

MECHANICALLY LINED PIPE (MLP) WITH UPSET ENDS FOR IMPROVED FATIGUE RESISTANCE

TECHNICAL FIELD

[0001] This invention relates to the production of piping materials for use in the offshore production of oil and gas, specifically corrosion-resistant pipes that can be used for rigid risers or pipelines exposed to high fatigue loads. In particular, it relates to methods of manufacturing a mechanically lined pipe (MLP) having upset ends that will increase the fatigue resistance of the pipe as well as of the girth weld between the pipes.

BACKGROUND OF THE INVENTION

[0002] As it is known in the art, bi-metallic pipes may be used to form corrosion-resistant pipelines for submarine transportation of corrosive fluids, such as gas or crude oil. A bi-metallic pipe is generally composed of two layers. The outer layer, usually made from a carbon steel metal, provides general strength to the design so as to resist external hydrostatic pressure as well as protection against buckling on the reel or seabed. On the other hand, the internal layer, also called a “liner”, protects the outer layer from damage caused by the corrosive fluids being transported. A corrosion resistant alloy (CRA) is therefore commonly chosen as the material for the liner. In this way, the bi-metallic pipes combine the strength of the low-cost carbon steel and the corrosion-resistance of the liner.

[0003] The CRA liner may be made from alloy 316L, 825, 625 or other alloys as defined in the American Petroleum Institute Specification for CRA Clad or Lined Steel Pipe Fourth Edition (March 2015) (API Specification 5LD). The minimum thickness of the liner in the API standard is 2.5mm, and the minimum thickness of the liner in the DNV standard is 3 mm.

[0004] One form of bi-metallic pipe as described above is a single “clad” pipe, whereby an internal CRA layer is metallurgically bonded to the carbon steel outer layer. The cladding

may be bonded by hot rolling, coextrusion, weld overlay, explosion bonding, powder metallurgy, or some other process that produces a metallurgical bond.

[0005] A second form of said bi-metallic pipe may be termed a mechanically lined pipe (MLP). According to the definition provided in the Det Norske Veritas (DNV) Offshore Standard DNV-OS-F101, a lined pipe is a “pipe with internal (corrosion resistant) liner where the bond between (linepipe) backing steel and liner material is mechanical”. The MLP may be manufactured using mechanical expansion, whereby a loosely fitting liner is plastically expanded from the inside, so as to elastically or plastically deform the outer carbon steel pipe, thereby tightly fitting the inner liner within the pipeline when the expanding internal pressure is removed and an interference stress, or “mechanical bond”, between the liner and the host pipe remains. It is this “mechanical bond” that gives MLP its reference name. MLP has the advantage of being much cheaper than either making the pipe entire from CRA or metallurgically bonding CRA to the backing pipe (clad pipe).

[0006] The liner at both ends of the MLP pipe is sealed to avoid fluids and/or moisture ingress between the outer pipe and the liner. This sealing is achieved by a ‘clad overlay weld’ at each end of the MLP. According to common practice, clad overlay welds are typically 100 mm long with minimum length of 20 mm to enable pipeline girth welds inspection and, if needed, to cut and reweld of the defective pipeline girth welds that could not be repaired.

[0007] For MLP the end of liner and start of weld overlay is termed transition area or triple point being the area of metallurgical junction between: carbon steel backing pipe, liner pipe and weld overlay (see points C-D in figure 1 - Typical MLP).

[0008] Rigid subsea pipelines and risers are commonly formed of lengths of steel pipe - 'pipe joints' -that are welded together end-to-end by a girth weld. A rigid riser is defined as the connecting piping between a submarine pipeline on the seabed and installations above water. Corrosion-resistant pipelines and risers are formed of bi-metallic pipes.

[0009] Rigid subsea pipelines and risers shall have adequate safety against fatigue failures within the design life of the system. Typical causes of stress fluctuations in pipelines and risers are: (a) direct wave and sea currents action; (b) vibrations of the pipeline system,

e.g. due to vortex shedding (current, waves, wind, towing) or fluid flow; (c) supporting structure movements, e.g. installation vessel; (d) fluctuations in operating pressure and temperature.

[0010] Guidance on fatigue design of steel structures is given on several codes. The codes mostly used for subsea structures are DNV Recommended Practice DNV-RP-C203 (Fatigue Design of Offshore Steel Structures) and British Standard BS 7608 (Fatigue Design and Assessment of Steel Structures). The characteristic fatigue resistance is normally given as S-N curves i.e. stress amplitudes, S versus number of cycles to failure, N. The S-N curve shall be applicable for the material and construction detail.

