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(54) **TITANIUM ALLOY BOLT MANUFACTURING FACILITY AND METHOD FOR MANUFACTURING TITANIUM ALLOY BOLT USING SAME**

ANLAGE ZUR HERSTELLUNG EINER TITANLEGIERTEN SCHRAUBE UND VERFAHREN ZUR HERSTELLUNG EINER TITANLEGIERTEN SCHRAUBE

INSTALLATION POUR FABRIQUER UN BOULON EN ALLIAGE DE TITANE ET PROCÉDÉ DE FABRICATION D'UN BOULON EN ALLIAGE DE TITANE L'UTILISANT

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to a method and apparatus for manufacturing a titanium alloy bolt through a warm forging process .

Description of the Related Art

[0002] Titanium alloys are generally better in strength and corrosion resistance and lighter in weight than ordinary carbon steels, stainless steels, and alloy steels for special application; among various metals which can be mined from the earth, titanium is after aluminum, iron and magnesium in order of abundance.

[0003] Document FR 2321351 A1 discloses hot forged blanks to provide bolts of steel or titanium alloy, e.g. for the aeronautical industry. These bolts are produced with high mechanical strength and very close dimensional tolerances, by forging round blanks by drawing and grinding. The blanks are coated with a lubricant resistant to heat and forging stress and are then heated and precision-forged to obtain predetermined dimensional tolerances.

[0004] A further titanium bolt and a manufacturing method thereof is described in document KR 100628030 B1.

[0005] Titanium is gradually replacing existing materials having been traditionally used as structural or functional materials. Demand for titanium in military and civilian applications, especially in aircraft and vessel parts, is remarkably increasing.

[0006] Studies for manufacturing a titanium alloy bolt have been made.

[0007] Manufacturing the titanium alloy bolt through a cold forging process requires multiple forging steps, since formability of the titanium alloy bolt is generally bad. Therefore, productivity is low and mass production is difficult.

[0008] On the other hand, when the titanium alloy bolt is manufactured through a hot forging process, machinability is low, since cracks are frequently generated in its oxidized layer.

[0009] Accordingly, a lot of studies have been focused on increasing formability and machinability of the titanium alloy bolt.

[0010] However, generally the titanium alloy bolt formed through the cold or hot forging process requiring multiple steps has the following problems: Faults such as cracks being frequently generated during the forging process lead to poor productivity.

[0011] Further, when a forging die is employed, the die is apt to failure, since sticking is caused by friction between the inner surface of the die and titanium alloy material, and also because of the characteristics peculiar to

the material itself. This leads to increased maintenance fees.

[0012] In addition, since the forged titanium alloy bolt usually needs a post processing step and also has a high hardness value, a tool for post processing abrades severely during the post processing step and, therefore, is frequently replaced. This leads to increased manufacturing expenses.

10 SUMMARY OF THE INVENTION

[0013] It is an objective of the present invention to provide a method and apparatus for continuously manufacturing a titanium alloy bolt through a warm forging process.

[0014] Another objective of the present invention is to provide a method and apparatus for manufacturing a titanium alloy bolt, in which sticking is prevented by lubricating the surface of raw material and the mechanical properties of the bolt are increased by applying an optimal heat treatment.

[0015] These objects are achieved by an apparatus as defined in independent claim 1 and a method as defined in independent claim 8. Further aspects are defined in the dependent claims.

[0016] According to the present invention, the titanium alloy bolt is manufactured through a warm forging process. Mechanical properties of the obtained bolt are severely improved and there are no faults such as cracks in the bolt.

[0017] According to the present invention, the amount of faulty bolts is minimized, the quality of the obtained bolts is high, and productivity is maximized. As a result, the expenses for manufacturing the bolt are significantly decreased.

[0018] Such forming technology fabricating the titanium alloy bolt using the warm forging process may also be applied to other mechanical parts having various shapes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

Fig. 1 schematically shows an apparatus for manufacturing a titanium alloy bolt according to the present invention.

Fig. 2 is a schematic perspective view showing a guiding device and a heating device of the apparatus according to the present invention.

Fig. 3 is a schematic perspective view showing a forging die of the apparatus according to the present invention.

Fig. 4 is a schematic perspective view showing the forging die into which raw material is being supplied.

Fig. 5 is a schematic perspective view showing the forging die into which raw material has been charged.

Fig. 6 is a side view showing the forging die into which raw material has been completely inserted.

Fig. 7 is an enlarged perspective view showing a portion of a feeding device of the apparatus.

Fig. 8 is a flow chart showing a sequence of steps for manufacturing a titanium alloy bolt using the apparatus according to the present invention.

Fig. 9 is a flow chart showing a surface treating step of the manufacturing steps in detail.

Fig. 10 is a flow chart showing a heating step of the manufacturing steps in detail.

Fig. 11 is a set of photos showing forgeability at various temperatures employed in the surface treating step.

Fig. 12 is a set of data obtained from a series of experiments for determining the process temperature of the heating step.

Fig. 13 is a set of photos obtained from the experiments shown in Fig. 12.

Fig. 14 is a set of photos showing shape changes of raw material during the warm forging step.

Figs. 15 to 21 are photos showing shape changes of forgings, when heating temperatures and keeping times are varied during the forging step.

Fig. 22 is a table showing changes in tensile properties of forgings versus heat treatment conditions of a heat treating step.

Fig. 23 is a couple of photos showing microstructures of a forging before and after the heat treating step.

Fig. 24 is a couple of photos showing a forging before and after the peeling step.

Fig. 25 is a photo showing a forging after the form rolling step.

Fig. 26 is a set of photos showing changes in an outer diameter of a titanium alloy bolt, when dipping times are varied during a cleaning step.

Fig. 27 is a set of photos showing microstructures of the titanium alloy bolt obtained from the present invention, which were taken under the guidelines of

ASTM.

Fig. 28 is a photo showing the thickness of α -scale on the surface of the bolt.

Fig. 29 is a table showing tensile properties of the bolts obtained from the present invention.

Fig. 30 is a set of photos showing fractured states of the bolts employed in Fig. 29.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] Referring to Figs. 1 to 3, an apparatus for manufacturing a titanium alloy bolt according to the present invention is described below.

[0021] Fig. 1 schematically shows the apparatus for manufacturing the titanium alloy bolt according to the present invention. Fig. 2 is a schematic perspective view showing a guiding device and a heating device of the apparatus. Fig. 3 is a schematic perspective view showing a forging die of the apparatus.

[0022] As shown in the Figures, the apparatus is constructed such that raw material, which is cut into a fixed length from a titanium alloy rod, is carried and heated, then forged, then heat-treated, and then machined in order.

[0023] In order to perform the series of processes as described above, an embodiment of the apparatus includes a feeding device (100) for supplying the raw material (W in Fig. 4) which is cut into a fixed length from the titanium alloy rod, a loader (200) for carrying the raw material (W) supplied from the feeding device (100), a heating device (300) for heating the raw material (W), a forging device (400) provided with a forging die (420 in Fig. 3) which fabricates a forging (F in Fig. 10) from the heated raw material (W), a guiding device (500) for conducting the heated raw material (W) into the forging die (420), a heat-treating device for heat-treating the forging (F), a peeling device for removing the oxidized layer on the heat-treated forging (F), a machining device for machining the desired portions of the forging (F) from which the oxidized layer is peeled, a form rolling device for forming a thread on an outer surface of the machined forging (F) in order to obtain the titanium alloy bolt, and a cleaning device for cleaning the entire surface of the titanium alloy bolt.

[0024] The heat-treating device, the peeling device, the form rolling device, and the cleaning device are not shown since they are generally employed in the art to which the invention belongs. Process conditions for each of the devices will be described hereafter.

[0025] First, the feeding device (100) supplies the raw material (W) to the loader (200), which carries the raw material (W) into the heating device (300). As shown in Fig. 7, the feeding device includes a feeding tube (120) that guides the raw material (W) along its longitudinal

direction, and a stopper (140) that selectively interferes with one end of the raw material (W) moving along the interior space of the feeding tube (120) in order to restrain the movement of the raw material (W).

[0026] The feeding tube (120) is made of a cylindrical hollow tube which has an inner diameter higher than an outer diameter of the raw material (W). The raw material (W) is fed from the upper end of the tube (120), and the lower end of the tube (120) is placed over the upper surface of the loader (200).

[0027] Therefore, the raw material (W) fed into the tube (120) is guided along the interior space of the tube (120), supplied to, and placed on the upper surface of the loader (200).

[0028] The stopper (140) is mounted near the lower end of the tube (120). The stopper is constructed such that the raw material's movement along the interior space of the tube (120) is selectively interfered with to a halt in order to supply the raw material to the upper surface of the loader (200) at regular time and space intervals.

[0029] To be more specific, the stopper (140) includes a pair of sensors (142) which are fixed near the lower end of the tube (120) with one end of the sensors passed through the tube, a pair of cylinders (144) which are interconnected to the sensors (142) and linearly reciprocate, and a pair of interfering plates (146) which are connected to each one end of the cylinders. The cylinders control the interfering plates such that one end of the interfering plates can be selectively inserted into the tube (120).

[0030] When the sensors (142) detect the raw material (W) moving along the interior space of the tube (120), each length of the cylinders (144) interconnected with the sensors is changed and, therefore each of the one ends of the interfering plates is inserted into the tube (120), halting the movement of the raw material (W).

[0031] It is preferable that each of the respective sensors (142), cylinders (144) and interfering plates (146) constitutes a controlling system and each of the interfering plates (146) is controlled to move to a direction different from each other.

[0032] That is, while one interfering plate (146) is inserted into the tube (120) and interferes with the movement of the raw material (W), the other interfering plate (146) is retracted from the tube (120). Therefore, the raw material (W) blocked by the other interfering plate can move toward a downstream direction.

[0033] As such, the stopper (140) can continuously supply the raw material (W) one by one at regular intervals.

[0034] The loader (200) is placed under the lower end of the tube (200). The loader (200) is constructed such that it circulates along a looped curve passing through an interior space of the heating device (300). In other words, the loader (200) is provided with a loading part on which the raw material is safely placed. The loading part forms a closed circle such as a conveyer belt and is rotated by a driving motor.

[0035] One end or the lower end of the loading part is placed at a lower position than the lower end of the heating device (300) so that the raw material (W) can be supplied from the feeding device (100) to the loading part, while the upper end of the loading part is placed within the interior space of the heating device (300).

[0036] The raw material (W) on the loading part moves along the moving direction of the loading part and falls from the loading part at the other or the farthest end of the loading part at which the moving direction of the loading part reversely changes.

[0037] Since the loading part passes through the heating device (300), it should bear the heat generated from the heating device. Various materials may be used in the loading part, if they can satisfy the conditions as described above.

[0038] The heating device (300) is placed over the upper side of the loader (200). The heating device (300) heats the raw material (W) moving along the loader (200) to a specific temperature in which the raw material can be forged.

[0039] A plurality of electric heaters (320) are provided within the heating device (300), and a plurality of infrared radiation thermometers (not shown) are also provided in the heating device (300) so that the interior temperature of the heating device (300) can be measured.

[0040] It is preferable that the heating device (300) is provided with a controller which controls the temperature of the heaters (320).

[0041] Further, the heating device (300) is constructed such that the raw material (W) can be heated to various temperatures. That is, the heating device (300) includes a main heating installation (340) that primarily heats the raw material (W) and an auxiliary heating installation (360) that secondarily heats the raw material (W) which exits the main heating installation (340).

[0042] The main heating installation (340) has a side shape similar to "└" and primarily heats the raw material (W) moving along the loader (200). As shown in Fig. 2, the other or the farthest end of the loader (200) is placed within the interior space and near the right end of the main heating installation (340).

[0043] The raw material (W) is heated when passing through the main heating installation (340) and freely falls at the other end of the loader (200).

