# Manufacturing of Large Steel Components for Nord Stream Project

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*Nord Stream is the gas supply route from Russia through the Baltic Sea to Europe and represents one of the new pipeline projects for guaranteeing Western European gas supply in the future. The project is the longest 48" offshore pipeline to date. The combination of large diameter and high design pressure meant that the materials for all components had to be carefully defined and specified. A considerable effort was made in the project to pre-qualify suppliers and to supervise the manufacturing phase to ensure that the high quality requirements were achieved. This paper describes some technical considerations made when selecting the suppliers of line pipe, valves and bends, and provides further details of bend manufacturing.*

*The Nord Stream Project requires several induction bends in the material grade L 485 and L 450 with high material strength, good ductility at low temperatures and with a high wall thickness due to the high design pressure. All bends are specified as fully quenched and tempered with tight geometric tolerances. Only a few companies were pre-qualified to supply large diameter bends according to the Nord Stream specification. Salzgitter Mannesmann Grobblech in Mülheim won the contract and supplied 38 bends with diameters from 28" to 48" to the Nord Stream Project. The production results showed that all requirements with regard to the mechanical properties and the dimensional tolerances were successfully met.*


**Fig. 1:** Nord Stream transportation system consists of two parallel gas pipelines from Vyborg, Russia through the Baltic Sea to Greifswald, Germany. Construction started in April 2010. The first pipeline is scheduled to be completed in late 2011, the second one in late 2012

## Introduction

Nord Stream is the pipeline supply route from Russia through the Baltic Sea to Europe, see **Figure 1**. The Nord Stream pipeline system consists of two parallel 48" (1153 mm) diameter pipelines, each 1,223 km long. The first of these two pipelines will be operative in late 2011, the second one in late 2012. The pipelines will be able to supply 55BCM of gas to Europe once both lines are on-stream. The Nord Stream system is designed for a maximum operating pressure of 220 barg.

The project is unique in the sense that it is the longest 48" offshore pipeline to date and it is the first time that a 48" offshore gas pipeline has been designed with more than 200 bar design pressure. The combination of large diameter and high design pressure meant that the Nord Stream Project had to carefully define and specify the materials needed for e.g. line pipe, bends, valves, tees, isolation joints and pig traps, and to carefully select the suppliers. A considerable effort was made within the project to pre-qualify suppliers and to supervise the manufacturing phase to ensure that the high quality requirements were achieved.

Due to the length of the Nord Stream pipelines (>1200 km), it proved to be economically favourable to design the system with three design pressures (220 bar / 200 bar / 177.5 bar). This concept has been applied successfully in the past to several North Sea pipelines and reduced the steel requirements for the Nord Stream Project by more than 300,000 tons. This meant several hundred million Euro savings vs. a more conventional design with a constant design pressure along the route. A sophisticated high integrity pressure safety system was developed and implemented to avoid over-pressurization of the two sections with the lowest design pressure of 200 and 177.5 bar. **Figure 2** shows the selected steel wall thickness (red line) and the water depth (blue line) along the route.

## Line Pipes

The selection of line pipe material and steel components meeting the requirement for 50 years design life under harsh conditions and very high operating pressures required

