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Non-destructive testing of helically welded pipes made of thermomechanically rolled materials used for sending of combustibles

Abstract: In the first part of the paper it has been presented the short information on methods of fabrication of helically welded pipes used for transporting of combustibles. In the second one it has been given the NDT methods used during inspection of the pipes in production plants. In the next parts it has been described the NDT methods for steel pipes focusing first of all on visual, ultrasonic and radiographic ones. The paper has been ended with the information about prospects of gas industry development in Poland and in the world.

Keywords: welding, non-destructive testing, helially welded pipes

Introduction

The golden age of pipelines has come with a permanently increasing demand for raw materials; the excavation of which is an enormously complicated undertaking. As of today, the best solution related to this type of transportation is a subterranean grid of main pipelines made of steel pipes. Poland's gas distribution system has approximately 17 thousand kilometres of high-pressure gas pipelines and approximately 79 thousand kilometres of distribution network, 23 gas pumping stations, and approximately 4 thousand 1st and 2nd degree pressure reducing and measuring stations. A growing consumption of energy combined with a growing demand for energy carriers, in particular for natural gas, shapes the development of the network of industrial pipelines. Great distances between the sources at which natural gas and oil are excavated and the places of their consumption require the construction of transit pipelines characterised by very high operating parameters, e.g. gas pipelines with a diameter of over 1000 mm and pressure of 10 MPa. Such pipelines must be made of pipes characterised by a strength of over 690 MPa (485MB, 555MB) and very good weldability. As a result, it is possible to observe the development of low-alloy steels (C 0.16%, Si 0.55%, Mn 1.9%), often with microadditions of Nb, Mo, or Ti. Such pipes are obtained by means of controller rolling referred to as thermoplastic or thermomechanical treatment. Pipes for the pipelines mentioned above are produced following the regulations contained in DIN standards or in their American (API5L) and European (EN 10208) counterparts. Large-diameter steel line pipes for transporting liquid and gaseous fuels are used as the following:

- seamless pipes (S), obtained by means of hot or cold working methods,
- welded pipes (W), produced by means of electric induction welding (EW) or butt welding (BW) as well as submerged arc welding (SAW) with a longitudinal weld (SAWL) or a helical weld (SAWH). Figure 1 presents the process of welding pipes with a helical weld (two-stage). Pipes can

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also be welded using the combination of gas-shielded welding of root runs and submerged arc welding of filling layers (COW) [1].

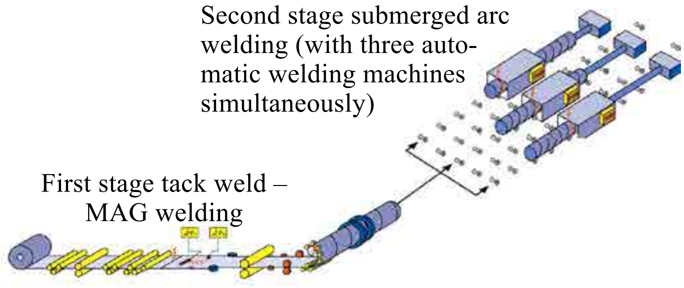

Fig. 1. Two-stage helical welding of pipes used by the German company of Salzgitter Mannesmann Grossrohr GmbH [5]

This article presents non-destructive testing of thermomechanically rolled helically submerged arc welded (SAWH) pipes L485MB and L555MB. These pipes were selected as they are typical and manufactured in many steelworks both in Poland and overseas. Following their manufacture the pipes undergo insulation application, usually with polyethylene or polypropylene and are painted inside with epoxy paints.

Non-destructive testing used during pipe manufacture

General information

The basic purpose of non-destructive testing (NDT) is to assess the condition of a material or welded joint and, on this basis, to issue an opinion related to the quality, durability and safe operation of a structure. The effectiveness and quality of non-destructive testing depends on numerous factors:

- personnel competence based on adequate training,
- experience,
- inspection procedures,
- equipment,
- environment in which testing is carried out,
- psychological pressure, to which NDT personnel are exposed,
- working time during the day,
- equipment features,
- supervision and how it is exercised,
- applied standards, requirements and guidelines,
- systems applied for the certification of personnel, procedures and equipment [1].

The basic NDT methods used in the production of pipes are the following:

- visual testing – VT,
- radiographic testing of pipe ends – RT,
- automatic fluoroscopic testing of a whole welded joint,
- ultrasonic testing of a burden material in the form of a strip unwound from a coil (laminar imperfection test) – UT,
- automatic ultrasonic testing of a whole welded joint – UT,
- manual ultrasonic testing of a welded joint on a pipe end – UT,
- manual ultrasonic testing of a welded joint being repaired – UT.

In addition, in order to determine precisely the size of welding imperfections, also other NDT methods, i.e. penetration testing (PT) and magnetic particle testing (MT), can be used.

