TFP and TFT back in town (Tight Fit CRA lined Pipe and Tubing)

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Abstract

At the end of the 1970s Kawasaki Heavy Industries, Ltd (KHI) developed CRA lined pipe for the Oil & Gas Industry, manufactured through a thermo-hydraulic shrink-fit process. These products were marketed as TFP (Tight Fit Pipe) for flow line use and TFT (Tight Fit Tubing) for down hole application.
In the mid 1980s KHI decided to transfer this shrink-fit pipe technology to Nippon Steel Corporation (NSC) who subsequently marketed it under their own trade name C-II pipe. Due to low demand in the 1990s NSC decided to stop manufacturing in 1995. Market conditions, however, have improved in later years due to strong focus in the Oil & Gas Industry on reduction of maintenance cost and a more serious interest into a life cycle approach for material selection. impulses especially for more environmentally friendly buildings. For this reason plans were developed to re-start manufacturing of TFP and TFT in Japan and Kuroki T&P Co, Ltd. have obtained an exclusive license from KHI for this manufacturing in 1999. It is Kuroki T&P Co's firm intention – besides the supply of TFP for flow line use – also to serve the OCTG market with CRA lined down hole production tubing (TFT). This tubing is available with the industry known NS-CC/CT premium connection. This paper presents an overview of existing know-how and expertise related to these thermo-hydraulic shrink-fitted CRA lined products including information on current testing exercises and R&D activities by Kuroki T&P Co.

1. Introduction

At the end of the 1970s Kawasaki Heavy Industries, Ltd (KHI) initiated R&D – in close cooperation with NAM in The Netherlands – on CRA lined flow line and down hole production tubing. Their pioneering work resulted in products with the trade names TFP (Tight Fit Pipe) and TFT (Tight Fit Tubing) for which KHI received Special Meritorious Awards for engineering innovation at OTC Conferences in 1980 and 1981 (1,2).

These products contain a corrosion resistant liner of high alloy material (any type of high alloy possible), which is mechanically fitted inside a carbon steel pipe through a thermo-hydraulic shrink-fit manufacturing process.
As KHI lacked a pipe and OCTG marketing and sales network, their management decided in 1985 to license the TF technology to Nippon Steel Corporation (NSC).

NSC subsequently built a plant to manufacture these CRA lined products and marketed their CRA lined flow line as C-II pipe.This pipe has proven to be a reliable product and has been applied successfully by Shell Oil (Mobil Bay-USA) and other Oil Cie's for severe corrosive service.

However, with low demand for this type of pipe in the1990s, NSC decided to discontinue manufacturing of C-II pipe in 1995.

Recent marketing studies have shown that demand for CRA lined products is growing because of strong focus nowadays on reducing maintenance cost and a more serious interest in life cycle approach for material selection.

For this reason plans were developed in Japan to re-start manufacturing of TFP/TFT and as a result Kuroki Tube & Pipe Co, Ltd. in Hikari City in Japan has obtained an exclusive manufacturing license from KHI for these products in 1999 and the new plant became ISO 9002 certified in 2002.

2. Principle of the Thermo-Hydraulic Shrink-fit Manufacturing Process and Field of Application for CRA Lined Pipe

In order to ensure a high and reliable fit-in (gripping) stress between inner and outer pipe, KHI opted in 1979 for a combination of hydraulic expansion and thermal shrinking for their double wall pipe manufacturing. This method comprises heating of a carbon steel outer pipe to about 300-400 degr. C in a so-called moving furnace after which this heated pipe is shifted over a high alloy water filled liner pipe.

The liner pipe is then hydraulically expanded till it fits tightly to the inner surface of the carbon steel outer pipe. The "composite" pipe is then further expanded but always within the elastic range of the carbon steel outer pipe. Thereafter the composed pipe is cooled in air during which process the CRA liner pipe is continuously cooled with water through its interior.

The effects of thermal and elastic shrinkage of the outer pipe as well as plastic expansion of the liner pipe ensure that the liner pipe is uniformly and well fitted against the outer pipe. The ultimate result is that the liner pipe is under compression (highly attractive for its resistance to stress corrosion cracking phenomena) and the outer pipe has a small residual tensile stress.
The fit-in stress can be arbitrarily controlled by its parameters i.e. the heating temperature of the outer pipe and the expansion pressure of the CRA liner pipe.

This thermal-hydraulic shrink-fit process is schematically shown in Figure 1.
Figure 3 shows the various parts of the equipment.

It is pointed out here that the resulting residual stresses in both pipes depend on the material flow stress characteristics of liner and outer pipe materials. High-alloyed nickel materials have usually a lower flow stress pattern than carbon steel, which results in a good fit-in stress between liner and outer pipe, see Figure 1. However, the situation is different if the flow stress of the liner pipe material is close to (or higher) than that of the carbon steel outer pipe, see Figure 2, where this situation is schematically indicated.

In the case of a higher flow stress pattern of the liner pipe material, see line b in Figure 2, a gap “g” between outer and liner pipe will result after assembly and it is only due to the thermal shrinking effect of the outer pipe during cooling that a compressive stress will develop in the liner pipe, although being lower in this case.The lower stress is then compensated by heating the carbonsteel outer pipe to a higher temperature prior to assembly (not drawn in Figure 2 in order to keep clearness in the picture). This situation occurs for example in a combination of duplex stainless steel material for the liner pipe and API-5L-Grade X60/65 for the outer pipe (usually selected for carbon steel flowline).

It is important to ensure that the surfaces of liner pipe (outside) and carbon steel outer pipe (inside) are clean, dry and defect free. The absence of oxides prior to assembly should get due attention because oxides often contain chemically bonded water which could lead to implosion of the CRA liner e.g. during external coating at elevated temperature or in service.

A defect free surface of both pipes at their interface is particularly important in case the pipe will be cold bent e.g. reeled because defects have the tendency to act as initiators for imperfect behaviour.

Furthermore, it is important to maintain a good control over the level and uniformity of the fit-in stress between outer and liner pipe after assembly. The residual compressive stress (fit-in stress) in the liner pipe can be measured with biaxial strain gages mounted on the inside surface of a lined pipe. From a pipe section containing the strain gauges the CRA liner is then taken out by saw cutting the outer pipe. The change in hoop strains and axial strains before and after take-out are measured from which data the fit-in stress can be derived.

It is complicated and costly to apply this destructive method and therefore NSC have developed a non-destructive sound reflecting method, which can be used on each produced pipe (3). In this system, an elastic wave emitted from one end of the assembled pipe by piezo-electric pulser is received at the other end of the CRA lined pipe, see Figure 4.

Thereafter the detected waves are processed and evaluated in terms of signal duration with a linear relationship found between this signal duration and the fit-in stress, see Figure 5. It should be noted that such a correlation has to be established for each pipe size.