[0011] The design life of rigid risers or pipelines exposed to cyclic loads is limited by the structural and geometric discontinuities of the girth welds between pipes. Moreover, for MLP another discontinuity that also limits the design fatigue life is the transition area (triple point). Areas susceptible to fatigue crack initiation are marked in figure 1 and 2 as: A and B for girth weld and C and D for transition area.

[0012] MLP is gaining popularity and has successfully been used so far in applications where applied cyclic loads are low. MLP with improved fatigue resistance, that could be used in corrosion resistant rigid risers and pipelines exposed to fatigue loads, offers the advantage of substantial cost savings in respect with clad pipes.

[0013] One solution to extend the design life of rigid risers or pipelines exposed to cyclic loads is to reduce the stress at pipe ends where the girth weld represents the area with the unfavourable construction configuration. This could be achieved by increasing the pipe wall thickness at pipe end (so called the upset pipe-end).

[0014] Upset ends pipe has been widely used in producing oil-well tubing and has the advantage of a bonelike structure having the joint area thicker. Generally, pipe-end upsetting is carried out by hot working the upset pipe end into an upsetting die. Said die has cylindrical and taper sections to form the outer surface of upset part and taper section behind upset part. Upset pipe-end inner surface is formed by upsetting punch with section for aforesaid forming.

[0015] The novelty of this invention is to fabricate the upset end by radial expansion of the outer carbon steel pipe ends by either cold or hot working without increasing the pipe wall thickness. Radial expansion is followed by application of a weld overlay deposit on the inner surface of the expanded area and counterbore the deposited weld overlay to match the outer pipe inside nominal diameter.

[0016] Once the upset pipe-end of outer pipe is manufactured and the nominal outer pipe internal diameter (ID) restored, the fabrication of MLP with upset end shall continue as for the standard MLP production procedure.

SUMMARY OF THE INVENTION

[0017] The current invention therefore seeks to provide methods of manufacturing a mechanically lined pipe (MLP) with upset ends that could be used in corrosion resistant, rigid risers and pipelines exposed to high fatigue loads. The upset pipe ends shall be fabricated by radial expansion of the outer carbon steel pipe ends by either cold or hot working without increasing the outer pipe wall thickness. Radial expansion is followed by application of a weld overlay deposit on the inner surface of the expanded area and counterbore the deposited weld overlay to match the outer pipe inside nominal diameter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Figure 1 represents the pipe end wall and joint girth weld - cross-sectional view - of a typical mechanically lined pipe (MLP). Areas susceptible to fatigue crack initiation are marked as: A and B for girth weld and C and D for transition area.

[0019] Figure 2 represents the pipe end wall and joint girth weld - cross-sectional view - of a mechanically lined pipe (MLP) with upset ends. It shows the 1st clad overlay layer (deposited before liner insertion under the expanded and tapered area) as well as the 2nd clad overlay layer (deposited after liner insertion). Areas susceptible to fatigue crack initiation are marked as: A and B for girth weld and C and D for transition area.

DETAILED DESCRIPTION OF THE INVENTION

[0020] References will now be made in detail to the description of the present invention, an example of which is shown in figure 2. The example is provided to explain the invention and not a limitation. Accordingly, changes and modifications obvious to one skilled in the art to which the invention pertains are deemed to be within the spirit, scope and contemplation of the invention.

[0021] The design life of rigid risers or pipelines exposed to cyclic loads is limited by the structural and geometric discontinuities of the girth welds between the pipes. Moreover, for MLP another discontinuity that also limits the design fatigue life is the transition area (triple point). MLP with improved fatigue resistance, that could be used in corrosion resistant rigid risers and pipelines exposed to fatigue loads, offers the advantage of substantial cost savings in respect with clad pipes.

[0022] Present invention is aiming to improve the fatigue life of rigid risers or pipelines made of MLP and exposed to cyclic loads, by increasing the pipe wall thickness at pipe end (so called the upset pipe-end) and produce an MLP with upset ends. Areas susceptible to fatigue crack initiation are marked in figure 1 and 2 as: A and B for girth weld and C and D for transition area.