The basic standard describing the selection of testing manners and assessment criteria is standard PN-EN 10208-2 “Steel pipes for pipelines for combustible fluids – Technical delivery conditions – Part 2: Pipes of requirements class B”. The standards describing testing manners and assessment criteria are the following:

- PN-EN 10246-9 Non-destructive testing of Steel Tubes – Part 9: Automatic Ultrasonic Testing of the Weld Seam of Submerged Arc Welded Steel Tubes for the Detection of Longitudinal and/or Transverse Imperfections;
- PN-EN 10246-10 Non-destructive testing of Steel Tubes – Part 10: Radiographic Testing of of the Weld Seam of Automatic Fusion Arc Welded Steel Tubes for the Detection of Imperfections;

- PN-EN 10246-15 Non-destructive testing of Steel Tubes – Part 15: Automatic Ultrasonic Testing of Strip/Plate Used in Manufacture of Welded Steel Tubes for the Detection of Laminar Imperfections;
- PN-EN 10246-16 Non-destructive testing of Steel Tubes – Part 16: Automatic Ultrasonic Testing of the Area Adjacent to the Weld Seam of Welded Steel Tubes for the Detection of Laminar Imperfections;
- PN-EN 10246-17 Non-destructive testing of Steel Tubes – Part 17: Ultrasonic Testing of Tube Ends of Seamless and Welded Steel Tubes for the Detection of Laminar Imperfections;
- PN-EN ISO 10893-6 Non-destructive testing of Steel Tubes – Part 6: Radiographic Testing of the Weld Seam of Welded Steel Tubes for the Detection of Imperfections;
- PN-EN ISO 10893-8 Non-destructive testing of Steel Tubes – Part 8: Automatic Ultrasonic Testing of Seamless and Welded Steel Tubes for the Detection of Laminar Imperfections;
- PN-EN ISO 10893-9 Non-destructive testing of Steel Tubes – Part 9: Automated Ultrasonic Testing for the Detection of Laminar Imperfections in Strip/Plate Used in the Manufacture of Welded Steel Tubes;

Table 1. Non-destructive tests used in manufacture of pipes [2]

Types of imperfections detected during pipe manufacture	Testing status	Types of tests, requirements and acceptance levels
Residual magnetism on pipe ends	Obligatory	Gaussmeter using Hall effect or equivalent; max. 30 gausses, random tests
Laminar imperfection on pipe ends	Optional	Ultrasonic testing according to PN-EN 10246-17 or PN-EN ISO 10893-8, inspection area: max. 6 mm from pipe ends on circumference
Longitudinal/transverse imperfections in welded joint	Obligatory	Ultrasonic testing according to EN 10246-9 or PN-EN ISO 10893-11, acceptance level U2/U2H or calibration method ”two lamb” (also for welds joining strip ends in helically welded pipes) Radiographic testing according to PN-EN 10246-10 or PN-EN ISO 10893-6, image quality class R1, used for T-type joints of helically welded pipes
Laminar imperfections on pipe body	Optional	Ultrasonic testing according to PN-EN 10246-15 or PN-EN ISO 10893-9, acceptance level U2
Laminar imperfections on strip edge where transverse weld was made	Optional	Ultrasonic testing according to PN-EN 10246-15 or PN-EN ISO 10893-9 or alternatively ultrasonic testing according to PN-EN 10246-16 or PN-EN ISO 10893-8, acceptance level U2
Non-destructive testing of weld in pipe ends (areas not tested previously) / testing of areas being repaired	Obligatory	Ultrasonic testing according to PN-EN 10246-9 or PN-EN ISO 10893-11 for longitudinal imperfections, acceptance level U2/U2H or (if not specified otherwise) Radiographic testing according to PN-EN 10246-10 or PN-EN ISO 10893-6, image quality class R1for longitudinal imperfections and Ultrasonic testing according to PN-EN 10246-9, (PN-EN ISO 10893-11) or radiographic testing according to PN-EN 10246-10 (PN-EN ISO 10893-6) for transverse imperfections

- PN-EN ISO 10893-11 Non-destructive testing of Steel Tubes – Part 11: Automated Ultrasonic Testing of the Weld Seam of Welded Steel Tubes for the Detection of Longitudinal and/or Transverse Imperfections.

The standards of the PN-EN 10246 series have been now replaced by the standards of the PN-EN ISO 10893 series. The basic product standard PN-EN 10208-2 (version in effect) still indicates older standards as those in effect. As a result, all the greater production plants continue to use these standards in the manufacturing of pipes. For this reason, in all cases this study refers to both standards as recommended for use. As far as ultrasonic manual testing is concerned, the standards applied are the basic standards concerned with the manner of the ultrasonic manual testing of welded joints and their assessment and are not discussed in this study. A detailed list of non-destructive tests applied in pipe manufacture is presented in Table 1.

