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NON-DESTRUCTIVE TESTING OF WELDED STRUCTURES

Abstract. The article describes methods for non-destructive testing of welded joints, with particular focus on structures of high strength. Examples of structural units tested at OBRUM are presented along with the justification of the choice of the test method applied. In summary, reference is made to the limitations of the test methods and to possible errors in the assessment of the correctness of the welded structures.

Keywords: welded structures, non-destructive testing, welded joint testing, welded joint defects.

1. INTRODUCTION

OBRUM's range of activities covers mainly the issues of design, modernization, testing and operation of armoured equipment and of development of military devices and ordnance. The principal topics cover equipment for ground forces (armoured and mechanized troops) and for engineer troops [1].

The completed projects included mostly those of structures of innovative design, which involved complex computer aided design processes (3D prototyping). The developed structures, especially those that transfer considerable forces and stresses (high-strength structures), are verified already at the design stage when strength calculations are made using FEM (finite element method). Multi-stage design verification takes place during the research and development cycle, during model, prototype and trial batch testing. Various fabrication technologies are applied in the implemented designs of vehicles, machines, equipment and units:

- adhesive joints;
- bolted joints;
- pressure welded joints;
- welded joints;
- other/mixed technology, where the above are combined.

Among the products developed at OBRUM, of special interest are welded structures at a very high level of complexity. These include a wide range of materials: from common carbon steel, through high strength steels (ReH min. 1100 MPa, Rm 1200–1500 MPa) [2] armour steels ARMSTAL 500T [3] ARMOX 500T [2], to aluminium and plastics.

The drawings below (Figs. 1, 2, 3 and 4) show selected examples of welded joint applications.

a)



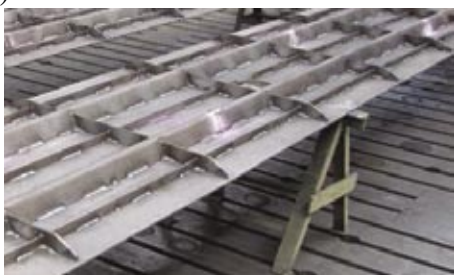
b)



Fig. 1. Fragment of supporting framework of JBR-15 radar station

a) view of welded joints; b) machine/device (view)

a)



b)



Fig. 2. PM-20 bridge span

a) view of welded joints; b) machine/device (view)

a)



b)



Fig. 3. Extendable crane section of MID Engineering and Road Vehicle

a) view of welded joints; b) machine/device (view)

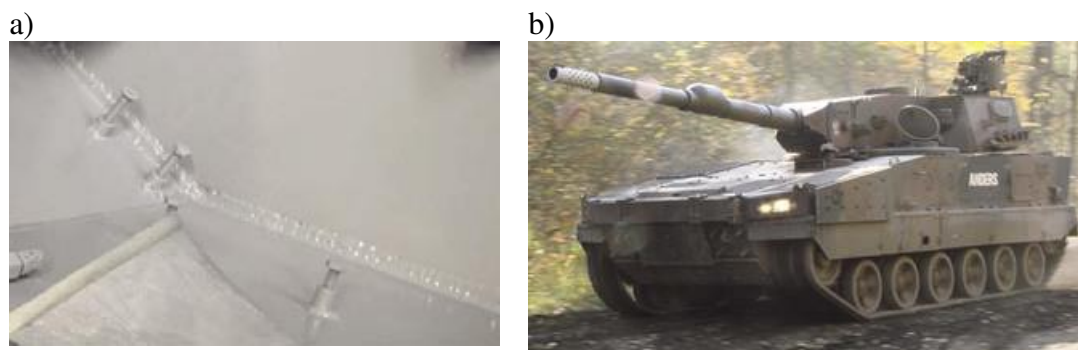


Fig. 4. Hull of UMPG / PLC (Anders) tracked vehicle

a) view of welded joints; b) machine/device (view)

2. TECHNOLOGY OF PRODUCING WELDED JOINTS

In order to assess and improve the quality of steel structures manufacture, in-process testing is carried out, of which inspections of welded joints are an important component. Testing is performed at the production site, using available methods and means, as well as in specialized laboratories where special equipment and instrumentation is used.