[0044] The auxiliary heating installation (360) is placed under the right end of the main heating installation (340). The auxiliary heating installation (360) moves or guides the raw material (W) to the forward direction and, at the same time, secondarily heats the raw material (W) which is primarily heated in the main heating installation (340).

[0045] For such guiding, the auxiliary heating installation (360) is downwardly inclined to the forward direction and has an opening (220) at its rear upper end. The opening (220) is interconnected with an exit pipe (240) mounted at the front end of the auxiliary heating installation (360).

[0046] After falling into the auxiliary heating installation (360) through the opening (220), the raw material (W) passes through the auxiliary heating installation (360) and exits through the pipe (240). An auxiliary heater (not shown) is provided within a body (260) of the auxiliary heating installation (360) so that the raw material (W) may be secondarily heated.

[0047] It is preferable that a vibrator (not shown) is provided on one side and is within the interior space of the auxiliary heating installation (360). When the raw material (W) is guided into the guiding device (500) which is also downwardly inclined to the forward direction, the vibrator generates vibrations in order to make such guiding easier; thereby, preventing the raw material (W) from being blocked.

[0048] The guiding device (500) is connected with the front end of the auxiliary heating installation (360), that is, the exit pipe (240). The guiding device (500) is constructed such that the raw material (W) heated in the auxiliary heating installation (360) is guided into the forging die (420).

[0049] That is, the guiding device (500) is a fixed length of a hollow circular tube bended in a proper position, as shown. The upper end of the guiding device (500) is connected to exit pipe (240) and the lower end of the guiding device is placed above the upper side of an inlet part (422) of the forging die (420).

[0050] Further, the guiding device (500) is provided with a heat insulator which prevents the raw material (W) moving along the guiding device (500) from cooling.

[0051] The forging die (420) is placed under the guiding device (500) and within the forging device (400). The raw material (W) is moved into the forging die (420) and pressed by a punch (440), which causes the general contour of the raw material to become similar to that of a bolt.

[0052] As shown in Fig. 3, the forging die (420) includes the inlet part (422), the punch (440) at its right side, and an ejector (460) at its left side. The inlet part (422) is placed under the left end or lower end of the guiding device (500). The punch (440) linearly reciprocating to left and right pushes the raw material (W) into the forging die (420) and, then, presses it to have a shape similar to a bolt. The ejector (460) pushes the forging (F) within the forging die (420) to the inlet part (422).

[0053] The raw material (W) is guided into the inlet part (422) by the guiding device (500) as shown in Fig. 4, is fallen to the lower side of the inlet part (422) as shown in Fig. 5, is pushed into the forging die (420) by the punch (440), and is then moved to a stable state as shown in Fig. 6. Then, the raw material is pressed by the press and becomes the forging (F).

[0054] The heat-treating device is a construction that heat-treats the forging (F) formed by the forging die (420). As far as it can heat the forging (F) under the conditions which will be described later, any heat-treating device may be employed.

[0055] The peeling device is a construction that removes an oxidized layer on the surface of the heat-treated

forging (F). The oxidized layer is sandblasted in the embodiment of the present invention.

[0056] The machining device is a tool that machines some portions of the forging (F) from which the oxidized layer is peeled. In the embodiment of the present invention, one end of the forging (F) and the lower surface of the head of the forging (F) are machined. As far as it can perform such machining, any device may be employed.

[0057] The form rolling device is a tool that forms a thread on an outer surface of the machined forging (F) to obtain the titanium alloy bolt. The forging includes a body and a head, and the thread is formed on the outer surface of the body. As far as it can perform such threading, any device may be employed.

[0058] The cleaning device is a construction that cleans the entire surface of the titanium alloy bolt. In the embodiment of the present invention, the surface of the bolt is pickled in a solution of 15wt% HNO₃, 3wt% HF and 82wt% H₂O.

[0059] Referring to Figs. 8 to 10, the method for manufacturing the titanium alloy bolt using the apparatus as disclosed above is hereafter described.

[0060] The method of the present invention includes a surface treating step (S100) for lubricating the entire surface of the raw material (W), a feeding step (S200) for supplying the raw material (W) to the loader (200) using the feeding device (100), a carrying step (S300) for transporting the raw material (W), a heating step (S400) for heating the raw material (W) on the loader (200) which passes through the interior space of the heating device (300), a warm forging step (S500) for fabricating the forging (F) using the forging die (420) into which the heated raw material (W) is charged, a heat-treating step (S600) for heat-treating the forging (F) using the heat-treating device, a peeling step (S700) for removing the oxidized layer on the surface of the heat-treated forging (F), a machining step (S800) for machining the desired portions of the forging (F) from which the oxidized layer is peeled, a form rolling step (S900) for forming the thread on the outer surface of the machined forging (F) in order to obtain the titanium alloy bolt, and a cleaning step (S1000) for cleaning the entire surface of the titanium alloy bolt.

[0061] The steps of the method are orderly described. The surface treating step (S100) is a step for increasing the dimensional accuracy of the forging (F) formed during the forging step (S500) and preventing sticking to the interior surface of the forging die (420) during the forging step.

[0062] The surface treating step (S100) includes a lubricating step (S120) for making a plurality of grooves on the surface of the raw material (W) and applying lubricant into the grooves, and an oxidizing step (S140) for heating the raw material (W) in order to make an oxidized film on the surface of the raw material (W).

[0063] In the lubricating step (S120), the raw materials (W) are charged into a proper container and vibrated so that the raw materials collide each other and, therefore the grooves are formed on the surface of the raw mate-

rials, and finally the lubricant is applied on the surface of the raw materials (W) and filled in the grooves.

[0064] In the embodiment of the present invention, 3 types of lubricants (OilDag, MoO₂, and Boron-Nitride) were employed. MoO₂ showed the best result during the forging step.

[0065] While the surface properties of the raw material (W) were improved and the sticking was decreased by the lubricating step (S120), the use of only the lubricating step (S120) did not show good results.

[0066] Therefore, the oxidizing step (S140) for making the oxidized film on the surface of the raw material (W) was performed. The step (S140) was employed because of its easy workability and high economic efficiency.

[0067] The oxidizing step (S140) was performed at various temperature in order to determine a proper temperature for heating the raw material (W) during the step. Fig. 11 shows the obtained results.

[0068] Fig. 11 (a) shows a sample not subjected to the oxidizing step (S140). Fig. 11 (b), Fig. 11 (c) and Fig. 11 (d) show samples heated to temperatures of 927°C, 850°C and 750°C respectively.

[0069] As shown, the sample (a) not subjected to the step (S140) shows the sticking on a large portion of the surface and cracks were found on some parts of the surface.

[0070] A yellow and thickened oxidized film was formed on the surface of the sample (b) and working of the forging die (420) was blocked several times during the forging step.

[0071] It is considered that this results from significant increase in the strength of the raw material due to a change in the structure of the raw material from an equiaxed structure to a bi-modal structure and cracks created in the thickened oxidized film which propagate into the interior part of the specimen.

[0072] The sample (c) shows that forgeability is improved and the sticking is found on a relatively small portion of the surface. However, as shown in an enlarged photo, stress-concentrated areas in the interior of the raw material (W) show shear bands which decrease the fatigue life and strength of a bolt.

[0073] The sample (d) heated to a temperature of 750°C during the step (S140) shows the smoothest surface. After forging the sample, the brittle oxidized film mostly disappeared and the thickness of the oxidized film remaining on some parts was measured to be below 5μm (refer to Fig. 11 (b)).

[0074] In addition, the amount of the shear bands resulting from unbalanced plastic deformation was decreased to a large degree and the forged raw material still had a fine equiaxed microstructure. The amount of the oxidized film on the surface of the raw material (W) was found to be below 0.2 mg/cm².

[0075] After the surface treating step (100), the feeding step (S200) is performed. In the step (S200), the raw material (W), with the grooves filled with the lubricant and the oxidized film, is supplied to the loader (200) using the

feeding device (100).

[0076] When the raw material (W) is safely loaded to the upper surface of the loader (200), the carrying step (S300) for transporting the raw material (W) is performed by the circulation of the loader (200) along the looped curve.

[0077] The heating step (S400) is performed at the same time during the carrying step (S300). The heating step (S400) includes a primary heating step (S420) for heating the raw material (W) to a temperature and a secondary heating step (S420) for heating the primarily heated raw material (W) to a temperature different from the temperature of the primary heating step.

[0078] Figs. 12 and 13 explain an experimental procedure to determine a proper temperature condition in the heating step (S400).

[0079] Firstly, the hot deformability of titanium alloys was investigated by a Gleeble system in order to survey the deformation characteristics of the titanium alloys. The temperatures employed ranged from 300 to 700°C and the strain rates employed ranged from 0.01/sec to 10/sec.

[0080] The test results show a general deformation behavior of Ti-6Al-4V alloys. The alloys drastically soften from a temperature of 600°C and, therefore, it is envisaged that the alloys should be forged at a temperature of 600°C.

[0081] The experimental results to determine a proper temperature in the heating step (S400) are described in Figs. 14 to 21.

[0082] Fig. 14 is a set of photos orderly showing shape changes of the raw material (W) during the warm forging step (S500). In the embodiment of the present invention, the raw material was gradually forged through 3 stages in the step (S500).

[0083] Referring to Figs. 15 to 21, a specific temperature condition to obtain the desired forging (F) in the step (S400) is shown.

[0084] Fig. 15 shows a set of the raw materials which were firstly forged after being heated to a temperature of 800°C in the main heating installation (340), secondly forged after being heated to a temperature of 800°C in the auxiliary heating installation (360) after 20 minutes from the end of the first forging stage, and thirdly forged after 5 minutes from the end of the second forging stage.

[0085] Scale debris was found within the forging die (420), which means that the raw material (W) may stick to the inner surface of the forging die.

[0086] Fig. 16 shows the set of the raw materials which were forged under the conditions where the temperatures in the main and auxiliary heating installations (340, 360) were set to 800°C.

[0087] The lubricant on the surface of the forging (F) was found to be cleared by heat, and the obtained photo shows the lower part of the forging (F) which does not have any trace of the lubricant.

[0088] The head part of the forging (F) shows marks reversely deformed against the moving direction of the

punch (440), which are considered to occur due to frictional resistance.

[0089] It is therefore considered that the longer the keeping time in the main heating installation (340) is, the worse the effects of the lubricant and workability are.

[0090] Fig. 17 shows a set of the raw materials which were forged under the conditions where the temperatures in the main and auxiliary installations (340, 360) were set to 900°C and the respective keeping times were set to 10 to 15 minutes.

[0091] The lubricant was apt to normally stay, and the obtained photo shows the forging (F) which has no sticking or deformation resistance, while the head of the forging shows a color of the lubricant oxidized to a degree.

[0092] It is therefore considered that the keeping time of the raw material (W) in the installation (340) should be shortened.

[0093] Fig. 18 shows a set of the raw materials which were forged under the conditions where the temperatures of the main and auxiliary heating installations (340, 360) were set to 840°C and the respective keeping times were set to 50 minutes.

[0094] The obtained photo shows the forging (W) having a good surface state. Any sticking was not found on the inner surface of the forging die (420) and the state of the punch (440) was good.

[0095] Fig. 19 shows the material which was forged under the conditions where the temperatures of the main and auxiliary heating installations (340, 360) were set to 840°C and the respective keeping times were set to 65 minutes.

[0096] While the temperature is within a forgeable temperature range, the obtained photo shows the forging (F) having a rough surface. Furthermore, sticking was not found on the inner surface of the forging die (420) and the state of the punch (440) was good.

[0097] Fig. 20 shows the materials which were forged under the conditions where the temperatures of the main and auxiliary heating installations (340, 360) were set to 840°C and the respective keeping times were set to 45 minutes.

[0098] The obtained photo shows the forging (F) having a rougher surface than in the previous case.

