**BERG-LAY®: A new production method for CRA Lined Steel Pipe based on sheet metal**

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**Abstract:**

Over the past 25 years, altogether more than a 1000 km of pipeline with Corrosion Resistant Alloys (CRA) have been successfully applied for carrying wet, corrosive oil and gas product streams providing an outstanding service record.

Still there is a growing demand for CRA Lined Pipe due to the fact that corrosive conditions will increase significantly in the future as the produced fluids will contain higher water cuts and greater concentrations of hydrogen sulphide H₂S and carbon dioxide CO₂. In addition, these increasingly corrosive products need to be transported over longer distances and with higher pressures, yet in a reliable and environmentally benign way.

Considering operating expenditures over the pipeline design life versus capital expenditure costs, CRA lined pipe is a very interesting solution for preventing corrosion related problems, if a suitable corrosion resistant material for the respective service condition is selected.

Owing to a lack of supply capability for CRA-pipes, however, which is partly due to the limited capacities of semi-finished CRA clad materials (i.e. hot roll-, weld-overlay and explosive bonding) potential exploration projects will be jeopardized.

The paper will give an introduction into the state-of-the-art processes to produce CRA clad and lined pipe, introducing BERG-LAY®, the new, innovative and patented way of manufacturing CRA rolled lined steel pipes based on flat plate materials.

This manufacturing process for mechanically bonded CRA Lined Steel Pipe is based on two separate plates, i.e. usually carbon steel to meet the pressure loads as backing material and CRA to suit the corrosion resistance, and offers several competitive advantages:

- A virtually unlimited range of materials can be combined
  - The applied process has no limitations due to mismatching material properties, i.e. mainly yield strengths
- Lower costs due to use of sheet metal instead of metallurgical bonded materials or pipes as semi-finished product material at the beginning of the manufacturing process
- Short “order to market”-time frame due to better availability of sheet metal
- Pipe diameters available ranging from 16 to 100 inches, pipe lengths random up to 40 feet
1. Introduction to corrosion resistant pipes for oil and gas production
In order to ensure the world's need for energy, there are continuing explorations of oil and gas fields which yield high levels of water, H₂S and CO₂, in combination with high pressures and high temperatures (HPHT). There is an increased emphasis to develop corrosion resistant solutions for the long-term transport of these products in a technical reliable, environmentally safe and cost efficient way since under these sour service conditions carbon steel pipe on its own cannot withstand both, mechanical loads (pressure, temperature) and chemical attacks resulting in various forms of corrosion, e.g. CO₂ corrosion, stress corrosion cracking or pitting. Measures against internal corrosion and providing corrosion control for pipelines are major cost items, and there are surveys indicating that in the U.S. about 60% percent of all maintenance costs in offshore oil & gas exploration and production are directly related to corrosion, adding up to several billions of US-$ per year for tubular corrosion in the U.S. oil and gas industry /1, 2/.

One way to prevent corrosion is to inject corrosion inhibitors into the flowing media during operation. However, this can become a very cost intensive method, since inhibitors, necessary inspection (pigging) and maintenance as well as the waste disposal add up operational expenditures (OPEX) over the whole operational life time of a pipeline, which can be in the range of 15 up to more than 25 years. In addition to variations in inhibiting efficiency, corrosion inhibitors therefore may face technical limitations especially in remote operations, in deep sea applications and at higher temperatures /2, 3, 4/.

Figure 1: CAPEX vs. OPEX for carbon steel + inhibitor and CRA pipes /3/

With a design life of more than 15 years and “Life Cycle”-costs in mind, the use of Corrosion Resistant Alloys (CRA) is a viable alternative to carbon steel in combination with a corrosion inhibitor injection (Figure 1). Despite higher capital expenditures (CAPEX) at the beginning due to higher materials costs and fabrication methods, it may be a more cost efficient solution in the long run after all, since it reduces inspection and maintenance costs, and costs for corrosion inhibitors and waste disposal don’t exist.

1.1 Introduction to materials for corrosion resistant pipes
Potential applications for pipes with CRA material are therefore subsea pipelines for sour gas and oil, water re-injection systems, saltwater pipelines, geothermal power plants,
process pipes in the chemical industry and multiphase pipelines for gas, fluids and solid parts.