The residual magnetism at the ends of each pipe, parallel in relation to the pipe axis, should not exceed 30 G (3mT). The measurement of magnetism should be carried out on a random basis on the butting face of the pipe end, by means of a calibrated meter (gaussmeter) using the Hall effect or by means of equivalent devices.

All non-destructive tests of welded joints should follow a hydraulic test of the pipe.

Visual testing (VT)

In accordance with the requirements of standard PN-EN 10208-2 each pipe should undergo a visual inspection of the entire outer surface. The inner surface of the pipe should be inspected on each side of the pipe if its outer diameter is 610 mm or less and in 100% of the entire inner surface if the outer diameter of the pipe is 610 mm or greater. Visual testing should be carried out by adequately trained personnel and with proper lighting of the surface being viewed (the light intensity should amount to a minimum of 300 lx).

Pipes should be free from imperfections as a finished product. The appearance of the outer and inner surfaces of the pipe should be typical for the production process and heat treatment applied. No surface imperfections requiring removal should be visible.

Below are presented manners of dealing with imperfections detected on the outer surface:

- imperfections with a depth equal to or below 12.5% of a required wall thickness, which do not reduce the nominal thickness of the pipe in the place of their occurrence should be treated as allowed imperfections (they can remain on the pipe surface or, in accordance with the manufacturer's decision, can be removed by cosmetic grinding);
- imperfections with a depth exceeding 12.5% of a required wall thickness, which do not reduce the nominal thickness of the pipe in the place of their occurrence are classified as imperfections and should be removed by grinding (after grinding it is necessary to apply a proper NDT method, e.g. MT, in order to check the pipe surface after grinding);
- imperfections which reduce the nominal thickness of the pipe in the place of their occurrence should be treated as unallowed imperfections and repaired by welding or the part of the pipe containing such imperfections should be cut out (the required length of the time should be maintained). If the aforesaid solution is impossible, a pipe with an unallowed imperfection should be rejected.

Geometrical deformations of the cylindrical contour of the pipe should not exceed the following:

- 3 mm (flattening, metal excess, cold-formed indentations with gentle edges);
- 6 mm (other indentations).

Outer imperfections can be removed only by machining or grinding. The thickness of a pipe wall in the areas being repaired cannot be less than the required nominal wall thickness. All machined/ground areas should gently pass into the contour of the pipe [2].

Ultrasonic testing (UT)

Ultrasonic testing of strip (pipe body) for laminar imperfections

The first type of ultrasonic testing used during pipe checks is testing for laminar imperfections of the strip surface. In this case it is possible to accept ultrasonic testing carried out at the sheet manufacturer's or test a (flat-formed) material used in the production of pipes, acting in accordance with the requirements of standards PN-EN 10246-15 or PN-EN ISO 10893-9 and acceptance level U2. Single laminar imperfections or laminar imperfections in groups exceeding acceptance level U2 are unallowed [2, 6, 11]. An example of a device for strip ultrasonic testing is presented in Figure 2.

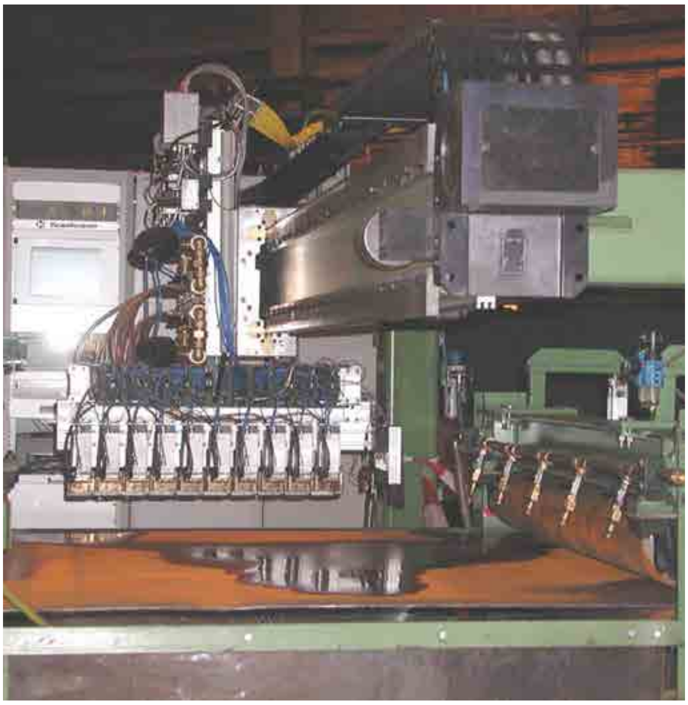

Fig. 2. Device applied in UT of strips for the presence of laminar imperfections, used in the Salzgitter Mannesmann Grossrohr GmbH compay, Germany [5]

Ultrasonic testing for the detection of longitudinal and transverse imperfections in welded joints

In order to ensure full NDT of welded joints it is required that helically welded pipes should undergo ultrasonic testing along their whole length. The test objective includes both longitudinal and transverse imperfections. Ultrasonic testing should be carried out in accordance with the requirements of standard PN-EN 10246-9 or PN-EN ISO 10893-11 [2]. As a rule, UT of pipes follows the completion of all the main operations of a production process. In order to ensure the reliability of ultrasonic testing, pipes should be sufficiently straight and free from foreign matter.

