Development of 3D clad bend fabricated from large diameter heavy wall X65 TMCP pipe

Markus Bockelmann, Curtis Prothe[1], Marion Erdelen-Peppler[2*], Gernot Heigl[3], Elke Muthmann[4]
* corresponding author

[1]Nobel Clad
Dr.-Hermann-Fleck-Allee 8
57299 Burbach
Germany

[2]Salzgitter Mannesmann Forschung GmbH
Ehinger Straße 200
47259 Duisburg
Germany

[3]Eisenbau Krämer
Karl-Krämer-Str. 12
57223 Kreuztal-Kredenbach
Germany

[4]Salzgitter Mannesmann Grobblech GmbH
Wiesenstraße 36
45473 Mülheim an der Ruhr
Germany

1   ABSTRACT

Increasingly challenging conditions especially with respect to corrosive oil and gas properties lead to an increase in demand for pipes and related products serving in transportation with outstanding corrosion resistance. The selection of most suitable material that is both technically and economically viable is a key issue in pipeline projects.

While carbon steel produced in thermo-mechanically controlled process (TMCP) has well documented mechanical properties including very good toughness alongside excellent weldability it does have certain limits concerning corrosion resistance. These can be overcome by utilising corrosion resistant alloy (CRA) material which, in case of large diameter products, is used as clad layer to protect the carbon steel that supplies the load carrying capacity. Production of TMCP clad bends requires additional dedicated experience and know-how to retain mechanical properties after induction heating as well as quenching and tempering of the mother pipe.

This investigation presents the results of a development of X 65 clad bends with an outer diameter of 24". The plate, that had a lean chemistry that is typical for a line pipe product, was produced by thermo-mechanical rolling followed by accelerated cooling (TMCP). It had a heavy wall of 39mm as is often used in deepwater projects. The plate material was explosion welded using a CRA plate of Alloy 625 with a thickness of 4mm. The clad plate was formed into a pipe in a JCO process and welded with a multilayer welding technique. Subsequently, a 3D bend was made by induction bending process. The paper presents a detailed description of each production step alongside the evolution of relevant properties throughout the process. The investigation proved the feasibility of producing a heavy wall bend that had undergone a full body quenching and tempering (QT) process stemming from a TMCP plate.

2   Introduction

Large diameter pipes and bends serving as part of pipelines to transport fluids under high pressure. The most widely used material is thermo-mechanically controlled process (TMCP) material that combines high strength and excellent toughness with good weldability. When it comes to corrosion resistance, TMCP material has its limits. The

boundaries of such material have been intensively investigated and are well documented. In cases where the corrosive properties do not suffice for dedicated requirements, alternatives have to be sought. These can be found in clad products in which the Carbon Manganese steel offers the mechanical properties needed for design of the pressure containment exposed to high internal pressure whereas the corrosion resistant alloy (CRA) material on the inside shields the Carbon Manganese steel from contact with the corrosive medium.

Manufacturing of TMPC clad pipe is a process that is documented, both for explosion and roll bonded clad material. On the other hand, producing hot induction bends poses a challenge as the finished pipe has to be heated to a temperature well above A_{c3} to form the bend and, if necessary, is full body quenched and tempered thereafter. This has to be taken into account when choosing a suitable chemical composition, typically with a higher content of alloying elements.

3 Manufacture of bends

3.1 TMCP Plate Production

Thermomechanical rolling process that was developed in the 1980's consists of a specific combination of controlled rolling and accelerated cooling, if necessary (Figure 1). The material itself is a Carbon Manganese steel that is micro alloyed to obtain the desired level of strength and toughness. The process promotes a highly homogenous microstructure over the wall thickness with a very fine grain of 2-5µm.
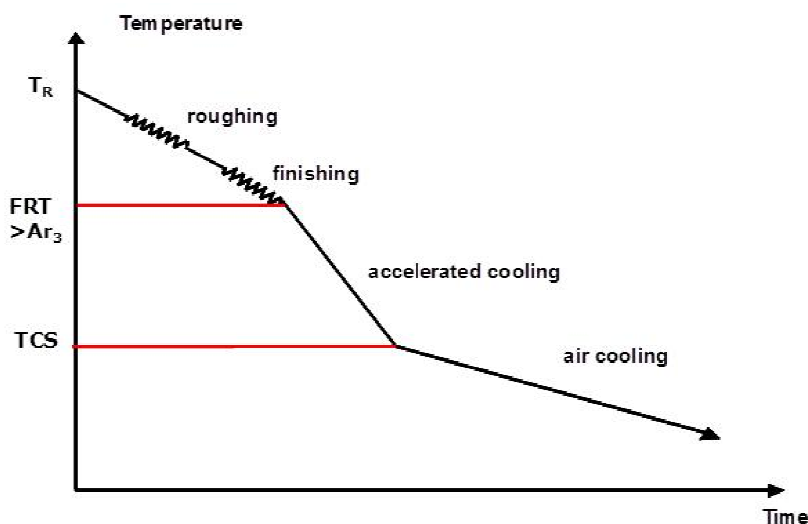

Figure 1:

The TMCP plate used for these trials was of API Grade X65 PSL2 with a nominal wall thickness of 39 mm, produced by the SMGB heavy plate mill. It had a chemical analysis as given in Table 1 that is characterised by a lean composition that is typical for linepipe material. As a matter of fact, in this specific case, no additions were made for pre-material for bending. In addition to choosing a suitable chemical analysis, an effective QT process

has to be applied to limit or avoid possible losses in strength imposed by process related heat treatment during bend production.