CRA materials with a long record of successful applications in oil and gas production are for example duplex stainless steels, super-duplex stainless steels, 316L, Incoloy 825 or Inconel 625. The selection depends on the corrosive and/or abrasive loads, as well as other operating conditions (pressure, temperature), but also on material costs. An overview of successfully applied materials for CRA pipes relating material costs and yield strength is shown in Figure 2.

Figure 2: Cost of pipeline materials related to yield strength

In order to manufacture corrosion resistant pipes with CRA’s, different approaches can be taken (Figure 3), i.e. they can be made of solid CRA material, or with as CRA clad (i.e. metallurgically bonded) or CRA lined steel pipe with a mechanically bond between CRA and backing steel.

Figure 3: Overview of manufacturing routes for corrosion resistant pipes

1.2 Pipes made out of solid CRA
This is a cost intensive way since these materials are expensive and in addition require specific heat treatments after forming and welding, e.g. in order to prevent formation of undesired metallurgic phases. In some applications, e.g. in acidic environments some stainless steels und mechanical loads show susceptibility towards specific types of corrosion, e.g. pitting corrosion or sulphide stress corrosion cracking (SSCC).
1.3 CRA clad and lined steel pipe
This approach combines the advantage of a high strength carbon steel outer pipe (backing steel) with an inner layer of corrosion resistant alloy, yielding improved pipeline availability at lower operational cost. Over the past 25 years altogether more than a 1000 km CRA pipelines have been successfully applied for carrying wet, corrosive oil and gas product streams providing an outstanding service record. Depending on the way of bonding of the CRA material to carbon steel, one distinguishes between metallurgical bond (CRA clad pipe) and mechanical bond (CRA lined pipe).

1.3.1 CRA clad steel pipe (metallurgical bond)
The metallurgical bond between 2 different metals is achieved by hot rolling, co-extrusion, weld overlay or explosive bonding. All these manufacturing methods are expensive since they do require additional steps and efforts, e.g. manufacturing, welding and special heat treatments of packages. In addition, these required processes are limiting the material selection, as e.g. not all metal combinations can be roll-bonded for reasons mainly related to basic material properties. Furthermore, the worldwide capacities for roll-cladding and explosive bonding are limited.

1.3.2 CRA lined steel pipe (mechanical bond)
In order to achieve mechanical bonding between the backing steel and a CRA material there are mainly two manufacturing routes: expanded lined and rolled lined steel pipe. In addition to the different manufacturing steps they differ significantly in the magnitude of the achievable bonding force between inner CRA layer and backing steel, which is also called gripping force or grip.

1.3.2.1 Expanded lined pipe
For expanded lined pipe a CRA liner, e.g. a seamless tube is inserted into an outer carbon steel tube followed by an expansion process. At first the inner liner pipe is expanded until it fits tightly into the inner surface of the outer carbon steel. Then this ‘double layer pipe’ is further expanded. When the expansion force is removed, both pipes will relax elastically due to the spring-back. The bond force is the result of the differences in yield stress of the outer pipe and the liner upon unloading, i.e. after the expansion process.

Taking into account that there is always a spring-back effect of the materials under consideration in the expansion type lining processes, the magnitude of the bond force is a direct function of material properties. The highest compression in the interface between CRA liner and backing steel pipe is achieved when the yield of the inner CRA liner is about 50% of the yield strength of the outer pipe.

In the case for a super-duplex stainless steel liner (1.4410; Rp_{0.2} ≥ 515 N/mm²), duplex stainless steel (1.4462; Rp_{0.2} ≥ 445 N/mm²) or Inconel 625 (2.4856; Rp_{0.2} ≥ 275 N/mm², solution annealed) this would “require” an outer pipe yield strength Rp_{0.2} of ~1000 N/mm² or 550 N/mm², respectively. However, API 5L describes for typical line pipe material like X52 a minimum yield ≥ ca. 360 N/mm² and for X65 ≥ ca. 450 N/mm², respectively.