[0099] Fig. 21 shows the material which was forged under the conditions where the temperatures of the main and auxiliary heating installations (340, 360) were set to 840°C and the respective keeping times were set to 55 minutes.

[0100] While the forgeability was good, the obtained photo shows the forging (W) having a poor surface state.

[0101] Lastly, the raw material (W) was heated for 35 minutes under the conditions where the temperature of the entrance of the installation (340) was set to 500°C or more and the temperature of the interior of the installation (340) was set to 780°C.

[0102] And the raw material was forged after heating it for 10 minutes in the auxiliary heating installation (360) which was set to a temperature of 840°C.

[0103] As shown in Fig. 14, the obtained results show that the continuously forgeable raw material can be obtained. Any sticking was not found on the inner surface of the forging die (420) and the state of the punch (440) and forging die (420) was good.

[0104] After the heating step (S400) is performed under the conditions described above, the warm forging step (S500) is performed. A warm forging process is employed in the step (S500), since the raw material (W) is pressed to change its shape, after having been heated to the optimum temperature during the heating step (S400), which is determined as described above.

[0105] The heat-treating step (S600) is performed after the warm forging step (S500). The step (S600) is a step for increasing the strength of the forging (F). Therefore, a lot of experiments were performed in order to obtain the forging with balanced strength and elongation values and a tensile strength of 1100 MPa or more. Fig. 22 is a table showing the experimental conditions and results.

[0106] As shown in Fig. 22, 6 experiments were performed under varying heat-treating conditions, and the solution treatment was performed at a fixed temperature of 927°C in order to dissolve a transformed-β structure completely.

[0107] Then, various cooling methods and aging temperatures (537°C and 480°C) were employed.

[0108] When the forging (F) was heat-treated according to the heat treatment route "E" in Fig. 22, it showed high strength and elongation values and had a bi-modal structure of equiaxed α and transformed β.

[0109] In the route "E", the forging (F) was heated for 1 hour at a temperature of 927°C, cooled to a temperature ranging from 850 to 900°C, quenched in water, and age-treated for 24 hours at a temperature of 480°C.

[0110] The forging (F) passes through the peeling step (S700) after being subjected to the heat treatment according to the conditions described above. The peeling step (S700) is a procedure for removing the oxidized film produced on the surface of the forging (F).

[0111] Since titanium alloys are highly apt to oxidize at a high temperature, a relatively thick oxidized film is generally produced on the surface of the forging (F), which is subjected to the heat-treating step. Since such oxidized film will significantly aggravate fatigue properties of the forging, the peeling step (S700) for removing the film is performed.

[0112] In the embodiment of the present invention, sand-blasting was applied in the peeling step (S700).

[0113] Fig. 24 is a couple of photos showing the forging (F) before and after the peeling step (S700). As shown in the lower side photo of Fig. 24, after the forging is subjected to the step (S700), the oxidized film on the surface of the forging (F) is completely removed.

[0114] The machining step (S800) is performed after the peeling step (S700). In the machining step (S800), one end of the forging (F) is slantly cut or the portion where the head and the body of the forging meet is cut to cave in.

[0115] The form rolling step (S900) is performed after the machining step (S800). In the step (S900), the thread is formed on the outer surface of the body of the forging (F) and the forging becomes a titanium alloy bolt. In the embodiment of the present invention, the forging (F) was subjected to the warm form rolling step at a temperature of 400°C.

[0116] Fig. 25 shows the forging subjected to the step (S900).

[0117] The cleaning step (S1000) is performed after the form rolling step (S900). When the forging becomes a bolt through the form rolling step (S900), scales attach to the surface of the obtained bolt. The scales are removed in the cleaning step (S1000). In the embodiment of the present invention, pickling is employed.

[0118] That is, the bolt was dipped in a solution of 15wt% HNO₃, 3wt% HF and 82wt% H₂O for 5 to 10 minutes.

[0119] Fig. 26 is a set of photos showing changes in the outer diameter of the titanium alloy bolt, when dipping times are varied during the cleaning step.

[0120] When the dipping time is less than 5 minutes, the scales still stay on the surface of the bolt. On the other hand, when the dipping time is more than 10 minutes, while the scales are totally removed, the dimensional accuracy of the thread is decreased due to the severe etching in the thread part.

[0121] Therefore, based on the effective removal of the scales and the dimensional accuracy of the thread, it is preferable that the dipping time of the step (S1000) is 5 to 10 minutes.

[0122] Fig. 27 is a set of photos showing microstructures of the titanium alloy bolt obtained from the present invention, which shows that all parts of the surface have the bi-modal structure of equiaxed α and transformed β and layered structures are not found at all.

[0123] Fig. 28 shows the surface of the bolt before the cleaning step (S1000) where the α -scale, having a thickness of about 48 μ m, is evenly distributed. Such thickness value was obtained from the bolt subjected to only the warm forging step (S500). It is therefore judged that, if the bolt having the α -scale of such thickness is subjected to the pickling step (S1000), the α -scale will be completely removed, and therefore, there will be no harmful effect on the mechanical properties of the bolt.

[0124] Figs. 29 and 30 show tensile properties of the bolts obtained from the present invention and photos taken of the fractured bolts respectively.

[0125] As shown in the Figs., a total of five bolts were used to test their tensile properties. Fig. 30 shows that all of the bolts were fractured at initial load bearing threads. This means that the micro-structures of the bolts were uniform.

[0126] Fig. 29 shows that all of the bolts have a tensile strength value of 1000 MPa or more; all were fractured after elongation of 3 mm.

[0127] It is understood that while particular forms or embodiments of the present invention have been illus-

trated, various modifications can be made without departing from the scope of the invention as defined by the appended claims.

[0128] For example, while the embodiment of the invention employs a three stage forging method in the forging step, a one stage forging method may be employed considering productivity and manufacturing cost.

10 Claims

1. Apparatus for manufacturing a titanium alloy bolt, the apparatus including:

a feeding device (100) for supplying raw material (W) which is cut into a fixed length from a titanium alloy rod,
a heating device (300) for heating the raw material (W),
a loader (200) for carrying the raw material (W) supplied from the feeding device (100), wherein the loader (200) is configured such that it passes through an interior space of the heating device (300),
a proper container adapted to be charged with the raw material (W) and being vibrated,
means for applying a lubricant on the surface of the raw material (W),
heating means for oxidizing the raw material (W) in order to make an oxidized film on the surface of the raw material (W),
a forging device (400) provided with a forging die (420) adapted to fabricate a forging (F) from the heated raw material (W),
a guiding device (500) for conducting the heated raw material (W) into the forging die (420),
a heat-treating device for heat-treating the forging (F),
a peeling device for removing the oxidized layer on the surface of the heat-treated forging (F),
a machining device for machining the desired portions of the forging (F) from which the oxidized layer is peeled,
a form rolling device for forming a thread on an outer surface of the machined forging (F) in order to obtain the titanium alloy bolt, and
a cleaning device for cleaning the entire surface of the titanium alloy bolt.

2. The apparatus according to claim 1, wherein the loader (200) circulates along a looped curve passing through an interior space of the heating device (300).

3. The apparatus according to claim 2, wherein the heating device (300) includes a main heating installation (340) for primarily heating the raw material (W) and an auxiliary heating installation (360) for secondarily heating the raw material (W) which exits the

main heating installation (340).

4. The apparatus according to claim 3, wherein a vibrator is provided on one side of the auxiliary heating installation (360), the vibrator being adapted to generate vibrations that help carry the raw material (W) smoothly out of the main heating installation (340). 5
5. The apparatus according to claim 1, wherein the feeding device (100) includes a feeding tube (120) that is adapted to guide the feeding direction of the raw material (W) and a stopper (140) that is adapted to selectively interfere with one end of the raw material (W) moving along an interior space of the feeding tube (120) in order to restrain the movement of the raw material (W). 10
6. The apparatus according to claim 5, wherein the feeding device (100) is provided with a plurality of stoppers (140). 15
7. The apparatus according to claim 1, wherein a heat insulator is provided on one side of the guiding device (500) in order to prevent the raw material (W) moving toward the forging die (420) from cooling. 20
8. A method for manufacturing a titanium alloy bolt, the method carried out in the given order including: 25

a surface treating step (S100) for lubricating the entire surface of raw material (W) which is cut into a fixed length from a titanium alloy rod, wherein the surface treating step (S100) includes a lubricating step (S120) that makes a plurality of grooves on the surface of the raw material (W) and applies lubricant into the grooves, and an oxidizing step (S140) that heats the raw material (W) in order to make an oxidized film on the surface of the raw material (W), 30

a feeding step (S200) for supplying the raw material (W) to a loader (200) using a feeding device (100), 35

a carrying step (S300) for transporting the raw material (W), wherein the raw material (W) is transported on the loader (200), 40

a heating step (S400) for heating the raw material (W) on the loader (200) which passes through an interior space of a heating device (300), 45

a warm forging step (S500) for fabricating a forging (F) using a forging die (420) into which the heated raw material (W) is charged, 50

a heat-treating step (S600) for heat-treating the forging (F) using a heat-treating device, 55

a peeling step (S700) for removing the oxidized layer on the surface of the heat-treated forging (F),

a machining step (S800) for machining the de-

sired portions of the forging (F) from which the oxidized layer is peeled,
a form rolling step (S900) for forming a thread on an outer surface of the machined forging (F) in order to obtain the titanium alloy bolt, and
a cleaning step (S1000) for cleaning the entire surface of the titanium alloy bolt.

9. The method according to claim 8, wherein the heating step (S400) includes a primary heating step (S420) for heating the raw material (W) to a temperature and a secondary heating step (440) for heating the primarily heated raw material (W) to a temperature different from the temperature of the primary heating step (S420). .
10. The method according to claim 8, wherein during the oxidizing step (S140) the raw material (W) is heated to a temperature of 750°C in order to make the oxidized film that has a thickness of 0.2 mg/cm² or less.
11. The method according to claim 8, wherein during the heat-treating step (S600) the material is heated to a temperature of 927°C and maintained for an hour at this temperature, cooled to a temperature of 850 to 900°C, quenched in water, and then subjected to an aging treatment for 24 hours at a temperature of 480°C.
12. The method according to claim 8, wherein during the peeling step (S700) the oxidized layer is peeled by sand blasting.
13. The method according to claim 8, wherein the form rolling step (S900) is performed in a temperature of 400°C.
14. The method according to claim 8, wherein during the cleaning step (S1000) the titanium alloy bolt is dipped in a solution of 15wt% HNO₃, 3wt% HF and 82wt% H₂O for 5~10 minutes in order to remove oxidized scales attached on the titanium alloy bolt.
15. The method according to claim 8, wherein during the heating step (S400) the raw material (W) is heated to a temperature of 780°C for 35 minutes and then to a temperature of 840°C for 10 minutes.
16. The method according to claim 8, wherein the warm forging step (S500) is performed in a temperature of 600°C or more.

