

METHODS FOR HEAT TREATING THICK-WALLED FORGINGS

Field of the Invention

[0001] The invention relates generally to the field of heat treating thick-walled forgings. More specifically, the invention relates to heat treating thick-walled forgings using low alloy steel of a specific composition and a controlled tempering and quenching process.

Background of Invention

[0002] Well control is an important aspect of oil and gas exploration. When drilling a well, for example, in oil and gas exploration applications, safety devices must be put in place to prevent injury to personnel and damage to equipment resulting from unexpected events associated with the drilling activities.

[0003] Drilling wells in oil and gas exploration involves penetrating a variety of subsurface geologic structures, or “layers.” Occasionally, a wellbore will penetrate a layer having a formation pressure substantially higher than the pressure maintained in the wellbore. When this occurs, the well is said to have “taken a kick.” The pressure increase associated with the kick is generally produced by an influx of formation fluids (which may be a liquid, a gas, or a combination thereof) into the wellbore. The relatively high pressure kick tends to propagate from a point of entry in the wellbore uphole (from a high pressure region to a low pressure region). If the kick is allowed to reach the surface, drilling fluid, well tools, and other drilling structures may be blown out of the wellbore. These “blowouts” may result in catastrophic destruction of the drilling equipment (including, for example, the drilling rig) and substantial injury or death of rig personnel.

[0004] Because of the risk of blowouts, blowout preventers (“BOPs”) are typically installed at the surface or on the sea floor in deep water drilling arrangements to effectively seal a wellbore until active measures can be taken to control the kick. BOPs may be activated so that kicks are adequately controlled and “circulated out” of the system.

[0005] Figure 1 shows a prior art annular BOP 101. The annular BOP 101 includes a housing 102, with a bore 102 extending therethrough and disposed about a

longitudinal axis 103. A packing unit 105 is disposed within the annular BOP 101 and is also about the longitudinal axis 103. The packing unit 105 includes an elastomeric annular body 107 and a plurality of metallic inserts 109. The annular BOP 101 is actuated by fluid pumped into opening 113 of a piston chamber 112. The fluid applies pressure to a piston 117, which moves the piston 117 upward to compress the packing 105 about the longitudinal axis 103. In the event a drillpipe is present along the longitudinal axis 103, the packing unit 105 will seal about the drillpipe. The annular BOP 101 goes through an analogous reverse movement when fluid is pumped into opening 115 of the piston chamber. The fluid then instead translates downward force to the piston 117, allowing the packing unit to radially expand. A removable head 119 also enables access to the packing unit 105, such that the packing unit 105 can be serviced or changed if necessary.

[0006] Because of the high pressures that BOPs must sustain, it is important that the walls of the BOP are thick and of uniform mechanical properties; tensile strength and hardness. Forgings, such as the forgings used in BOPs, are generally made of low alloy steel which has been heat treated to increase strength and meet specific minimum mechanical properties. Heat treatment of the low alloy steel is typically done by normalizing, austenitizing, quenching, and tempering the steel. Normalizing involves heating the steel above a critical temperature for a sufficient period of time to refine the ferritic grain size of the steel, reduce residual non-uniform stresses and to produce more uniform mechanical properties. The forging is then allowed to cool in still air from the normalizing temperature. In order to achieve maximum hardness, the metals are liquid quenched after austenitizing. Austenitizing involves heating the steel above a critical temperature for a sufficient period of time to transform the grain structure to austenite preparatory to quenching. During quenching, the austenitized metal is immersed into a quench bath of a quench media, such as water, oil or polymer and in very rare cases brine which may be vigorously agitated to achieve a critical rate of cooling to achieve transformation to a predominately bainitic or martensitic microstructure, to increase the hardness and mechanical strength of the metal. Finally, the low alloy steel used for this application is always tempered by reheating the forging to a temperature below the lower critical temperature, which reduces the high strength and hardness of the as quenched metal and increases the ductility and toughness of

the metal. Tempering is also known as “drawing the temper” or more simply “drawing.”