At Kuroki T&P Co. both methods i.e. strain gage (at random) and production control with the sound reflecting method are applied during manufacturing of TFP and TFT.

CRA lined pipe is typically suitable for long(er) length pipelines and not for plant piping where fittings, valves etc. have to be connected (welded) and which usually contain sharp bends.
Very suitable applications are flow lines for corrosive oil and gas transport, for example from the well to manifolds or treating stations and for down hole production tubing in the case of production from corrosive oil and gas fields (CO_2/H_2S/chlorides etc.).

A typical advantage of CRA lined pipe is that liner and outer pipe can be optimally heat treated (strength for carbon steel outer pipe and corrosion resistance for CRA liner), prior to assembly.

CRA lined pipe products can compete with full body (solid) high alloy pipe materials if the required wall thickness is not too small, say over 6 to 8 mm, and becomes more attractive with increasing wall thickness of the load carrying outer pipe.
Economics are also influenced - apart from the liner thickness - by the type of high alloy required, particularly its nickel and molybdenum content, and savings will be larger if the required alloy contain more of these expensive alloy elements.
Application of CRA lined flow line could be much extended for offshore pipelines if it can be reeled. Installation cost for offshore lines usually exceed material cost and without reeling it is difficult to compete with full body high alloy pipe if this can be reeled.
For this reason a research project has recently been initiated in order to investigate, demonstrate and confirm the possibilities for reeling of TFP, see section 6.2.

3. Fit-in Stress Between Inner and Outer Pipe

With fit-in (gripping) stress, the circumferential residual stress at the internal surface of the inner pipe is meant in this paper.
A high and well-controlled fit-in stress can be seen as the core technology of Kuroki’s thermo-hydraulic lined pipe manufacturing process.
The parameters involved are the hydraulic pressure needed for liner and outer pipe expansion and the heating temperature of the outer pipe.

If only hydraulic expansion would be applied, very high pressures would be required to obtain a good fit-in stress. On the other hand, if the fit-in stress would only be obtained through shrinking of the heated outer pipe, a very tight gap between inner and outer pipe would be required in order to achieve a positive fit-in stress. Both conditions are schematically shown in Figure 6a (2) where, as an example, the relation ship between both parameters is plotted for various fit-in stresses in case of 7 mm thick 2 7/8 inch, API – 5CT, Grade L-80 outer pipe and 2 mm thick Inconel 625 as liner pipe material.

Figure 6a shows that if no heating of the outer pipe is applied and a fit-in stress of
10 kg/mm2 (or higher) is aimed, 2000 bar or more water pressure would be necessary whereby the outer pipe would be plastically deformed.
In case the outer pipe is heated to 350 degr. C without applying hydraulic pressuring, a maximum clearance of only 0.26 mm would be permissible between liner and outer pipe.This would be impractical for shifting the outer pipe over the liner pipe.

The advantage of the thermo-hydraulic system is that much lower hydraulic pressures can be applied and that the outer pipe need only be loaded elastically during expansion, see point 1 in Figure 6a.
The practical problem of shifting the outer pipe over the liner pipe is solved by applying a positive clearance of a few millimetres between liner and outer pipe and by

subsequently removing this clearance by plastic deformation of the liner pipe through hydraulic expansion.

Yoshida et al (1,2) and Mizumura et al (4) have done extensive investigations on thermo-hydraulically fitted double wall pipe. They studied, amongst others, the influence of the interfacial gap and fit-in stress on the risk of implosion of the CRA liner, its burst pressure, and the behaviour under cold bending load.
Matsui (6) also investigated the influence of heating TFP/TFT on the fit-in stress after manufacturing.

3.1 Risk for Liner Collapse (Implosion)

Concerns are sometimes expressed about a possible risk of liner collapse (implosion) due to the generation of hydrogen either from a corrosion action on the liner pipe surface or - more likely - due to cathodic overprotection of a pipe line.The hydrogen developed will diffuse as H+ ions through the walls of liner pipe and outer pipe respectively and will recombine as (non diffusable) H2 molecules at the interface of liner pipe and outer pipe and can result in a high hydrogen pressure at this location.
Such pressure build-up is also possible if cracks are present in the liner or due to the presence of - in this respect - harmful weld defects. Risk for implosion then occurs during rapid decompression of the line.

A close fit of the liner reduces the possibility of this dynamic buckling phenomenon although there is no common consensus on the specific influence of the height of the fit-in stress.

Mizumura et al (4) did not observe such an influence contrary to Yoshida et al (1) who observed a clear advantage of a higher fit-in stress on the onset of implosion, see Figure 6b.

Laboratory experiments at Battelle Columbus (USA) by Colwell et al (7) have shown that liner collapse of TFT does not occur under severe hydrogen charging.

Miyasaka et al (8) have demonstrated in a theoretical study that it would take more than hundred years for hydrogen pressure to reach the liner collapse pressure.
All these investigations support a conclusion that there is no reason for concern for implosion of the liner as long as there is an adequate mechanical bond between liner and outer pipe.

3.2 Burst Pressure

Regarding burst pressure it was found that this is higher for a double wall pipe (tests on C-II pipe of NSC) compared to a single wall pipe but that its actual value depends on the strength characteristics of the CRA liner material, see Figure 7 (4).

Two types of fracture modes were identified i.e. fracturing of the outer pipe only and fracture of both liner and outer pipe. Which fracture mode will occur depends on the rupture elongation of liner and outer pipe. For example, the first mentioned fracture mode usually occurs in case of an Inconel 625 liner pipe (has large rupture elongation) and the second one in case of duplex as liner material (4).

3.3 Cold Bending

Four point bending tests have been carried out on C-II pipe with 5.5 inch and 6 5/8 inch O.D. carbon steel outer pipe (API-5L, Grade X60 and X70) and Incoloy 825 liner pipe containing a girth weld at midlength (4).

Specimens were bent to a radius of curvature of 11 times the outside diameter. No buckling of the liner or crack in the weld occurred. However, on sectioning of the pipes after bending a regular pattern of wrinkles became visible at the compression side of the liner pipe.
These wrinkles were about 35 mm in pitch and about 1 mm in height. Subsequent implosion testing showed that these wrinkles did not reduce the implosion behaviour. On the contrary, implosion pressures appeared to be somewhat higher, most probably due to a slight thickness increase of the liner and strainhardening of the liner material prior to wrinkling (4).

Further tests by NSC on C-II pipe (5) have shown that wrinkling did not occur in C-II pipe if the bending curvature was more 25 times the outside diameter commensurate with 2% plastic deformation (axial) of the pipe according to the somewhat simplified formula:

R(adius)= 0.5xO.D(=outside diameter of the pipe)/e(=strain).

This would mean that for a 6 inch O.D. and a 10 inch O.D. thermo-hydraulically fitted double wall pipe the minimum curvature (R) should be 3.8 meter and 6.4 meters respectively to avoid buckling/wrinkling when subjected to bend loading.