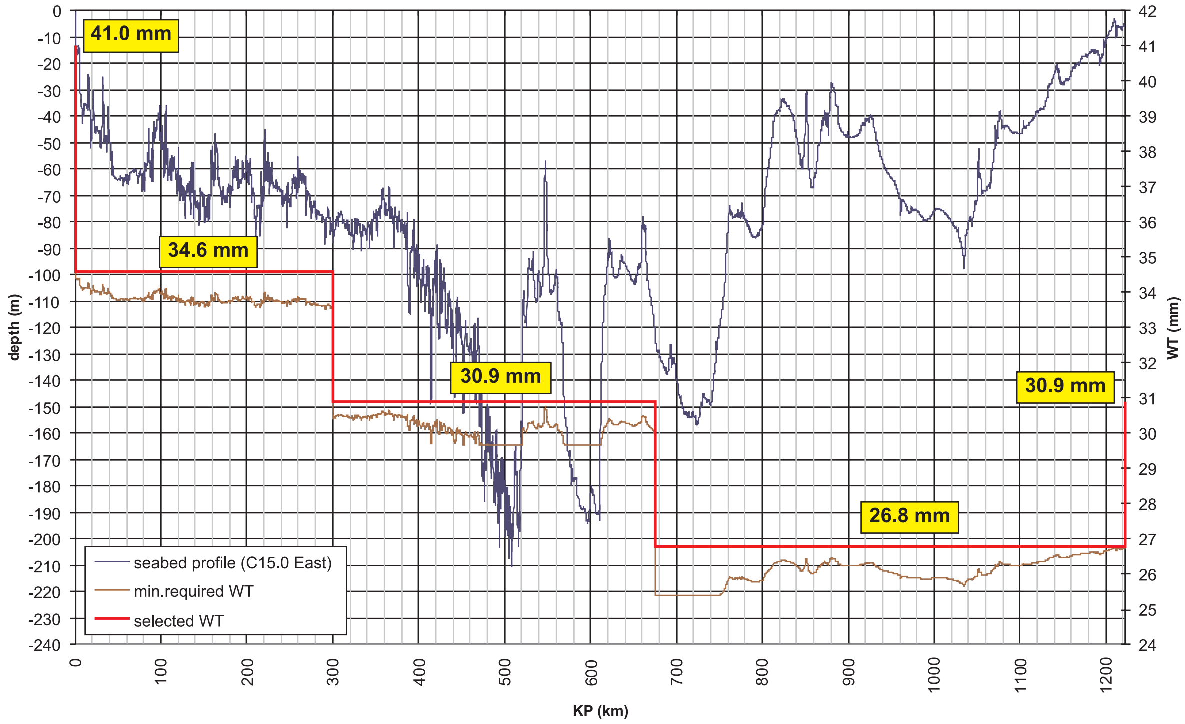


**Fig. 2:** Due to the length of the Nord Stream pipelines, the project saved more than 300.000 tons of steel by designing the pipelines with three different design pressures (220 barg from KP 0 to KP300, 200 barg from KP 300 to KP 675 and 177.5 barg from KP675 to KP1223). The figure shows the selected steel wall thickness (red line) and the water depth (blue line) along the route. Russian landfall (Vyborg) is to the left, German landfall (Greifswald) to the right

the project start an extensive qualification program for pipe mills and other suppliers of materials. Only very few of the large diameter pipe mills in the world could prove that they had a sufficient track record with DNV-grade SAWL 485 (similar to grade X70) for wall thicknesses ranging from 26.8 to 41mm. Therefore, some additional pipe mills, with promising potential but with lack of relevant track record, were invited by Nord Stream to perform a trial production and to demonstrate their capability. The trial production requirement was to produce 20 plates (all produced in sequence) and thereafter to produce 20 pipes from these plates, all of which had to meet the Nord Stream specification. These requirements proved to be tough and some of the pipe mills invested in new equipment, procedures and personnel in order to improve their capabilities. Three pipe mills managed to pre-qualify through a trial production, so that in total six pipe suppliers were qualified to participate in the tender. The volume of line pipe required by the Nord Stream Project exceeded 2 million tons of steel, and there was strong interest from the pipe industry