[0007] When using large forgings to produce pressure vessels, it is important that after heat treatment the increased strength of the steel is as uniform as possible throughout the forging's entire section thickness. Uniform steel strength can be difficult to achieve when the steel is many inches thick. When quenching a large forging, the outer surfaces of the forging in contact with the quench media can have the necessary high cooling rate to achieve maximum transformation and the attendant mechanical properties. However, the cooling rate of the metal mass inside toward the center of the forging becomes progressively slower as the metal mass is located further from the surface and the quench media. Thus, in steel with several inches of section thickness, the metal mass deepest inside of the forging will be most difficult to increase the metal's mechanical properties and hardness because the mass cannot be quenched as rapidly and in many cases fails to meet the minimum critical cooling rate for phase transformation to occur.

[0008] When using large forgings to produce pressure vessels, it is important that after heat treatment the increased strength of the steel is uniform throughout the forging's entire thickness. Uniform steel strength can be difficult to achieve when the steel is many inches thick. When quenching a large forging, the outer surfaces of the forging in contact with the quench media can have the necessary high cooling rate to maximize hardness. However, the cooling rate of the metal mass inside of the forging becomes progressively slower as the metal mass is located further from the quench media. Thus, in steel with several inches of thickness, the metal mass deepest inside of the forging will be most difficult to increase the metal's hardness because the mass cannot be quenched as rapidly.

[0009] Depth of hardenability is the ability of a metal to respond to heat treatment uniformly in relatively large section thicknesses. Low alloy steel has been known to the industry for good depth of hardenability. The low alloy steel AISI 4130 has a yield strength range from 75 to 80 Ksi with a depth of hardenability generally limited to about two inches, meaning the given yield strength range can be expected to be maintained in a region of two inches from the heat treatment process. AISI 4140, another low alloy steel, has a similar yield strength range

from 75 to 80 Ksi and a range generally limited to six inches for depth of hardenability.

[0010] For large BOPs and pressure vessels, cross-sections of steel can be more than twenty inches thick. Therefore, steel compositions with large depths of hardenability in order to achieve high strength levels are desired.

Summary of Invention

[0011] In one aspect, the present invention relates to a method for heat treating thick-walled forgings. The method includes heating a low alloy steel to an austenitizing temperature, wherein the low alloy steel comprises carbon of about 0.05-0.2 wt.%, manganese of about 0.3-0.8 wt.%, and nickel of about 0.25-1.0 wt.%. The method further includes quenching the low alloy steel in a quench media, and then tempering the low alloy steel for less than about thirty minutes per inch of critical section thickness plus about two hours.

[0012] In another aspect, the present invention relates to a forging. The forging includes carbon of about 0.05-0.2 wt.%, manganese of about 0.3-0.8 wt.%, and nickel of about 0.25-1.0 wt.%. The forging further includes a cross-section thickness of at least about 8 inches, an internal yield strength of greater than about 85Ksi, and a Brinell hardness value of at most about 237.

[0013] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

Brief Description of Drawings

[0014] Figure 1 shows a cutaway view of a prior art annular blowout preventer.

[0015] Figure 2 shows a flow chart illustrating one method of heat treating a forging in accordance with an embodiment of the present invention.

[0016] Figure 3 shows a graph of the cooling power of water versus the temperature of water.

[0017] Figure 4 shows a graph of the hardness results for steel quenched in water and in brine.

