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MECHANICAL PROPERTIES OF HFI-PIPES FOR OFFSHORE APPLICATIONS

H. Brauer, H. Löbbe*
Salzgitter Mannesmann Line Pipe GmbH, Hamm, Germany

* presenting author

Abstract

The use of High Frequency Inductive (HFI) welding is a highly productive process for the manufacture of longitudinally welded pipes from hot rolled strip. Longitudinally welded HFI pipes are nowadays used in the most diverse range of applications. Typical applications are for example, pipelines for the transport of liquid and gaseous hydrocarbons, potable and utility water, brine, district heating systems, hollow sections, and Oil Country Tubular Goods. Salzgitter Mannesmann Line Pipe (MLP), Germany, produces HFI pipes with Outside Diameter 114.3-610.0 mm (4”-24”) and wall thicknesses up to t = 25.4 mm (1”). Special requirements originating from the offshore sector are fulfilled using high quality steel grades with increased pipe wall thicknesses. For this application, HFI pipes are increasingly coming into use.

Some technological preconditions necessary for offshore purpose, especially with regard to mechanical properties for different pipe laying techniques, are discussed in this paper. Depending on the laying technique a significant plastic pre-deformation of the pipe material may occur. Small-scale tests on specimens out of HFI-welded pipes have been performed to evaluate the effect of mechanical deformation on the mechanical properties, within this report especially yield strength and Y/T-ratio. Different pipe grades, wall thicknesses and annealing technologies are included.

1. INTRODUCTION

Over the last decades a trend towards demanding specifications for pipe lines for medium transport can be noticed as a consequence of an increased exploration and exploitation of natural gas and oil resources in remote environments under aggravated conditions. Meanwhile an elevated attention has been turned to a resource- and cost-saving installation and operation of pipelines, as well as an accelerated increase of safety awareness. This led on the one hand to an advanced ability of pipe producers for manufacturing pipes with an increased wall thickness. For economic reasons high-strength steels were developed in order to reduce pipe wall thickness or to increase the operation pressures of transportation pipelines on the other hand. At the same time the use of HFI-pipes as line pipe subject to elevated external pressure and as casing has become increasingly attractive in recent years due to excellent mechanical-technological and geometric properties and concurrently favorable costs.

One of the major issues in offshore pipeline design is the material property requirements during pipe laying. Especially the installation by the reel laying method introduces reverse plastic bending and straightening deformation cycles. Other pipeline offshore installation techniques like J- or S-lay may also introduce plastic strain in different extent. However the loading is highly dependent on the individual lay barge design. This plastic straining is an irreversible process and modifies pipe properties by strain hardening and/or Bauschinger-effect. If the strain hardened material is subject to aging processes, simulated in laboratory by exposition to elevated temperatures, the properties are modified again. The amount of variation depends considerably on the direction and the level of pre-deformation. To meet the requirements of design specifications for such load scenarios it is essential to demonstrate the relevant material properties by using common strain aging and small-scale reeling tests. Furthermore designs have to be performed in a way that the needs can be met by pipes and especially by the material. The main emphases of this article are on the one hand the pipe geometry and on the other hand the mechanical properties, especially yield strength and Y/T-ratio in longitudinal direction.

2. PIPE GEOMETRY

HFI pipes are well known for their tight geometrical tolerances. The reasons for that can be seen in the production process by using hot wide strip as prematerial. MLP purchases hot wide strip with very tight tolerances only from qualified premium rolling mills. During pipe production the hot wide strip has to be formed uniformly to a v-shaped pipe which is welded accordingly [1]. A uniform forming process, e.g. forming by cage roll technique, is essential for tight geometrical tolerances as well as for the later discussed mechanical properties. Typical geometry ranges of HFI pipes for offshore use are diameters between 273 and 406 mm (10 ¾ to 16”) and wall thickness up to 20.6 mm (0.811”).

For offshore purpose one main topic with regard to pipe geometry topic is the pipe laying itself. For that purpose tight tolerances are required in order to ensure an economic pipe preparation and laying on the vessel. Particularly the pipe ends are of interest since these are - needless to say - welded one to another.

In the following some representative geometrical values of a typical pipe dimension for offshore application out of a thermo-mechanically rolled X65MO with a wall thickness to diameter ratio t/D of 4.9 are shown. The distribution of the outer diameter at the pipe end is given in **Figure 1**. One can see that the pipe size measured by tape is in very narrow range of less than 1 mm in this case. This is due to the outside calibration and sizing of the entire pipe string in the welding line during production [1].