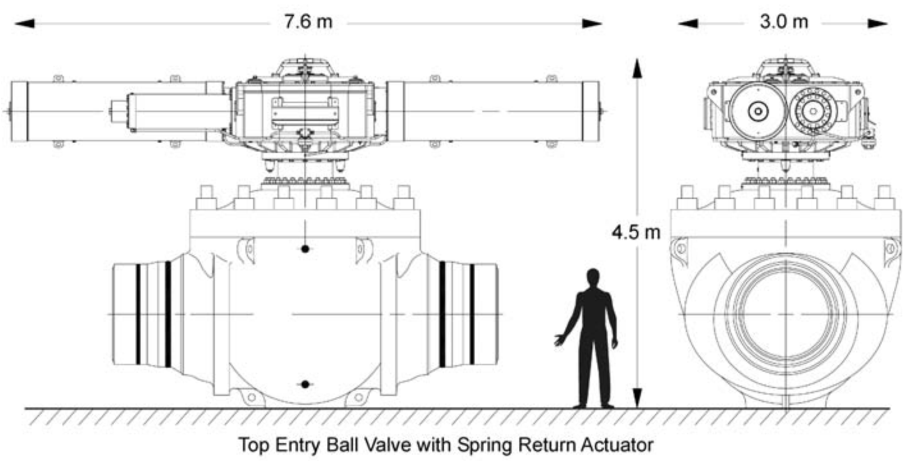


**Fig. 3:** 48-inch top entry ball valves for Nord Stream Project are designed for 220 bar design pressure. The spring return type actuator is designed to close the pipeline gas inlet or outlet in less than 60 seconds if needed. The weight of each ball valve is more than 100 tons

**Fig. 4:** The large 48" double expanding gate valves are installed in order to isolate the pig traps from the pipeline. They are 10.4 m high and have a weight of 102 tons (Petrolvalves srl, Italy)

**Table 1:** Pipe Bending Plant of Salzgitter Mannesmann Grobblech/ Europipe is supplying 38 large diameter bends to the Nord Stream Project

| Qty. | Size | Angle | Radius | WT after bending | Grade | ton/pcs |
|---|---|---|---|---|---|---|
| Pieces | [ inch ] | [ Deg] | | [mm] | | |
| 16 | 28 | 90 | 3D | 28.5 | L485 | 2.67 |
| 3 | 28 | 60 | 3D | 28.5 | L485 | 1.98 |
| 3 | 48 | 93.33 | 5D | 35.0 | L450 | 12.59 |
| 7 | 48 | 90 | 5D | 35.0 | L450 | 12.19 |
| 9 | 38 | 45 | 3D | 30.2 | L485 | 2.75 |
| 38 | | | | | | |

**Table 2:** Mother pipe dimensions and fabrication standards for the Nord Stream bends

| NPS | Material | Mother pipe dimensions [mm] ID x min. wt | Fabrication standard | Location |
|---|---|---|---|---|
| 28” | L 485 | 654.0 x 35.0 | ISO 3183 | Russia |
| 38” | L 485 | 904.6 x 35.4 | EN 10208-2 | Germany |
| 48” | L 450 | 1153.0 x 38.0 | DNV-OS-F-101 | Germany |

to participate. The line pipe supply contracts were awarded to Europipe (Germany), OMK (Russia) and Sumitomo (Japan). Pipe delivery started in May 2008 and is scheduled to be completed by mid 2011.

## Large Valves for the Nord Stream Project

A similar qualification program was initiated by Nord Stream for the suppliers of large valves. In 2007, there was no manufacturing experience in the valve industry with 48'' top entry ball valves and 48'' double expanding gate valves and with a design pressure of 220 barg. Hence Nord Stream initiated a ‘design competition’ where potential valve suppliers were invited to present a detailed design for the safety critical pipeline valves. The design work was compensated by Nord Stream to assure that all vendors involved their most qualified engineers and resources to develop the best possible valve designs.

The valve designs were assessed by Nord Stream experts in detail and the main criterion for the selection of the valve supplier was the confidence that the valves would be safe, functional and practically maintenance free for the next 50 years. The 20 large valves have now been manufactured at *Petrolvalves Srl*, Castellanza, Italy, and, after successfully passing the extensive factory acceptance programe, they are ready for shipment to site in Germany and Russia, see **Figure 3 and 4**.

## Hot Induction Bends for the Nord Stream Project

The companies which were experienced and sufficiently qualified to supply large diameter bends to Nord Stream specifications were also very few. At both the Russian and German landfalls, the Nord Stream Project required several induction bends with high material strength, good ductility at low temperatures, and with a high wall thickness due to the high design pressure. All bends were specified as fully quenched and tempered (QT) with tight geometric tolerances.

