Destructive testing of welded joints - overview of standard requirements and most common errors

Kubik, K.[1]

[1] ŁUKASIEWICZ – INSTYTUT SPAWALNICTWA

(kamil.kubik@lukasiewicz.is.gov.pl)

Abstract

Destructive Testing (DT) is a common way of determining and evaluating the properties of materials by analysing the behaviour of the test object under stress until its failure. This article focuses on the most common methods of destructive testing used in welding, the normative requirements for these tests and the possible mistakes that can be made during the tests.

Introduction

Destructive Testing (DT) is testing method to find a point of failure. Destructive tests are carried out in order to identify material properties such as strength, ductility, toughness or hardness. Other applications where DT methods are used include failure analysis, process validation or engineering critical assessment. Some of the most common destructive test types:

- aggressive environment and corrosion testing, which is used to test components properties under exposure to aggressive environments or corrosion,
- fracture and mechanical testing, which include different test methods like bend test, impact test, tensile test or weld fracture test,
- fatigue testing, which examines endurance of component under cyclic loading.

Given the number of types of destructive testing, test can be conducted in accordance to specific standard or can be tailored to specific product requirements, for example in case of mass production, destructive testing of finished component is most common, as the cost of destroying small number of specimens is negligible [1, 2].

Destructive testing of welded joints are mostly fracture, mechanical and fatigue testing which are most common used for failure analysis and welding procedure specification approval in accordance to standards like ISO 15614-1 [3] (steels) or ISO 15614-2 [4] (aluminium and its alloys). Example set of destructive tests for specification and qualification of welding procedure for butt weld with full penetration for level 2, in accordance to ISO 15614-1, consists of:

- transverse tensile test (2 specimens),
- transverse bend test (4 specimens),
- impact test (2 set of 3 specimens),
- hardness test (1 specimen),
- macroscopic examination (2 specimens) [3].

Erasmus+

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.
ERASMUS + KA2: 2020-1-PL01-KA202-081820

Tensile test

Tensile testing is one of the most common destructive testing methods. The test is based on loading sample with controlled tension until it fully failures (breaks). For such a simple test it gives surprisingly many properties of tested material such as ultimate tensile and yield strength, ductility, strain hardening characteristics, Young's modulus and Poisson's ratio. The specimens used in tensile test are usually standardized and consist of two shoulders and gauge section between them. The gauge section has reduced area to ensure that elongation and failure occurs in that area. For metallic materials the most commonly used standards are ASTM E8/E8M [5] and ISO 6892-1 [6]. It is also possible to conduct tensile test at elevated (ISO 6892-2 [7]) or low temperature (ISO 6892-3 [8]).

In welding industry, tensile test is usually used to confirm quality of welded joint for purposes of welding procedure qualification. In that case two specimens are machined of test plated in such way that weld is in middle of the gauge section, as shown in Figure 1. As can be seen specimen is made of three different areas with different mechanical properties: parent metal, heat affected zone (HAZ) and weld metal. While it would be possible to measure properties like yield strength, elongation or reduction of area, such measurements would be unreliable and inaccurate.

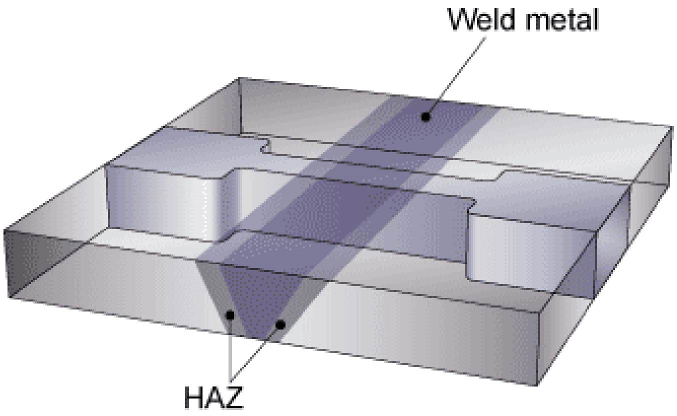

Figure 1. Transverse tensile test specimen [1]

Usually (when qualifying welding procedure in accordance to ISO 15614-1) specimens are made to meet requirement of ISO 4136 [9]. In Table 1 are presented required dimensions of specimens and the Figure 2 show specimen for plates and for pipes.

Table 1. Dimensions for plates and pipes [9].