The illustrated ovality is measured outside at the pipe end. It is calculated in this case by the difference between the maximum and minimum diameter measured with a caliper. This difference is divided by the pipe size, measured with a circumferential tape. The so measured ovality in this example is as an average around 0.5 %, with maximum values up to 0.7 % (**Figure 2**).

Due to the narrow wall thickness range within the entire production of approximately 0.4 mm (**Figure 3**) and especially within one coil and therefore within one pipe one can conclude directly on the basis of the outside measurement to the inside ovality. In practice during production the inside geometry is often checked additionally by go-disk and a no-go-stick. This equipment is adapted to the combination of the required ovality and inside diameter.

At the end the pipe length is important. Typically offshore pipe length is around 12 m (40 ft.). Due to the continuous pipe production from coils and pipe cutting to the required length the pipe length distribution is typically as shown in **Figure 4**. By far the highest amount of pipes has a length close to the maximum required pipe length, in this case more than 95 % of over 1,000 pipes. This leads to a minimization of girth welds and therefore cost savings.

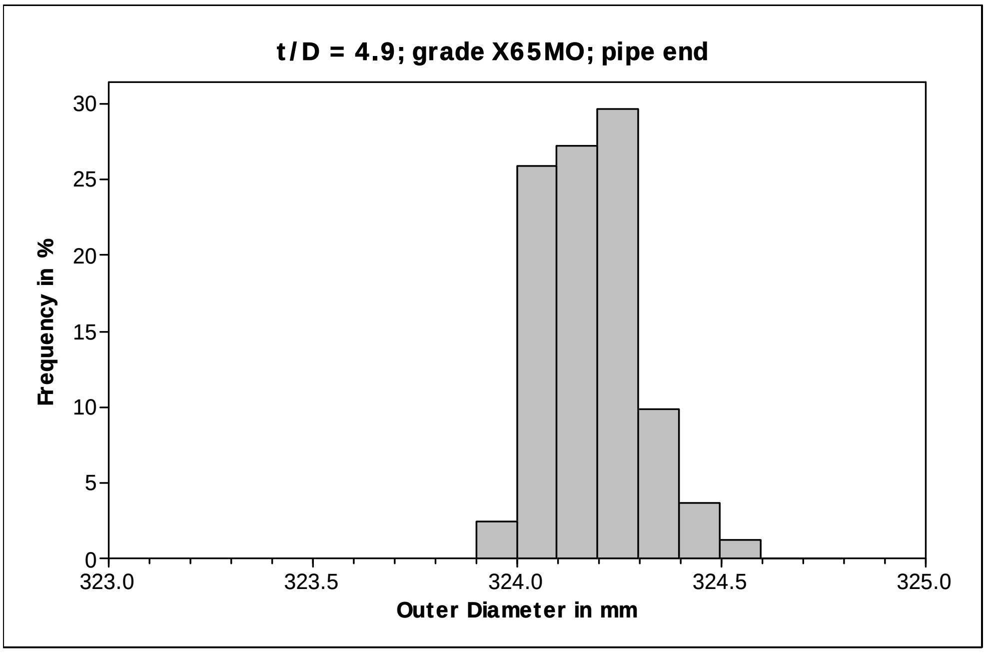