Craig and Eckroth (9) have carried out cold bend tests with C-II pipe (6 5/8 inch O.D. API-5L- Grade X65 outer pipe, wallth. 7.1 mm and 3 mm thick Alloy 825 liner pipe).
They have investigated the tendency for wrinkling and buckling after 1, 2, 5.8 and 10 degrees bend angles corresponding to R/D of 63, 31,11 and 6 respectively.
They observed that some wrinkling started to appear at a 5.8 degree bend angle and that several buckles were visible at a 10 degree angle.
No wrinkling or buckling was observed after 1 and 2 degree bend angles (R/D of 63 and 31 respectively).

3.4 Heating of TFP/TFT after Manufacturing

Tests have been carried out by Matsui (6) to investigate the change of fit-in stress when TFP/TFT is heated after manufacturing. This could happen when the pipe is coated on the outside and will usually be the case under service conditions, particularly for down hole application (TFT).
Ring samples have been heated in an electric furnace to temperatures in the range of R.T to 750 degr. C.

The fit-in stress was measured by fixing strain gauges on the liner pipe surface and the stress change was measured by removing (saw cutting) the outer pipe material.
These measurements were done on 50mm wide ring samples of API-5L-Grade X52,
O.D. 273 mm, wallth. 9.3 mm outer pipe and AISI316L, wallth. 3 mm liner pipe), which were warmed up in an electric furnace to temperatures in the range of R.T to 750 degr. C.
The results are shown in Figure 8a.

It can be seen in this figure that the initial compressive stress i.e. fit-in stress in the liner pipe (9 kg/mm2 at R.T.) is maintained till about 200-250 degr. C.
This temperature is indicated as Ts.
Thereafter the fit-in stress decreases gradually and becomes zero when heated to
450 degr. C, which is called the vanishing temperature (Tv).

Further tests have shown, see Figure 8b, that Ts and Tv will increase if the fit-in stress is higher. It was also found that the higher the 0.2 % proof strength of the liner material, the higher Ts and Tv will be. With a fit-in stress of about 20 kg/mm2, the Ts and Tv for most CRA liner materials are about 350 degr. C and 600 degr. C respectively, and both temperatures are somewhat higher for duplex material types because of a higher 0.2 % proof strength.

These investigations confirm the importance of the fit-in stress on the behaviour of the mechanical bond and should therefore be taken into consideration in the design stage and in technical specifications.

4. Application as Flow Line (TFP)

4.1 Material Selection

The double pipe concept enables the selection of outer and liner pipe materials, which can each, be separately heat treated in the most optimum manner and thus can be freely selected for their respective roles.

In the case of TFP the maximum strength that can be selected for the outer pipe of flow lines (load carrier) will in almost all cases be determined/restricted by the strength properties of the welding consumables to be used for joining (circumferential welding) the pipes in the field. This welding can normally only be done from the outside.

Welding consumables will often be high Ni alloys or (super) duplex in case of a duplex stainless steel type liner pipe.
Real high strength properties in high nickel alloys can only be achieved if these can be age-hardened. However, such a heat-treatment is not permitted for thermo – hydraulically fitted double wall pipe because this would deteriorate the mechanical bond and the fit-in stress would be lost (even a positive clearance could appear).

Kuroki T&P Co can manufacture TFP (and TFT) with an outside diameter of 3.5 to 12 inch and with a wall thickness (carbon steel outer pipe) up to 32 mm. The min. CRA liner thickness is 1.5 mm for small diameter pipe and 2.0 - 3.0 mm for 6 -12 inch diameter pipe.
TFP (and TFT) is manufactured in standard length of 11.4 meters.

It is mentioned here that the quality of carbon steel ERW pipe has much increased over the years.There is ERW pipe on the market nowadays (HF-ERW type) with a quality comparable to that of seamless pipe or even better. This can equally be used for the manufacturing of TFP and TFT. The maximum wall thickness of HF-ERW pipe is currently restricted to 19 mm.

The longitudinal weld in ERW pipe is often regarded as the weak link from a corrosion point of view; however, this argument is not relevant for TFP/TFT because of the presence of the CRA liner pipe.

HF-ERW pipe has advantages for TFP/TFT manufacturing because of tighter tolerances and a better surface quality than seamless pipe (important for the quality of the mechanical bond in TFP/TFT). It is therefore the intention of Kuroki T&P Co to investigate the use of HF-ERW pipe for the outer pipe of TFP/TFT.

4.2 Welding Aspects

In order to make high quality circumferential welds it is necessary to seal the ends of the pipe first to prevent the possibility of contamination due to moisture, grease or dust accumulating between the liner and the outer pipe during the period between manufacturing and eventual installation. Such contaminants could lead to cracking as has been experienced in the past, see 4.4.1.

This seal welding can be achieved in various ways.The two methods which have been applied for TFP and C-II pipe in the past are shown in Figure 9 and prevent dilution of the root pass with carbon steel from the outer pipe.The seal weld filler metal is chosen such that the corrosion resistance of the seal weld preferably exceeds that of the liner material.
Method 1 has the advantage that no re-sealing is necessary in case of a cut-out of the weld (cumbersome in the field or on a lay barge).
The U-groove is favoured as weld preparation because the root pass is normally TIG welded (GTAW). For the hot and subsequent passes GTAW or pulsed GMAW welding is usually applied.

4.3 Specific Inspection Items

4.3.1 During Manufacturing and Construction / Installation

Apart from the normally applied destructive and non-destructive quality control measures during manufacturing of outer and liner pipe, it is important to inspect the full internal surface of the liner pipe visually and by eddy-current testing after its expansion (plastically) during manufacturing. It is also important to check at random the compressive residual stress (fit-in stress) on rings cut from the manufactured pipe. Furthermore, to check the fit-in stress non-destructively on every produced pipe. Both methods are standard procedure at Kuroki T&P Co. The sound reflecting method described in section 2. is applied as the non-destructive test method.

Specific attention (dye penetrant inspection) is also required for the pipe ends after preparation for circumferential welding (overlay welding/machining).

Inspection of circumferential welds during construction/installation needs special attention. X-ray is no problem, but the X-ray inspector should be aware that a double wall pipe is involved with a mechanical bond and he should be informed about the pipe end weld preparation (e.g. method 1 or 2 mentioned in 4.2).

If ultrasonic inspection is specified by the client special procedures should be developed due to the presence of two, three or four different materials in the welded joint i.e. carbon steel outer pipe, high alloy CRA liner, high alloy weld overlay at pipe ends and high alloy material of the circumferential weld (the high alloy materials are not necessarily the same). Furthermore, the mechanical bond, although not ending at the weld bevel, could cause deflection/scattering of ultrasonic waves during inspection of the circumferential weld. In this regard Method 1 as pipe end preparation is to be preferred, see Figure 9.