Table 1: Chemical composition of carbon steel plate

C	Si	Mn	Nb	Others	CE (IIW)
0,06	0,18	1,65	0,04	Cu, Cr, Ni, V	0,41

3.2 Explosion welding

Explosion welding, EN ISO 4063 process No. 441, also called explosion cladding (Figure 2), is the most versatile clad plate manufacturing technology. It is a cold welding technology that produces very high bond strength between two metallic materials, even between materials that cannot be combined by conventional welding techniques. This welding technology is suitable for joining virtually any combination of common engineering metals. The dimensional capabilities of the process are broad; cladding metal layers can range from 0.25 mm to over 50 mm; base metal thickness, width and length dimensions are primarily limited by the size capabilities of the world's plate production mills and transportation limitations. Maximum width and length is approximately 5 m and 15 m, dependent upon alloy type and thickness. Explosion welding is used to clad an extensive range of metals including steels, aluminum, titanium, zirconium, nickel alloys and exotic or precious metals.
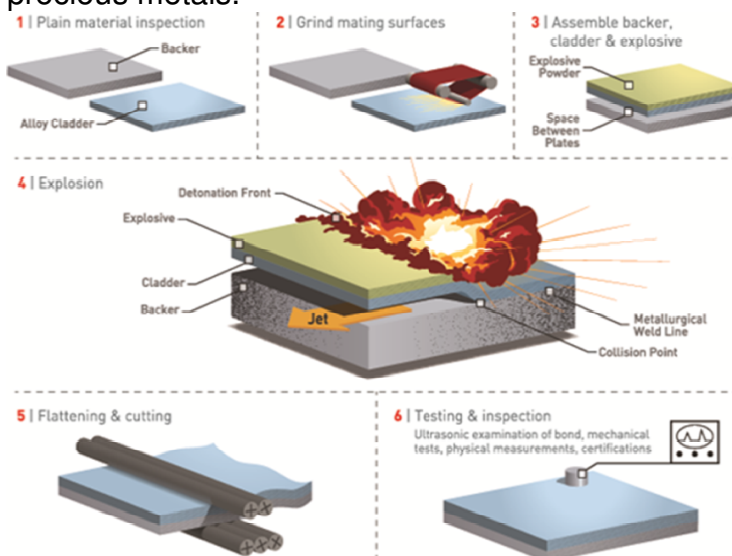

Figure 2: Schematic representation of the explosion welding process

Explosion welding (EXW) is accomplished by creating a high-velocity collision between two metal plates. The explosive detonation causes shock loading of one of the metals, the flyer plate (cladder), accelerating it downward, causing an oblique impact with the other metal, the backing plate (backer). It is necessary that this impact has sufficient energy to cause the colliding metal surfaces to flow hydrodynamically. Due to the angularity and the extremely high velocity of the collision a plasma-like jet is created during the welding process. This jet, ejected outward from the collision point, removes oxides and impurities and activates the metal surfaces. The activated metal surfaces are then forced together

under high pressure, resulting in an electron-sharing metallurgical bond between the two metal components.

These characteristics in turn allow the manufacture of clad line pipe steel plates that fully utilize modern TMCP line pipe steel production practices that are not compromised by the cladding process. The process is also favourable for special products in smaller quantities made of customised material, as it is the case in bend production.

Explosion welding was performed by NobelClad Europe. The CRA plate used within this investigation was an Alloy 625 with a wall thickness of 4mm. The chemical analysis is given in Table 2.

Table 2 Chemical analysis of Alloy 625

C	Si	Mn	Fe	Cr	Al	Mo	Nb+Ta	Ni
0,04	0,3	0,2	4,4	22	0,2	8,3	3,5	Bal.

3.3   Pipe forming

Pipe forming is a multi-step cold forming process. There are different forming methods that are commonly used to produce a large diameter longitudinally welded pipe, UOE and JCO being the two most important ones for heavy wall material. The letters in the abbreviation substitute a dedicated forming step each. The JCO process is cost-effective and flexible in terms of the geometry of the finished pipes. Production begins by milling the edges of the heavy plate to prepare for welding (Figure 3). Thereafter, the actual forming process starts by crimping the edges to a radius corresponding to that of the final pipe. Forming into a pipe is then performed by the JCO process in which a vertically-guided forming tool shapes the plate to an open pipe step-by-step.

