through a second harmonic generator. If the preamplifier produces a pulse at 60 mJ, 240 ns FWHM and 105.4 .mu.m, the output from second harmonic generator will be a pulse of about 16 J, at greater than 500 ns and 527 nm wavelength.

(0022) The 45 degree Faraday and quartz rotator set result in a totally passively switched beam train. The beam enters the amplifier system from the oscillator through the anamorphic telescope which takes it from a square 25.times.25 mm size to the 8.times.120 mm required by the glass amplifier aperture. In this design, the output passes back through the same telescope, restoring the 25.times.25 mm square beam shape. The input beam enters the regenerative amplifier ring in p-polarization through a polarizing beamsplitter, and undergoes two gain passes. The polarization is then rotated 90 degrees by the quartz rotator and it now reflects from the same beamsplitter in s-polarization and undergoes two more gain passes. When the polarization is returned to the original p- state after the second pass through the rotator the beam is coupled out through a polarizing beamsplitter in the ring and directed into the SBS four-wave mixing conjugator. The reflected beam from the conjugator retraces the path of the input beam, resulting in four more gain passes for a total of eight. The polarization rotation of the 45 degree Faraday rotator and the 45 degree quartz rotator canceled each other in the input direction but now, in the output direction, they add resulting in a full 90 degree rotation, and the amplified beam is reflected off the first polarizing beamsplitter and enters the doubler.

(0023) Referring to FIG. 2, another embodiment of a system for the generation of high strength metal through the formation of nanocrystalline structure by laser peening is illustrated. FIG. 2 is a flow chart illustrating a method of processing a metal piece. The method is designated generally by the reference numeral 20. The method 20 uses laser peening in creating high strength steel and other alloys through the creation of nanocrystalline structure (NS). Favorable conditions to create NS include a large strain and a high strain rate.

(0024) The method of processing a metal piece 20 comprises a number of steps. The first step 21 comprises directing a laser beam onto the metal piece for laser peening the metal piece. The next step 22 comprises causing relative movement between the laser beam and the metal piece. The next step 23 comprises providing a tamping material between the laser beam and the metal piece. The next steps 24 and 25 comprise continuing the laser peening to induce rapid strain and substantial strain in the metal piece and inducing the formation of anocrystalline structure in the metal piece.

(0025) Formation of nanocrystalline structure (grain size smaller than 100 nm) in eutectoid steel and other metal alloys by severe plastic deformation has been of keen interest over the past decade. Various severe plastic deformation (SPD) methods including ball drop, ball milling, high pressure torsion, ultrasonic shot peening and air blast shot peening have been employed to produce nanocrystalline materials. Nanostructuring has been used to improve the mechanical properties of bulk metals and alloys. According to the current theories of strengthening of Fe-C steels refinement of ferrite grain size and of the carbide particle size promotes essential rise of strengthening. Moreover, microcrystalline materials can demonstrate high strain-rate superplasticity (HSRS) state at high temperature. Super high mechanical properties could be expected when extrapolating this tendency to nanocrystalline structures. Traditional deformation methods (elongation, compression, ruling, draft, etc.) are effective only on thin samples (e.g., wires).

(0026) Nanocrystalline solids, in which the grain size is in the nanometer range, often have technologically interesting properties such as increased hardness. Nanocrystalline metals can now be produced in several ways resulting in a polycrystalline metal with the grains randomly oriented. The hardness and yield strength of the material typically increase with decreasing grain size according to the relation known as the Hall-Petch effect. At the smallest grain sizes the opposite effect is sometimes reported. This is explained as follows. Most of the plastic deformation occurs in the grain boundaries in the form of a large number of small "sliding" events, in which only a few atoms (or sometimes a few tens of atoms) move with respect to each other. Occasionally a partial dislocation is nucleated at a grain boundary and moves through a grain. Such events are responsible for a minor part of the total deformation, but in the absence of diffusion they are required to allow for deformations of the grains as they slide past each other. As the grain size is reduced, a larger fraction of the atoms belongs to the grain boundaries, and grain boundary sliding becomes easier.

