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# Testing of Welded Joints between Pipes for Pressure Vessels Made of Hot Rolled Fine-Grained Steel P460NL1

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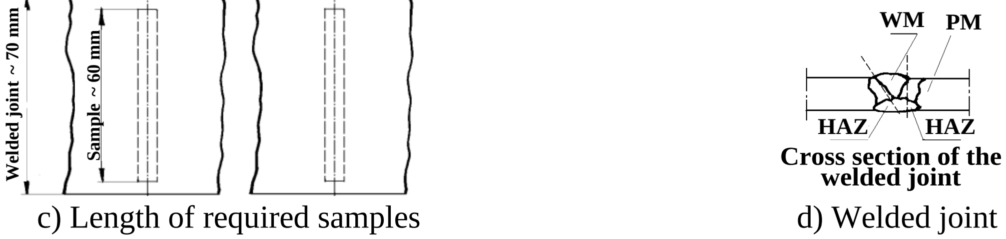
**Abstract.** This paper contains results of tests performed in order to determine mechanical properties of steel P460NL1, used as filler material during the execution of welded joints. Arc welding of samples from which the specimens were taken was carried out through the application of welding process 111, because it is one of the processes for the execution of pipelines for pressure equipment. Microspecimens with diameter of ∅1,5 mm were tested in order to determine tensile properties of material taken from the heat-affected zone and weld metal, while specimens with diameter of ∅6 mm were tested in order to determine tensile properties of parent material. Standard Charpy V-notch specimens were used in order to determine impact energy. Results of metallographic tests which refer to the structure of a pipe welded joint are also presented.

## Introduction

Hot rolled fine-grained steels with improved strength for pressure equipment are defined in standards EN 10027-4 [1] and EN 10028-3 [2]. Longitudinally welded pipes are being produced through the application of high frequency welding, while spirally welded pipes are being produced through the application of flux-cored arc welding. Samples of 8 mm thick sheet metal were joined through the application of electrode EVB 50Ni [3] by arc welding.

**Sampling and manufacturing of specimens for tensile testing.** Microspecimens were extracted from weld metal (WM) and heat-affected zone (HAZ), as presented in Fig. 1. Appearance of the specimen is shown in Fig. 2. Microspecimens are being made as follows: samples taken from WM and HAZ are being machined in order to obtain 3 mm diameter and afterwards create an M3 mm thread, while test sections of specimens are being machined with a displacement at ∅1.5 mm. Standard shape of a ∅6 mm specimen, taken from parent material (PM), is presented in Fig. 3. Tensile tests [4] were carried out at an electromechanical tensile testing machine SCHENCK-TREBEL RM 100.

a) Samples taken from heat-affected zone b) Samples taken from weld metal



c) Length of required samples d) Welded joint

Figure 1. Appearance of samples from which the microspecimens were extracted

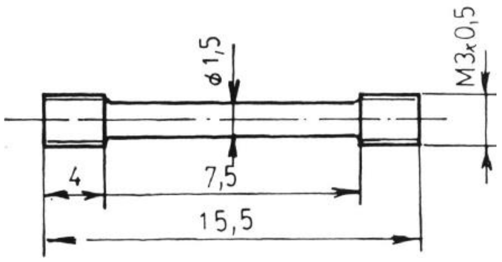


Figure 2. Dimensions of microspecimens taken from heat-affected zone and weld metal samples

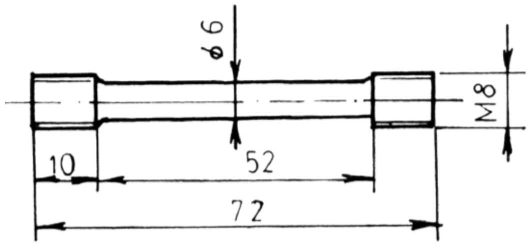


Figure 3. Dimensions of microspecimens taken from parent material sample

**Sampling and production of specimens for impact energy tests.** In order to determine the impact energy specimens were extracted from samples of PM, WM and HAZ (three specimens from each sample), in accordance with Fig. 4. Dimensions of specimens are shown in Fig. 5 [5]. Tests were carried out through the use of SCHENCK TREBELL 150/300 Charpy pendulum, which enables division of overall impact energy into 2 components: crack initiation energy and crack propagation energy.