Denomination		Symbol	Dimensions (mm)
Total length of test specimen		L_t	to suit particular testing machine
Width of shoulder		b_1	b+12
Width of the parallel length	plates	b	12 for $t_s \leq 2$ 25 for $t_s > 2$
	pipes	b	6 for $D \leq 50$ 12 for $50 < D \leq 168.3$ 25 for $D > 168.3$
Parallel length		L_c	$\geq L_s + 60$
Radius at shoulder		r	≥ 25

Erasmus+

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.
ERASMUS + KA2: 2020-1-PL01-KA202-081820

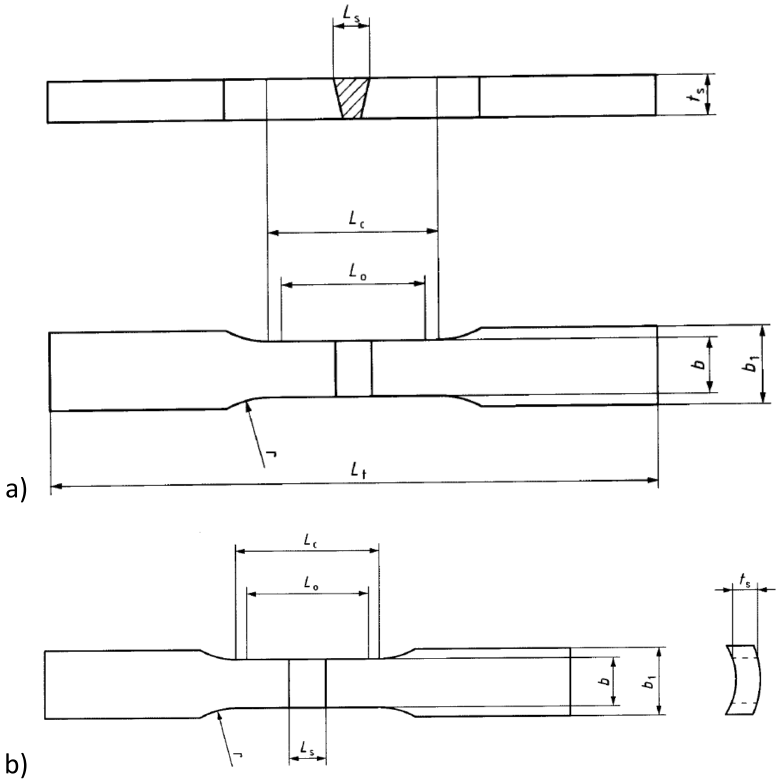

Figure 2. Transverse tensile test specimen for a) plates, b) pipes [9]

There is a number of factors that influence the outcome of a test for example the size of a product or direction which specimen was machined from (in relation to rolling direction). Some factors are human-dependant like proper specimen preparation and dimension measurements or choice of the rate of loading. In Table 2 are presented different ultimate tensile strengths results calculated from the same maximum force Fm but with different measurements of specimen width and thickness, this shows how important accurate measurements are, especially when determining properties like Young's modulus or Poisson's ratio. An example of poorly prepared specimen is shown in Figure 3. The specimen dimensions are not homogenous over the whole cross-section, in area A there is a deep trace of incorrect removal of weld face resulting in thinner cross-section. Area B shows that welding pad was not removed, also in this particular joint the pad was placed in a specially prepared groove, resulting in smaller thickness in the weld than in parent metal. Specimen should be machined to this smaller thickness on whole gauge section. Figure 4 shows the influence of testing speed on tensile strength and ductility of the material. The tensile strength increases with testing speed, when ductility decreases, therefore tensile test standards specify stress rate range of 6 MPa/s to 60 MPa/s.

Table 2. Influence of measured cross-section area on tensile strenght with constant measure maxium force F_m = 163.4 kN.

Measured width (mm)	Measured thickness (mm)	Cross-section area (mm^2)	Ultimate Tensile Strength R_m (MPa)	Difference to nominal (%)
25.00	10.00	250.00	653.60	0.00
24.90	10.00	249.00	656.22	+0.40
24.90	9.90	246.51	662.85	+1.42
25.1	10.10	253.51	644.55	-1.38