In order to detect longitudinal and transverse imperfections, helical welds should undergo ultrasonic testing. In both cases the testing should be conducted in two opposite beam propagation directions. During the test the converter unit should remain in the proper position in relation to a weld so that the entire weld could be searched through. A searching rate should not oscillate by more than 10% than the adopted basic rate. Depending on the thickness and roughness of the pipe surface, the frequency used in UT should be contained within a 1 MHz÷15 MHz range. The maximum width of each single converter, measured parallel to the main axis of the pipe, should amount to 25 mm. By means of an ultrasonic monitor connected with a marking and/or sorting system, the equipment should enable the classification of pipes as accepted or rejected. If it is not possible to test welds on pipe ends by means of automatic ultrasonic testing equipment, the testing of pipe ends should be conducted by the manufacturer using either manual ultrasonic testing or radiographic testing.

Ultrasonic equipment for detecting longitudinal imperfections should be calibrated by means of four longitudinal grooves, two on the outer surface and two in the inner surface of pipe masters and/or by means of a datum hole (Fig. 3). Converters used for detecting transverse imperfections should be calibrated by means of a hole and/or two grooves transverse in relation to the weld, one on the outside and one inside a sample being tested. The decision whether to choose grooves or a hole is at the manufacturer's discretion.

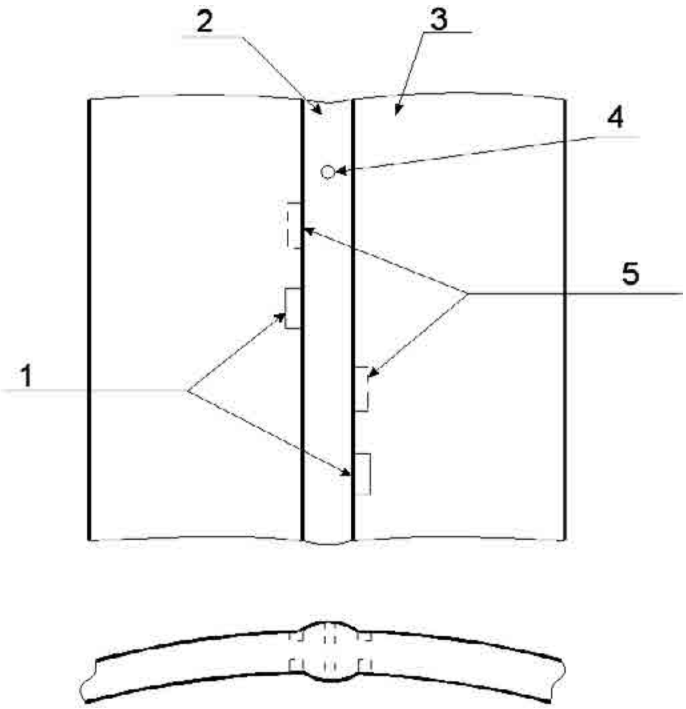

Fig. 3. Arrangement of reference grooves and datum hole [3, 9]

1. longitudinal outer grooves
2. submerged arc made weld
3. pipe master or pipe section
4. right-through hole
5. longitudinal inner grooves

A test sample should have the same nominal diameter, wall thickness, surface roughness, heat treatment state and similar acoustic properties (e.g. wave propagation velocity and wave damping coefficient) as the pipe being tested. The manufacturer should have the possibility of removing the inner and outer weld run in accordance with the pipe curvature. The outer and inner grooves as well as the datum hole should be sufficiently distant from the pipe ends and from each other so that clearly separate indications of signals coming from the grooves and the hole can be obtained.

A reference groove should be of an "N-type" (Fig. 4). The sides of the groove should be parallel to each other and the bottom should be perpendicular to the sides.

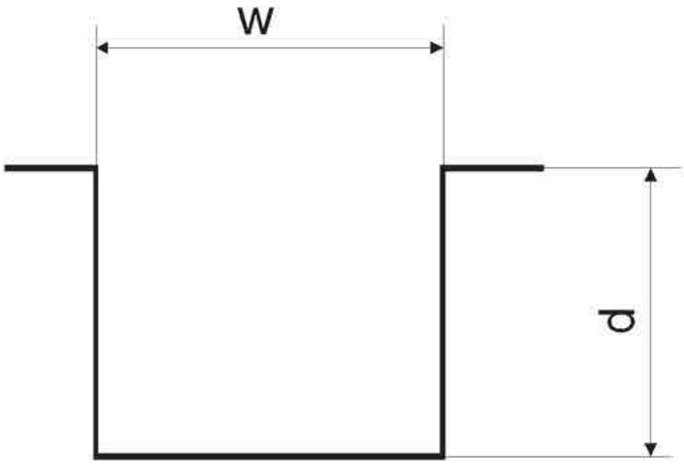

Fig. 4. "N-groove" [3, 9].
w – width, d - depth

Longitudinal reference grooves should be located in the parent metal near the edge of the weld and in parallel to the weld run (Fig. 3).