Figure 1: Distribution of outer diameter at pipe end

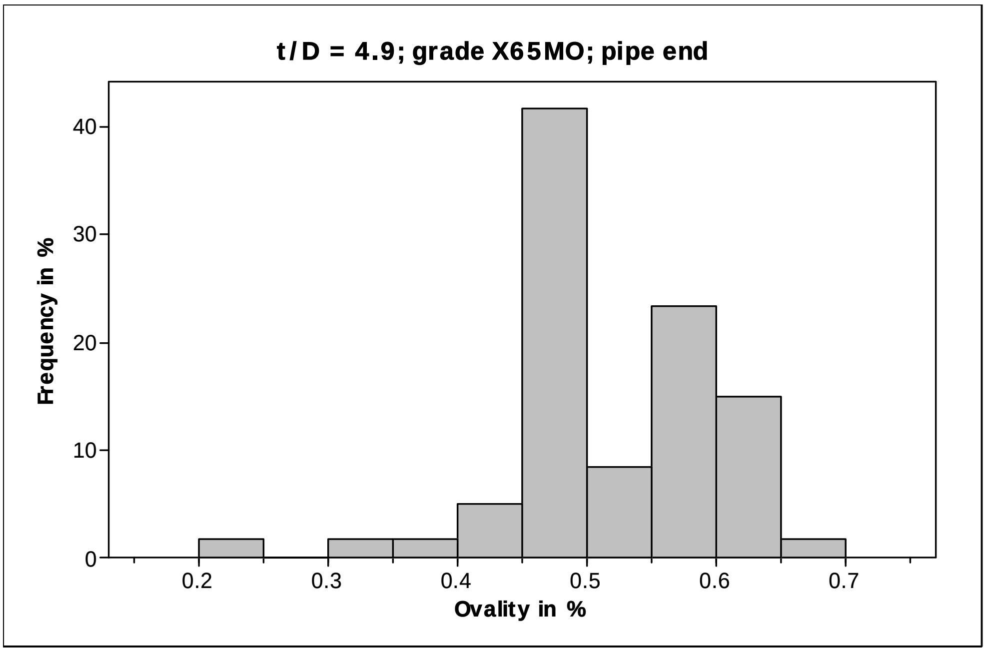

Figure 2: Distribution of ovality at pipe end

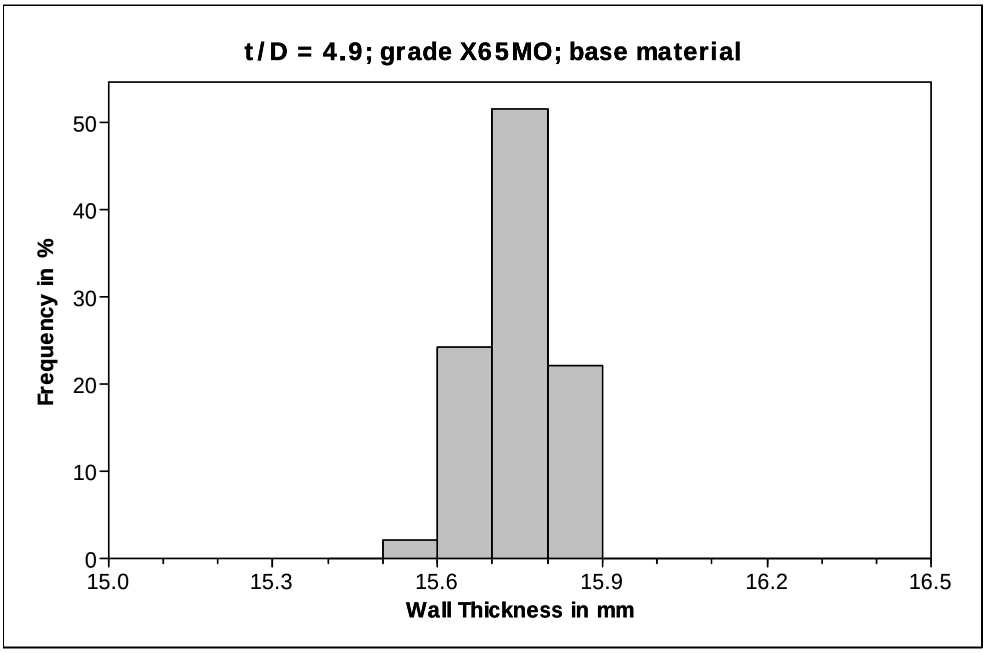

Figure 3: Distribution of wall thickness of base material

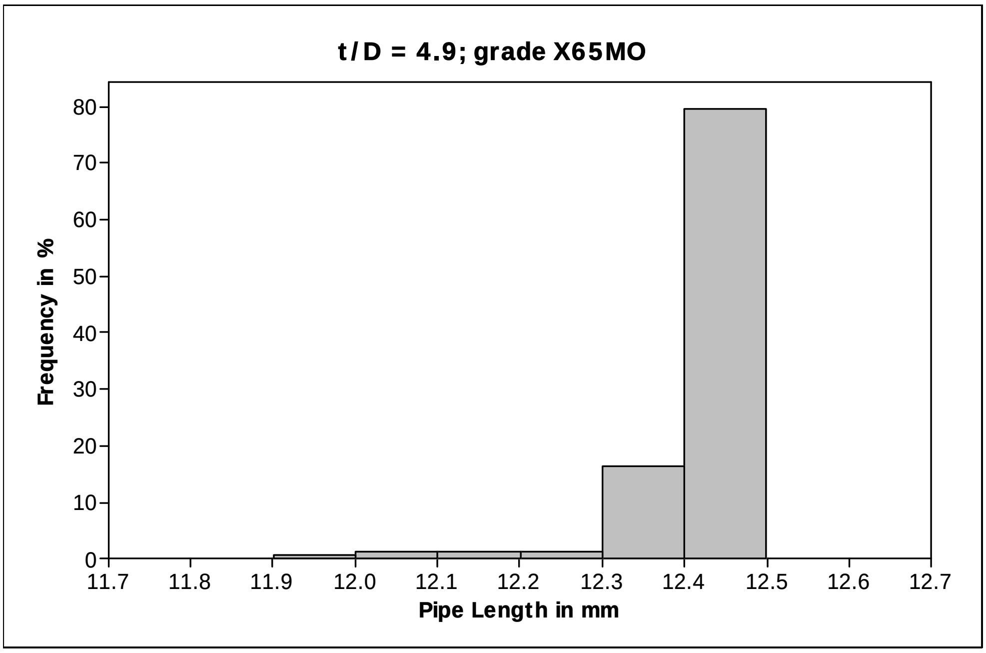

Figure 4: Distribution of pipe length

3. STRAIN AGING BEHAVIOUR OF HFI-WELDED PIPES

Dependent on the pipe laying technique during offshore installation, pipes undergo substantial mechanical load. One possibility to look for the behaviour of the material is the performance of a strain aging test, which is required frequently in different specifications and standards. The following figures deal with results of typical pipe materials X52NO and X65MO, which are used for offshore purposes. Especially for thermo-mechanical rolled hot wide strip and therefore thermo-mechanical rolled pipe like X60MO, X65MO or X70MO the cold forming during pipe production and therefore the wall thickness to diameter ratio (t/D) is of essential importance. Due to this fact mechanical test results refer to the t/D-ratio. The other considered pipe grade is an X52NO in full-body normalised (FBN) condition. Due to the full-body normalising this material in general has a comparative low yield-to-tensile ratio.

Figure 5 shows the dependence of the yield strength from the percent of strain in connection with a subsequent artificial aging in an oven at 250 °C for 1 hour. It can be seen that in the full-body annealed condition the yield strength in the as-delivered condition is around 400 MPa in longitudinal direction in this case. An aging in connection with longitudinal strain of up to 1.5 % does not lead to a change in yield strength. At 2 % strain there is a very slight increase and up to 3 % strain the increase in yield strength is still very moderate and in this case around 25 MPa. However an additional significant increase up to 5 % single strain would also result in a significant increase of the yield strength of roughly 70 MPa. Since the tensile strength is more or less not influenced at all the Y/T-ratio develops accordingly (**Figure 6**). Up to 2 % strain it is more or less constant around 0.74. Afterwards it increases about 0.03 points. In general it can be concluded that even under substantial plastic strain during pipe laying there is only a slight influence on the mechanical properties of the material, depending on the amount of tensile elongation. Anyhow, the Y/T-ratio is well below known technical requirements. Of course the above described material behaviour is mainly influenced by the Lüders plateau due to the full body normalizing.