4.3.2 During Service

The possibilities for in service inspection are not as straight forward as for carbon steel pipe which can

be inspected by intelligent pigs, both ultrasonic and by flux leakage testing. Of these techniques only ultrasonic testing can be applied for crack detection in the CRA liner of double wall pipe with a mechanical bond.
Another possibility would be to provide an intelligent pig with an eddy-current device to check on the presence of cracks in the CRA liner. For both techniques, special practices/procedures have to be developed for application on CRA lined pipe.

4.4 Examples of Field Application

4.4.1. NAM -The Netherlands

The first application of TFP was at NAM in The Netherlands in 1981 (at that time TFP was manufactured by Kawasaki Heavy Industries). It concerned 10 inch O.D. API 5LX-Grade X52 outer pipe, wall thickness 9.3 mm and with a 3 mm thick AISI316L seam welded liner pipe.

Problems have occurred in the field because initially no seal welding at the pipe ends had been applied. During external coating of the pipe in The Netherlands (PE powder coating applied at around 380 degr. C) a very small - undetected - gap had been formed between liner and outer pipe at the pipe ends. During subsequent storage in the field (pipes were delivered in August 1980 and field installation took place in June 1981) moisture and dirt entered the gap. This eventually caused cracks to initiate at the location of this gap (triple point of three materials) during circumferential welding. These cracks propagated thereafter into the fusion line of the circumferential welds
After the pipe ends were cut off, re-machined and seal welded no further problems were experienced. These pipes had been in operation for several years without any problems. Thereafter wells in that area were shut-in and the lines taken out of service.

4.4.2. Mobil Bay - USA

Other applications, which are worth mentioning, are some executed projects of Shell (10), Louisiana Land and Exploration and Mobil in Mobil Bay-USA, where C-II pipe has been applied (installed in 1991-1996). The project involved the transport of high pressure, hot, sour gas from wellhead platforms to a central facility platform.

A typical example of the gas composition was: 2.1 % H2S, 6.0 % CO2 and 4.9 % water with a temperature of 110 degr. C at the well head before entering the flow line which was designed for a pressure of 757 bar. All these applications have been successful.

4.4.3. Madden Field - Burlington Resources, Wyoming, USA

Corrosive conditions in the Madden field are amongst the most severe in the world of oil & gas production and a typical example is:

Wellhead temperature 149-163 degr. C Wellhead pressure: 345 bars
12 % H2S and 20 % CO2
15bbl water per MMSCF with 500 ppm chloride elemental sulphur in gas phase (progressively condensing as the gas cools).

C-II pipe has been used for the transport of this gas and in all cases API 5L-Grade X65 was used as outer pipe and a 3 mm thick Incoloy 825 seam welded pipe as liner pipe. Details of these applications, which have been very successful, are well described in communications of Craig et al (9,11).

5. Application as Down Holeproduction Tubing (TFT)

As yet there is not much experience with the use of CRA lined down hole production tubing.
Smith and Celant (12) have indicated six possible reasons why clad tubing has not seen wider application but feel that "despite of these reservations, it seems that clad tubing is an under-utilized product". Colwell et al (7) concluded in 1989 from an extensive study on bi-metallic tubing (with TFT also tested) that this type of tubing is feasible as production tubing although they stated that more efforts would be required, especially in the area of connections.

Other possible reasons for this scarce application are:

1. Despite many efforts by leading pipe manufacturers in the world, it has not been possible in the past to manufacture defect free metallurgical bonded seamless clad pipe with diameters beyond 6 inch in sufficient length. Disbonding problems led to production yields too low for commercial production.
2. Clad and CRA lined tubing ask for a threaded connection, for which special manufacturing methods are necessary, particularly overlay welding of pin-end and coupling.

Eventually only NSC had the firm intention to go into the OCTG market in the early 1990s, however, not with metallurgical bonded but with CRA lined production tubing (C-II pipe). They carried out much development work in this respect including laboratory and field tests with their NS-CT/CC premium connection until 1995 when - as mentioned in the introduction - it was decided to stop with the manufacturing of C-II pipe altogether.

Kuroki T&P Co. can manufacture similar CRA lined production tubing in the diameter range 3.5 -12 inch with the NS-CT/CC premium connection which has been adopted as their standard connection for TFT (see also 4.1)

Kawasaki Heavy Industries (KHI) have manufactured in the past (1984) some down hole production tubing (TFT) for NAM in The Netherlands and BEB in Germany (1987), details of which are as follows:

5.1 NAM - The Netherlands

The application was one full string of 3.5 inch tubing with API 5CT, Grade L-80 outer pipe (wallth. 4.94 mm) and a 1.5 mm thick seamless duplex liner (2205 type). A VAM type (Vallourec) threaded connection was applied. Field conditions (oil with large amount of water) were:

well head pressure: 90 bars
well head temperature: 43 degr. C
H2S: 30 ppm
CO2: 1.2 %
NaCl: 83 gr/l

This string has been in operation for about two years. Unfortunately the well was shut-in after that period due to the decline of the oil field. No corrosion issues have been reported during the exposure time.

5.2 BEB - Germany

At BEB a 6 meter long 3.5 inch O.D. TFT tubing with two connections has been installed in a corrosive gas well in 1990. Outer pipe was C90-S with a wall thickness of 4.95 mm and the liner pipe consisted of 1.5 mm thick Inconel 625. A TDS (Mannesmann) threaded connection had been applied.

Field conditions were (12) :

well head pressure: 200 bars
well head temperature: 140 degr. C
H_2S: 30 %
160,000 ppm Cl-
elemental sulphur

This test piece was inspected after two years service and returned to service at that time. The performance has been very successful albeit that the tubing was not subjected to the above mentioned worst anticipated corrosive conditions.

6. Current Testing and R&D

6.1 Current testing

Testing efforts at Kuroki T&P Co are focused on qualification testing of TFT with the NS-CT/CT premium connection in accordance with ISO Specification 13679 (Casing and Tubing Connection Testing). At this moment (July 2003) such qualification testing is being carried out at Oil States Industries (UK) Ltd in Aberdeen on TFT i.e. 7 5/8 inch O.D, 33.7lb/ft, Grade L-80 outer pipe and 2 mm thick Alloy 31 as CRA liner and a NS-CC premium connection.

In addition to this ISO qualification testing, also corrosion testing - both coupon and full scale testing - is/will be carried out in order to test the welded joint of Alloy 31 and the weld overlay material (725NDUR) in the pin-end area in a corrosive environment specified by one of our potential customers.

The full-scale corrosion test is mainly a test to confirm the tightness of the connection under simulated field conditions.

6.2 R&D

Kuroki T&P Co is of the opinion that TFP is suitable for reeling installation for which - in the authors' opinion - a high fit in stress is most probably a prerequisite.