2.1. Classification of welding imperfections

According to EN ISO 3834 [4] welding is a special process, meaning that its final effect depends on many factors. OBRUM has implemented a Quality Management System that meets the requirements of EN ISO 9001 [5] and of AQAP 2110 [6]. In accordance with the above, in order to ensure quality in welding processes, welding schedules that take into account approved welding technologies have to be followed. The welding schedules must also include quality control of the joints made. Welding joints may be tested using destructive and/or non-destructive methods. Non-destructive testing of welded joints is intended to detect welding defects and imperfections resulting from material, metallurgical, structural and technological nature of the joint.

Every welded joint may be assigned its required quality level in accordance with EN ISO 5817 [7]. Three quality levels are identified: stringent B, intermediate C and moderate D. These are affected by the assessment of the joints made. A possible classification of imperfections in joints is described in EN ISO 6520-1 [8]. The standard distinguishes the following imperfections:

- cracks;
- cavities;
- solid inclusions;
- lack of fusion and penetration;
- imperfect shape and dimensions;
- miscellaneous imperfections.

An imperfection becomes a structural defect when it causes the joint to fail to meet design requirements. The type of nondestructive testing should be selected with a view to detect surface and internal imperfections, in accordance with current standards.

2.2. Inspection of welded joints

The following types of non-destructive testing are applied to assess the quality of joints [9]:

- VT – visual;
- PT – penetrant;
- MT – magnetic;
- RT – radiographic;
- UT – ultrasonic;
- ET – eddy current.

Choice of the method depends on a number of factors, such as: base metal and filler, joint type, its geometry, dimensions and shape.

Joint testing should be performed by qualified persons certified for the given test type. Three qualification levels of non-destructive testing personnel may be distinguished:

- A person of the first level can carry out non-destructive testing in accordance with instructions under the supervision of level two and level three personnel. Such person may also participate in the following operations: setting of testing equipment, recording test results based on criteria set out in writing, reporting test results.
- Level two person has competence to carry out tests in accordance with defined procedures. Such person is responsible for selecting the testing technique, for determining the limitations in the application of the testing method, for setting instrumentation and verifying the settings, for carrying out the tests and analysing the test results, for drawing up written test instructions, listings and reports.
- Level three person is responsible for performing and managing activities in the process of non-destructive testing. Such persons may be authorised to take on full responsibility for a testing laboratory. Such person is responsible for drawing up and approving non-destructive instructions and procedures, for interpreting standards, regulations, procedures, specifications, and for determining specific methods of non-destructive testing within the scope of its competence.

In a typical inspection of a welded structure it is assumed that prior to testing, the presence and correct positioning of all joints is verified. In the quality control of the welding process consideration must also be given to the preparation of parts for welding, to the preparation of the weld groove and to the execution of the weld itself: tacking and welding. Detailed requirements are specified in EN ISO 3834: 2007 [4]. All joints should be verified by visual inspection (VT) in accordance with the standard in terms of compliance with the adopted level of quality. Joints should be inspected along their entire length including zones of filler spattering. Visual inspection should be followed by penetration testing (PT) or magnetic particle testing (MT) of 30% of the joints made. This should then be followed by radiographic testing (RT) or ultrasonic testing (UT) of 30% of the joints. The scope of testing may also depend on the load class. Repaired joints should be subjected to testing in a wider scope, 100% of the repair made.

Every time a welding technology engineer should perform an analysis of the causes of technological imperfections. Use of that analysis should be made when performing corrective actions aimed at improving welding operations. Persons responsible for supervision and Quality Control representative are responsible for keeping a register of imperfections and for related corrective actions.

3. NON-DESTRUCTIVE TESTING OF WELDED JOINTS

Inspection processes of welded joints, their locations and types are listed in the appropriate technology. Selected tests are performed depending on the structural unit that performs a defined function and on process requirements.

The non-destructive tests most often performed at OBRUM include: visual testing, penetrant testing and magnetic particle testing. These tests are fast and do not require special instrumentation.