Figure 3: Schematic representation of pipe production

These pipes are then tack-welded on their entire length before producing the longitudinal weld by submerged-arc welding. For heavy wall thickness, these are multi-layer welds that introduce comparatively little heat input through the process. This ensures good weld and heat affected zone properties.
At Eisenbau Krämer, the clad plate produced in the step before was formed to a pipe with an OD of 609.6mm and a total nominal wall thickness of 42mm. The CRA plate was welded with electro-slag welding process (Figure 4).
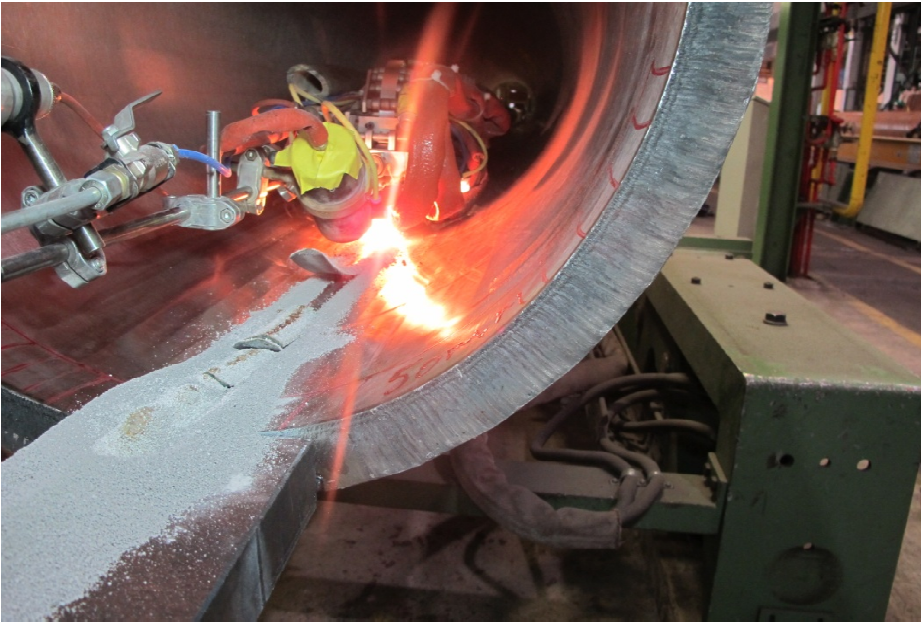
Figure 4: Electro slag welding of alloy 625

3.4 Hot induction bending process

At Salzgitter Mannesmann Bending Plant the clad pipe was bent by means of the induction bending process to a 3D bend (radius=1830 mm) with a bending angle of 90° and two straight tangents of 700 mm length. This bend was full body quenched and tempered. A second bend with a bending angle of 45° was subjected to tempering only and was produced to assess the effect of QT heat treatment on strength properties.

Induction bending is a largely automated, free forming process. The necessary heat for bending is induced in a narrow circumferential band by means of an induction coil (**see detail 2 in** Figure 5), which advances continuously along the length of the pipe during bend forming operation. The width of the bending area must be limited to avoid uncontrolled deformation in the bend body. The formed material is cooled by water spray immediately behind the inductor. During bending, the temperature of the bending zone is measured continuously and held constant at a predetermined value above A_{c3}. This results in a short-time austenitizing cycle and a quenched metallurgical structure for the CMn-alloyed base material.
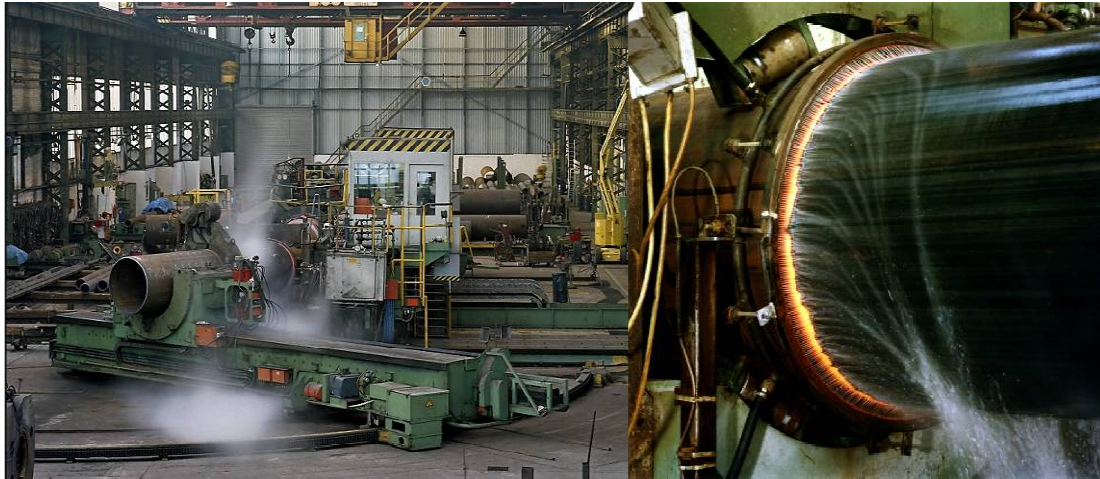
Figure 5: Hot induction bending of SAWL pipe and detailed view on induction coil and heated zone during bending process