This leads to a softening of the material as the grain size is reduced. This so-called reverse Hall-Petch effect has been observed experimentally.

(0027) In the method 20, laser light of typically 100 to 200 J/cm2 passes through a confining layer (typically 1 mm thickness of water) and is incident on an ablation layer (typically a plastic of a few hundred micron thickness) to create a high pressure shock wave. Although the laser pulse lasts for only 20 ns, the shock wave propagates through the blade at acoustic sound speed which is approximately 4000 meters per second for titanium 6-4 alloy. In order to travel a thickness of 1 mm to 2 mm requires 250 ns to 500 ns.

(0028) In the method of processing a metal piece 20 the laser peening can be accomplished with a laser producing nanosecond pulse duration and controllable high peak pressure sufficient to induce rapid strain and substantial strain in the metal piece and induce the formation of nanocrystalline structure. The laser beam has nanosecond pulse duration and controllable high peak pressure sufficient to induce rapid strain and substantial strain in the metal piece and induce the formation of nanocrystalline structure. In one embodiment of the method 20 the laser beam provides an output of approximately 20 J per pulse at 18 to 25 ns pulse duration directed onto the surface of the metal piece at an irradiance of approximately 200 J/cm2 and a power density of approximately 10 GW/cm2. The method 20 can include applying multiple layers of laser peening to the metal piece. In one embodiment of the method of processing metal 20, the laser beam is directed onto the metal piece at a point of the laser beam incidence and a tamping material is provided between the laser beam and the metal piece. This may be accomplished by applying a laminar stream of water to the metal piece at the point of the laser beam incidence.

(0029) While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

Claims

1. A method of processing a metal piece, comprising the steps of:

directing a laser beam onto the metal piece for laser peening the metal piece,

causing relative movement between said laser beam and the metal piece,

providing between said laser beam and the metal piece a tamping material that is essentially transparent to the laser beam, and

continuing said laser peening to induce rapid strain and substantial strain in the metal piece and inducing the formation of nanocrystalline structure in the metal piece.

2. The method of processing a metal piece of claim 1 wherein said laser peening is accomplished with said laser producing nanosecond pulse duration and controllable high peak pressure sufficient to induce rapid strain and substantial strain in the metal piece and induce the formation of nanocrystalline structure.

3. The method of processing a metal piece of claim 1 wherein said laser beam has pulse duration in the range of several hundred picoseconds to 10s of nanoseconds and controllable high peak pressure sufficient to induce rapid strain and substantial strain in the metal piece and induce the formation of nanocrystalline structure.

4. The method of processing a metal piece of claim 1 wherein said laser beam provides an output of approximately 20 J per pulse at 18 to 25 ns pulse duration directed onto the surface of the metal piece at an irradiance of approximately 200 J/cm2 and a power density of approximately 10 GW/cm2.

5. The method of processing metal of any preceding claim wherein said step of continuing said laser peening comprises applying multiple layers of laser peening to the metal piece.

6. The method of processing metal of any preceding claim wherein said step of relative movement between said laser beam and the metal piece comprises moving said laser beam over the metal piece.

7. The method of processing metal of any preceding claim wherein said step of causing relative movement between said laser beam and the metal piece comprises moving the metal piece relative to said laser beam.

8. The method of processing metal of any preceding claim wherein said steps of directing a laser beam onto the metal piece and continuing said laser peening comprise applying peening to metal plate.

9. The method of processing metal of any of claims 1 to 7 wherein said steps of directing a laser beam onto the metal piece and continuing said laser peening comprise applying peening to metal sheet.

10. The method of processing metal of any preceding claim wherein said laser beam is directed onto the metal piece at a point of the laser beam incidence and said step of providing a tamping material between said laser beam and the metal piece comprises applying a tamping material that exhibits the electro-strictive effect, is transparent to the laser light, and has a low SBS gain coefficient between said laser beam and the metal piece.