Patentansprüche

1. Gerät zur Herstellung einer titanlegierten Schraube, wobei das Gerät umfasst:

- eine Zuführvorrichtung (100) zum Bereitstellen von Rohmaterial (W), das aus einem titanlegierten Stab in eine feste Länge geschnitten wird,
- eine Heizvorrichtung (300) zum Erhitzen des Rohmaterials (W),
- eine Ladevorrichtung (200) zum Befördern des Rohmaterials (W), das von der Zuführvorrichtung (100) bereitgestellt wird, wobei die Ladevorrichtung (200) so ausgelegt ist, dass sie einen Innenraum der Heizvorrichtung (300) durchläuft,
- einen geeigneten Behälter, der dafür ausgebildet ist, mit dem Rohmaterial (W) befüllt zu werden und in Vibration versetzt zu werden,
- eine Einrichtung zum Auftragen eines Schmiermittels auf die Oberfläche des Rohmaterials (W),
- eine Heizeinrichtung zum Oxidieren des Rohmaterials (W) zum Bilden eines oxidierten Films auf der Oberfläche des Rohmaterials (W),
- eine Schmiedevorrichtung (400), die mit einem Schmiedegesenk (420) vorgesehen ist, das dafür ausgebildet ist, aus dem erhitzten Rohmaterial (W) ein Schmiedeteil (F) herzustellen,
- eine Führungsvorrichtung (500) zum Leiten des erhitzten Rohmaterials (W) in das Schmiedegesenk (420),
- eine Wärmebehandlungsvorrichtung zum Wärmebehandeln des Schmiedeteils (F),
- eine Abziehvorrichtung zum Entfernen der oxidierten Schicht auf der Oberfläche des wärmebehandelten Schmiedeteils (F),
- eine Bearbeitungsvorrichtung zum maschinellen Bearbeiten der erwünschten Abschnitte des Schmiedeteils (F), von dem die oxidierte Schicht abgezogen wird,
- eine Formwalzvorrichtung zum Formen eines Gewindes auf einer Außenfläche des bearbeiteten Schmiedeteils (F) zum Erlangen der titanlegierten Schraube und
- eine Reinigungsvorrichtung zum Reinigen der gesamten Oberfläche der titanlegierten Schraube.
2. Gerät nach Anspruch 1, wobei die Ladevorrichtung (200) entlang einer schleifenförmigen Kurve zirkuliert, während sie einen Innenraum der Heizvorrichtung (300) durchläuft.
3. Gerät nach Anspruch 2, wobei die Heizvorrichtung (300) eine Hauptheizanlage (340) zum primären Erhitzen des Rohmaterials (W) und eine Hilfsheizanlage (360) zum sekundären Erhitzen des Rohmaterials (W), das aus der Hauptheizanlage (340) austritt, umfasst.
4. Gerät nach Anspruch 3, wobei eine Vibrationseinrichtung an einer Seite der Hilfsheizanlage (360) vorgesehen ist, wobei die Vibrationseinrichtung dafür ausgebildet ist, Vibrationen zu erzeugen, die eine reibungslose Beförderung des Rohmaterials (W) aus der Hauptheizanlage (340) heraus unterstützen.
5. Gerät nach Anspruch 1, wobei die Zuführvorrichtung (100) eine Zuführrohre (120), die dafür ausgebildet ist, die Zuführrichtung des Rohmaterials (W) zu lenken, und einen Anschlag (140), der dafür ausgebildet ist, während der Bewegung entlang eines Innenraums der Zuführrohre (120) ein Ende des Rohmaterials (W) selektiv zu behindern, um die Bewegung des Rohmaterials (W) zu beschränken, umfasst.
6. Gerät nach Anspruch 5, wobei die Zuführvorrichtung (100) mit einer Mehrzahl von Anschlängen (140) vorgesehen ist.
7. Gerät nach Anspruch 1, wobei an einer Seite der Führungsvorrichtung (500) ein Wärmeisolator vorgesehen ist, um zu verhindern, dass das Rohmaterial (W), das sich in Richtung des Schmiedegesenks (420) bewegt, abkühlt.
8. Verfahren zur Herstellung einer titanlegierten Schraube, wobei das Verfahren in der vorgegebenen Reihenfolge durchgeführt wird, die umfasst:
- einen Oberflächenbehandlungsschritt (S100) zum Schmieren der gesamten Oberfläche von Rohmaterial (W), das aus einem titanlegierten Stab in eine feste Länge geschnitten wird, wobei der Oberflächenbehandlungsschritt (S100) einen Schmierschritt (S120), der eine Mehrzahl von Vertiefungen auf der Oberfläche des Rohmaterials (W) bildet und Schmiermittel in die Vertiefungen einbringt, und einen Oxidationschritt (S140), der das Rohmaterial (W) erhitzt, um einen oxidierten Film auf der Oberfläche des Rohmaterials (W) zu bilden, umfasst,
- einen Zuführschritt (S200) zum Bereitstellen des Rohmaterials (W) an eine Ladevorrichtung (200) unter Verwendung einer Zuführvorrichtung (100),
- einen Beförderungsschritt (S300) zum Transportieren des Rohmaterials (W), wobei das Rohmaterial (W) auf der Ladevorrichtung (200) transportiert wird,
- einen Erhitzungsschritt (S400) zum Erhitzen des Rohmaterials (W) auf der Ladevorrichtung (200), die einen Innenraum der Heizvorrichtung (300) durchläuft,
- einen Warm Schmiedeschritt (S500) zum Herstellen eines Schmiedeteils (F) unter Verwendung eines Schmiedegesenks (420), in das das erhitzte Rohmaterial (W) gefüllt wird,
- einen Wärmebehandlungsschritt (S600) zum

- Wärmebehandeln des Schmiedeteils (F) unter Verwendung einer Wärmebehandlungsvorrichtung, einen Abziehschritt (S700) zum Entfernen der oxidierten Schicht auf der Oberfläche des wärmebehandelten Schmiedeteils (F), einen Bearbeitungsschritt (S800) zum maschinellen Bearbeiten der erwünschten Abschnitte des Schmiedeteils (F), von dem die oxidierte Schicht abgezogen wird, einen Formwalzschritt (S900) zum Formen eines Gewindes auf einer Außenfläche des bearbeiteten Schmiedeteils (F) zum Erlangen der titanlegierten Schraube und einem Reinigungsschritt (S1000) zum Reinigen der gesamten Oberfläche der titanlegierten Schraube.
9. Verfahren nach Anspruch 8, wobei der Erhitzungsschritt (S400) einen primären Erhitzungsschritt (S420) zum Erhitzen des Rohmaterials (W) auf eine Temperatur und einen sekundären Erhitzungsschritt (S440) zum Erhitzen des primär erhitzten Rohmaterials (W) auf eine Temperatur, die sich von der Temperatur des primären Erhitzungsschritts (S420) unterscheidet, umfasst.
10. Verfahren nach Anspruch 9, wobei das Rohmaterial (W) während des Oxidationsschrittes (S140) auf eine Temperatur von 750°C erhitzt wird, um den oxidierten Film zu bilden, der eine Dicke von 0,2 mg/cm² oder weniger hat.
11. Verfahren nach Anspruch 8, wobei das Material während des Wärmebehandlungsschrittes (S600) auf eine Temperatur von 927°C erhitzt wird und eine Stunde lang bei dieser Temperatur gehalten wird, auf eine Temperatur von 850 bis 900°C abgekühlt wird, in Wasser abgeschreckt wird und dann für 24 Stunden einer Alterungsbehandlung bei einer Temperatur von 480°C unterzogen wird.
12. Verfahren nach Anspruch 8, wobei die oxidierte Schicht während des Abziehschritts (S700) durch ein Sandstrahlverfahren abgezogen wird.
13. Verfahren nach Anspruch 8, wobei der Formwalzschritt (S900) bei einer Temperatur von 400°C durchgeführt wird.
14. Verfahren nach Anspruch 8, wobei die titanlegierte Schraube während des Reinigungsschritts (S1000) für 5~10 Minuten in eine Lösung aus 15 Gew.% HNO₃, 3 Gew.% HF und 82 Gew.% H₂O getaucht wird, um an der titanlegierten Schraube haftenden oxidierten Zunder zu entfernen.
15. Verfahren nach Anspruch 8, wobei das Rohmaterial

(W) während des Erhitzungsschritts (S400) für 35 Minuten auf eine Temperatur von 780°C und dann für 10 Minuten auf eine Temperatur von 840°C erhitzt wird.

16. Verfahren nach Anspruch 8, wobei der Wärmeschmiedeschritt (S500) bei einer Temperatur von 600°C oder mehr durchgeführt wird.

Revendications

1. Appareil pour la fabrication d'un boulon en alliage de titane, l'appareil comprenant :

un dispositif d'avance (100) visant à fournir une matière première (W) coupée à une longueur fixe à partir d'une tige en alliage de titane, un dispositif de chauffage (300) destiné à chauffer la matière première (W), un chargeur (200) visant à transporter la matière première (W) fournie par le dispositif d'avance (100), dans lequel le chargeur (200) est configuré de telle manière qu'il traverse un espace intérieur du dispositif de chauffage (300), un propre récipient adapté pour être recevoir la matière première (W) et soumis à des vibrations, des moyens d'application de lubrifiant sur la surface de la matière première (W), des moyens de chauffage pour oxyder la matière première (W) afin de fabriquer un film oxydé sur la surface de la matière première (W), un dispositif de forgeage (400) muni d'une matrice de forgeage (420) convenant à la fabrication d'une pièce forgée (F) à partir de la matière première chauffée (W), un dispositif de guidage (500) visant à conduire la matière première chauffée (W) dans la matrice de forgeage (420), un dispositif de traitement thermique pour le traitement thermique de la pièce forgée (F), un dispositif de pelage pour ôter la couche oxydée à la surface de la pièce forgée traitée thermiquement (F), un dispositif d'usinage pour usiner les parties souhaitées de la pièce forgée (F) à partir desquelles la couche oxydée est pelée, un dispositif de formage par roulement pour former un filetage sur une surface extérieure de la pièce forgée usinée (F) afin d'obtenir le boulon en alliage de titane, et un dispositif de nettoyage pour nettoyer toute la surface du boulon en alliage de titane.

2. Appareil selon la revendication 1, dans lequel le chargeur (200) circule le long d'une courbe en boucle traversant un espace intérieur du dispositif de chauffage (300) .

3. Appareil selon la revendication 2, dans lequel le dispositif de chauffage (300) comprend une installation de chauffage principale (340) visant à assurer le chauffage primaire de la matière première (W) et une installation de chauffage auxiliaire (360) visant à assurer le chauffage secondaire de la matière première (W) sortant de l'installation de chauffage principale (340). 5
4. Appareil selon la revendication 3, dans lequel un vibreur est prévu sur un côté de l'installation de chauffage auxiliaire (360), le vibreur convenant à la génération de vibrations aidant à acheminer délicatement la matière première (W) hors de l'installation de chauffage principale (340). 10 15
5. Appareil selon la revendication 1, dans lequel le dispositif d'avance (100) comprend un tube d'avance (120) adapté pour guider la direction d'avance de la matière première (W) et un bouchon (140) adapté pour interférer sélectivement avec une extrémité de la matière première (W) se déplaçant le long d'un espace intérieur du tube d'avance (120) afin de limiter le mouvement de la matière première (W). 20
6. Appareil selon la revendication 5, dans lequel le dispositif d'avance (100) est muni d'une pluralité de bouchons (140). 25
7. Dispositif selon la revendication 1, dans lequel une isolation thermique est prévue sur un côté du dispositif de guidage (500) afin d'empêcher le refroidissement de la matière première (W) se déplaçant vers la matrice de forgeage (420). 30
8. Procédé de fabrication d'un boulon en alliage de titane, le procédé réalisé dans l'ordre indiqué comprenant : 35
 - une étape de traitement de surface (S100) pour lubrifier toute la surface de la matière première (W) coupée à une longueur fixe à partir d'une tige en alliage de titane, l'étape de traitement de surface (S100) comprenant une étape de lubrification (S120) durant laquelle une pluralité de rainures sont réalisées sur la surface de la matière première (W), puis garnies d'un lubrifiant, et une étape d'oxydation (S140) qui chauffe la matière première (W) afin de générer un film oxydé sur la surface de la matière première (W), 40
 - une étape d'avance (S200) pour fournir la matière première (W) à un chargeur (200) au moyen d'un dispositif d'avance (100), 45
 - une étape de transport (S300) pour transporter la matière première (W), dans laquelle la matière première (W) est transportée sur le chargeur (200), 50
 - une étape de chauffage (S400) pour chauffer la matière première (W) sur le chargeur (200) qui traverse un espace intérieur d'un dispositif de chauffage (300), 55
 - une étape de forgeage à chaud (S500) pour fabriquer une pièce forgée (F) au moyen d'une matrice de forgeage (420) dans laquelle la matière première chauffée (W) est chargée,
 - une étape de traitement thermique (S600) pour le traitement thermique de la pièce forgée (F) au moyen d'un dispositif de traitement thermique,
 - une étape de pelage (S700) pour ôter la couche oxydée à la surface de la pièce forgée traitée thermiquement (F),
 - une étape d'usinage (S800) pour usiner les parties souhaitées de la pièce forgée (F) à partir desquelles la couche oxydée est pelée,
 - une étape de formage par roulement (S900) pour former un filetage sur une surface extérieure de la pièce forgée usinée (F) afin d'obtenir le boulon en alliage de titane, et
 - une étape de nettoyage (S1000) pour nettoyer toute la surface du boulon en alliage de titane.
9. Procédé selon la revendication 8, dans lequel l'étape de chauffage (S400) comprend une étape de chauffage primaire (S420) pour chauffer la matière première (W) à une température et une étape de chauffage secondaire (440) pour chauffer la matière première (W) après son chauffage primaire à une température différente de celle de l'étape de chauffage primaire (S420). 30
10. Procédé selon la revendication 8, dans lequel la matière première (W) est chauffée à une température de 750°C afin de fabriquer le film oxydé d'une épaisseur maximale de 0,2 mg/cm² durant l'étape d'oxydation (S140). 35
11. Procédé selon la revendication 8, dans lequel le matériau est chauffé à une température de 927°C et maintenu pendant une heure à cette température, refroidi à une température de 850 à 900°C, trempé dans l'eau, puis soumis à un traitement de vieillissement pendant 24 heures à une température de 480°C durant l'étape de traitement thermique (S600). 40 45
12. Procédé selon la revendication 8, dans lequel la couche oxydée est pelée par sablage durant l'étape de pelage (S700). 50
13. Procédé selon la revendication 8, dans lequel l'étape de formage par roulement (S900) est réalisée à une température de 400°C. 55
14. Procédé selon la revendication 8, dans lequel, durant l'étape de nettoyage (S1000), le boulon en al-