The front end of the pipe is clamped to a pivoted arm (1), the bending force acts axially on the pipe, induced by a hydraulic ram, pushing the pipe through the machine. Set to the desired bending radius, the bending arm (3) then describes a circular arc around is pivot point. As a result of the radial thrust applied to it, the pipe automatically follows this curve up to the desired bending angle.

The schematic operation steps applied to the clad bend can be gathered from Figure 6. Prior to bending the wall thickness and out of roundness of the pipe was measured in the designated bending area, along the extrados, intrados and neutral axis line. After bending same measurement were repeated. The longitudinal weld of the LSAW multi layer welded pipe was located in the neutral axis, 10° towards the extrados, as this is the area on the circumference of the pipe with the minimum deformation during hot induction bending.
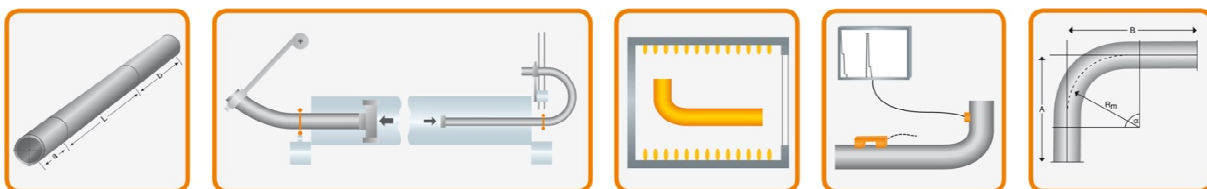

Figure 6: Operation Steps of Induction Bend Fabrication

Bending was followed by a full body QT heat treatment in a gas fired hearth boogie furnace (Figure 7). Heat treatment was carried out at 920 °C/40'/water quenching with subsequent tempering at 500 °C/80'/ cooled down to ambient temperature in still air. The tempering level should be limited in accordance with the recommendations of the plate supplier to avoid any sensitizing of the clad material.
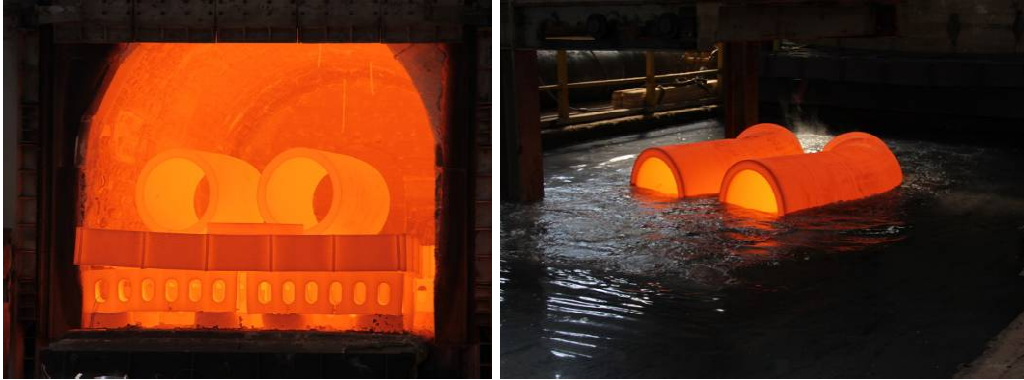
Figure 7 : QT Heat treatment on bends in Mülheim plant

After heat treatment the bend was 100% UT inspected for disbonding, longitudinal and transverse defects without any indications.
The dimensions of the bend were checked in final heat treated condition.
Actual values for thinning in the extrados were determined at 10-11%, thickening in the intrados up to 19%. Ovalisation of the pipe before bending was at 0.5%. After bending a maximum of 2% was measured in the bend body.

Figure 8: 3D Clad Bend, 24" x 42mm WT

4 Material Properties

Possible changes in material properties imposed by the individual production steps were monitored throughout the process. The relevant tests according to API 5LD were conducted at Salzgitter Mannesmann Forschung to obtain the information needed to judge the final product in case of the QT bend whereas the tempered bend was subjected to tensile tests only, to confirm the grade it had achieved. It was expected that it would be lower than that of the QT bend due to the heavy wall.