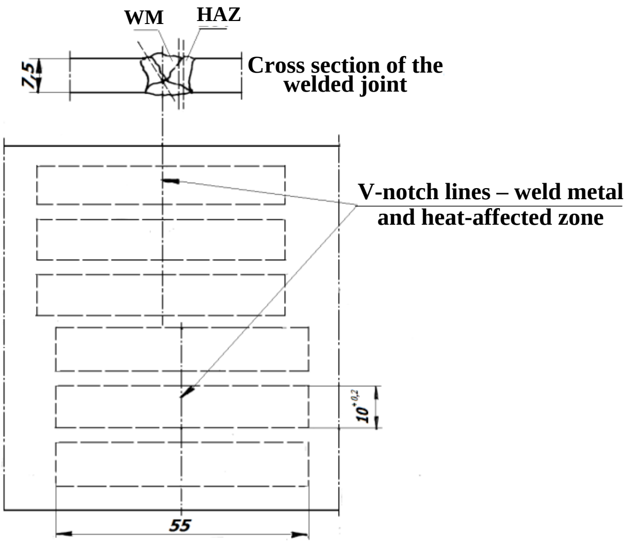


Figure 4. Position of specimens within the sample

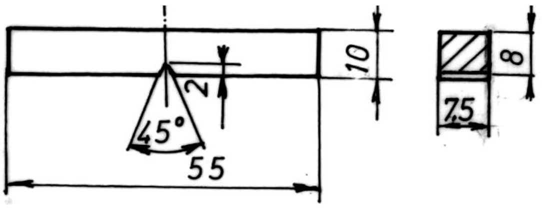


Figure 5. V-notch specimen

**Sampling and microstructural testing.** Locations where samples in the area of welded joints (WJ) at pipes Ø139.8 x 8 mm were taken in order to perform structural tests are presented in Fig. 6.

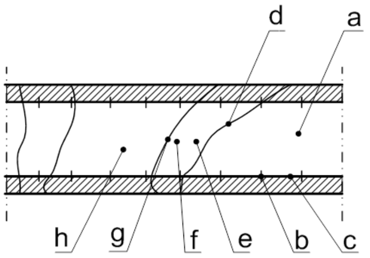


Figure 6. Arrangement of pipe samples taken for microstructural tests

## Analysis of Test Results

**Analysis of chemical composition.** Results of quantometric analysis of chemical composition of steel P460NL1 which was used during these tests are presented in Table 1. The analysis showed that the above mentioned steel has a significantly lower content of carbon than the maximum value predicted by standard [2] and that it is, according to the value of carbon equivalent, prone to cold cracking,

Table 1. Chemical composition of steel P460NL1, mass percentage

| C | Si | Mn | P | S | Cr | Ni | Nb | Cu | Al | Cek |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.123 | 0.266 | 1.334 | 0.015 | 0.007 | 0.026 | 0.019 | 0.004 | 0.14 | 0.03 | 0.398 |

**Tensile testing.** Basic mechanical properties of material (stress – strain curve) are being determined by tensile testing [2]. Results that refer to tensile properties of PM, WM and HAZ of steel P460NL1 are presented in Tables 2, 3 and 4. Mean values of yield strength for PM and WM are almost equal and 22% lower than mean value of yield strength for HAZ. The situation is similar regarding the value of elongation. Situation's practically the same when it comes to elongations. A curve obtained during the testing is shown in Fig. 7.