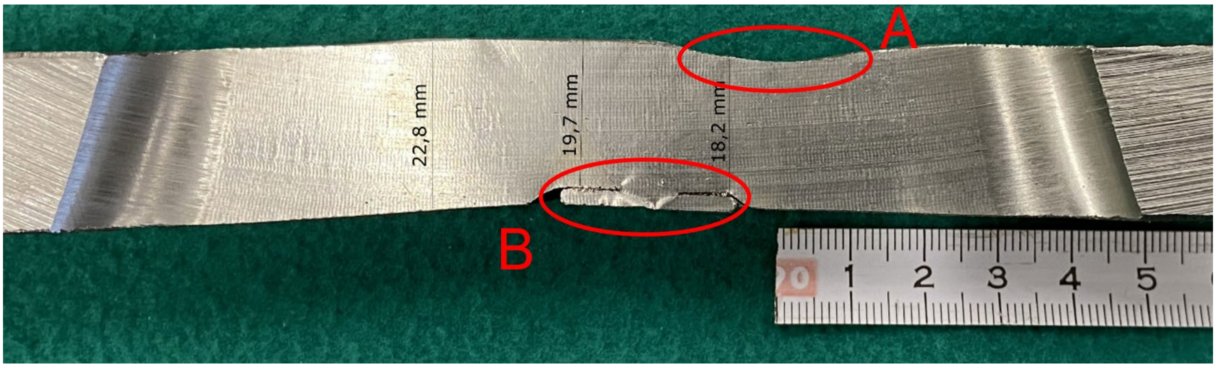

Figure 3. Example of poorly prepared test specimen

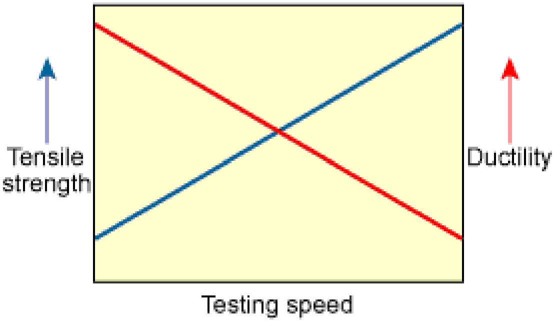

Figure 4. Effect of loading rate on mechanical properties [1]

Bend test

Bend test is really simple qualitive test that can be used to quickly check ductility of material. Bend test can be both free formed or guided. The former can even be conducted on workshop floor if needed. Guided bend test is where specimen is wrapped around mandrel of specified diameter. The mandrel diameter varies and depends on standard used, material ductility and strength. For welded joints most common standard is ISO 5817 which is required by ISO 15614-1. While the test is simple, the specimen should be prepared with care. The edges of the specimen should be rounded (to a radius smaller than 3 mm) and face and root of the weld should be grinded flat to avoid excess stress. Figure 5 shows example of poor preparation of specimen that caused the specimen to break. Figure 6 shows specimen after bend test taken from the same joint but properly prepared.

a)

b)

Figure 5. Specimen a) before bend test (visible sharp edge) b) after bend test (visible crack)

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.
ERASMUS + KA2: 2020-1-PL01-KA202-081820

Figure 6. Specimen with grinded sharp edge after bend test

Another factor which can impact bend test result are material of the joint. Dissimilar metal joint or joint where HAZ, parent metal and weld metal strength are significantly different have tend to result in so called “peaking” of bend specimen. It means that most of deformation occurs in the weaker metal. It happens mostly in joint made of high tensile steels, hardened aluminium alloys and most dissimilar metal joint. Example of such specimen is shown in Figure 7. In these instances it is best to use bending method with roller illustrated in Figure 8. Unlike standard three point bending, a specimen is fixed on one end, then the outer roller wraps specimen around mandrel in centre. The test is ended when outer roller makes 180° turn from starting position.

Figure 7. Example of "peaking" specimen

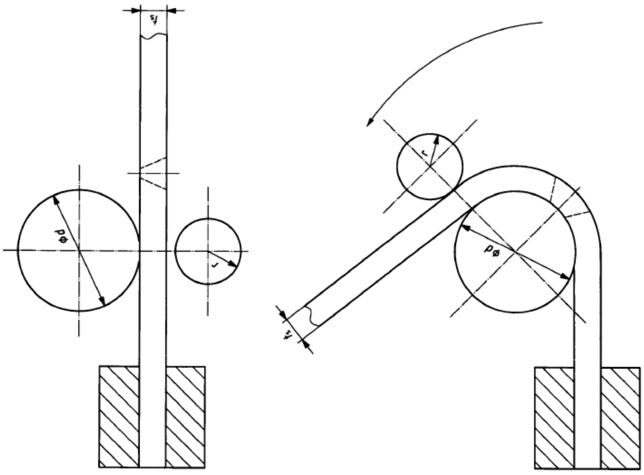

Figure 8. Method of bend testing using roller [10]