[0023] According to one aspect of the present invention, there is provided a method of manufacturing a MLP with upset ends comprising at least the steps of: (a) forming the carbon steel outer pipe as a single length; (b) radial expanding of the carbon steel outer pipe ends by either cold or hot working; (c) applying weld overlay deposit on the inner surface of the expanded area and counterboring the deposited weld overlay to match the outer pipe inside nominal diameter; (d) forming the inner liner pipe made of a Corrosion Resistant Alloy (CRA); (e) inserting the CRA liner pipe into the outer pipe; (f) fitting tightly the inner liner within the pipeline to create the mechanical bond by expanding radially the liner inside the outer pipe; (g) sealing the liner to outer pipe at each end of the MLP by seal weld / weld overlay and (h) machining the seal weld / weld overlay area at each pipe end to match the nominal inside diameter of MLP.

[0024] According to this aspect of the invention, the MLP comprises a carbon steel host outer pipe and a Corrosion Resistant Alloy (CRA) liner. The outer pipe for the MLP can be formed as a single length using one of the processes known in the art, including, but not limited to, continuous forming as a single piece or by welding a plurality of outer pipe stalks together. Similarly, the forming of a CRA liner being of the same length as the outer pipe could be provided by a number of processes known in the art, including, but not limited to, continuous forming.

[0025] The methods of manufacturing MLPs described herein are not limited to the size, shape, design, physical and/or chemical properties of the outer pipe and/or the inner liner. However, according to one embodiment of the present invention, the CRA liner may be made from alloy 316L, 825, 625 or other alloys as defined in the American Petroleum Institute Specification for CRA Clad or Lined Steel Pipe Fourth Edition (March 2015) (API Specification 5LD).

[0026] As it is known in the art, the API Specification 5LD covers seamless and welded clad steel line pipe and lined steel line pipe with enhanced corrosion-resistant properties suitable for use in pipeline transportation systems in the petroleum and natural gas industries. The clad and lined steel line pipe specified in the API Specification 5LD comprises a carbon steel backing or base material outside, and a CRA liner inside of the pipe. The API Specification 5LD thus provides guidance on industry standard for the manufacture of lined steel pipe, and is accordingly referred to for the purposes of the present invention.

[0027] The upset end area of the outer carbon steel pipe shall be made by radial expansion of the pipe. Expanded area is made of: (a) a constant diameter area (upset end) toward the pipe end having a longitudinal length of minimum 100 mm and (b) a tapered area to merge the pipe nominal outside diameter to upset end diameter.

[0028] The outside diameter of the expanded area shall be calculated based on estimated fatigue loads and desired fatigue life. The difference between outside diameter of expanded area and nominal outside diameter of the pipe divided by 2 (two) represents the increase of the nominal wall thickness of the pipe. It is estimated that, depending on pipe diameter as well, an increase of 40% of the nominal pipe wall thickness will result in a fatigue

life of the girth weld similar with the rest of the pipe, thus, providing an optimised fatigue life along the entire pipeline structure.

[0029] The tapered area shall provide a smooth transition from pipe nominal outside diameter to upset end diameter in order to reduce the stress intensification factor that affects the fatigue resistance of the pipe. The tapered area of the upset end shall have a taper not steeper than 1:4 (14 degrees) and shall blend smoothly on both ends of the tapered area by a fillet radius not less than 50 mm. Both, the taper slope and the fillet radiuses on both sides of the tapered area may be determined (optimised) using finite element (FE) analysis.

[0030] According to a preferred embodiment of the present invention the transition area shall be made with a taper of 1:5 (11 degrees) to 1:6 (9.5 degrees) having a fillet radius of R 100 mm on both sides of the taper area.

[0031] Upon expansion of the outer pipe, in order to restore a constant internal diameter of the pipe, weld overlay deposit shall be applied on the inner surface of the expanded area to overmatch the required wall thickness of the upset end followed by counterboring of the deposited weld overlay to match the inside nominal diameter of the outer pipe.

[0032] In another embodiment of the present invention, the upset end of the outside host pipe may be formed applying first the weld overlay deposit on the internal surface of the pipe, on the area that shall be expanded followed by the radial expansion of the pipe end section that include the weld overlay. Upon expansion of the pipe end the inside pipe face shall be machined (counterboring) to match the outer pipe inside nominal diameter.