Table 2. Tensile properties of PM

| Specimen designation | Yield strength, YS [MPa] | Tensile strength, TS [MPa] | Elongation, A5 [%] |
|---|---|---|---|
| Epr-1 | 444 | 551 | 25.2 |
| Epr-2 | 435 | 540 | 23.4 |
| Epr-3 | 446 | 556 | 24.8 |

Table 3. Tensile properties of material in HAZ

| Specimen designation | Yield strength, YS [MPa] | Tensile strength, TS [MPa] | Elongation, A5 [%] |
|---|---|---|---|
| Epr-1 | 524 | 583 | 18.7 |
| Epr-2 | 614 | 657 | 18.4 |
| Epr-3 | 603 | 648 | 15.1 |

Table 4. Tensile properties of WM

| Specimen designation | Yield strength, YS [MPa] | Tensile strength, TS [MPa] | Elongation, A5 [%] |
|---|---|---|---|
| Epr-1 | 433 | 583 | 25.3 |
| Epr-2 | 442 | 596 | 21.7 |
| Epr-3 | 444 | 618 | 23.7 |

**Determination of impact energy.** Testing of notched specimens enables the determination of impact energy required in order to cause the fracture of the specimen [4]. It is most commonly used in order to check the quality and homogeneity of material. This kind of testing is useful when it comes to determination of proneness toward brittle cracking, or proneness toward ductility reduction during service. Test results are presented in Table 5.

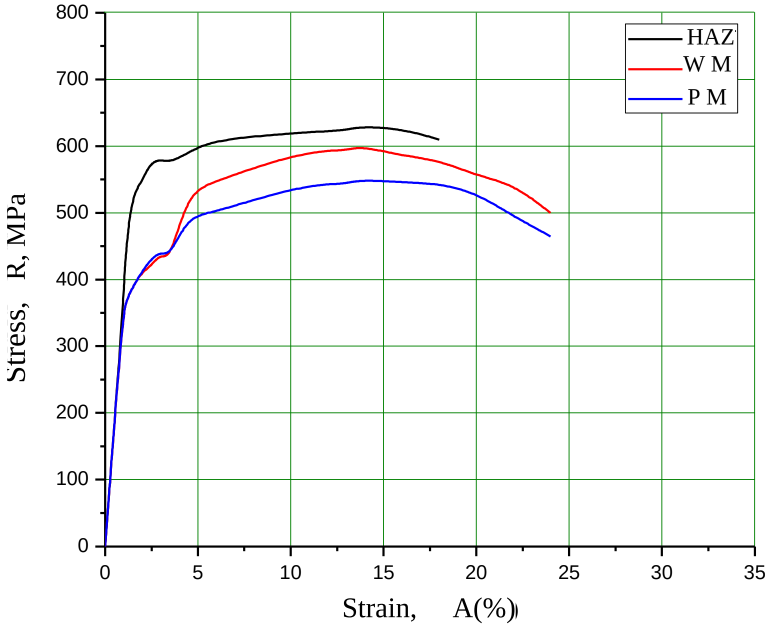


Figure 7. Stress – strain curve for HAZ, WM, PM at 20°C

Table 5. Results of impact energy testing

| Sample designation | Specimen designation | Overall impact energy, $E_I$ [J] | Crack initiation energy, $E_{ci}$ [J] | Crack propagation energy, $E_{cp}$ [J] |
|---|---|---|---|---|
| PM | 1 | 115,3 | 28,2 | 87,1 |
| | 2 | 104,4 | 23,4 | 81,0 |
| | 3 | 112,3 | 27,6 | 84,7 |
| WM | 1 | 118,7 | 35,3 | 83,4 |
| | 2 | 130.4 | 40,9 | 89,5 |
| | 3 | 89,9 | 25,7 | 64,2 |
| HAZ | 1 | 52,7 | 22,6 | 30,1 |
| | 2 | 50,2 | 21,5 | 28,7 |
| | 3 | 46,4 | 20,4 | 26,0 |

Mean values of overall impact energy for PM and WM are practically equal, while in comparison with results obtained for material taken from the HAZ they are more than 2 times higher. Through the analysis of energy necessary for initiation and propagation of cracks it was determined that the ratio of those energies is very good when it comes to PM and WM. It was also determined that the critical location for crack initiation is the HAZ.