Salzgitter Mannesmann Grobblech GmbH (MGB) in Mülheim, Germany, was successful with their bid and won a contract for the supply of 38 large diameter bends to the Nord Stream Project, see **Table 1**.

Ten 48'' bends were required at the German Receiving Terminal. The 28'' and 38'' bends listed in **Table 1** are installed near the compressor station on the Russian coast and near the Receiving Terminal on the German side. Due to their different application, different specification standards and test requirements had to be respected, as shown in **Table 1 and 2**. To meet the low-temperature test requirements, the bends were fabricated from multilayer longitudinal submerged arc welded (LSAW) mother pipes, produced by pipe mill Eisenbau Krämer (EBK), which also supplied the buckle arrestors in 48'' x 41 mm WT for the Nord Stream Project.

The 28'' and 38'' bends were fabricated in material grade L 485, the same grade used for the line pipes. In the case of the 48'' bends, however, the requirement was reduced to grade L 450. The reason for this was the necessity to “overdesign” the wall thickness of the 48'' bends in order to maintain suitable geometric stability during full body QT post bending heat treatment. Regarding the operational conditions for the main line and the adjoining line pipe dimension, 48'' bends in material grade L 485 fabricated from mother pipes in dimension of 48'' x 34 mm wall thickness would have been sufficient, but due to the unfavourable ratio of wall thickness to outer diameter (OD) regarding the risk of deformation and collapse during austenitisation, the wall thickness for these mother pipes had to be increased to a minimum of 38.0 mm. For this reason, the required strength level of the 48'' bends could be reduced to grade L 450.

**Fig. 5:** Transfer of a 48” bend for the Nord Stream Project from the heat treatment furnace to the quenching bath at the MGB bending plant

In order to achieve the required strength after hot induction bend fabrication, heavy plates produced using the thermomechanical controlled process (TMCP) with a carbon equivalent CE(IIW) of 0.42 containing 0.09 % C, 1.5 % Mn as well as Mo and Nb & V was chosen as pre-material for the bends. Microalloying with vanadium leads to precipitation strengthening during the tempering treatment. Vanadium is very effective, especially in the case of hot induction bend fabrication, because it has sufficient solubility in the austenite during austenitising and forms fine precipitates in the nanometer range during tempering [1]. Niobium, on the other hand, has a lower solubility in the austenite but plays an essential role during thermomechanical rolling of the heavy plate material, where it reduces the temperature range in which recrystallisation is possible between rolling passes. Deformation of the austenite below the temperature range where recrystallisation is possible leads to pancaking and strengthening of the austenite grains. This promotes the refinement of the microstructure during the transformation to ferrite or bainite [2,3]. All different bend dimensions for the Nord Stream Project were manufactured with this chemical composition.

The post bend heat treatment consisted of an austenitisation at 910° C for 50 to 60 minutes followed by water quenching and tempering at 600–650° C for 90 minutes. The slight differences of heat treatment parameters were related to the different dimensions of the bends. During heat treatment, all bends were stabilised from the inside with struts to avoid any flattening. With an overall dimension of 10,200 mm length and 3,200 mm width, 48'' diameter 90° bends were larger than the available pallet used for quenching and were also close to the chargeable furnace room size.

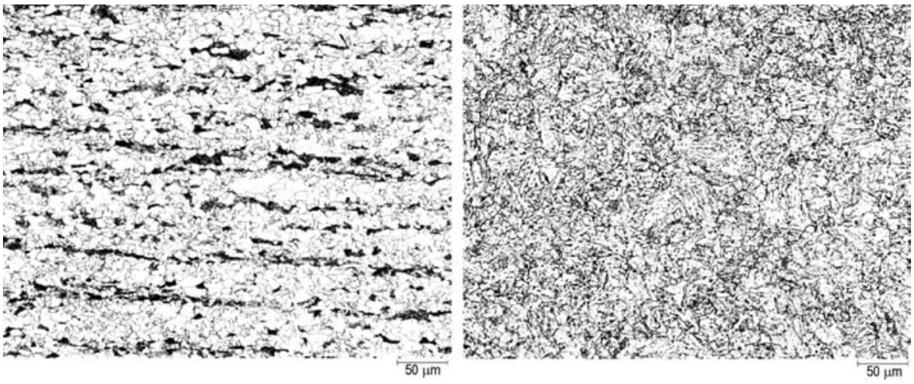


**Fig. 6:** Microstructure of the base metal of the mother pipe (left) and after the quench and tempering treatment (right) at a magnification of 200:1