3.1. Visual testing (VT)

Visual testing VT is the basic and most common type of non-destructive testing. This method is used to inspect welded joints with the naked eye; optical instruments with a magnification of up to 20x can be used. This method is often used to indicate areas to be tested using more advanced methods. The tested area must be cleaned mechanically or chemically to reveal possible surface defects hidden under the fouling. The tested area should be properly illuminated to attain appropriate contrast and light intensity. Contrast depends on the light incidence angle and on the angle of observation. Light intensity should be at least 350 lx; usually the light used has 500 to 1000 lx.



Fig. 5. Joint defects detected using VT – imperfect shape and dimensions, cavities, lack of fusion and penetration

3.2. Penetrant testing (PT)

Penetrant testing is applied mainly to detect surface imperfections of magnetic and non-magnetic metal bonds. The defects most often detected using this method include cracks, lack of fusion or gas bubbles on the surface. The principle of this method is based on the phenomenon of capillarity. Penetrant has a strong affinity to penetrate into fissures in the tested surface. A typical penetrant test consists of the following steps: cleaning of the tested surface, applying penetrant onto the surface and allowing it to penetrate, removing penetrant from the surface and drying the surface, applying a developer onto the surface. After a defined development time, the results are analysed and the surface is cleaned.



Fig. 6. Examples of joint penetrant testing results – welding imperfections in the form of cracks

3.3. Magnetic particle testing (MT)

Magnetic particle testing (MT) consists in detecting defects in ferromagnetic materials with the use of magnetic field. Magnetic field is dissipated when defects are encountered. The lines of magnetic field are visualised by means of a ferromagnetic powder material. This method is used to detect both surface defects as well as slightly subsurface defects. The procedure of a magnetic particle test includes the following steps: Surface preparation - cleaning and demagnetizing the tested part, magnetizing, applying magnetic powder, visual inspection and registering the results, demagnetizing and surface cleaning.



Fig. 7. Examples of joint MT results – welding imperfections in the form of cracks

Another group of tests applied includes ultrasonic and radiographic testing which requires special instrumentation. OBRUM commissions this type of tests to specialized laboratories.

3.4. Radiographic testing (RT)

Radiographic testing is used most often to detect internal defects in welded joints. Its feature is simplicity of registering and evaluating measurement results. The test makes use of the phenomenon of absorption of X and gamma radiation by various materials. The rays pass through the tested weld and strike a photographic film creating an image of the tested weld in the form of a plan view. The image can be analysed to detect surface and internal defects.

Imperfections are presented as dark areas against the background of a light weld or in the fusion and heat affected zones. Only tungsten inclusions and sagging is lighter than the weld. The welds subjected to testing should be cleaned of all fouling and marked in a permanent way. An image quality indicator should be positioned near the weld, and when the tested welds

are long, the films should overlap and be additionally marked with indicators. The direction of the rays should be perpendicular to the face of the weld. This method is recommended particularly for testing butt joints. The area of tests should be properly protected by screening the scattered radiation.

3.5. Ultrasonic testing (UT)

Ultrasonic testing UT employs the phenomenon of reflection and diffraction of waves of a frequency of over 20 kHz. This method utilizes the phenomenon of reflecting acoustic waves on discontinuities of the material within the tested welds. Ultrasonic testing enables determining the type and dimensions of the imperfection. A defectoscope (flaw detector) is the instrument used in ultrasonic testing. Waves are generated in special heads. Depending on the direction of wave incidence, normal and angular heads can be distinguished. The type and size of a defect is registered as an amplitude of an echo while the head is moved dynamically. The scanned areas are selected so as to include the weld, heat affected zone and base metal. The gap between the head and the tested material should not exceed 0.5 mm; the space between should be filled with couplant.

4. SUMMARY

4.1. Defect detectability by the various non-destructive testing methods

Physical phenomena, on which the individual non-destructive testing methods are based, define the application thereof in particular cases.