Detailed Description

- [0018] In one aspect, the present invention provides methods for heat treating thick-walled forgings. More specifically, the methods disclosed can be used to create BOPs which require high hardness levels throughout the entire width of the walls.
- [0019] As explained above, for thick-walled forgings to sustain high pressure environments, the low alloy steel of a certain preferred composition must be heat treated to increase hardness and strength.
- [0020] A method in accordance with one embodiment of the invention uses a low alloy steel comprising carbon of about 0.05-0.2 wt.%, manganese of about 0.3-0.8 wt.%, and nickel of about 0.25-1.0 wt.%. With such a chemical composition, the low alloy steel can have a depth of hardenability of greater than eight inches when heat treated in accordance with one embodiment of the present invention. In another embodiment, the percent of nickel may be limited to about 0.5-1.0 wt.%. In addition to carbon, manganese, and nickel, the low alloy steel chemical composition of one embodiment can also include phosphorous of greater than 0 up to about 0.04 wt.%, sulfur of greater than 0 up to about 0.04 wt.%, silicon of greater than 0 up to about 0.5 wt.%, chromium of about 2.0-2.5 wt.%, and molybdenum of about 0.45-1.15 wt.%. In one embodiment, the molybdenum may be 0.90-1.10 wt%.
- [0021] In addition to a large depth of hardenability, the low alloy steel should exhibit a very high fracture toughness. Fracture toughness measures the amount of energy absorbed by the material during a high strain fracture. Tougher materials absorb more energy than brittle materials. The low alloy steel of the present invention can provide the fracture toughness needed for use in large high pressure vessels, such as BOPs.
- [0022] General state of the art steel melting technology makes available low alloy steels with a preferable phosphorous and sulfur content much lower than the maximum provided above. The use of reduced amounts of phosphorous and sulfur helps to obtain a high fracture toughness of the steel. Also, the low alloy steel may be calcium treated in the melting process when the alloy steel is originally melted together from the original elements to provide sulphide morphology control and

improve fracture toughness. Further, the low alloy steel may include aluminum and/or vanadium for deoxidation and grain refinement.

[0023] In one embodiment of the invention, heat treatment of the low alloy steel is performed in accordance with the standard practice for heat treating metals: normalizing, austenitizing, quenching, and tempering. The optional normalizing treatment is typically performed so that the low alloy steel is controlled to within about ± 25 °F (± 14 °C) of the selected normalizing temperature. The normalizing temperature is typically chosen to be 25-50 °F (14-28 °C) above the austenitizing temperature. The forgings are then re-heated to form austenite at an austenitizing temperature, such as at least 1725 °F (940 °C), with the selected temperature controlled to within about ± 25 °F (± 14 °C). After austenitizing, the forgings are then quenched in a vigorously agitated immersion quench bath with the initial temperature of a quench media not exceeding about 75 °F (24 °C). Holding the initial quench media temperature to less than about 75 °F at the start of the quench provides a more efficient quench by increasing the cooling rate of the low alloy steel. For forgings with section thickness greater than about 8 inches (about 20 cm), the temperature of the quench media should not be allowed to exceed about 95 °F (35 °C) at the end of the quench. For forgings of up to about 20 inches (51 cm) of thickness, the temperature of the quench media should not be allowed to exceed about 75 °F (24 °C) at the end of the quench. To accomplish this, the selected temperature rise of the quench media would determine the minimum amount of the quench media necessary for effective and adequate quenching. A smaller selected temperature rise in the quench media would require larger amounts of quench media to receive the same amount of heat from the forgings. Optionally, the quench tank would have to be overflowed with 75 °F (24 °C) or cooler quench media, or the quench media would have to be circulated through a cooling system to maintain the temperature below 75 °F (24 °C).

[0024] Control of the initial quench media temperature to less than about 55 °F and above about 32 °F should result in an even greater depth of hardening than when the forgings are quenched in a warmer, higher temperature, quench media. Figure 3, from Metals Handbook, Ninth Edition, Volume 4, page 35, shows the cooling power of the quench media versus the initial quench media temperature, in which water was used as the quench media. As shown in Figure 3, the cooling power of

water decreases rapidly as the initial temperature increases, indicating water can quench forgings more rapidly and allow greater depth of hardening in lower initial temperature water. However, as the initial quench media temperature is reduced, the forgings become more susceptible to cracking and fracturing, also known as "quench cracking." Therefore, efforts should be taken to not allow too low of an initial quench media temperature as to avoid quench cracking and fracturing.