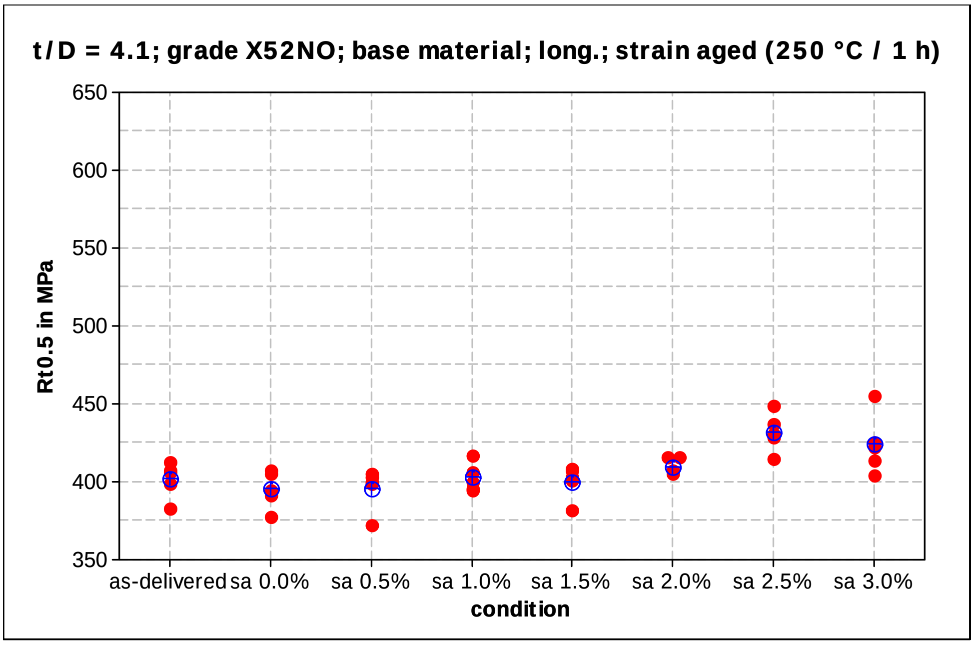

Figure 5: Comparison of yield strength $R_{t0.5}$ for different strain aged (sa) conditions

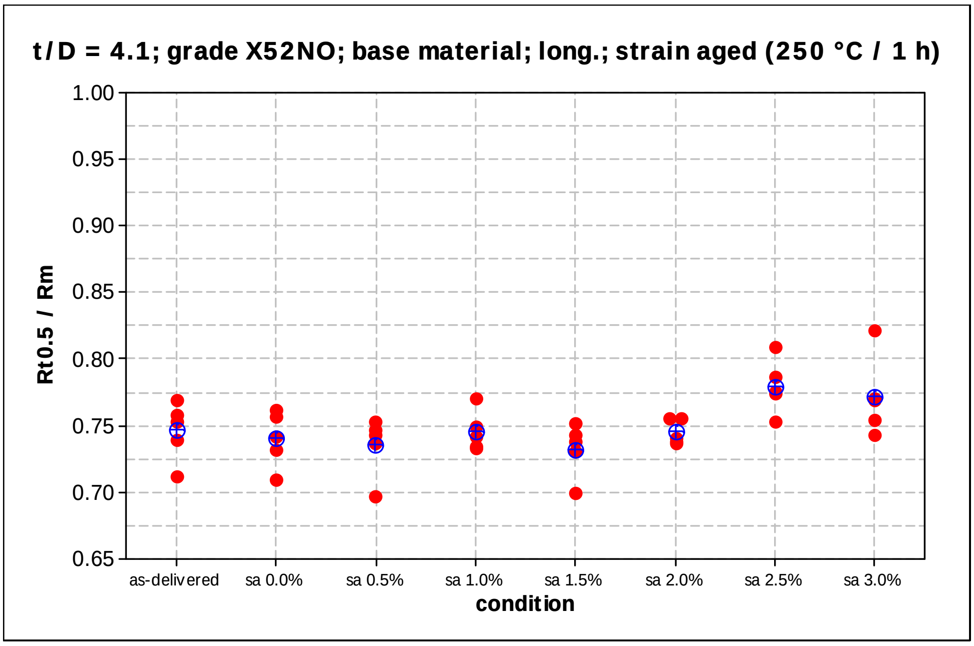

Figure 6: Comparison of yield-to-tensile ratio $R_{t0.5}/R_m$ for different strain aged (sa) conditions

Using a thermo-mechanical rolled steel in grade X65MO without adjacent full-body heat treatment significantly different results to those illustrated above occur. Due to the totally different stress-strain-curve with a round curvature even at low strains naturally a significant increase of the yield strength occurs (**Figure 7**). 0.5 % strain with subsequent artificial aging at 250 °C / 1 h leads to an increase in yield strength of about 30 to 40 MPa. A further increase up to 1 % strain leads to an additional increase in yield strength of roughly 20 MPa. From 1 to 2 % strain the yield strength remains more or less constant. This behavior copies the stress-strain-curve of the material itself. Slight differences in the original stress-strain-curves naturally lead to a scatter at the different strain levels.

Setting the yield strength in relation to the tensile strength one can see that the Y/T-ratio increases with increased yield strength (**Figure 8**). In the initial stage the Y/T-ratio is at 0.85 as an average with maximum values below 0.90. Artificial aging without straining leads to a slight increase. Additional strain with an amount of 1-2 % leads to Y/T-ratios with 0.94 as an average and higher single values. This is in line with investigations on seamless pipe [3].