For reasons of physics and material properties rather low grip can therefore be achieved for expanded lined pipes with these material combinations. Taking this manufacturing route, a sufficient grip can be expected only for liner materials such as 316 L SS (1.4404; Rp_{0.2} ≥ 205 N/mm²), 304 L (1.4306; Rp_{0.2} ≥ 185 N/mm²), 904 L (1.4539; Rp_{0.2} ≥ 205 N/mm²), or Incoloy 825 (2.4858, Rp_{0.2} ≥ 240 N/mm²), in combination with X52 or X65 as typical backing steels.
Some lined pipe manufacturers therefore apply additional heat to the outer pipe before and during the expansion process in order to provide additional compressive stress through shrinkage when the heat is removed afterwards (thermo-hydraulic manufacturing method).

Gripping force and how it really affects the pipes’ integrity during installation and service is still under research, yet is viewed to be beneficial to prevent buckling and wrinkling during bending of the liner, which takes place e.g. during reeling processes for off-shore pipeline laying.

1.3.2.2 Rolled lined pipe
Lined pipe may alternatively be made by co-rolling a sandwich of a carbon steel plate and a CRA plate into a cylinder followed by longitudinally welding the long edges to form a seam in the backing steel and the CRA liner materials /5/. This is exactly the unique path of manufacturing CRA lined pipe described as BERG-LAY®, which over-comes the restrictions mentioned and provides additional advantages and benefits.

2. The unique BERG-LAY® manufacturing process for CRA pipes
The manufacturing of BERG-LAY® starts with separate 2 flat plates from materials that suit the different needs, e.g. corrosion or erosion resistance for the inner layer and pressure containment for the outer pipe. No complex semi-finished CRA products (clad plate or seamless pipes) are required. Flat plates of these plain materials as base materials are available from several suppliers without extensive lead time.

Cut to calculated dimensions, these flat plates (after inspection and cleaning) are partially tack welded together, before the normal pipe forming process starts, e.g. with a 3-roll bending machine, see Figure 4. When a specific, through calculation pre-determined state in that forming process is reached (see Figure 5), the inner liner plate is fixed by TIG welding to the backing carbon steel plate on both sides along a line parallel to the long seam. Then the pipe forming process is continued (Figure 6).

Figure 4: The beginning of the BERG-LAY® manufacturing process of a pipe in a 3-roll bending machine; backing steel X 52 (22.7 mm) and duplex liner (3 mm, 1.4462)
The generation of the gripping force takes place during this final pipe forming process, i.e. the completion of the pipe. As it is independent of the selected materials and therefore specific material property combinations like yield stress, the maximum physically attainable grip is achieved. The relationship between material properties of backing steel and CRA liner is shown for different manufacturing paths for mechanically bonded lined pipe in Figure 7.
For BERG-LAY\textsuperscript{®}, the whole range of Rp\textsubscript{0.2} for typical backing steels and liner materials is technically feasible. Especially interesting for “sour service conditions” of oil & gas production is the upper range of liner materials with Rp\textsubscript{0.2} values ≥ 350 N/mm\textsuperscript{2}, e.g. Inconel 625 in the soft annealed condition, duplex steels and super duplex steels. With values for Pitting Resistance Equivalents (PRE) of ≥ 40 these materials guarantee a high resistance against pitting corrosion.

As described earlier (refer to 1.3.2.1), standard manufacturing processes of expanded lined pipe can reach maximum gripping forces only when Rp\textsubscript{0.2} liner / Rp\textsubscript{0.2} backing steel ∼ 0.5 is given. Beyond that line, expansion processes cannot work due to physics and materials science. Thermo-hydraulic manufacturing routes for expanded lined pipe may reach a little bit into the region between values for (Rp\textsubscript{0.2} liner / Rp\textsubscript{0.2} backing steel) ∼ 0.5 and 1.

As indicated in Figure 7, the full spectrum of materials feasible is a significant advantage of BERG-LAY\textsuperscript{®} compared to the small range of material combinations suitable for expanded lined pipe. In Figure 10 the tight fit due to the compressive stress is shown for duplex stainless steel as liner material, in Figure 11 for CuNi10 as liner material.

BERG-LAY\textsuperscript{®} offers here a truly free selection of materials, tailored for any specific applications that require for example lining materials with high yield strengths.