11. The method of processing metal of any preceding claim wherein said laser beam is directed onto the metal piece at a point of the laser beam incidence and said step of providing a tamping material between said laser beam and the metal piece comprises applying a laminar stream of water to the metal piece at the point of the laser beam incidence.

12. The method of processing metal of any preceding claim wherein said step of providing an ablation material between said laser beam and the metal piece comprises covering the metal piece an ablation/absorption layer.

13. A method of processing a metal piece, comprising the steps of:

directing a laser beam onto the metal piece for laser peening the metal piece,

causing relative movement between said laser beam and the metal piece,

providing an ablative/insulating material adhered to or in intimate contact with the metal piece between said laser beam and the metal piece,

providing a tamping material that is essentially transparent to the laser beam, and

continuing said laser peening to induce rapid strain and substantial strain in the metal piece and inducing the formation of nanocrystalline structure in the metal piece.

14. The method of processing a metal piece of claim 13 wherein said laser peening is accomplished with said laser producing nanosecond pulse duration and controllable high peak pressure sufficient to induce rapid strain and substantial strain in the metal piece and induce the formation of nanocrystalline structure.

15. The method of processing a metal piece of claim 13 wherein said laser beam has pulse duration in the range of several hundred picoseconds to 10s of nanoseconds and controllable high peak pressure sufficient to induce rapid strain and substantial strain in the metal piece and induce the formation of nanocrystalline structure.

16. The method of processing a metal piece of claim 13 wherein said laser beam provides an output of approximately 20 J per pulse at 18 to 25 ns pulse

duration directed onto the surface of the metal piece at an irradiance of approximately 200 J/cm2 and a power density of approximately 10 GW/cm2.

17. The method of processing metal of any of claims 13 to 16 wherein said step of continuing said laser peening comprises applying multiple layers of laser peening to the metal piece.

18. The method of processing metal of any of claims 13 to 17 wherein said step of causing relative movement between said laser beam and the metal piece comprises moving said laser beam over the metal piece.

19. The method of processing metal of any of claims 13 to 18 wherein said step of causing relative movement between said laser beam and the metal piece comprises moving the metal piece relative to said laser beam.

20. The method of processing metal of any of claims 13 to 19 wherein said steps of directing a laser beam onto the metal piece and continuing said laser peening comprise applying peening to metal plate.

21. The method of processing metal of any of claims 13 to 20 wherein said steps of directing a laser beam onto the metal piece and continuing said laser peening comprise applying peening to metal sheet.

22. The method of processing metal of any of claims 13 to 21 wherein said laser beam is directed onto the metal piece at a point of the laser beam incidence and said step of providing a tamping material between said laser beam and the metal piece comprises applying a laminar stream of water to the metal piece at the point of the laser beam incidence.

23. The method of processing metal of any of claims 13 to 21 wherein said step of providing an ablation material between said laser beam and the metal piece comprises covering the metal piece an ablation/absorption layer.

24. The method of processing metal of any of claims 13 to 21 wherein said step of providing a ablation/insulation material between said laser beam and the metal piece comprises covering at least a portion of the metal piece with PVC tape.

25. The method of processing metal of any of claims 13 to 21 wherein said step of providing a ablative material between said laser beam and the metal piece comprises covering at least a portion of the metal piece with aluminum tape.

26. The method of processing metal of any of claims 13 to 21 wherein said step of providing an ablative material between said laser beam and the metal piece comprises covering at least a portion of the metal piece with paint.

27. A method of processing metal substantially as described hereinabove with reference to Figures 1 and 2 of the accompanying drawings

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INVESTOR IN PEOPLE

21

Application No: GB0519611.8 **Examiner:** Tony Martin

Claims searched: All claims **Date of search:** 27 October 2005

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X,Y	1 and 13 at least	US5827378 A ACDS Technologies see claim 1
Y	" "	FR2714320 A GEC see claim 5
Y	" "	US4937421 A GEC see claim 1

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application

Field of Search:

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B3V

Worldwide search of patent documents classified in the following areas of the IPC^{07}

C21D

The following online and other databases have been used in the preparation of this search report

On line databases WPI,EPODOC,JAPIO