liage de titane est plongé dans une solution de 15 %m de HNO_3 , 3 %m de HF et 82 %m de H_2O pendant 5 à 10 minutes afin d'éliminer les dépôts oxydés figurant sur le boulon en alliage de titane.

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15. Procédé selon la revendication 8, dans lequel la matière première (W) est chauffée à une température de 780°C pendant 35 minutes, puis à une température de 840°C pendant 1 minute durant l'étape de chauffage (S400).

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16. Procédé selon la revendication 8, dans lequel l'étape de forgeage à chaud (S500) est réalisée à une température de 600°C ou plus.

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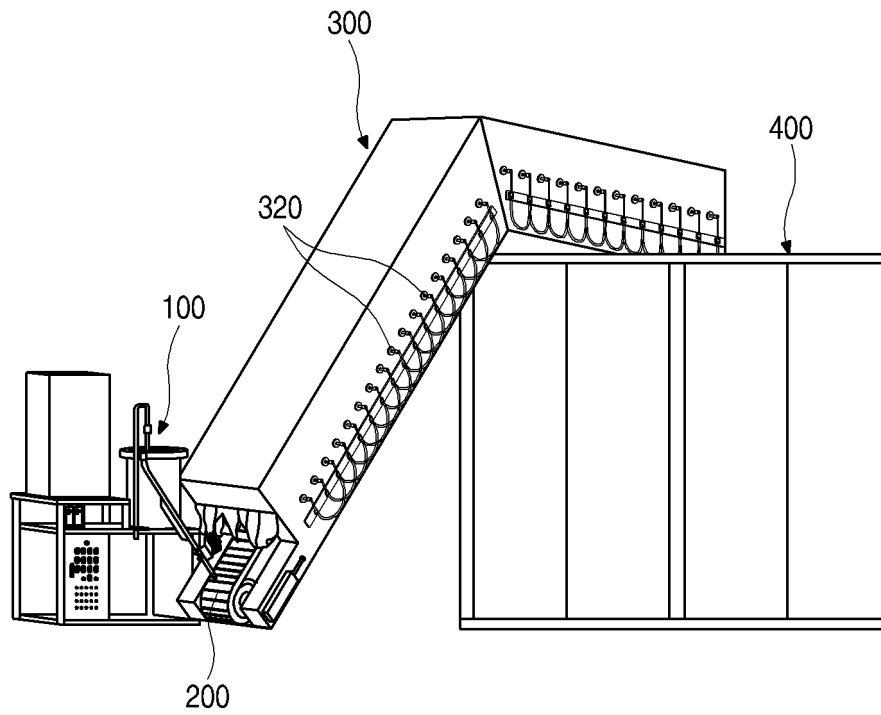


Fig. 1

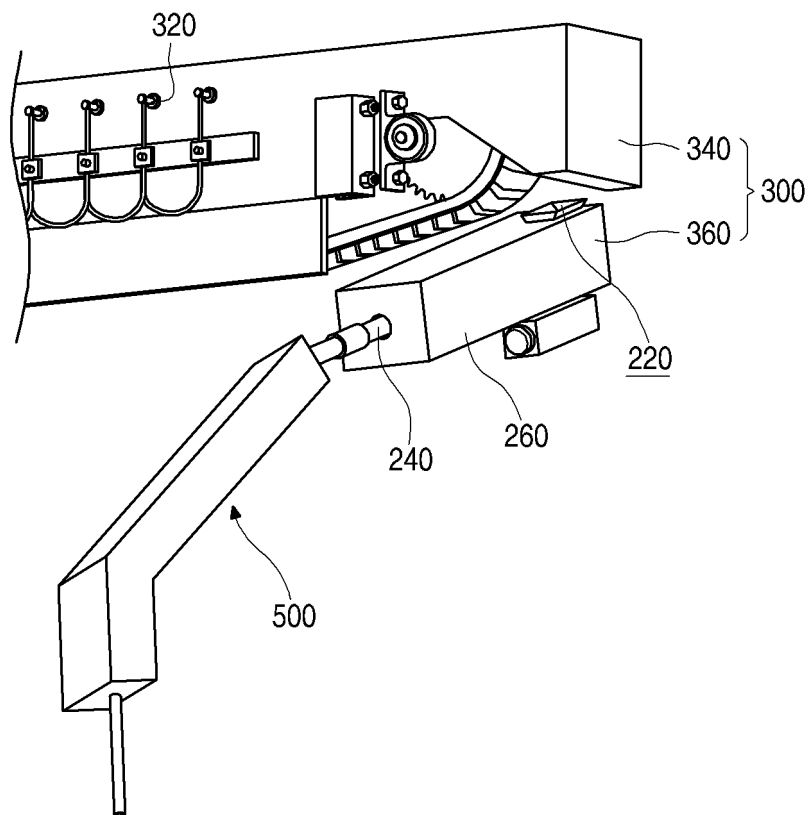


Fig. 2

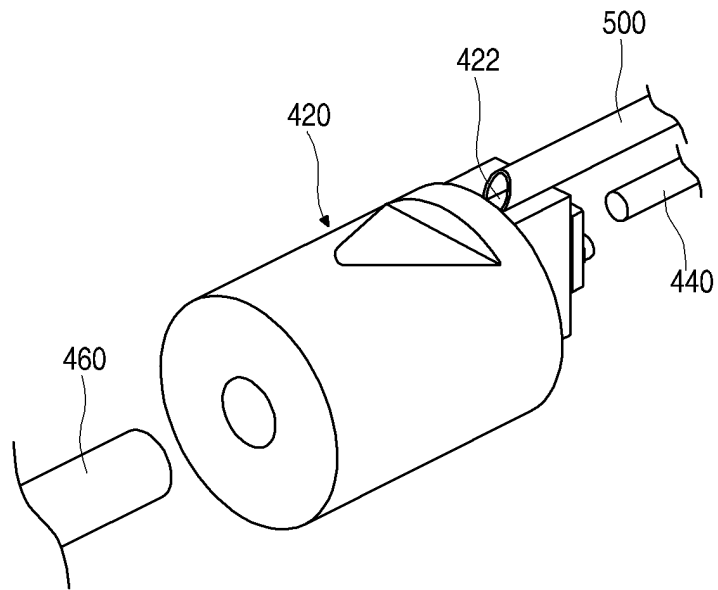


Fig. 3

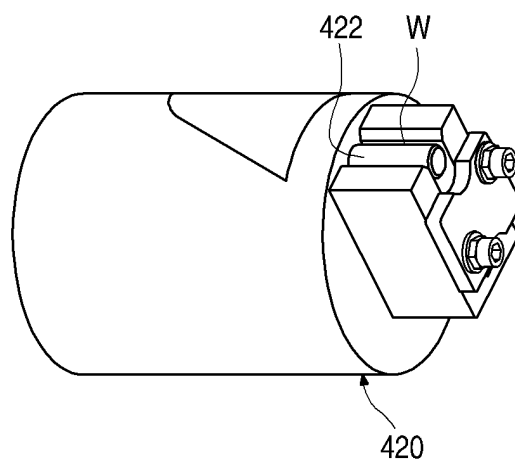


Fig. 4

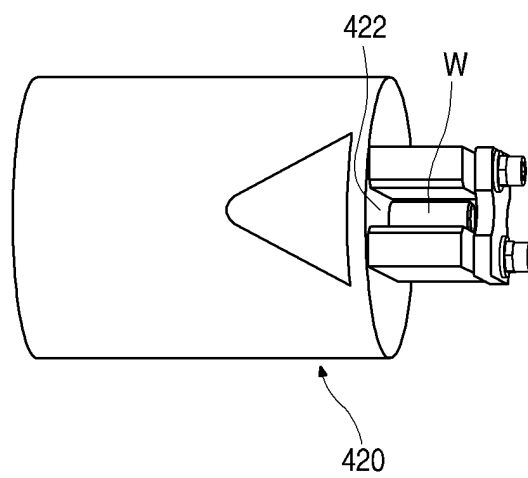


Fig. 5

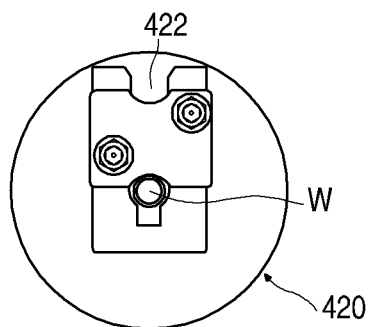


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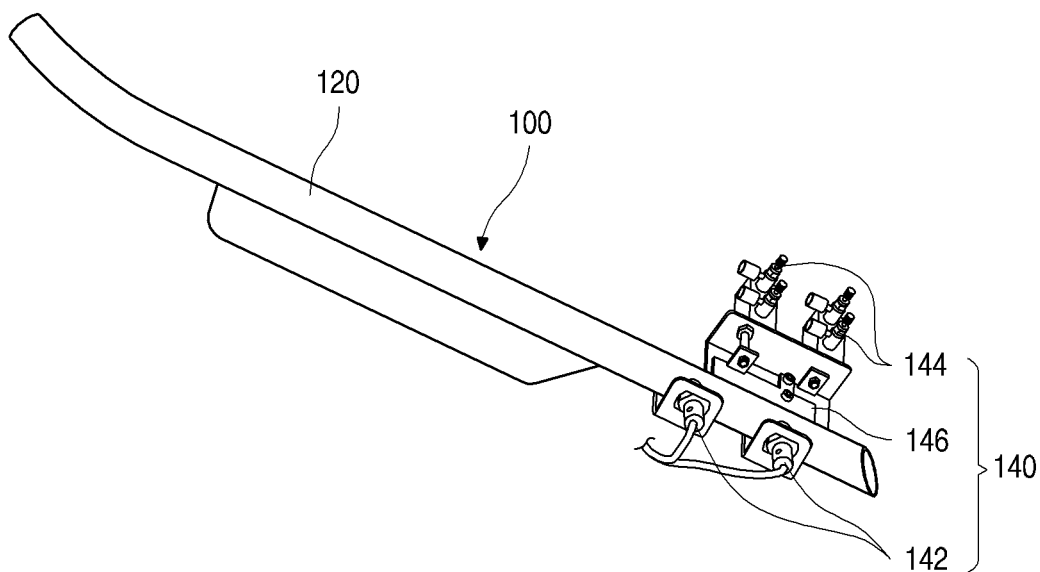