When forming is completed, common steps like longitudinal outside tack welding, inside SAW welding and outside SAW welding of carbon steel, followed by NDT are standard for longitudinal welded pipes, following known specifications and standards, e.g. DNV OS-F101, API 5L or API 5LD, respectively.
After circumferential seal welds on both ends of the liner are made, the longitudinal gap between the liner ends is overlay welded as well (Resistance Electro Slag Welding, RES), see Figure 8.

**Figure 8:** View of a BERG-LAY® pipe in the process of longitudinal RES welding to provide corrosion protection

The welding material is selected to overmatch the corrosion resistance properties of the liner material. The same material is used for the circumferential overlay welding, see Figure 9. Where applicable, all these steps are quite common for CRA lined and clad pipe, both metallurgically and mechanically bonded /6/.

**Figure 9:** View of a BERG-LAY® pipe during circumferential RES overlay welding
The pipe is then tested and inspected, and finally a pipe end bevelling takes place according to customer specifications, an overview of all manufacturing steps, from plate preparation up to testing and bevelling is given in Figure 12.

Figure 10 shows the tight fit due to the compressive stress for a duplex stainless steel liner material, in Figure 11 for a CuNi10 liner material.

**Figure 10:** View of the tight fit between liner plate (3 mm, 1.4462) and backing steel plate (22.7 mm, X 52)

![Figure 10 Image]

**Figure 11:** View of the tight fit between liner plate of a test pipe, outside: carbon steel plate (9.5 mm, grade B); inside: CuNi10 (5 mm)

![Figure 11 Image]
2.1 Advantages of BERG-LAY® pipes  
The manufacturing process described above is a very flexible one and by-passes some of the known limitations of other existing CRA clad or lined pipe manufacturing.

The advantages are:

- Practically unlimited combination of materials
- Inside and/or outside linings are possible
- Lower costs due to use of sheet metal instead of metallurgical bonded materials or pipes at the beginning of the manufacturing process
- Short “order to market”-time frame due to easier availability of sheet metal
- The attainable grip can reach the maximum of the physically achievable limits

All these allow efficient manufacturing of BERG-LAY® even for small lots, an overview of manufacturing steps taken from plate preparation to final release is given in Figure 12.

**Figure 12:** Overview of the manufacturing processes for BERG-LAY®
3. Existing BERG-LAY\textsuperscript{\textregistered} applications and passed tests

In the following some of the manufactured BERG-LAY\textsuperscript{\textregistered} pipes are shown, e.g. for an application in chemical industry (Figure 13).

Figure 13: View of 2 pipes manufactured for ENI (Italy/Iran)
Diameter 914 mm, Liner plate (3 mm, Inconel 625) and outer carbon steel plate (34 mm, X 65)

CalEnergy in the U.S. needed corrosion resistant pipes for geothermal energy power plants. The hot water from geothermal sources contains very aggressive ingredients causing severe corrosion. After several preliminary tests they therefore selected CRA lined pipes with liners of duplex (1.4462) and super duplex (1.4410) stainless steels. The pipes were delivered in February 2009, installed in April 2009. First field test results are still to be collected.

Figure 14: View of 5 pipes manufactured for CalEnergy (USA), Diameter 610 mm, Liner plate (3 mm / 5 mm, duplex) carbon steel plate (12.7 mm, X 52) and Liner (5 mm, super duplex) carbon steel plate (12.7 mm, X 65)
4. Conclusions
Meeting the increasing demand for CRA clad and lined pipe for the future is an important challenge worldwide. Limited supplies for metallurgical bonded material combined with high material and process costs are blocking further exploration of gas and oil fields with increasingly sour service conditions.

In this environment, BERG-LAY® is providing a tailored material combination with a very high compressive stress (gripping force) in a mechanical bonded CRA lined pipe at significantly reduced CAPEX compared to other lined or clad pipe solutions due to

- less expensive base material (i.e. flat plate)
- short lead times due to availability of flat plate and
- simple manufacturing process chains allowing for high output rates

in a short “order-to-delivery” time frame.

Following worldwide acknowledged standard, e.g. API 5LD, BERG-LAY® provides additional higher grip, yet faster and at lower cost and thus fulfils all of the desired properties of CRA lined pipes for future applications.

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