**Figure 5** shows the transfer process of a 48'' bend for the Nord Stream Project from the natural gas fired furnace to the quenching bath. As one 90° bend including the struts had an actual weight of about 13 tonnes plus the weight of the C-hook and the pallet used for the transfer to the quenching pool. It was necessary to increase the capacity of the crane at the bending plant especially for this order.

The effect of the heat treatment on the microstructure of the base metal is shown in **Figure 6**. The mother pipe has a microstructure containing predominantly ferrite with islands of pearlite and bainite which is typical for thermomechanical processing followed by air cooling. After quenching and tempering, however, a homogeneous bainitic microstructure is realised.

## Mechanical properties

The requirements for the different types of bends for the Nord Stream Project are listed in **Table 3**. The tensile properties of the bends were measured in the final heat treated condition in transverse directions using strip specimens. The results of the tensile tests are shown in **Figure 7** for the intrados, the extrados and the tangent of the bend compared to the estimated level of the mother pipe. The yield strength of the bends was in the range of 545 MPa to 570 MPa, the tensile strength between 640 MPa and 690 MPa. The results show that the required strength levels were reached comfortably with the base metal composition used and were on a similar level or even higher compared to the mother pipe. This can be attributed to the fact that the strengthening contribution related to precipitation hardening with vanadium carbonitrides is higher after the heat treatment compared to the as-rolled condition. An additional contribution is caused by quenching which promotes the formation of a fine-grained bainitic microstructure. The yield strength and tensile strength of the 48'' bends was on the same level as that of the 28'' and 38'' bends which shows that the X70 (L 485) strength level

**Table 3:** Required tensile and toughness properties of the bends for the Nord Stream Project

| NPS | 28'' | 38'' | 48'' |
|---|---|---|---|
| $R_{t0.5}$ [MPa] | ≥485 | ≥485 | ≥450 |
| $R_m$ [MPa] | ≥570 | ≥570 | ≥535 |
| Y/T | ≤0.93 | ≤0.90 | ≤0.92 |
| A5 [%] | ≥18 | ≥18 | ≥18 |
| CVN test temp. [°C] | –38 | –25 | –35 |
| Base metal min. [J] | 36 | 49 | 65 |
| Base metal av. [J] | 48 | 65 | 80 |
| Weld metal min. [J] | 30 | 30 | 40 |
| Weld metal av. [J] | 40 | 40 | 50 |