A reference groove should be electrodischarge machined or made with another method. The dimensions of reference grooves should be the following:

a) width, *w*, (Fig. 4) of a reference groove should not exceed 1.5 mm;
b) depth, *d*, (Fig. 4) should be as specified in Table 2, subject to the following restrictions:
   - minimum groove depth: 0.3 mm for pipes of categories U2 and U3 and 0.5 mm for pipes of category U4;
   - maximum groove depth: 2.0 mm for pipes of categories U2 and U3 and 3 mm for pipes of category U4;
c) depth tolerance for a reference groove should amount to ± 15% depth or ± 0.05 mm, whichever value is greater;
d) length of reference grooves should be equal to at least double width of each single converter, but not more than 50 mm.

A datum hole should be drilled through the wall of a test sample, in the weld centre, perpendicularly to the sample surface (Fig. 3).

The diameter of the drill used to make the datum hole should be selected in accordance with Table 3. The diameter of a datum hole should be checked and cannot exceed the nominal diameter of a drill by more than 0.2 mm.

Table 2. Designation of acceptance level and related depth of reference groove [3, 9]

Acceptance level	Groove depth in % of nominal wall thickness
U2	5.0
U3	10.0
U4	12.5
U5	15.0

The equipment should be calibrated so that it would ensure (e.g. in three subsequent passes of the test sample through the equipment) obtaining clearly distinguishable signals of the reference standard. The peak value of the amplitude of these signals should be used for adjusting the level of the gate/alarm monitor in the equipment. The rate of the test sample travel in relation to the set of ultrasonic converters during the verification of calibration should be the same as during the tests of a product. Calibration can be verified by means of a semi-dynamic method. During the testing of pipes with the same nominal diameter, wall thickness, and made of the same steel grade, it is necessary to verify the calibration of the equipment at regular intervals. The equipment calibration is verified by putting the pipe master through the testing equipment. The verification of calibration should be carried out at least once every four hours as well as each time the equipment operator changes. Calibration should also be verified at the beginning and end of production. In addition, the equipment should be calibrated if any of the parameters set during the initial calibration have been altered. If while verifying calibration during production, calibration requirements are not satisfied even after increasing testing sensitivity by 3 dB (to compensate equipment indications), it is necessary to carry out equipment calibration again as well as to check all the pipes tested since the previous calibration verification.

Table 3. Designation of acceptance level and related drill diameter [3, 9]

Acceptance level	Drill diameter
U2H	1.6
U3H	3.2
U4H	4.0

Following testing, a pipe revealing signals below the monitor/gate sensitivity threshold should be classified as meeting the requirements. And a pipe having signals equal to or greater than the monitor/gate sensitivity threshold should be classified as questioned or, at the manufacturer's request, should undergo another test. If during the subsequent test of the same pipe no signal equal to or greater than the monitor/gate sensitivity threshold was obtained, the pipe should be regarded as meeting the requirements. Depending on the requirements of a product standard, pipes questioned during testing should be dealt with in accordance with one or several following manners:

a) Subject to an agreement between the purchaser and the manufacturer, the area which has been questioned should be tested by means of another NDT technique or method (usually radiographic), on the basis of agreed acceptance criteria;
b) The questioned area should be cut out. The manufacturer should guarantee that the whole questioned area has been removed;
c) The pipe should be classified as not satisfying the requirements [3, 9].

Testing of helically welded pipes is carried out for acceptance level U2/U2H, taking into account the following inspection criteria:

a) the maximum groove depth should amount to 2.0 mm;
b) Using inner and outer longitudinal grooves in the middle of the weld run for the purpose of equipment calibration is unallowed;
c) In the case of acceptance level U2, for the purpose of detecting transverse imperfections, as an alternative to the datum hole one may use the inner and outer grooves positioned at a right angle and centred in the weld. In such a situation both inner and outer weld reinforcements should be ground evenly with the pipe contour, in the direct vicinity and on both sides of reference grooves. The grooves should be sufficiently distant from each other in a longitudinal direction. They should also be sufficiently distant from any other reinforcements. Such an approach is necessary to obtain a clear and distinguishable ultrasonic signal response. In order to determine the level of the gate/alarm of the measuring equipment it is necessary to use the complete amplitude of a signal from each of these grooves.
d) For acceptance level U2 and by prior agreement, as an alternative to using reference grooves for calibration purposes, it is possible to use inner and outer grooves of a constant depth and increase testing sensitivity using electronic methods (by increasing dB amplification). In this case, also referred to as the „two lamb method", the depth of grooves should be twice as big as the length of an ultrasonic wave.