Some tests have already been carried out in the past at Heriot Watt University in Edinburgh on C-II pipe of 7.28 inch, 10.75 inch (2x) pipes (13). Two tests were successful and one of the tests on 10.75 inch dia pipe failed. Subsequent investigations showed that the inner surface of the carbon steel pipe contained a significant spiral shaped defect where wrinkling / buckling had initiated.

In order to investigate and confirm under which quality conditions TFP can indeed be reeled and to establish the boundary conditions for reeling installation, a research project has been initiated in The Netherlands (CPR project).
Partners in this project are Heerema Marine Contractors, Delft University of Technology (Faculty of Civil Engineering and Geosciences), DOSTO Engineering (materials & corrosion consultancy) and Kuroki T&P Co. in Japan.

This 3-year project, which is financially supported by the Netherlands Ministry of Economic Affairs has commenced in October 2002.

7. Conclusions

7.1

There is proven experience that CRA lined pipe manufactured by the thermo-hydraulic fitted manufacturing process is a reliable product.

7.2

There is good operational experience with the use of this type of CRA lined pipe in corrosive environments in the Oil & Gas industry, as flow line (both on and offshore) and as down hole production tubing (only onshore and limited experience).

7.3

The thermo-hydraulic manufacturing process has the advantage that CRA lined pipe can be manufactured with:

1. A well controlled fit-in stress and a wide range of fit-in stress levels.
2. Wall thickness of the carbon steel outer pipe up to 32 mm.
3. All kind of CRA liner pipe materials incl.duplex types.

7.4

Own experiments (KHI and NSC) and investigations by Battelle Columbus (USA) have demonstrated that TFP/TFT is not susceptible to liner implosion under severe hydrogen charging.

7.5

Tests have demonstrated that TFP/TFT can be cold bent to a curvature of about 25-30 times the outside diameter without causing wrinkling and/or buckling of the liner pipe.

7.6

When TFP/TFT will be heated, the fit-in stress will be maintained to a temperature dependent on the initial fit-in stress and the 0.2 % proof strength of the liner material after expansion in the carbon steel outer pipe.

7.7

The authors are of the opinion that TFP can be reeled. However, the conditions under which this can be done have still to be established and is subject of a current research project.

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Figures

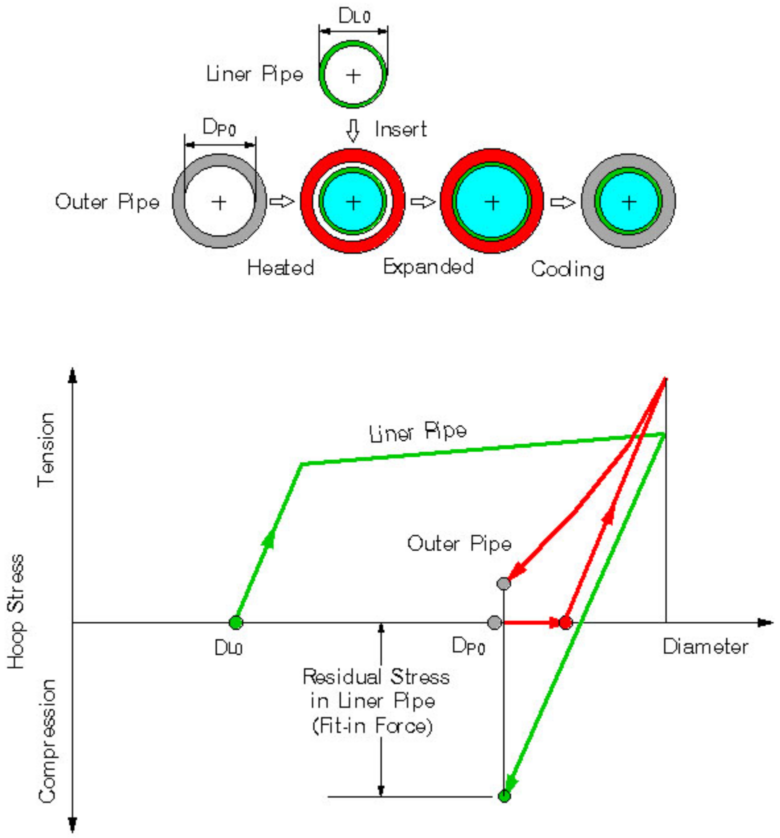

Figure 1 Thermo-hydraulic fitting method for TFP & TFT

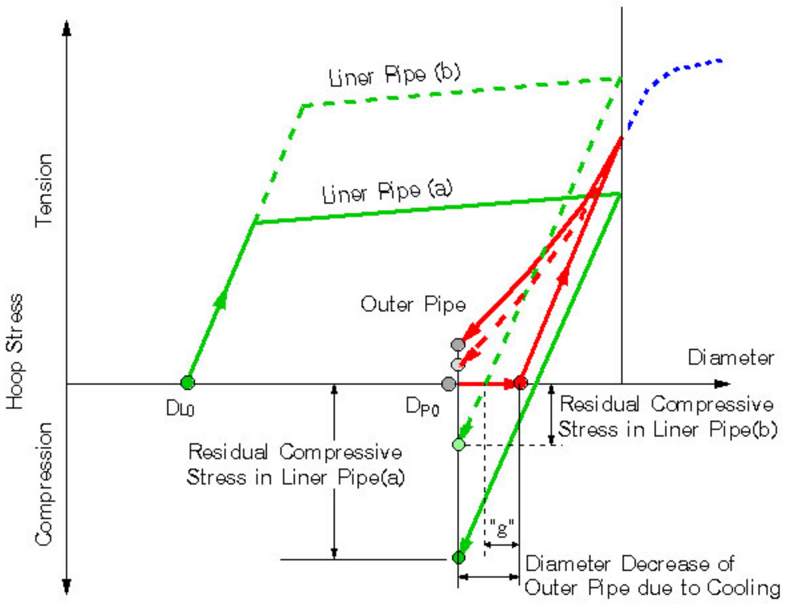

Figure 2 Fit-in stress in case of lower (a) and higher (b) flow stress pattern of liner pipe material