4.1 Tensile properties

Transverse strength properties were measured according to ISO 6892-1 on round bar specimens B16 at ambient temperature whereas full wall strip specimens were extracted in longitudinal direction in accordance with API.

The transverse strength values are given in Figure 9. The results are colour coded as denoted in the upper part of the diagram. Coming from the values of the mother plate, there is an increase in yield strength to clad plate that is reversed after stress-relieving. The temperature induced in the bending process changes yield properties once again. All values found on the bend meet the requirements of X65 with the exception of the intrados that is very slightly lower. The difference was around 5%. As the wall thickness in this position increased by more than 15%, this effect is compensated and the product of wall thickness multiplied by yield strength is in the same region as that of the pipe itself. Consequently, design would not be influenced.
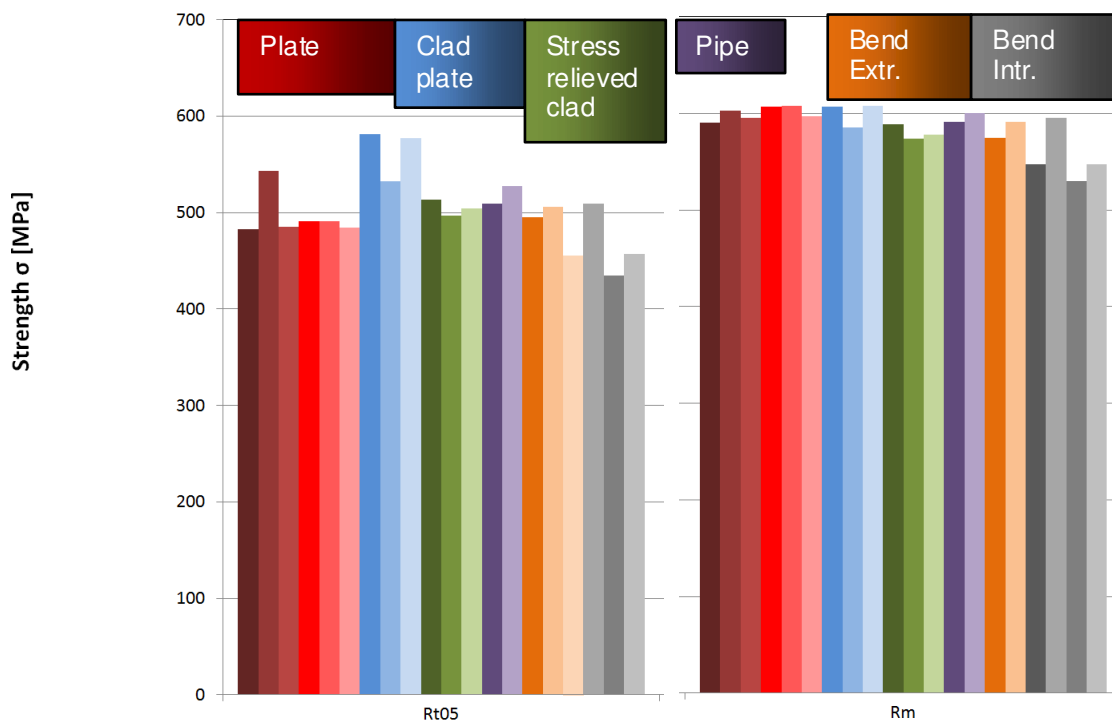

Figure 9: **Transverse tensile strength**

The longitudinal values met the requirements of API 5L.
The tempered bend that was produced to compare the strength properties to the full body quenched and tempered bend did not comply with the strength requirements of X65 in any the different positions that were tested. Instead, it met X60 requirements.

4.2   Impact toughness

Charpy impact (CVN) tests were conducted according to ISO 148-1 with a hammer tip radius of 8mm. Transverse full wall specimens were extracted and tested different temperatures to obtain transition curves, both in terms of energy values and shear area fractions.
Figure 10 shows the energy values obtained in base material tests conducted after the relevant production steps in a temperature interval between ambient and -90 °C. Each