A required increase in testing sensitivity should depend on a pipe wall thickness. The manufacturer should adequately assure the purchaser that obtained testing sensitivity is basically equivalent to that obtained while using grooves for acceptance level U2. In the case of helically welded pipes the entire length of the weld joining strip edges should also undergo ultrasonic testing. Testing sensitivity and parameters should be the same as during the initial testing of the pipe helical weld. In addition, cruciform joints, in which the weld ends of strip edges meet the helical weld should undergo radiographic testing [2].

Following the tests, the manufacturer should provide the ordering party with a report containing at least the following information:

a) reference to standards PN-EN 10246-9 or PN-EN ISO 10893-11 and PN-EN 10208-2;
b) date of test report;
c) acceptance level;
d) declaration of conformity;
e) product specification, i.e. steel grade and dimensions;
f) type and details of testing technique;
g) description of a master/standard [3, 9].

An example of a device for UT of helically welded pipes is presented in Figure 5.

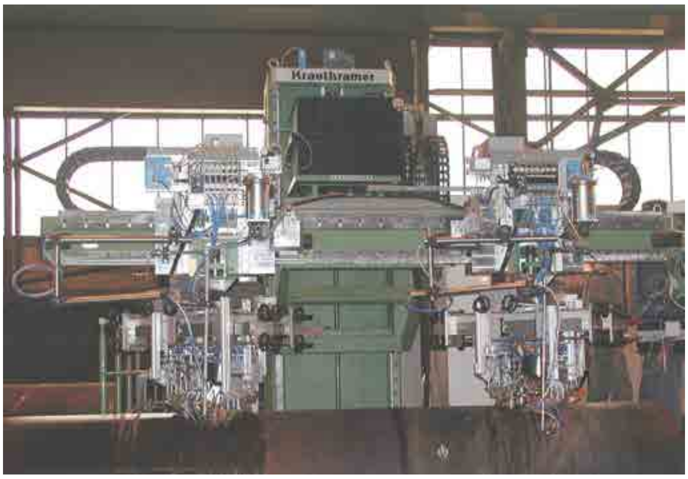

Fig. 5. Automatic multichannel device for ultrasonic testing of helically welded pipe weld and strip-joining weld used in the Salzgitter Mannesmann Grossrohr GmbH company, Germany[5]

Laminar imperfections in strip area adjacent to welded joint

In such a case it is possible to accept ultrasonic testing carried out at steel sheet manufacturer's or carry out post-weld testing at the pipe manufacturer's, following the requirements of standard PN-EN 10246-16 or PN-EN ISO 10893-8 and acceptance level

U2. The tests are conducted within a 15mm-wide zone along both longitudinal edges of a helical weld. In the case of transverse welds joining the edge of a strip testing is conducted along areas adjacent to this butt weld. Requirements concerned with ultrasonic testing of laminar imperfections in the area adjacent to the weld are dealt with in standard PN-EN 10246-15 (PN-EN ISO 10893-9) or PN-EN 10246-16 (PN-EN ISO 10893-8). Single laminar imperfections or imperfections in groups exceeding acceptance level U2 are not allowed [2].

Non-destructive testing of helically welded joints on pipe ends and in areas being repaired

Sections of welded joints on pipe ends which cannot be tested by means of automatic ultrasonic equipment and repaired areas of welds should undergo the following tests:

a) in order to detect longitudinal imperfections – manual or semiautomatic ultrasonic testing using the same testing parameters and sensitivity as in the case of the automatic testing of the whole helical weld. Radiographic testing is also possible.
b) in order to detect transverse imperfections – manual or semiautomatic ultrasonic testing using the same testing parameters and sensitivity as in the case of the automatic testing of the whole helical weld. Radiographic testing is also possible.
c) It is also necessary to carry out testing for the laminar imperfections of the pipe body areas on pipe ends which cannot be checked by means of automatic ultrasonic equipment. In such a case it is also possible to carry out manual ultrasonic testing using the same testing parameters and sensitivity as those used while testing areas adjacent to the weld. Laminar imperfections with a length ≥ 6 mm occurring in girth direction are unallowed if they are present 25 mm away from each pipe end;
d) While carrying out manual ultrasonic testing a scanning rate should not exceed 150 mm/s [2].