Fig. 7

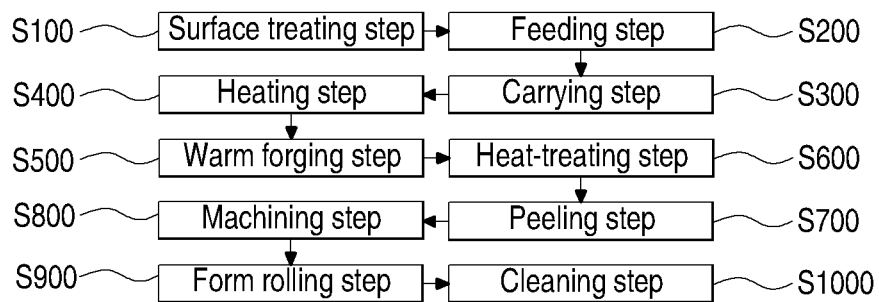


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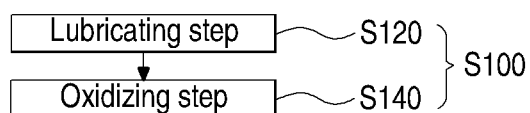


Fig. 9

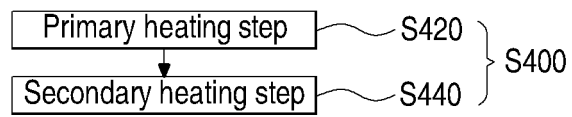


Fig. 10

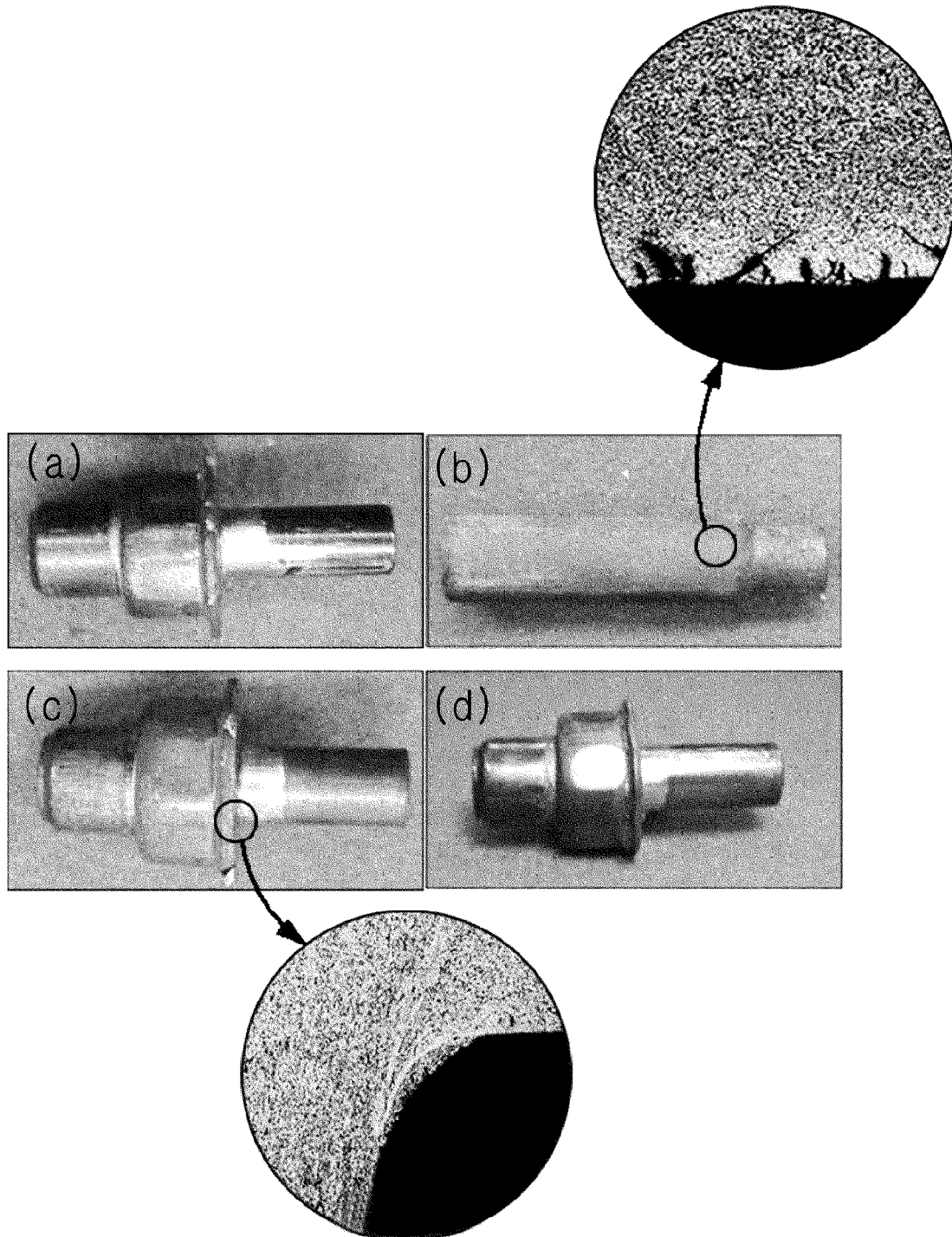


Fig. 11

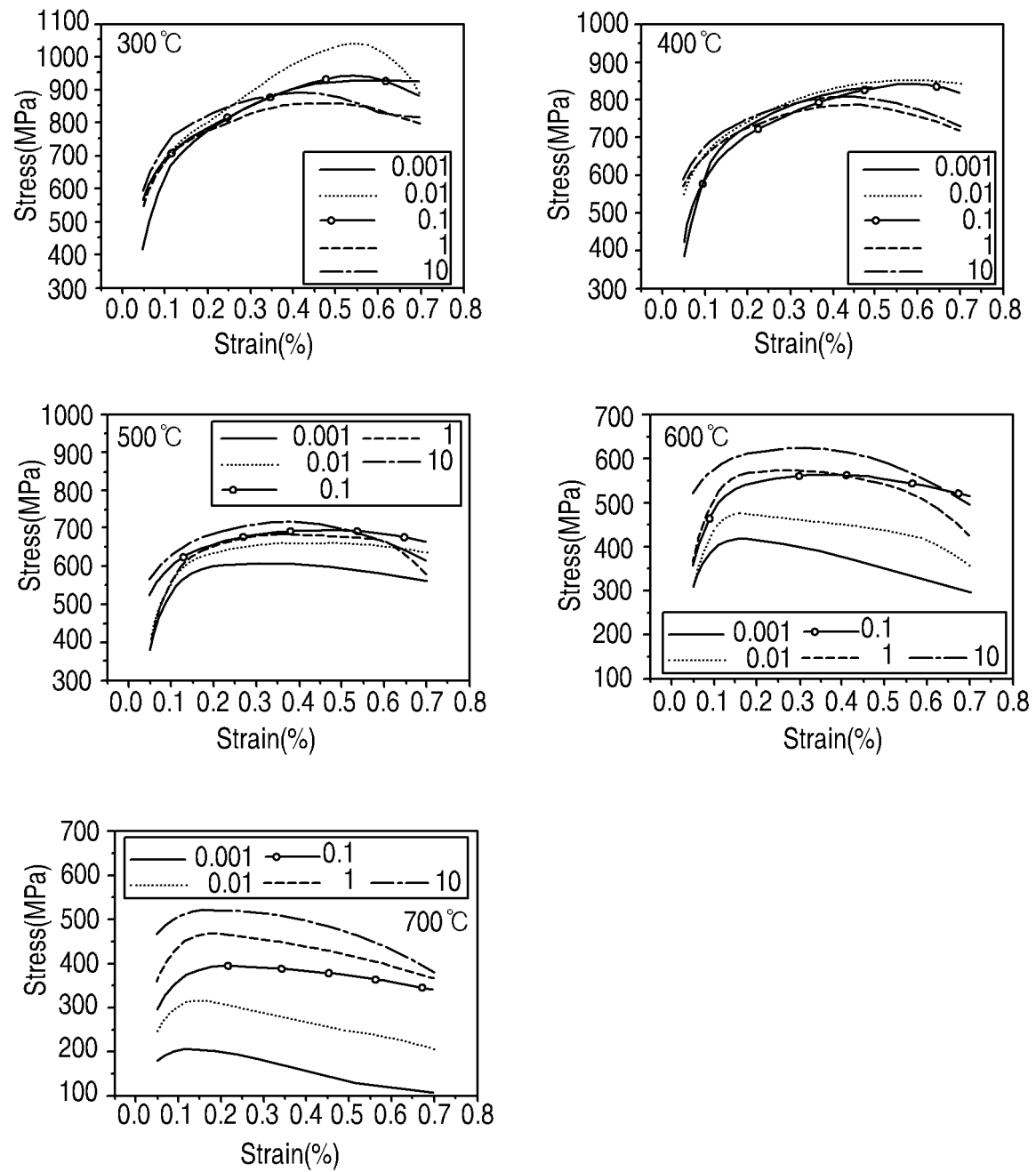


Fig. 12

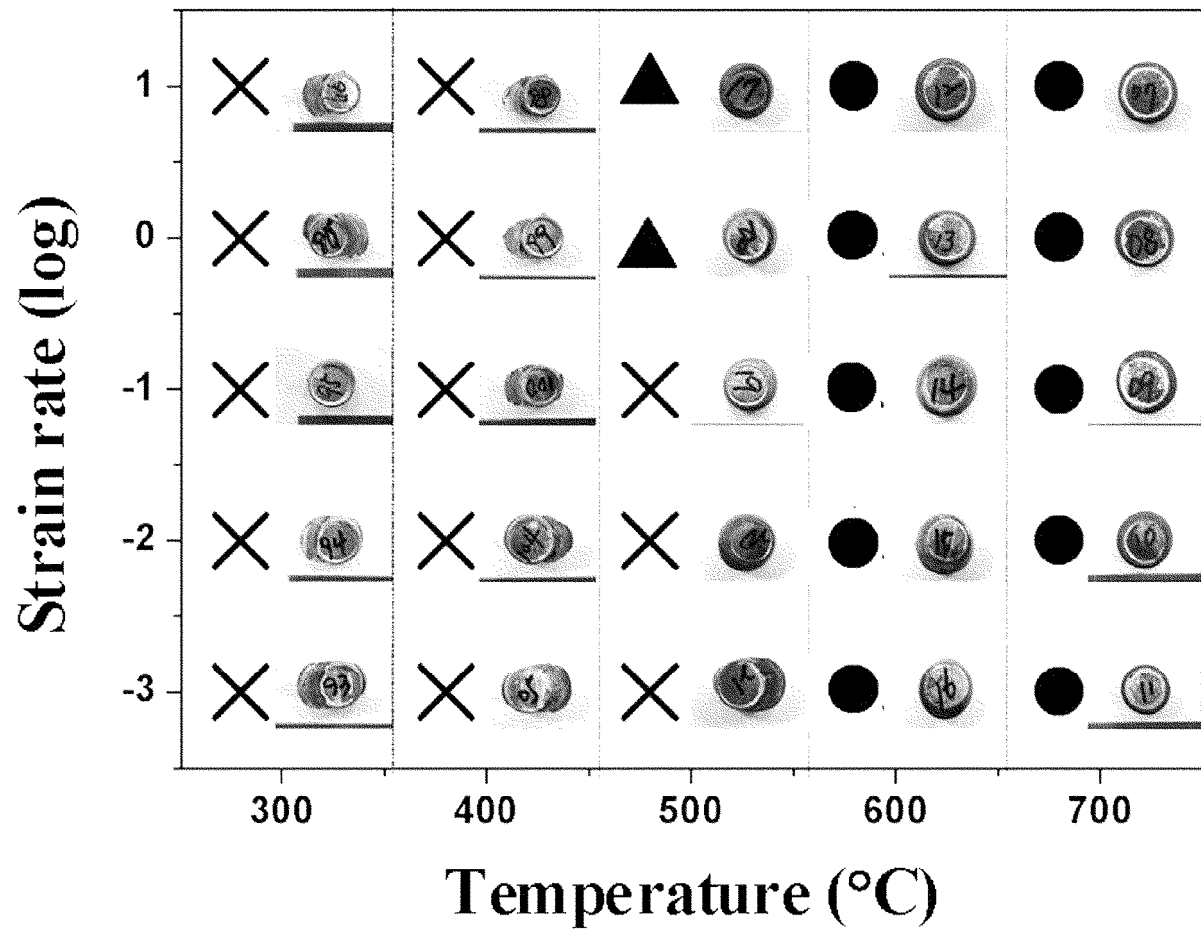


Fig. 13

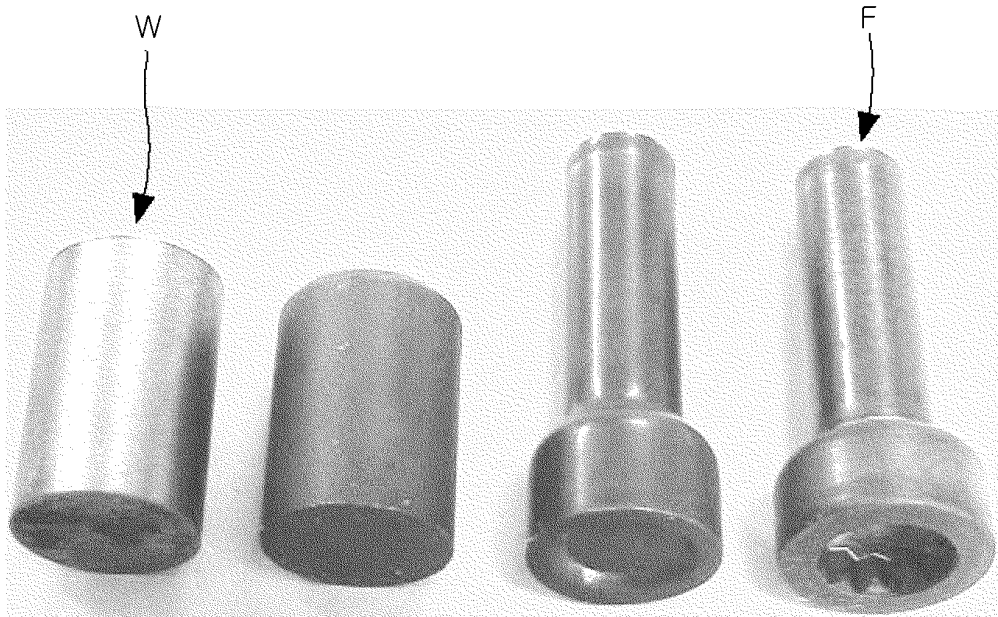


Fig. 14

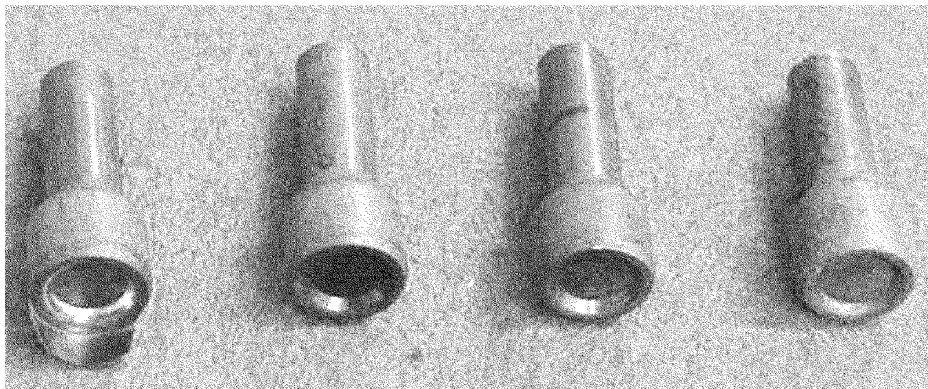


Fig. 15



Fig. 16

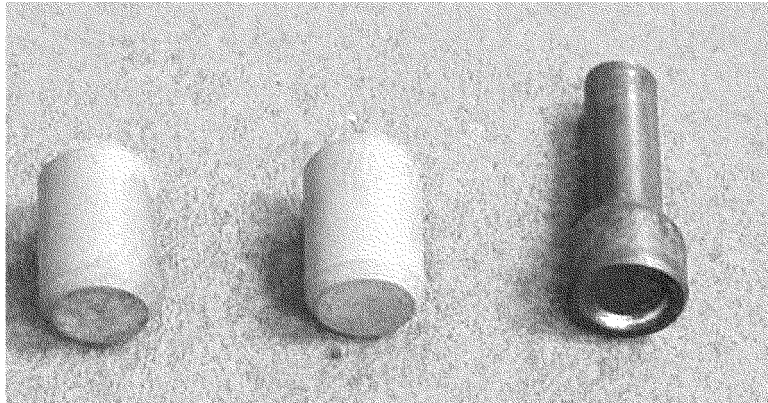


Fig. 17



Fig. 18



Fig. 19

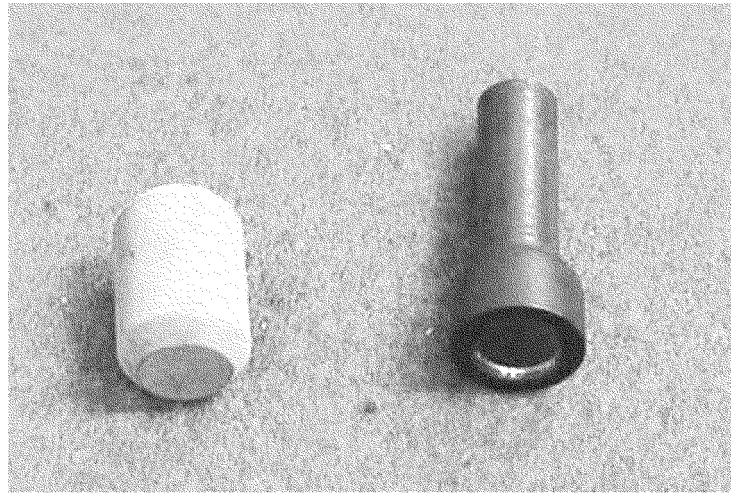