In the case of surface testing, the main selection factor are the magnetic properties of the tested joint and capillarity occurring on the surface. Ferritic steels can be tested using visual inspection (VT) methods, penetration testing (PT) and magnetic particle tests (MT). Austenitic steels and non-ferrous metals, due to their magnetic properties, are tested using visual testing (VT) and penetration testing (PT).

Table 1. Applications of non-destructive surface methods

| Test method | Application | Defect type | Detectable faults |
|------------------------|-------------------------|---------------------|--|
| Visual (VT) | No contraindications | Surface | <ul style="list-style-type: none"> • undercut • cavity in crater • concavity, excess weld metal • lack of fusion • cracks |
| Penetrant (PT) | No contraindications | Surface | <ul style="list-style-type: none"> • cracks |
| Magnetic particle (MT) | Ferromagnetic materials | Surface, subsurface | <ul style="list-style-type: none"> • lack of penetration • cracks • lack of fusion |

As part of the pre-defined non-destructive methods for subsurface defects, attention should in the first place be paid to the location and size of the test area and to the type of imperfections to be registered.

Table 2. Applications of non-destructive surface and subsurface methods

| Test method | Use | Defect type | Detectable faults |
|-----------------|----------------------|---------------------|---|
| Ultrasonic (UT) | No contraindications | Surface, subsurface | <ul style="list-style-type: none"> • gas bubbles • slag inclusions • foreign metal inclusions • lack of penetration • undercuts • lack of fusion • cracks |
| X-ray (RT) | No contraindications | Surface, subsurface | <ul style="list-style-type: none"> • gas bubbles • slag inclusions • foreign metal inclusions • lack of penetration • sagging • undercuts • surface geometry • lack of fusion • cracks |

4.2. Conclusions

Non-destructive testing of welded joints made in the course of a manufacturing process enables detecting welding defects and imperfections resulting from material, metallurgical, structural and technological nature of the joints. The test methods described in the article allow for continuous efforts to eliminate defects by introducing corrective actions to avoid the generation of similar defects in the future.

The testing methods of welded joints applied at OBRUM enable detecting imperfections created during the welding process at the stage of manufacture, which in most cases eliminates the cost of repairs conducted during equipment operation and the risk of putting the equipment out of use. The test methods described in the article are efficient enough, and their selection depending on the individual project is conducted in such manner as to optimize its effect on the manufacturing process and to avoid excessive extension of test duration, while at the same time fulfilling the requirements specified in the technical requirements of acceptance or in tactical and technical specifications.

All basic non-destructive testing methods of welded structures applied at OBRUM are listed in the article. Non-destructive testing is a common method of analysing a structure at every product life cycle stage. The choice of appropriate methodology and methods of testing affects the detectability of defects of particular type. Some methods are more suited to detect defects of one type than the other. The quality of product quality control depends on the developed testing plan which should be related to the welding instructions.

5. REFERENCES

- [1] OBRUM Sp. z o.o. - www.obrum.gliwice.pl [Retrieved:10.02.2017].
- [2] Marketing materials SSAB S.A. - <http://www.ssab.pl> [Retrieved: 10.02.2017].
- [3] Marketing materials Huta Stali Jakościowych S.A. <http://hsjsa.pl/pl/> [Retrieved: 10.02.2017].
- [4] PN-EN ISO 3834-2:2007 Quality requirements for fusion welding of metallic materials – Part 2: Comprehensive quality requirements.
- [5] PN-EN ISO 9001:2015-10 Quality Management Systems – Requirements.
- [6] AQAP 2110 – NATO Quality Assurance Requirements for Design, Development and Production.
- [7] PN-EN ISO 5817:2014-05 Welding – Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections.
- [8] PN-EN ISO 6520-1:2009 Welding and allied processes -- Classification of geometric imperfections in metallic materials – Part 1: Fusion welding.
- [9] Goćkowski S.: Poradnik spawalniczy. WNT. Warszawa 1970.
- [10] Szustakowski J.: Poradnik spawacza elektrycznego. WNT. Warszawa 1985.
- [11] Pilarczyk J.: Poradnik inżyniera. Spawalnictwo Tom 1. WNT. Warszawa 2004.