point represents the mean value of a set of tests. Red coloured symbols stand for properties of the mother plate that were measured at two different longitudinal positions. The upper shelf toughness is very high approaching 500J and is measured even at -30 °C. At lower test temperatures, there is a very gradual decrease of the energy that remains above 200J down to -80 °C. The toughness in the as-clad plate (blue triangles) and the stress-relieved clad plate (green triangles) are at roughly the same upper shelf energy but do fall very slightly below the plate values at lower temperatures. Nevertheless, the energy remains to be high down to -70 °C, too. The toughness of the bend was measured at both extrados (grey triangles) and intrados (grey circles). These values are mostly higher than the plate values giving the impression of a certain recovery effect. Effectively, these small differences do not play a major role as the absolute energy level is so high that it is well in excess of any requirement, even at temperatures well below typical design temperature levels.
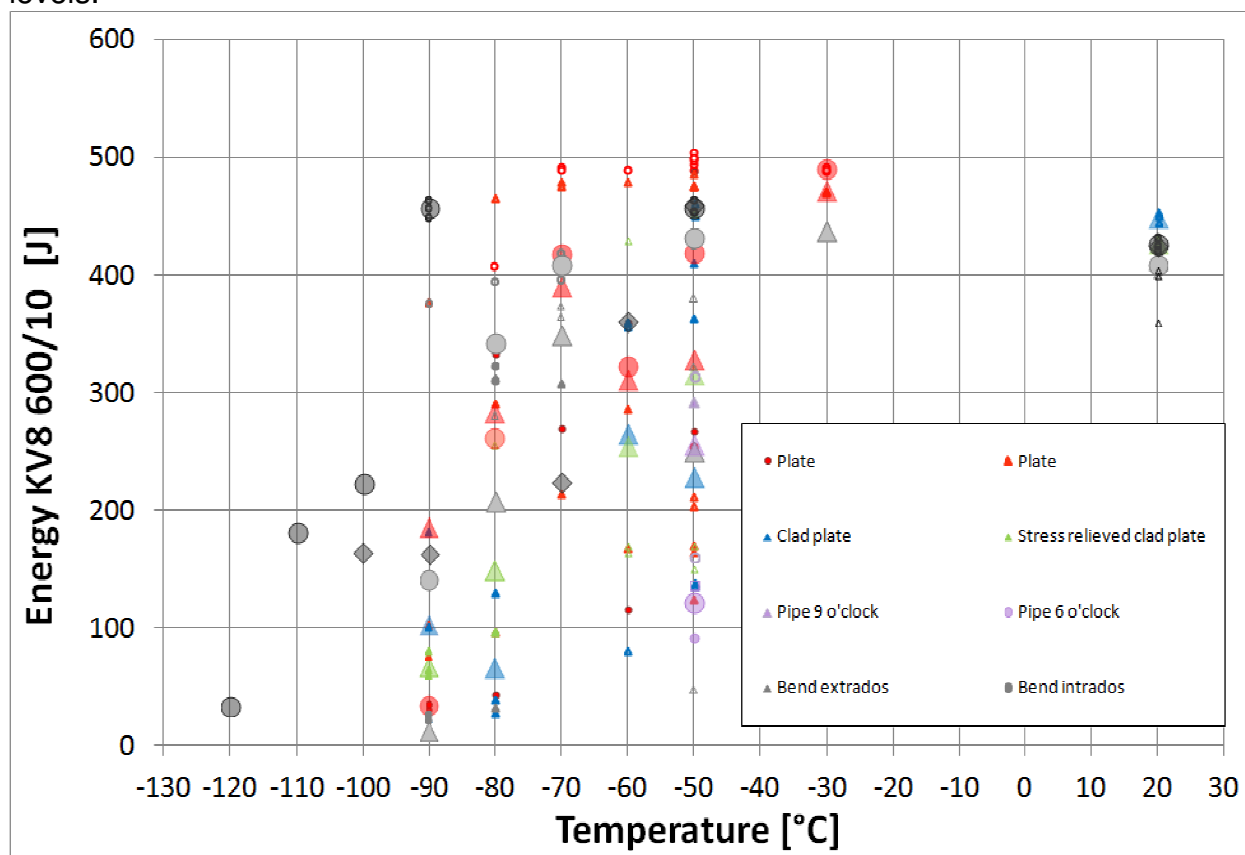