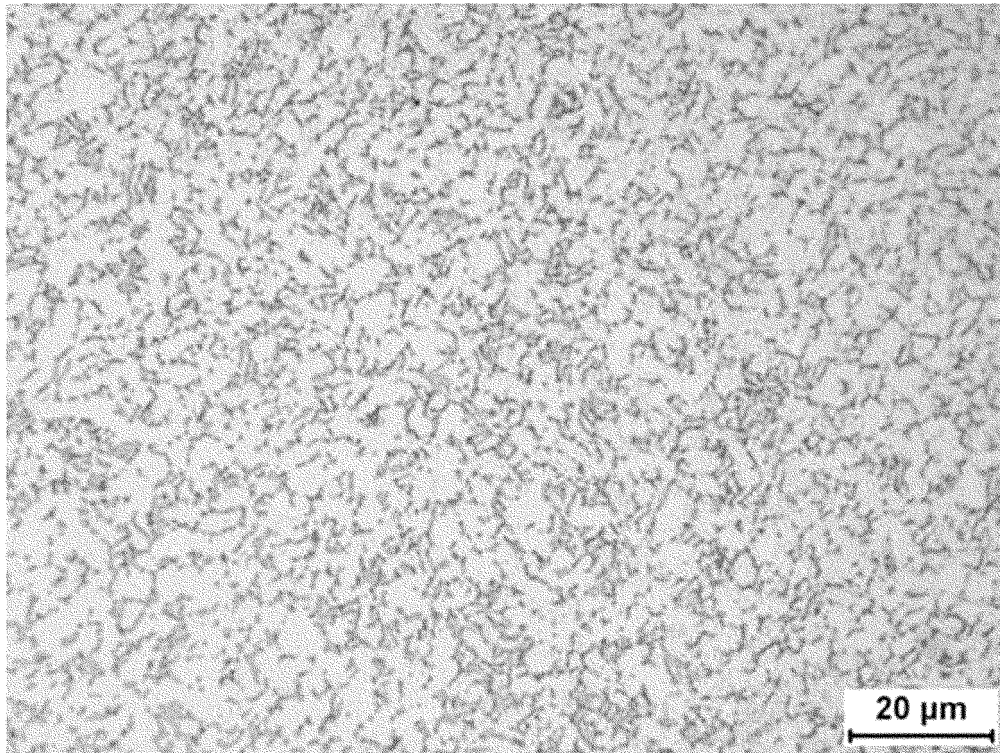
Fig. 20



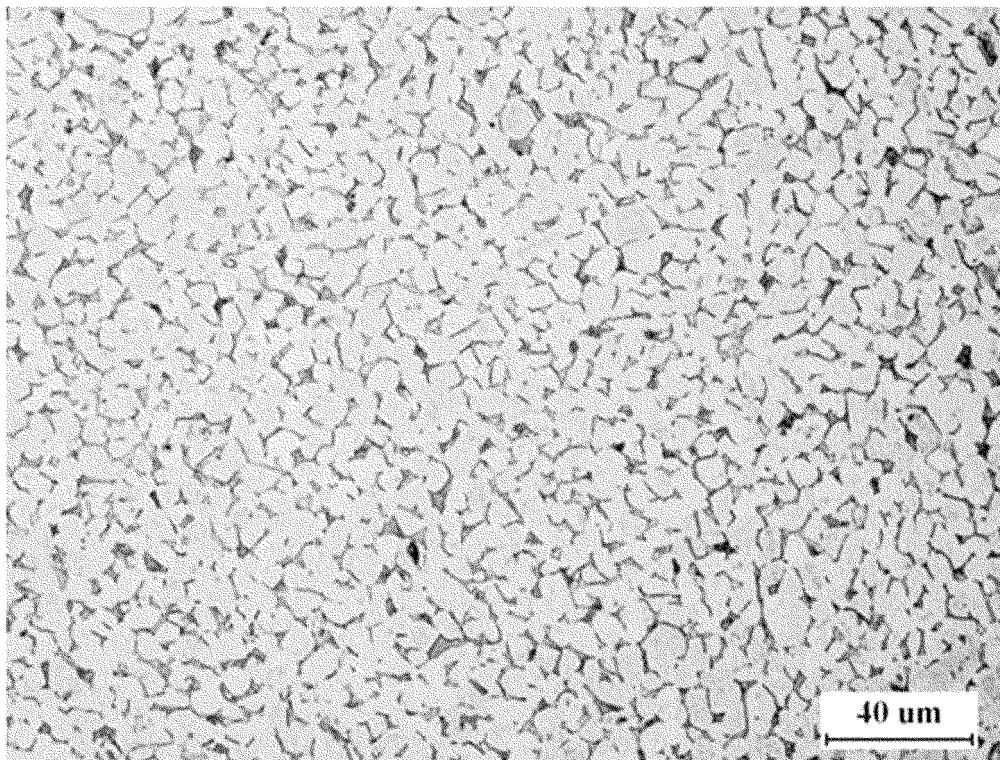
Fig. 21

Heat-treatment		Tensile properties		
Solid solution	Aging	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
A 927 °C for 1hr / WQ	-	880	1142	18.7
B 927 °C for 1hr / WQ	537 °C for 3hrs	1067	1183	17.2
C 927 °C for 1hr / FC to 720 °C / W.Q.	-	726	963	22.3
D 927 °C for 1hr / FC to 720 °C / WQ(담금)	537 °C for 3hrs / AC	938	1011	20.6
E 927 °C for 1hr / FC to 900 °C / WQ	480 °C for 24hrs / AC	1074	1136	19.2
F 927 °C for 1hr / FC to 850 °C / WQ	480 °C for 24hrs / AC	1059	1096	20.2