Radiographic and radioscopic testing (RT)

Another testing method used in the manufacture of helically welded pipes is radiographic testing, usually carried out on pipes after the completion of all principal production operations. In order to ensure an appropriate testing class, pipes intended for tests should be sufficiently straight and free from foreign matter impurities. The surfaces of welds and adjacent parent metal should be free from foreign matter and surface imperfections as they could impede the interpretation of radiograms. Grinding surfaces is allowed if it can ensure obtaining a surface condition acceptable for tests. If a weld reinforcement must be removed, it is advisable to place markers (usually lead arrows) in order to identify the weld location in a radiogram. In order to ensure the unambiguous identification of a given weld section, each section should be provided with identification symbols (usually lead letters) so that their images can be visible in a radiogram. It is necessary to apply permanent marking on the pipe surface from the side of the radiation source. This is done in order to provide reference points for the accurate assignment of each radiogram location. If it is impossible to strike markers due to the type of a product and/or its intended operating conditions, it is necessary to provide other appropriate means of radiogram assignment, e.g. by marking with paint or preparing accurate sketches. In order to ensure that each part of the weld undergoes testing, during X-raying a longer weld section with several films it is necessary that neighbouring films should overlap over a minimum length of 10 mm.

Longitudinal or helical welds of pipes should undergo radiographic testing with x-rays. The use of radioscopic methods is allowed (Fig. 6), yet only in cases when the manufacturer can demonstrate their appropriate sensitivity.

Fig. 6. Example of device for radioscopic testing of welded joints

There are two image quality classes, i.e. R1 and R2:

- class R1 (class B): radiographic testing technique by means of X-radiation of heightened sensitivity;
- class R2 (class A): radiographic testing technique by means of X-radiation of normal sensitivity.

For image quality class R1 it is necessary to use at least fine-grained films (at least C4 class), whereas for image quality class R2 one should use at least medium-grained films (at least C5 class). For both image quality classes (R1 and R2), the thickness of front intensifying screens should be between 0.02 mm and 0.25 mm. Rear intensifying screens can have other thicknesses. Fluorescent intensifying screens should not be used.

The amount of backscattered and internal X-radiation should be limited to a minimum. When in doubt as to the efficiency of protection against backscattered radiation, it is advisable to fix a characteristic sign (usually a 1.5mm-thick letter B) behind the film holder or film frame and make a radiogram in a normal manner. The density of the symbol image in the radiogram lower than the background density indicates that the protection against backscattered radiation is insufficient and that additional precautions should be used. A radiation beam should be directed onto the centre of a weld section being tested and should be perpendicular to the pipe surface at this point. A length subjected to an assessment should be so that the thickness X-rayed at the ends of the usable length of a radiogram does not exceed the thickness X-rayed in the radiogram centre by more than 10% for image quality class R1 and by more than 20% for image quality class R2. It is necessary to use a technique of X-raying through one wall. If, due to the size of the object, such a technique cannot be used, it is allowed to use a technique of X-raying through two walls (by prior agreement). The distance between the film and the weld surface should be as small as possible.

The minimum distance between the source and the sample ,*f*, should be selected using appropriate formulas or diagrams. The conditions of exposition should be so that the density of a radiogram in the tested area of weld material free from imperfections is not lower than 2.0 for image quality class R1 (2.3 for image quality class B) and not lower than 1.7 for image quality class R2 (2.0 for image quality class B).

The quality of an image should be determined using an image quality indicator (IQI) made of mild steel, grade specified in standards PN-EN 462-1 (PN-ISO 19232-1) and PN-EN 462-2 (PN-ISO 19232-2). An IQI should be placed on the surface from the radiation source side or next to the weld or, in the case of a wire-type IQI – across the weld. Image quality indicators should be placed from the film side only if the surface from the source side is inaccessible. In such cases it is necessary to place a letter "*F*" next to an IQI and make a note of this change of the procedure in the test report [4, 10].

The radiographic testing of helically welded pipes is carried out following the requirements of standard PN-EN 10246-10 or PN-EN ISO 10893-6, image quality class R1, and in accordance with the following conditions:

a) The conformity with sensitivity-related requirements presented in Table 4, determined on the basis of a base metal should be verified by means of a wire-type image quality indicator, in accordance with standard PN-EN 462-1 (PN-ISO 19232-1) or by means of an equivalent hole-type IQI according to PN-EN 462-2 (PN-ISO 19232-2);
b) Radiographic testing should be carried out using only X-radiation, fine-grained and high contrast films as well as lead screens. It is possible to use fluoroscopic methods, yet only when the manufacturer can demonstrate their equivalence with a method based on X-ray films;
c) The optical density of an X-ray photograph cannot be lower than 2.0 and should be selected so that the density in the thickest area of the weld is not lower than 1.5 and that the maximum contrast for a given film type is maintained.