[0025] For low alloy steels, brine is a preferable quench media to water because brine is able to provide higher hardness results in low alloy steels than water. Brine produces less gas bubbles than water, and therefore can wet the surface of the low alloy steel. This allows brine to cool the low alloy steel almost twice as fast as water, enabling the low alloy steel to have higher hardness results. Figure 4, from Metals Handbook, Ninth Edition, Volume 4, page 37, shows the results of steel quenched in water and in brine. As shown in Figure 4, the hardness results for brine are higher than that of water when quenching at the same temperature of 180 °F (80 °C). Though, brine allows for a faster quench to increase the depth of hardening of the low alloy steel, brine is more caustic and corrosive than water. Therefore, efforts would also need to be taken to protect the quenched materials and the quenching equipment from the brine.

[0026] After quenching, the forgings are tempered at a selected tempering temperature for at least thirty minutes per inch of section thickness plus one or two hours of additional soak time. The selected tempering temperature should be maintained within about ± 15 °F (± 8 °C).

[0027] In the prior art, low alloy steels are tempered for forty five minutes to one hour per inch of section thickness, plus one to two hours time at the tempering temperature. However, such long tempering hold times can result in over tempering of the alloy, resulting in an unnecessary loss of mechanical properties of the low alloy steel. As a result, the low alloy steel may fail to meet the requirements for tensile strength and hardness.

[0028] The temperatures for normalizing, austenitizing, and tempering is dependent upon the alloys and the composition of the steel. Material specifications for particular compositions may be referred to in order to determine appropriate

normalizing, austenitizing, and tempering temperatures, and the appropriate quench media.

[0029] Figure 2 shows a flow chart illustrating a method of heat treating a forging in accordance with an embodiment of the present invention. The low alloy steel forging used in the method is made from the chemical composition of the present invention and is typically greater than 8 inches in cross-section thickness. The method begins with the optional normalizing process 210, in which the forging is heated to a normalizing temperature within about ± 25 °F (± 14 °C). After the optional normalizing process 210, the forging is then re-heated into the austenite temperature range in the austenitizing process 220 within about ± 25 °F (± 14 °C) of a selected austenitizing temperature. Then, using a vigorously agitated immersion quench bath, the forging is immersed in a quench media in the quenching process 230. The quench media used in the quenching process 230 should have an initial temperature less than about 75 °F (24 °C). However, a greater depth of hardening of the forging can be achieved if the initial temperature of the quench media is controlled between about 55 °F (13 °C) and 32°F (0 °C). For a forging less than about twelve inches of thickness, the quench bath should be large enough as to not allow the quench media to exceed about 95 °F (35 °C) by the end of the quench. For a forging less than about twenty inches of thickness, the quench bath should be large enough as to not allow the quench media to exceed about 75 °F (24 °C) by the end of the quench. Also, in the quenching process 230, brine is a preferable quench media over water for quenching the large forging. The tempering process 240 of the forging follows the quenching process 230. The forging is heated to a selected tempering temperature within about ± 15 °F (± 8 °C). Specifically, the forging is tempered for thirty minutes per each inch of thickness, plus an additional one or two hours of soak time. For example, a forging of ten inches of thickness comprised of the chemical composition of the present invention should be tempered for about six to seven hours. A forging created by method 200 will have a depth of hardenability greater than eight inches, and will be able to meet the specific mechanical properties necessary for safety for use as a BOP. Specifically, the forging will be able to meet the standards of the American Petroleum Institute ("API") for pressure containing members, as indicated in the API Specification 16A / ISO 13533 section 6.3.