It should be mentioned that results are slightly dependent on the sequence of the performance of straining and aging and on the level of temperature used for aging. This can reduce the increase in yield strength and therefore the Y/T, even though slightly.

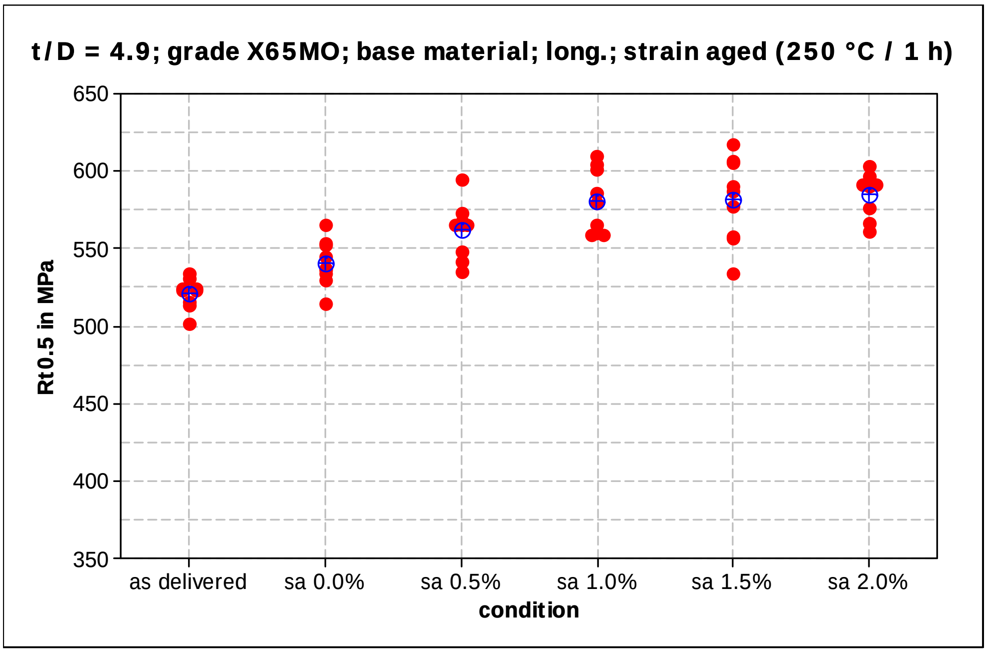

Figure 7: Comparison of yield strength $R_{t0.5}$ for different strain aged (sa) conditions

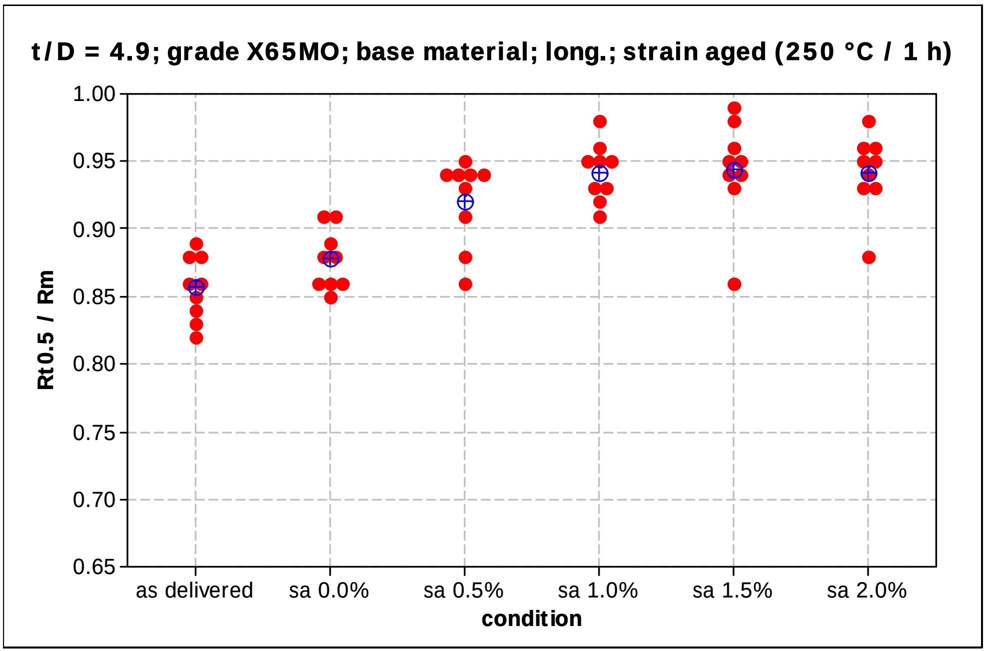

Figure 8: Comparison of yield-to-tensile ratio $R_{t0.5}/R_m$ for different strain aged (sa) conditions