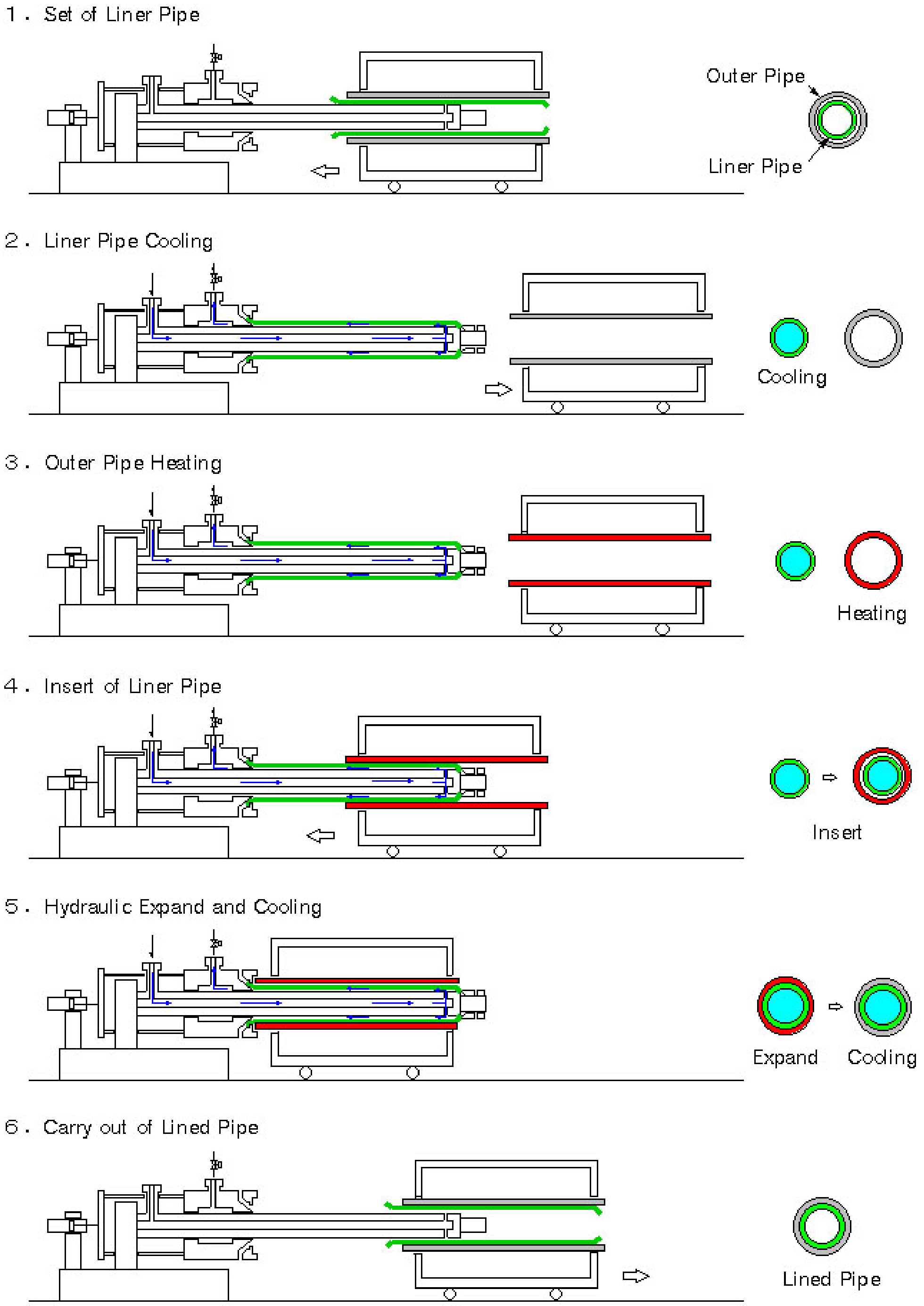

Figure 3 Thermo-hydraulic fitting process

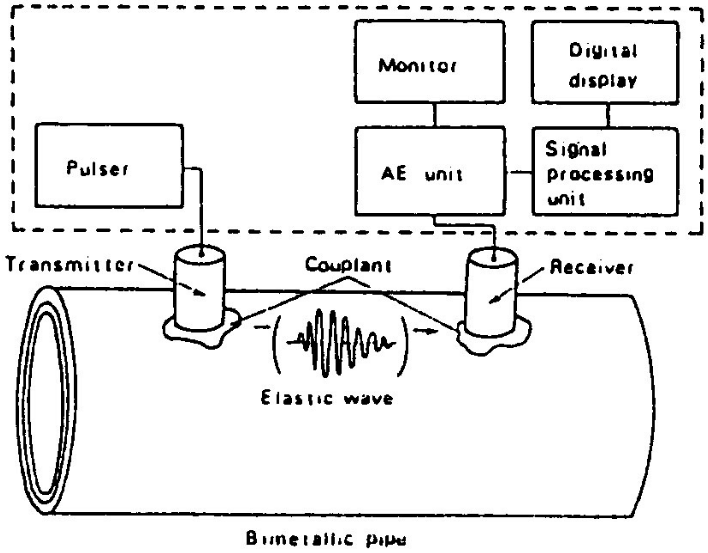

Figure 4 Measuring system of fit-in stress (3)

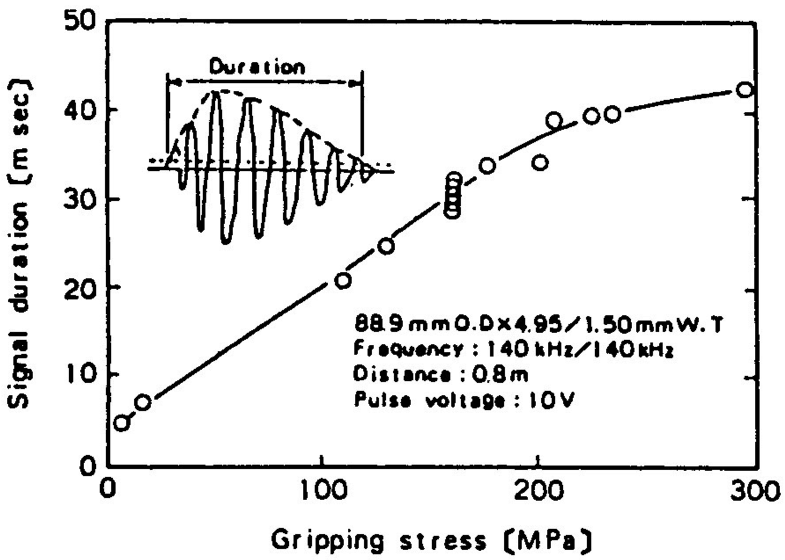

Figure 5 Signal duration vs. fit-in stress (3)