Fig. 22



Before heat treatment



After heat treatment

Fig. 23



Fig. 24

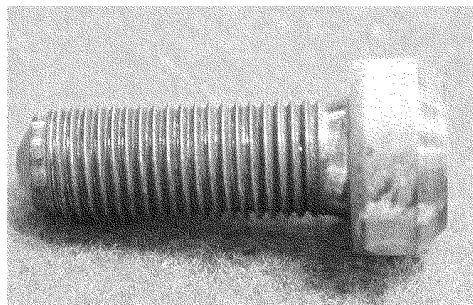


Fig.25

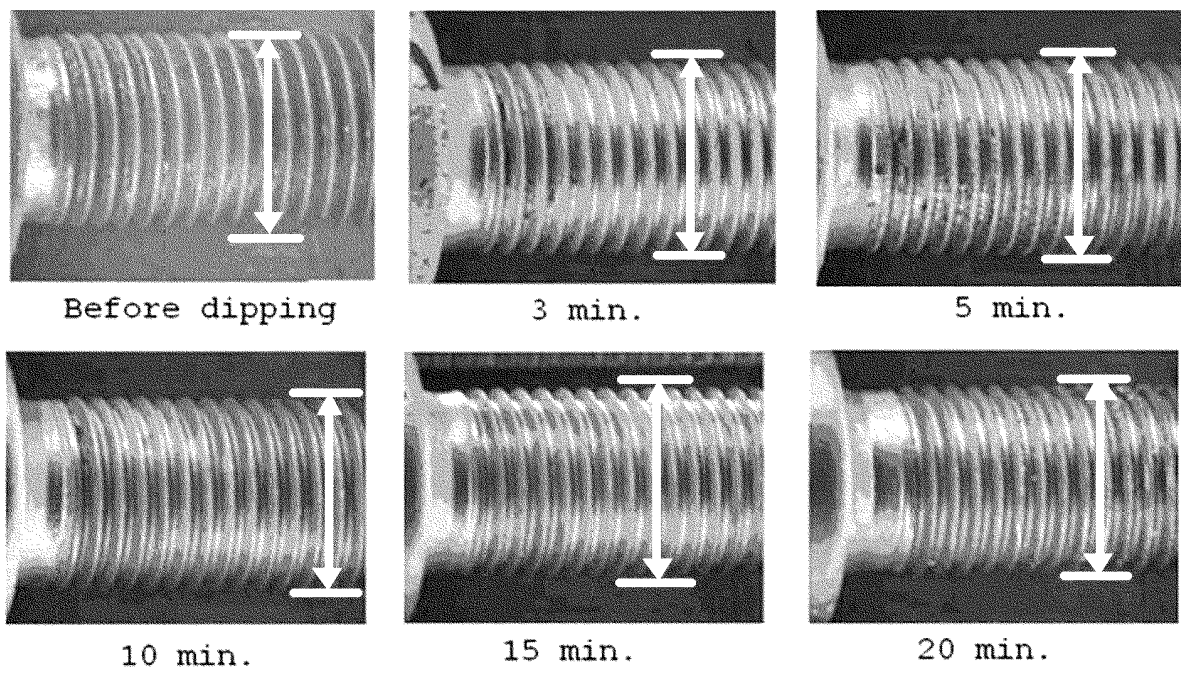


Fig. 26

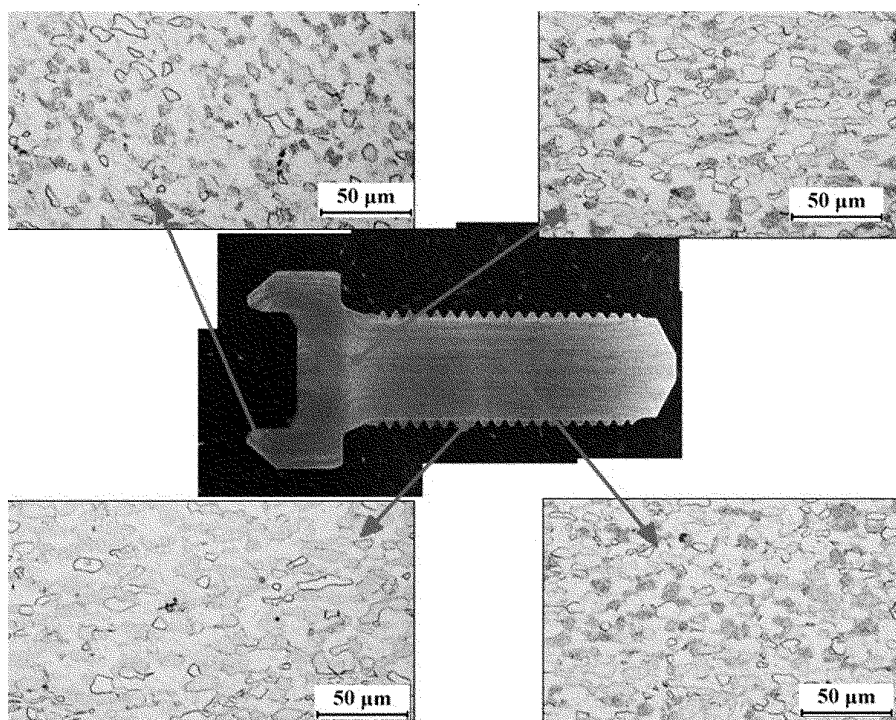


Fig. 27

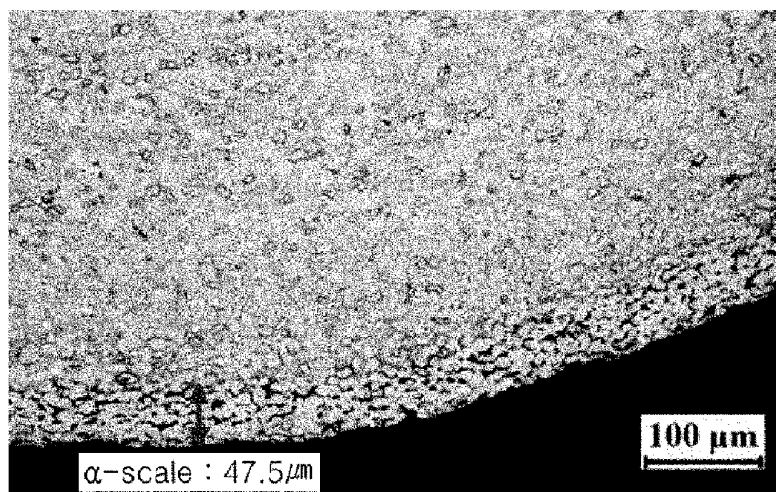


Fig. 28

Number	Tensile load at break (kN)	Tensile stress at break (MPa)	Engineering Strain (%)
1	62.7	1217	12.7
2	61.8	1200	12.4
3	58.0	1126	12.2
4	58.0	1126	10.9
5	56.5	1097	12.0
Average	59.39	1153	12.1

Fig. 29

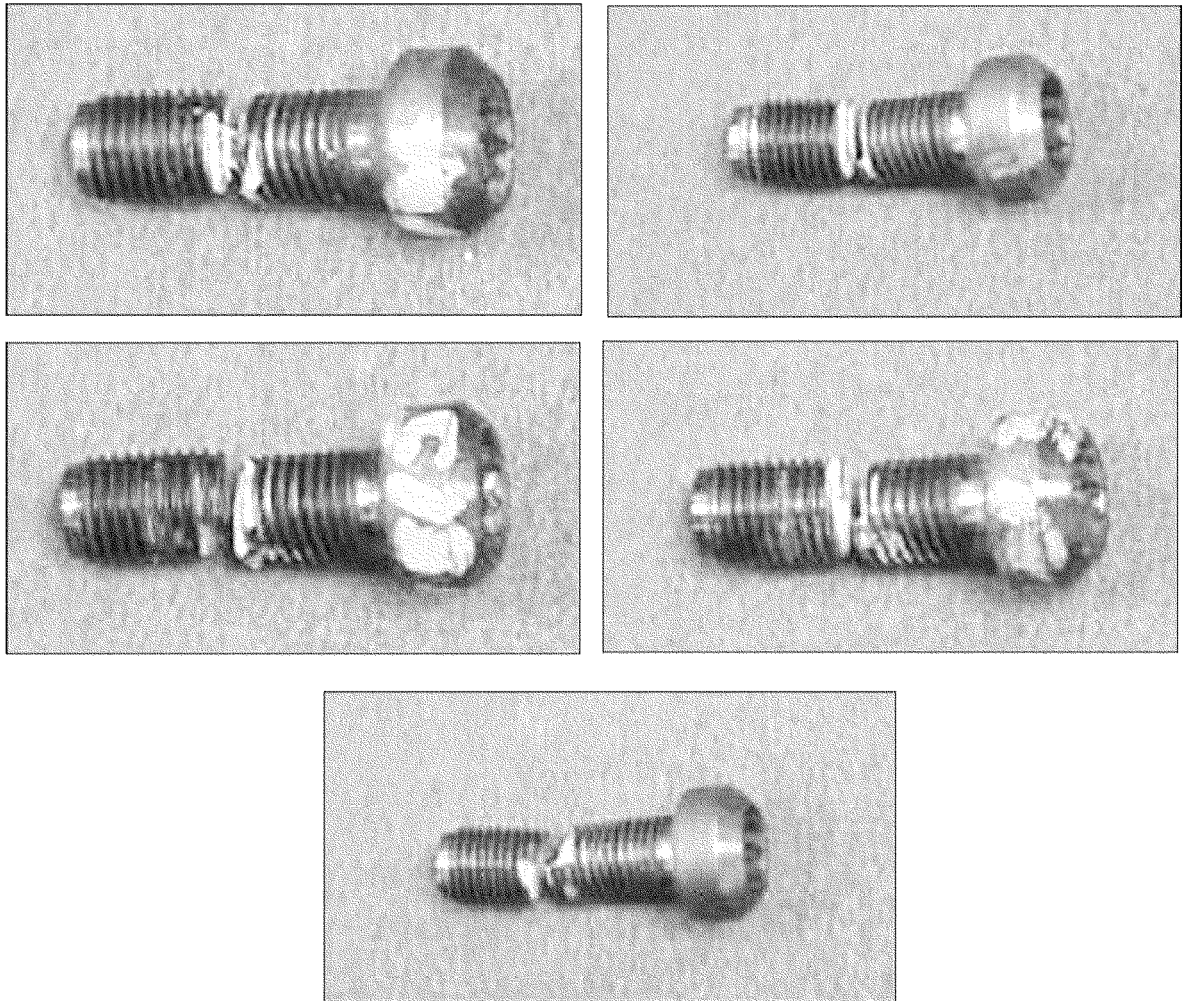


Fig. 30

REFERENCES CITED IN THE DESCRIPTION

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- KR 100628030 B1 [0004]