[0030] The combination of the disclosed chemical composition, heat treatment temperature control, quench media control, and tempering time control is able to produce forgings with at least about 85 Ksi internal yield strength, at least about 100 Ksi ultimate strength, at least 20% elongation, at least 70% reduction of area, and a surface hardness range of about 217 to 237 Brinell hardness value. Yield strength refers to the applied stress that the low alloy steel can experience before plastic deformation. Ultimate strength refers to the applied stress the low alloy steel can experience before failing or breaking. Elongation refers to the change in length the low alloy steel can experience relative to the original length of the steel before failing in tension. Reduction in area refers to the largest change in cross-sectional area the low alloy steel can experience relative to the original cross-sectional area of the steel before failing in tension. The Brinell hardness value of at least about 217 is to ensure that the low alloy steel meets the minimum mechanical properties with regard to yield strength and ultimate strength. The Brinell hardness value of at most about 237 is to ensure the low alloy steel meets the provisions of NACE MR0175 / ISO 15156 for low alloy steels intended to be used in sour service. BOPs are sometimes exposed to sour service and therefore are required by API 16A to meet necessary requirements of the provisions of NACE MR0175 / ISO 15156. Sour service refers to the use of metallic alloys in wellbore fluid environments that contain Hydrogen Sulfide, H₂S, in concentrations great enough to cause SSCC, Sulfide Stress Corrosion Cracking of susceptible metallic alloys exposed to those environments.

[0031] The major components of the prior art annular BOP 101 that can be created from the low alloy steel of the present invention include the housing 102, the piston 117, and the removable head 119. Those having ordinary skill in the art will appreciate that the low alloy steel of the present invention is not limited to pressure vessels. Other embodiments which incorporate the use of thick-walled forgings may be manufactured from the low alloy steel of the present invention.

[0032] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

Claims

What is claimed is:

1. A method for heat treating thick-walled forgings, the method comprising:
heating a low alloy steel to an austenitizing temperature, wherein the low alloy steel comprises carbon of about 0.05-0.2 wt.%, manganese of about 0.3-0.8 wt.%, and nickel of about 0.25-1.0 wt.%;
quenching the low alloy steel in a quench media; and
tempering the low alloy steel for less than about thirty minutes per inch of critical section thickness plus about two hours.
2. The method of claim 1, wherein the low alloy steel further comprises phosphorous of greater than 0 up to about 0.04 wt.%, sulfur of greater than 0 up to about 0.04 wt.%, silicon of greater than 0 up to about 0.5 wt.%, chromium of about 2.0-2.5 wt.%, and molybdenum of about 0.45-1.15 wt.%.
3. The method of claim 1, wherein the low alloy steel comprises nickel of about 0.5-1.0 wt.%.
4. The method of claim 1, wherein the low alloy steel further comprises aluminum.
5. The method of claim 1, wherein the low alloy steel further comprises vanadium.
6. The method of claim 1, wherein the low alloy steel is calcium treated during a melting process.
7. The method of claim 1, further comprising normalizing the low alloy steel prior to heating the low alloy steel to an austenitizing temperature.
8. The method of claim 1, wherein the quench media is brine.
9. The method of claim 1, wherein the finish temperature of the quench media is less than about 95 degrees Fahrenheit (35 degrees Celsius).
10. A blowout preventer made using the method of claim 1.

11. A forging comprising:
 - carbon of about 0.05-0.2 wt.%;
 - manganese of about 0.3-0.8 wt.%;
 - nickel of about 0.25-1.0 wt.%;
 - a cross-section thickness of at least about 8 inches;
 - an internal yield strength of greater than about 85Ksi; and
 - a Brinell hardness value of at most about 237.
12. The forging of claim 11, further comprising phosphorous of greater than 0 up to about 0.04 wt.%.
13. The forging of claim 11, further comprising sulfur of greater than 0 up to about 0.04 wt.%.
14. The forging of claim 11, further comprising silicon of greater than 0 up to about 0.5 wt.%.
15. The forging of claim 11, further comprising chromium of about 2.0-2.5 wt.%.
16. The forging of claim 11, further comprising molybdenum of about 0.45-1.15 wt.%.
17. The forging of claim 11, further comprising an ultimate strength of at least about 100Ksi.
18. The forging of claim 11, further comprising an elongation of at least about 20%.
19. The forging of claim 11, further comprising a reduction of area of at least about 70%.
20. The forging of claim 11, further comprising a Brinell hardness value of at least about 217.