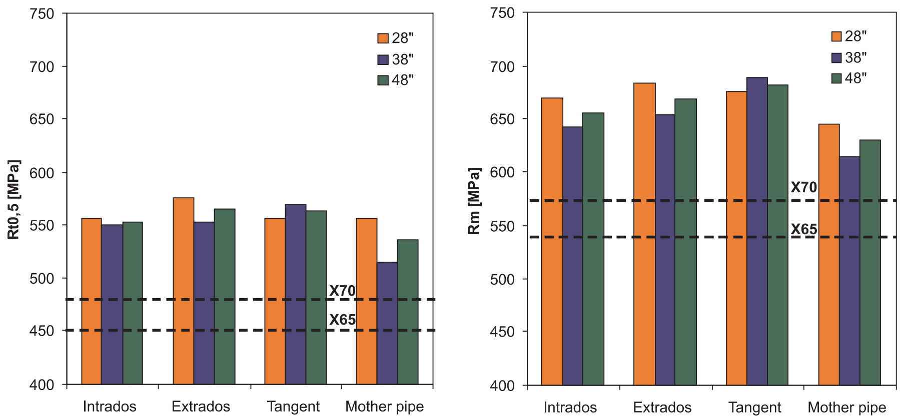


**Fig. 7:** Yield and tensile strength in the base material of the bends versus the mother pipes

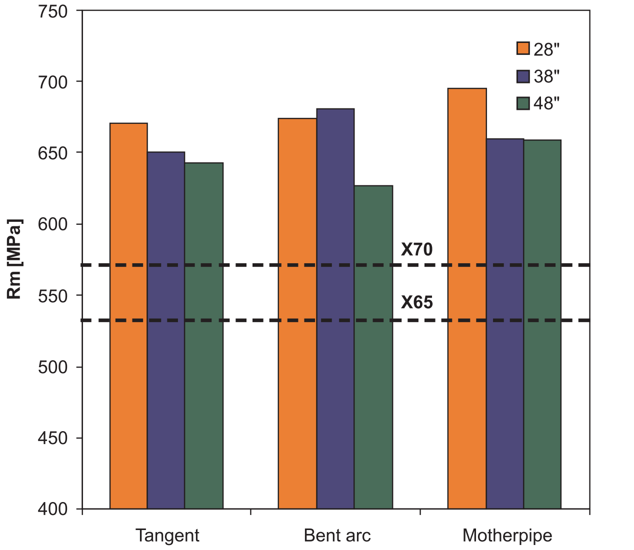


**Fig. 8:** Cross weld tensile strength of the bends versus the mother pipes

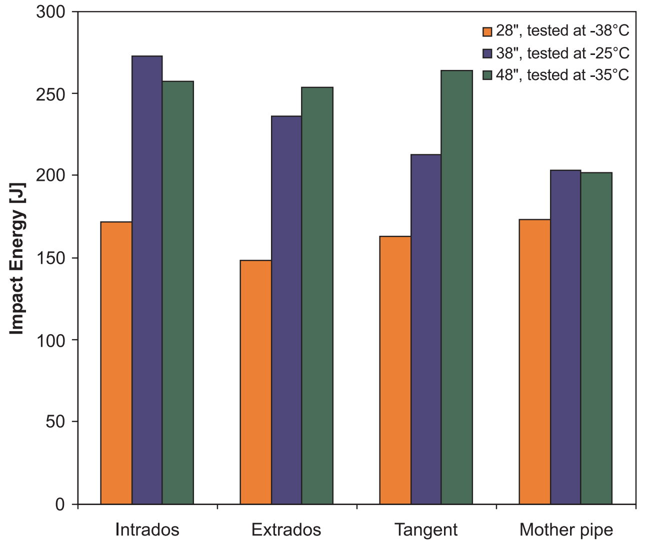


**Fig. 9:** Average CVN impact energy of the base metal of the Nord Stream bends in the intrados, extrados and tangent in comparison to the mother pipes

could be maintained even though a lower strength level was required. The strength of the weld was measured by cross-weld tensile tests in the tangent, the bent arc and compared to the mother pipe. The results show that the required tensile strength of 570 MPa for L 485 (X70) and 535 MPa for L 450 (X65) was safely reached with fracture in the base metal in all cases, see **Figure 8**.

The requirements regarding the toughness of the bends in the base metal and the weld are also shown in **Table 3**. The testing temperature depended on the operational conditions, e.g. -38° C test temperature for the 28'' bends on the Russian Compressor Station, -25° C for the 38'' bends on the German side. The required impact energies could be fulfilled safely with average values above 100 J in all cases, as shown in **Figure 9**.

Full body QT of the bends increases the toughness in the heat affected zone (HAZ) to the level of the base material [4,5]. This is a significant improvement compared to the mother pipe HAZ toughness, as can be gathered from **Figure 10** which exemplarily shows results for samples taken from test positions on weld metal (WM), fusion line (FL), FL+2 and FL+5 from the bent arc of a 48'' test bend.

The hardness distribution was measured by Vickers hardness testing in the base metal and weld metal. The maximum allowable hardness in the base metal was 260 HV 10 and 270 HV 10 in the weld seam area. The hardness distribution across the weld is shown exemplarily in **Figure 11** for a weld cross section taken from a 48'' bend in the bent arc (macro section shown in **Figure 12**). All values measured were safely below the specified maximum level.