**Metallographic tests.** Structures of PM, HAZ and WM of pipe samples obtained by metallographic testing are shown in figures 8 and 9.

a) Parent metal b) Parent metal

c) Parent metal d) Parent metal and heat – affected zone

Figure 8. Microstructure of parent metal and transition area between the parent metal and HAZ

a) Fine-grained section of the heat – affected zone b) Coarse-grained section of the heat – affected zone

c) Fusion line between the heat – affected zone and weld metal d) Weld metal

Figure 9. Microstructure of transition areas between heat – affected zone and weld metal

Basic properties of obtained microstructures are as follows:

- Parent metal has a typical ferrite-pearlite structure, figure 10 (a-c).
- Section of the HAZ next to PM is being characterized by fine grains with structure similar as PM, figures 10 (d) and 11 (a).
- Coarse-grained section of HAZ possesses complex microstructure which consists of bainite, small amount of proeutectoid ferrite and secondary ferrite, figure 11 (b).
- Transition area between HAZ and WM possesses a similar mixed structure – predominant bainite, a bit of coarse proeutoctoid ferrite and secondary ferrite, figure 11 (c).
- Weld metal possesses complex microstructure which consists of secondary bainite, coarse proeutoctoid ferrite, acicular ferrite and bainite, figure 11 (d).

Parent metal has a typical ferrite-pearlite structure. It should be noted that the volumetric share of ferrite and pearlite in various areas differs, figure 10 (a-c). In the local areas of PM microstructure bandiness is detectable, or in other words clusters of secondary phase particles and inclusions fractured during the process of rolling in oriented formation, figure 10 (b-c). Differing volumetric share of ferrite and pearlite in tested areas, as well as presence of bands in local areas indicate that the structure of PM is non-homogeneous. Strongly expressed inhomogeneity of microstructure in the area of HAZ, figures 10 (d) and 11 (a-b), is a consequence of microstructural transformations that occurred due to various rates of heating and cooling of particular zones in this area during the welding process. In the transition area between PM and HAZ the structure is similar to the structure of PM but significantly finer grained, figures 10 (d) and 11 (a). As can be detected on photographs presented in figures 10 (d) and 11 (a-c), fine-grained structure characteristic for the transition area between HAZ and PM is getting coarser towards the fusion line between HAZ and WM. In the middle section of the HAZ, figure 11 (b), as well as in the fusion area between the HAZ and WM, figure 11 (c), microstructure consists of upper and lower bainite, ferrite and secondary phases. In figure 11 (d) the microstructure that consists mostly of ferrite and bainite, with a small volumetric share of secondary phases, is shown.

## Conclusion

On the basis of results of executed tests and earlier researches it can be concluded that the procedure and welding technology for steels with improved strength have critical influence on mechanical properties of welded joints, as well as on the reliability of pipelines for pressure equipment. Welding of welded pipes should be carried out with as little heat input as possible.

## Acknowledgement

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## References

[1] EN 10027-4: Designation systems for steels - Part 1: Steel names, European Committee for Standardization, 2016.

[2] EN 10028-3: Flat products made of steels for pressure purposes - Part 3: Weldable fine grain steels, normalized, European Committee for Standardization, 2017.

[3] EN 499: E 50 4 1 Ni B 42, Welding consumables. Covered electrodes for manual metal arc welding of non alloy and fine grain steels, Classification, European Committee for Standardization, 1995.

[4] EN ISO 6892-1: Metallic materials - Tensile testing - Part 1: Method of test at room temperature, European Committee for Standardization, 2016.

[5] EN ISO 148-1: Metallic materials - Charpy pendulum impact test - Part 1: Test method, European Committee for Standardization, 2010.