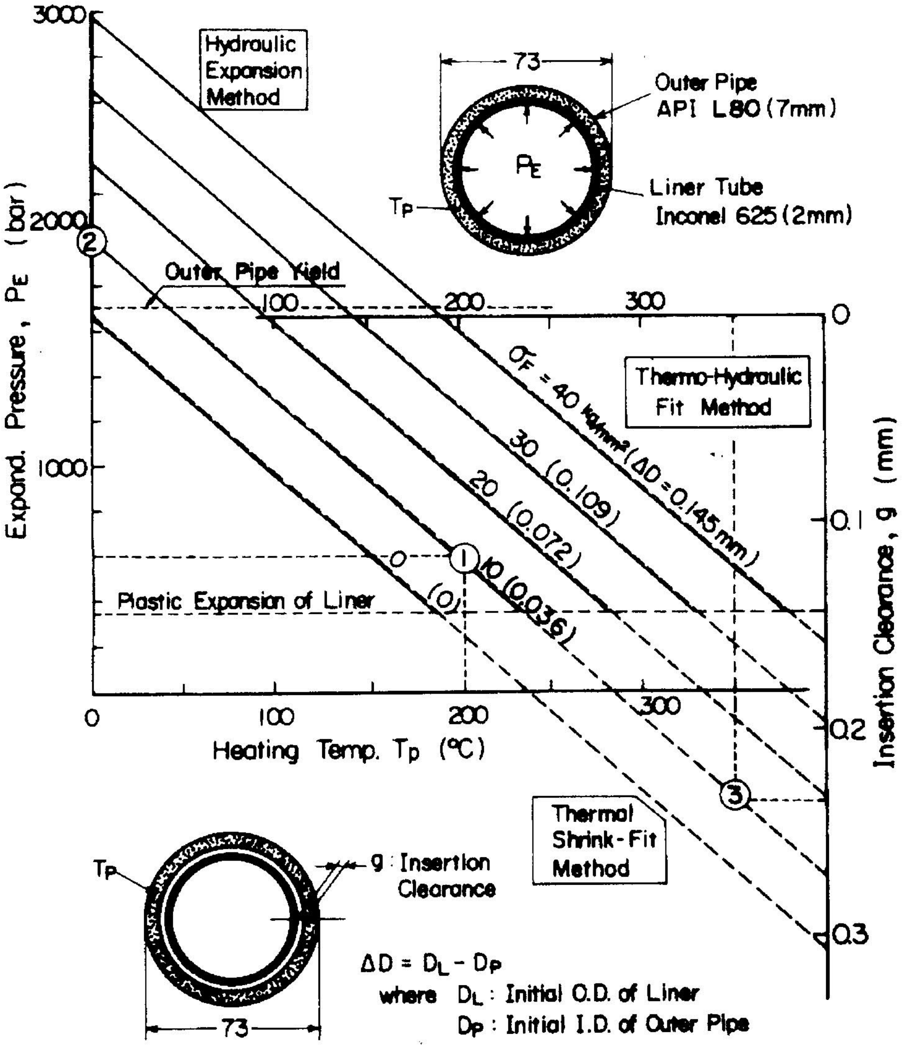

Figure 6a Basics of thermo-hydraulic expansion process (2)

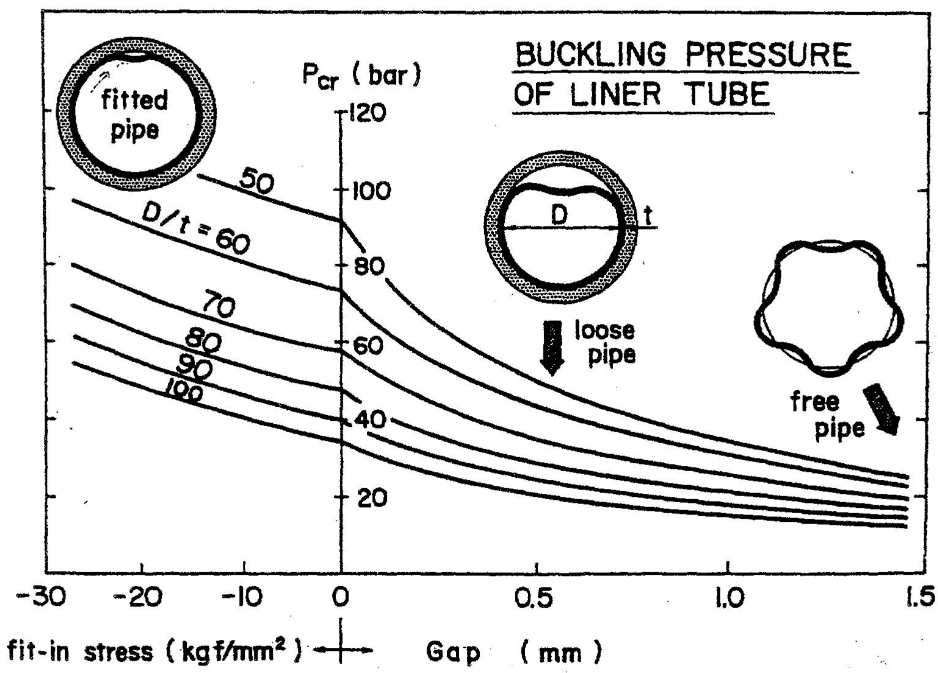

Figure 6b Buckling (implosion) strength of liner tube (1)

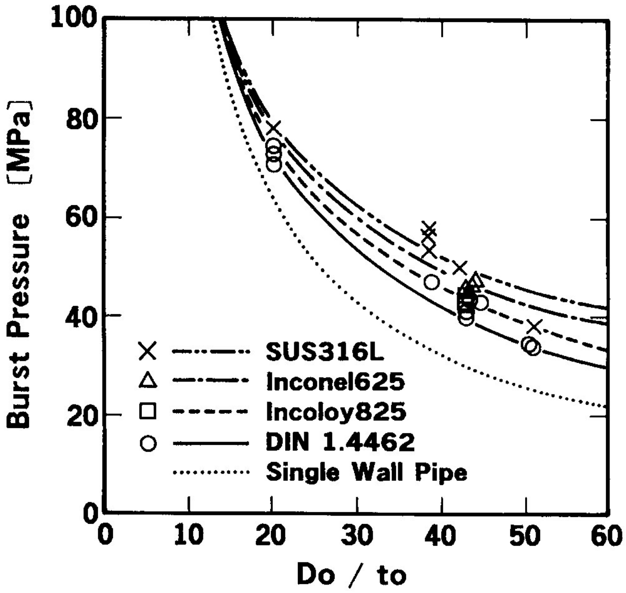

Figure 7 Burst pressure of double-wall pipe (4)