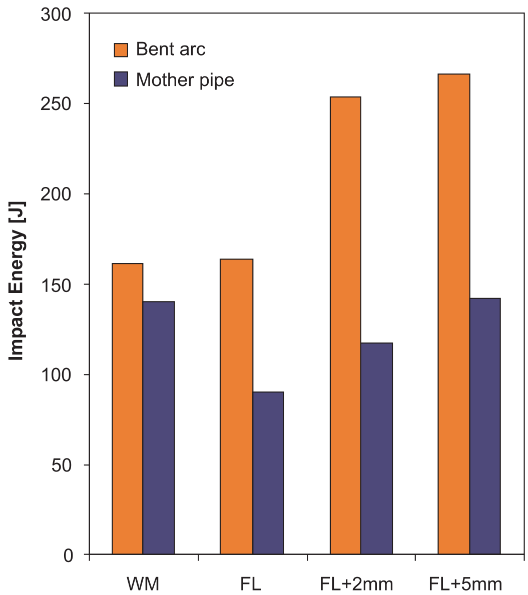


**Fig. 10:** Average CVN impact energy at -35°C of the weld seam in the bent arc of a 48" bend in comparison to the mother pipe in different test positions

## Summary

Due to the large diameter and high design pressure required for the Nord Stream Project, a considerable effort was made within the project to specify material requirements, pre-qualify various suppliers and to supervise the manufacturing phase in order to assure that the high quality requirements were achieved for all components. A particular effort was made to qualify manufacturers for large steel components such as line pipes, valves and bends.

Salzgitter Mannesmann Grobblech GmbH supplied all 38 large diameter bends for the Nord Stream Project. The bends with diameters of 28'' and 38'' were delivered in the material grade L 485. In the case of the 48'' bends, the requirement was reduced to grade L 450 because of the necessity to "overdesign" the wall thickness of the 48'' bends in order to maintain suitable geomet-

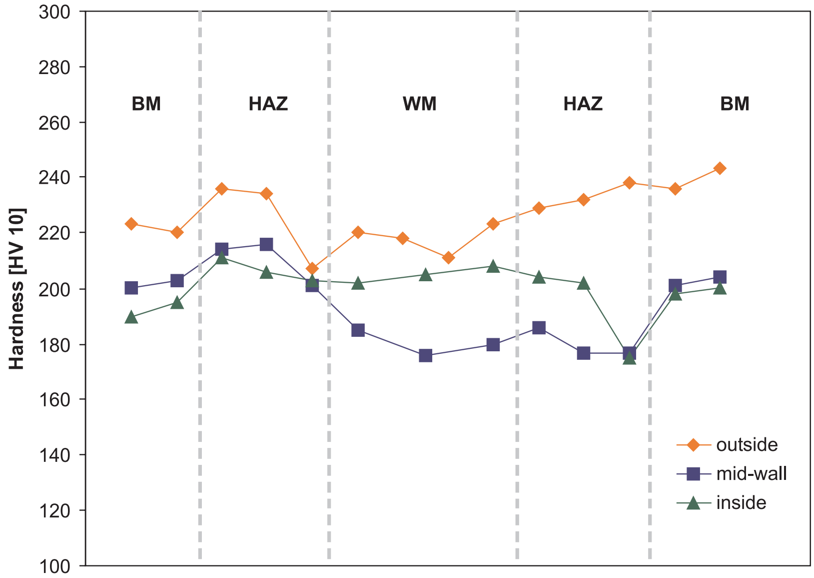


**Fig. 11:** Hardness distribution across of the weld in the bent arc of a 48" bend


**Fig. 12:** Macrosection across the longitudinal multi-layer weld after full-body QT treatment (48" bend)

ric stability during full body QT post bending heat treatment. All three dimensions were produced using TMCP material with one single steel composition.

Handling of the 48" bends required extension of the crane capacity at the bending plant especially for this order because of their large size and weight. These challenges were successfully overcome and all requirements with regard to mechanical and dimensional properties were fulfilled safely.

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