4. REELING SIMULATION

In case of using reeling technique during pipe laying often a small-scale reeling test is used as a simulation. Results of different reeling simulation tests can be seen in the following figures. Pipe grades are equivalent to those described for the strain aging tests. Shown reeling tests were performed in that way, that the first step was a tensile load and the last step a compressive load. After two or three cycles artificial aging was performed. Performing the test the other way round, starting with compression and ending with tension, leads to results “similar to simple straining” when using seamless pipes in a X65Q grade [3]. It cannot be assumed that this behaviour is imperatively valid for all grades in the present investigations, especially for the grade X52NO in FBN condition due to the behaviour of the Lüders plateau during multiple compression and tension loading.

Tensile test specimens for the as-delivered condition were longitudinal flat bar tension specimens, for the test in the as-reeled condition round bar specimens. One can see that within the performed tests the yield strength for the X65MO grades after the reeling test are different with regard to their shifting (**Figure 9**). The yield strength of the X65MO is slightly increased with the triple 3 % cycles by approximately 30 MPa as an average. In contrast to that more or less constant values can be noticed for the two times 2 % cycles with a slight decrease of approximately 10 MPa as an average. However there are of course some differences to be noticed: the accumulated plastic stain during reeling simulation test, the t/D-ratio, the cold forming during production, and the used material chemistries, e.g. micro alloying elements. For the full-body annealed pipe grade X52NO the yield strength remains constant after the performed reeling test as an average. Of course the work hardening and primarily the Bauschinger-effect play an important role with regard to the reversal strains in the material in all cases [4].

Determining the Y/T-ratio the tensile strength is considered additionally to the yield strength. However the tensile strength is slightly affected by the reeling tests and due to that the Y/T-ratio reacts comparable to the yield strength itself. For the X65MO there is a change in the one or the other direction in the amount of about 0.03 points, for the X52NO grade there is no considerable decrease of the Y/T-ratio (**Figure 10**).

The described results for the X65MO are well in line with results on a comparable grade X65Q performed on seamless pipes [3]. Therein it is mentioned that after this kind of reeling test the values scatter within a range of about +/- 10 %.

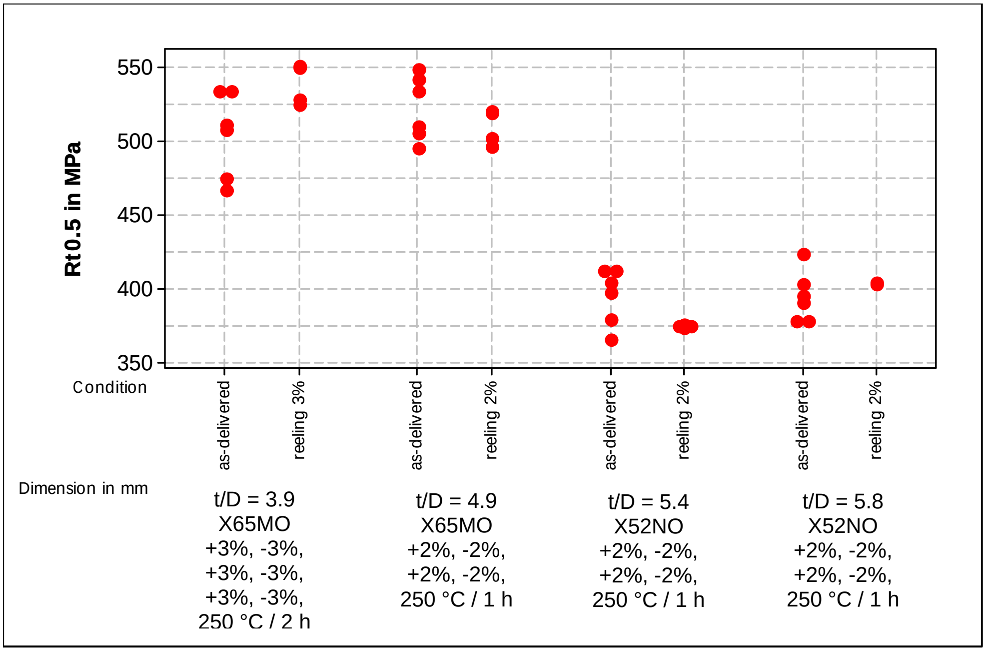

Figure 9: Comparison of yield strength $R_{t0.5}$ after reeling simulation tests (base material, longitudinal)