Figure 10:   **Charpy impact test results of base material**

The toughness of the weld was assessed by testing weld metal and heat affected zone specimens extracted from both pipe and bend. The orientation of the specimens was transverse, the notch placed in through-thickness position. In Figure 11, each symbol represents an individual test result. Red symbols represent tests on pipe, grey symbols tests on bends. The temperature range in which the tests were conducted was between ambient and -60 °C. In this full interval, the energy values are in excess of typically required values of 37/45J.
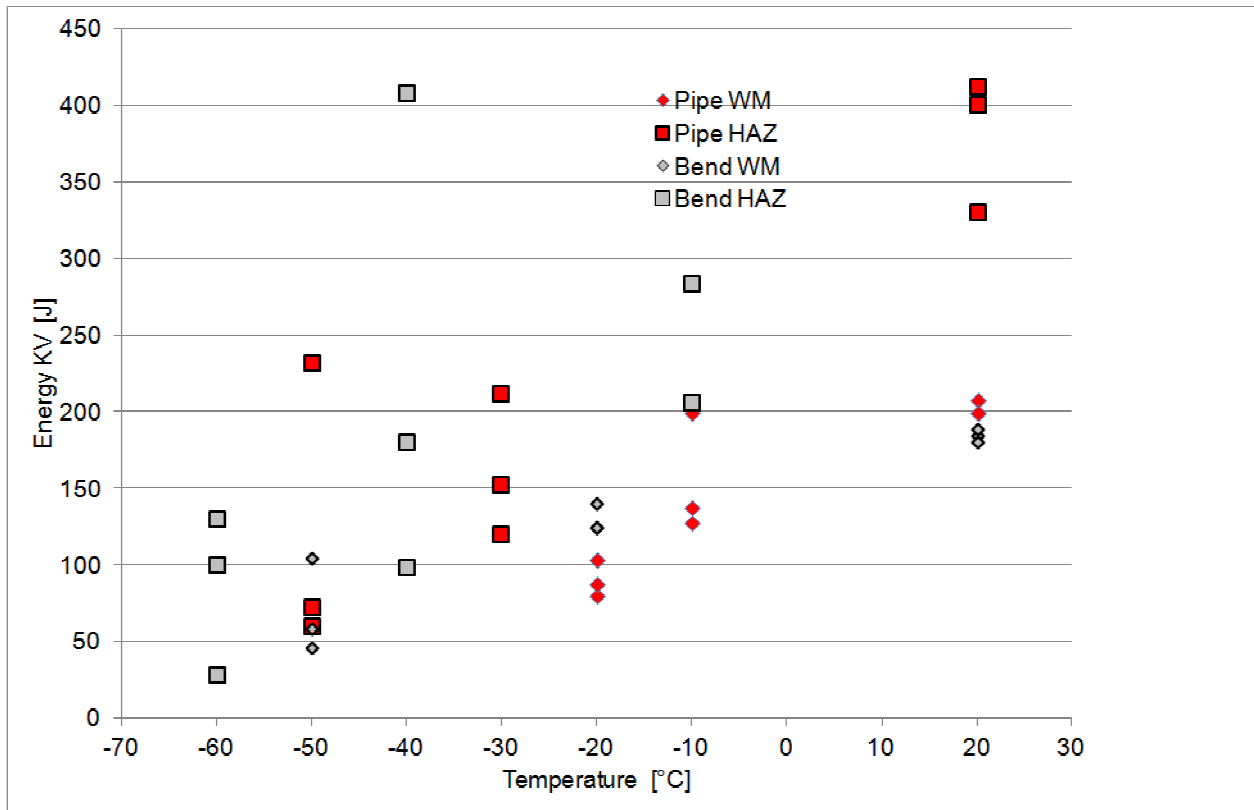
Figure 11: Charpy impact energy of weld and heat affected zone

4.3   Hardness measurements

Vickers hardness measurements in terms of HV10 were conducted on specimens sampled after each production step (Figure 12). The traverses were taken in outside, mid-wall and inside position as well as the clad, when applicable, in accordance with API 5LD. The measured values of the mother plate were well below 250HV10 in all cases. There is a tendency to higher values at the inner wall. Comparing the results achieved on clad plate and stress-relieved clad plate, there is no expressed difference. The bend shows homogenous values in a small scatterband in all positions, mostly below 200HV10. The clad shows higher values of around 350HV10, typical for Alloy 625. These are noticeably reduced on the bend, where the tangent has the highest hardness measurements around 300HV10 and the bend area is lower at around 250HV10.
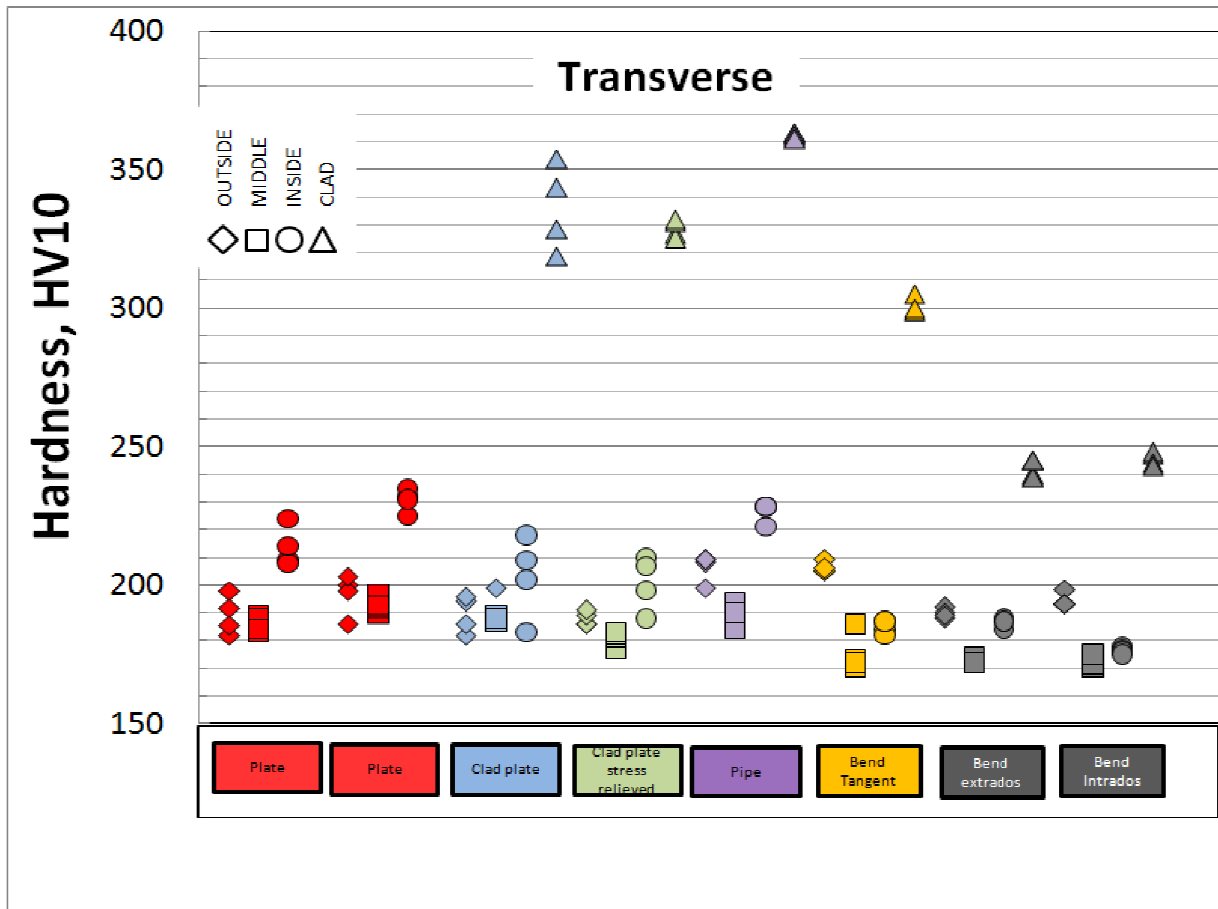
Figure 12: Vickers hardness HV10 measurements