Requirements related to the assessment of welded joints are the following:

a) Cracks, no joint penetration and incomplete fusion are unacceptable;
b) Single slag inclusions and blowholes are acceptable if characterised by the following dimensions: size up to 3.0 mm or a diameter T/3 (T – wall thickness), whichever is smaller;
c) The sum of the diameters of all acceptable single imperfections in each section of a weld with the following dimensions: a length of 150 mm or 12 T, whichever is smaller, should not exceed the smaller of the following values: 6.0 mm or 0.5 T, where the distance between single inclusions should be smaller than 4 T;
d) Single longitudinal slag inclusions with a length of 12.0 mm or 1 T, whichever is smaller or with a width not exceeding 1.6 mm are acceptable. The total length of all acceptable single imperfections in each section of a weld with the following dimensions: a length of 150 mm or 12 T, whichever is smaller, should not exceed 12.0 mm, where the distance between single inclusions should be smaller than 4 T;
e) Single undercuts of any length and with a maximum depth of 0.4 mm are acceptable;
f) In addition, single undercuts with a maximum length of T/2 and a maximum depth of 0.8 mm which does not exceed 10% of a specified wall thickness are allowed provided that there are not more than two such undercuts on a weld section with a length of 300 mm and that all such undercuts will be levelled;
g) All undercuts exceeding the above values should be repaired; in other cases the area under suspicion should be cut out or the pipe should be rejected;
h) All undercuts, of any length and depth, on the inner and outer side of the weld, overlapping in the longitudinal direction are unacceptable [2].

Pipes not exceeding allowed values/indications should be classified as passing the test. Pipes exceeding allowed values/indications should be clas-

Table 4. Requirements for radiographic testing sensitivity and image quality class R1 according to PN-EN 10246-10 and PN-EN ISO 10893-6 [2]

Wall thickness		**Required visibility**	
Over [mm]	Up to [mm]	Hole diameter [mm]	Wire diameter [mm]
4.5	10	0.40	0.16
10.0	16	0.50	0.20
16.0	25	0.63	0.25
25.0	32	0.80	0.32
32.0	40	1.00	0.40

sified as questioned. Questioned pipes should be dealt with in one of the following manners:

a) A questioned area should be levelled by means of an appropriate method. In order to ensure that the imperfection has been removed entirely, after checking that the remaining thickness is still within a tolerance range, the area should undergo another check using magnetic particle testing or penetration testing. Afterwards, the pipe should be classified as passing the test. If the recommended removal of the faulty area has decreased the thickness below the acceptable value, the questioned area should be repaired by welding carried out in accordance with an approved welding procedure specification. After that, the repaired area should undergo radiographic testing following the requirements of PN-EN 10246-10 or PN-EN ISO 10893-6;
b) A questioned area should be cut out. The manufacturer should ensure that the whole questioned section has been cut out;
c) A pipe should be classified as failing to meet the requirements.

In required cases the manufacturer should write a test report containing at least the following information:

a) reference to PN-EN 10246-10 or PN-EN ISO 10893-6 and PN-EN 10208-2;
b) test report date;
c) declaration of conformity;
d) designation of a product providing grade and dimensions;
e) type of and detailed information about the testing technique used;
f) each deviation from specified procedures, agreed or not agreed;
g) image quality class;
h) operator's name, signature and certificate number [4, 10].

Conclusion

In recent years the manufacture of helically welded pipes has seen an intensive development owing to new gas pipelines under construction both in Poland and abroad. The production of these pipes requires the use of materials characterised by the highest mechanical properties in a given material group. NDT devices are usually provided with modern and recently developed technical solutions. Investment-related expectations for the years to come make the manufacture of welded pipes the area of interest for investors and manufacturers all over the world.

References

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3. PN-EN 10246-9:2004 *Non-destructive testing of steel tubes - Part 9: Automatic ultrasonic testing of the weld seam of submerged arc welded steel tubes for the detection of longitudinal and/or transverse imperfections*
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7. PN-EN 10246-16:2002 *Non-destructive testing of steel tubes - Part 16: Automatic ultrasonic testing of the area adjacent to the weld seam of welded steel tubes for the detection of laminar imperfections*
8. PN-EN 10246-17:2002 *Non-destructive testing of steel tubes - Part 17: Ultrason-*

ic testing of tube ends of seamless and welded steel tubes for the detection of laminar imperfections

9. PN-EN ISO 10893-6:2011 *Non-destructive testing of steel tubes - Part 6: Radiographic testing of the weld seam of welded steel tubes for the detection of imperfections*
10. PN-EN ISO 10893-8:2011 *Non-destructive testing of steel tubes - Part 8: Automated ultrasonic testing of seamless and welded steel tubes for the detection of laminar imperfections*
11. PN-EN ISO 10893-9:2011 *Non-destructive testing of steel tubes - Part 9: Automated ultrasonic testing for the detection of laminar imperfections in strip/plate used for the manufacture of welded steel tubes*
12. *PN-EN ISO 10893-11:2011 Non-destructive testing of steel tubes - Part 11: Automated ultrasonic testing of the weld seam of welded steel tubes for the detection of longitudinal and/or transverse imperfections*