[0033] The CRA liner is then inserted into the carbon steel outer pipe using one or more simple mechanical operations known in the art. The cut-back of the inserted liner shall be shorter than the longitudinal length of the upset end in order to place the transition area (triple point) in the upset end zone, thus reducing also the stress imposed to the triple point (points C-D on figure 2). The difference between the longitudinal length of the expanded upset end area and the cut-back should be at least equal or bigger than pipe nominal wall thickness.

[0034] Upon completion of the previous step the MLP manufacturing shall continue by the typical operations known in the art and in line with API Specification 5LD: (a) fitting tightly the inner liner within the pipeline to create the mechanical bond by expanding radially the liner inside the outer pipe; (b) sealing the liner to outer pipe at each end of the MLP by seal weld / weld overlay and (c) machining the seal weld / weld overlay area at each pipe end to match the nominal inside diameter of MLP.

[0035] To preserve the fatigue resistance of the MLP with upset ends, the residual stress resulted in the seal weld (between the liner and the outer host pipe) upon liner expansion shall be removed. Thus, if the liner shrinks longitudinally during expansion operation and the seal weld is applied before liner expansion then, in order to release the residual stress, the seal weld shall be removed by machining and re-welded.

CLAIMS

1. A method of manufacturing a mechanically lined pipe (MLP) with upset pipe ends comprising at least the steps of:

- (a) forming the carbon steel outer pipe as a single length;
- (b) radial expanding of the carbon steel outer pipe ends by either cold or hot working;
- (c) applying weld overlay deposit (on several layers if needed) on the inner surface of the expanded area to overmatch the required wall thickness of the upset end followed by counterboring of the deposited weld overlay to match the inside nominal diameter of the outer pipe;
- (d) forming the inner liner which is a Corrosion Resistant Alloy (CRA) liner made from alloy 316L, 825, 625 or other alloys as defined in API Specification 5LD and with a wall thickness of at least 2mm and at most 6mm
- (e) inserting the CRA liner pipe into the outer pipe;
- (f) fitting tightly the inner liner within the pipeline to create the mechanical bond by expanding radially the liner inside the outer pipe;
- (g) sealing the liner to outer pipe at each end of the MLP by seal weld / weld overlay and
- (h) machining the seal weld / weld overlay area at each pipe end to match the nominal inside diameter of MLP.

2. A method of manufacturing a mechanically lined pipe (MLP) with upset pipe ends comprising at least the steps of:

- (a) forming the carbon steel outer pipe as a single length;
- (b) applying weld overlay deposit (on several layers if needed) on the inner surface of the carbon steel outer pipe to overmatch the required wall thickness of the upset end;
- (c) radial expanding of the carbon steel outer pipe ends and weld overlay by either cold or hot working followed by counterboring of the pipe end internal surface on the expended area to match the inside nominal diameter of the outer pipe;
- (d) forming the inner liner which is a Corrosion Resistant Alloy (CRA) liner made from alloy 316L, 825, 625 or other alloys as defined in API Specification 5LD and with a wall thickness of at least 2mm and at most 6mm

- (e) inserting the CRA liner pipe into the outer pipe;
 - (f) fitting tightly the inner liner within the pipeline to create the mechanical bond by expanding radially the liner inside the outer pipe;
 - (g) sealing the liner to outer pipe at each end of the MLP by seal weld / weld overlay and
 - (h) machining the seal weld / weld overlay area at each pipe end to match the nominal inside diameter of MLP.
3. A method as claimed in claim 1 or claim 2 wherein the diameter of the upset end is increased by at least 2 mm in respect with the nominal outside MLP pipe diameter.
4. A method as claimed in claim 1 or claim 2 wherein the upset end area, excluding the tapered area, is at least 50 mm and at most 250 mm.
5. A method as claimed in claim 1 or claim 2 wherein the tapered area of the upset end shall have a taper not steeper than 1:4 (14 degrees) and shall blend smoothly on both ends of the tapered area.
6. A method as claimed in claim 1 or claim 2 wherein the cut-back of the inserted liner shall be shorter than the longitudinal length of the upset end in order to place the liner to weld overlay transition area (triple point) in the upset end zone, thus reducing also the stress imposed to the triple point (points C-D on figure 2).
7. A method as claimed in claim 1 or claim 2 wherein the step (h) is not performed and the pipe end surface is left in as welded condition.
8. A manufactured MLP which is made up of:
- (a) a carbon steel outer pipe having upset ends; and
 - (b) a CRA liner inner pipe.