4.4 Corrosion tests

Pitting corrosion tests according to ASTM G48, method A, that were conducted at 70 °C for 72h passed without issues. The samples were taken from stress-relieved clad plate and bend. Susceptibility to intergranular corrosion was tested according to ASTM G28, method A, on pipe and bend and passed without objections, too.

4.5 Shear test

Shear tests were conducted on two specimens each sampled from stress-relieved plate, pipe and bend. The results are depicted in Figure 13. All values exceed the typically required shear strength of 140 MPa by far.
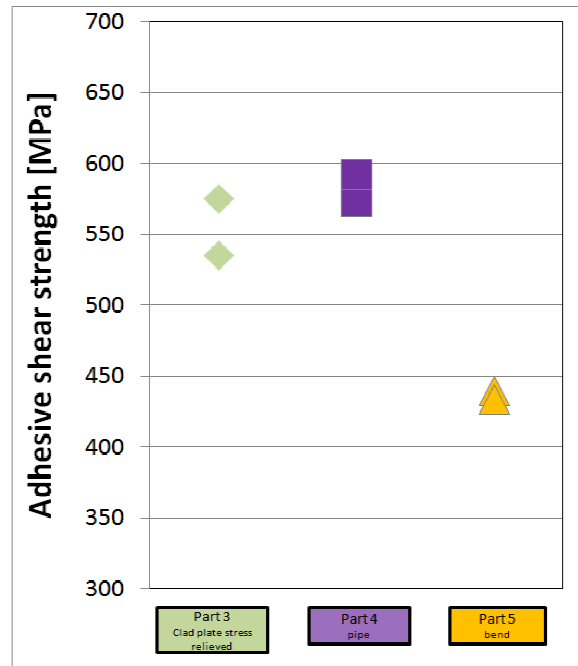
Figure 13:   **Shear strength**

5   Summary

Clad pipes and bends are used for transportation of corrosive fluids which cannot be transported with standard Carbon-Manganese steel for sour gas application. The process of explosion welding is attractive to be used when highest resistance against disbonding is required, e.g. for high forming degree of heavy wall clad material. In addition, explosion welded clad plates are also available in smaller quantities, as it is typically the case for bends in pipelines. It also has its advantages in combination with TMCP plate material as it can be expected that beneficial properties will not be irreversibly impaired.

Within this investigation, a TMCP mother plate with a heavy wall thickness stemming from a linepipe order was used to be cladded by explosion welded process and to produce a quenched and tempered as well as a tempered bend subsequently. The mother plate had an extremely lean chemical composition as it is typical for linepipe.

The mechanical tests conducted after each production step allowed for an assessment of the influence of each step on properties. It was shown that the explosion welding process had little influence on the original properties with the exception of strength properties that were slightly elevated. This effect was compensated by stress-relieving the plate.

All requirements of API 5LC were principally fulfilled by the QT bend. The tempered bend reached a strength level of grade X60.