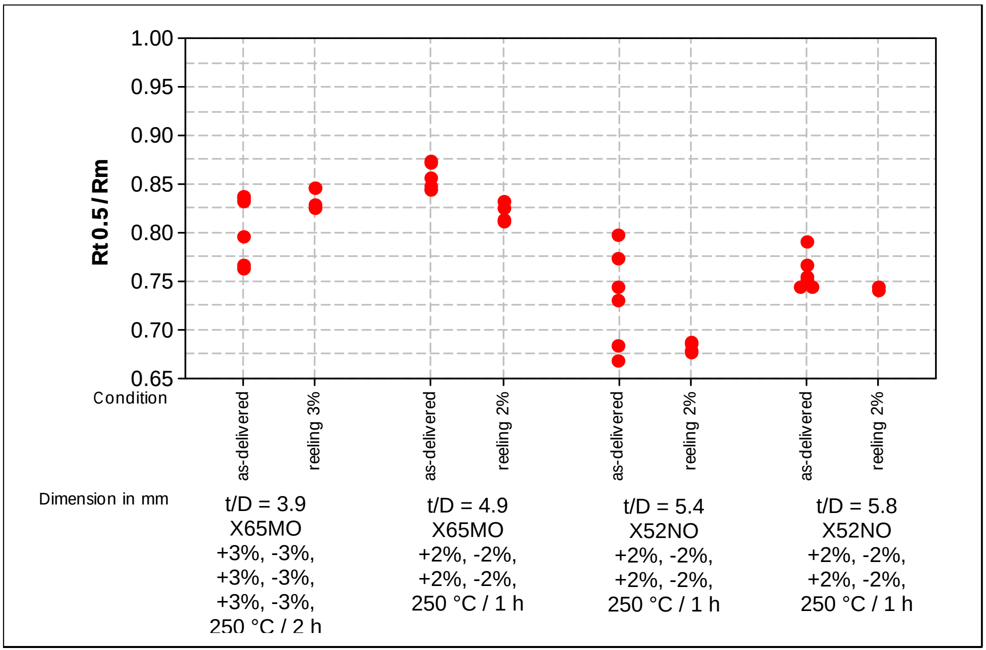

Figure 10: Comparison of Y/T-ratio $R_{t0.5}/R_m$ after reeling simulation tests (base material, longitudinal)

5. CONCLUSION AND OUTLOOK

HFI pipes are a recommendable alternative in terms of offshore pipe laying aspects. Beneficial are tight geometries with regard to different aspects as pipe size, ovality, wall thickness distribution or pipe length.

The response of the pipe material to the deformation during pipe laying is among others dependent on the pipe material and the manufacturing route. The mechanical deformation with different detailed aspects like percentage of tension or compression strain affects the pipe material with regard to yield strength and Y/T-ratio in longitudinal direction. Concerning the demonstrated investigation single tension strain with additional aging results in an increase of both yield strength and Y/T-ratio for grade

X65MO from 0.5 % onwards. Using a full body heat treated X52N this effect starts in the area of 2.5 % tension strain onwards.

Looking at the presented reeling tests with tension in the beginning and decompression at the end the result is again dependent on the grade, e.g. the chemistry, and the performance of test. In this case the influence of the pipe grade and the performance of full body annealing is considerable minor with regard to the strain aging tests.

Further ongoing investigations will deal with the comparison of the small-scale reeling simulation tests and full-scale reeling tests on pipes, using the limit state analyser of the Salzgitter Mannesmann Research Center (SZMF), Germany [5].

At the end it has to be mentioned that in the area of offshore pipeline installation technique as well as in other pipeline business areas it has always to be a balance between the needs for an economic installation, the needs during operation of the pipeline and the mechanical-properties of the pipes itself. Line Pipe from MLP covers these requirements mentioned.

6. REFERENCES

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