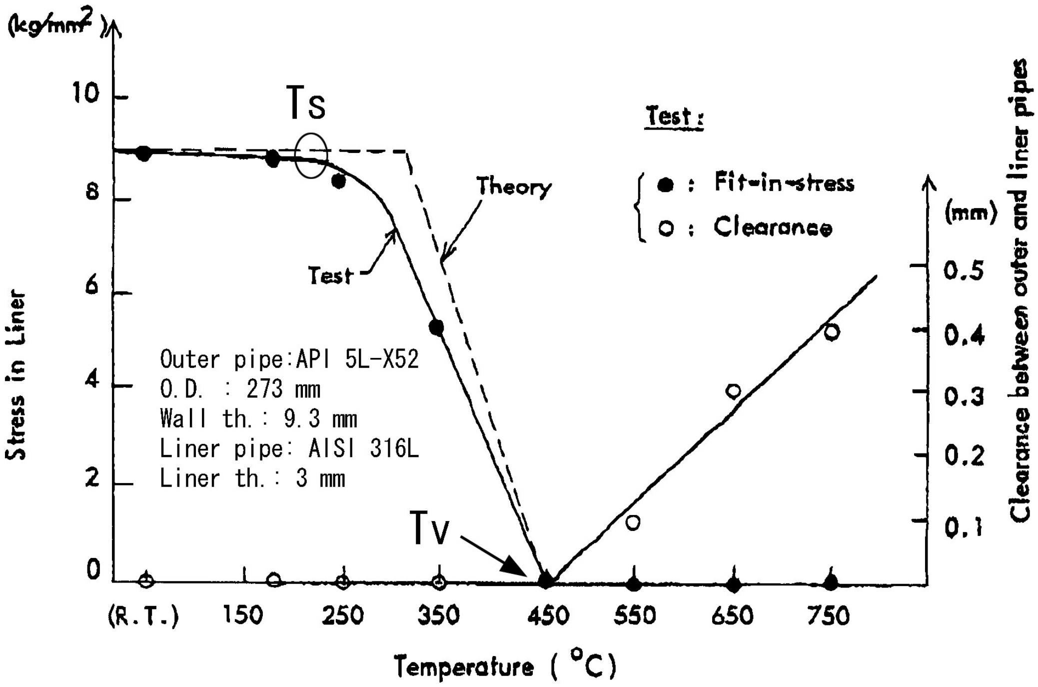

Figure 8a Influence of heating on fit-in stress of TFP/TFT with initial fit-in stress of 9 kg/mm2 (6)

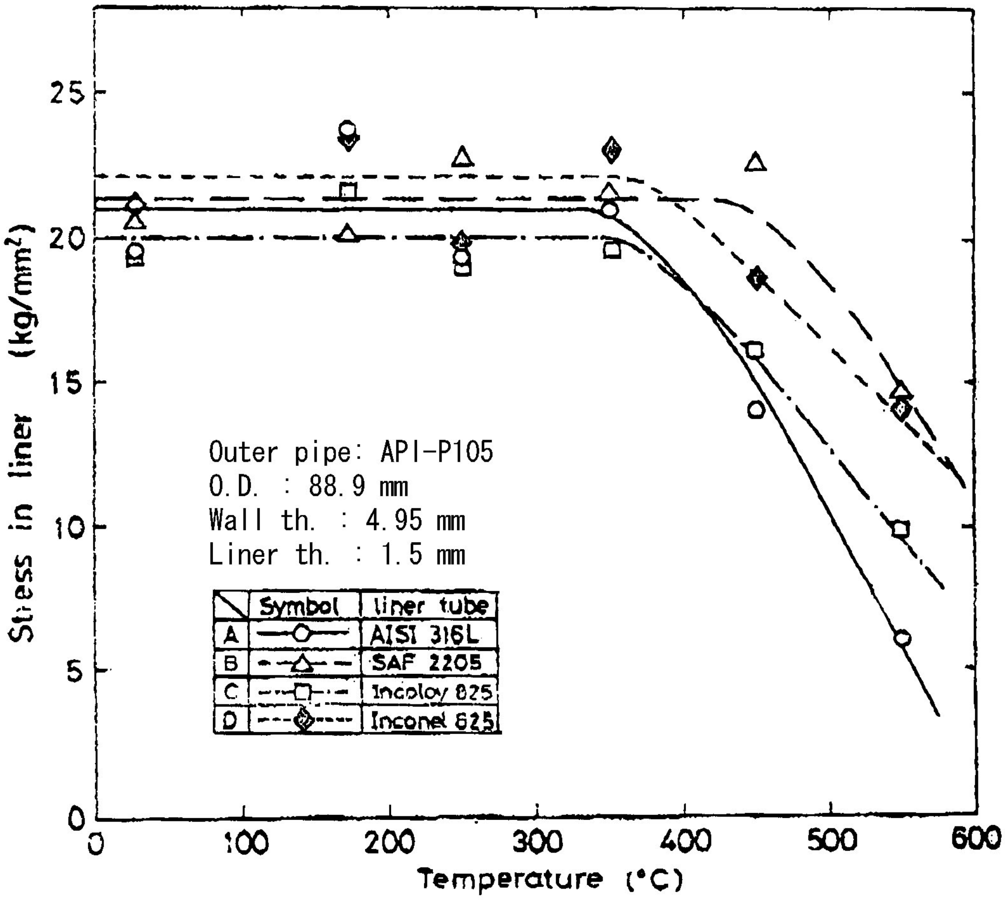

Figure 8b Influence of heating on fit-in stress of TFP/TFT with initial fit-in stress of ~ 22 kg/mm2 (6)

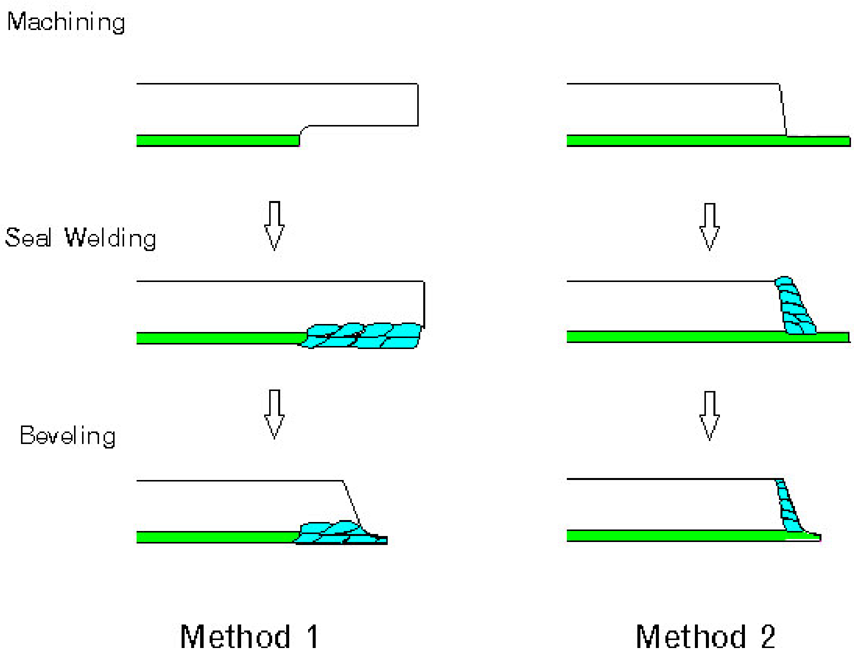

Figure 9 Methods for weld preparation at pipe ends of TFP