Erasmus+

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.
ERASMUS + KA2: 2020-1-PL01-KA202-081820

Charpy impact test

Charpy impact test is a standardized test that involves striking a notched specimen with pendulum of set weight from a set height. Energy absorbed in the impact test, the lateral expansion and the shear fracture appearance are normally determined. The test can be carried out either at room temperature or low temperature depending on standard requirements. The standard specimen has dimensions of 55 mm × 10 mm × 10 mm with either 2 mm deep V notch or 5 mm U notch. In welding, as per ISO 15614-1 requirements, V notch is used. For qualification purposes, two sets of three specimens shall be taken from welded joint. The test should be conducted in accordance to ISO 9016 standard [11], with one set being VWT (Charpy V notch, W- notch in weld line, T- notch through thickness) specimens and second set VHT (Charpy V notch, H- notch in HAZ, T- notch through thickness). Specimen should be sampled from a maximum of 2 mm below the upper surface of parent metal and transverse to weld. In the HAZ, the mid-point of the notch should be at 1 to 2 mm from the fusion line, in some materials it may be necessary to etch specimens to reveal the fusion line and accurately machine notch. When it’s not possible to sample full sized specimen it is possible to machine specimens of reduced area with thickness of either 7.5 mm, 5 mm or 2.5 mm. The radius of the striker should be 2 mm unless otherwise specified (e. g. ASTM E23 may require striker radius up to 2.5 mm whereas ISO 148-1 can use either 2 mm or 8 mm striker). While the test procedure is relatively simple and there is not much room for mistakes, it is crucial that specimens are made with precision and dimensions are within tolerances. Specimen geometry and dimensions with tolerances according to ISO 148-1 [12] are presented in Figure 9. Also some extra care should be taken when marking notch in HAZ, because even 1 mm mistake can greatly impact test results.

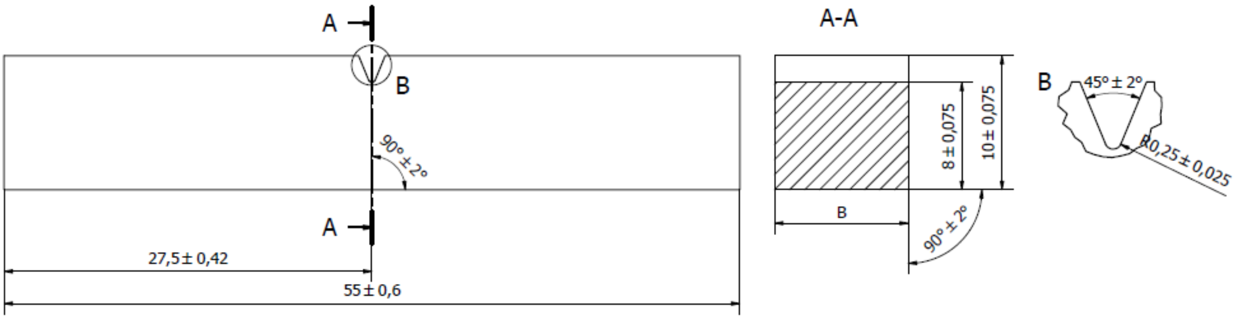

Figure 9. Charpy-V notch specimen geometry and dimensions.

B = {2.5±0.05 mm, 5±0.06 mm, 7.5±0.11 mm, 10±0.11 mm)

Conclusion

The aim of this paper was to inform readers about the use of destructive testing in welding and the specific normative requirements of the basic testing methods. Despite the relatively simple test procedures, a lot of mistakes can be made in these tests that can have a significant influence on the test result, so it is important that the tests are performed by appropriately trained personnel, in an informed and precise manner.

ERASMUS + KA2: 2020-1-PL01-KA202-081820

References

[1] TWI (n.d.) Technical Knowledge FAQs, Retrived from https://www.twi-global.com /technical-knowledge/faq/ (accessed on January 2022)

[2] Flyability (n.d.) “Destructive Testing: A Guide”. Retrieved from https://www.flyability.com/destructive-testing (accessed on January 2022)

[3] ISO 15614-1:2017: “Specification and qualification of welding procedures for metallic materials. Welding procedure test. Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys” (2017)

[4] ISO 15614-2:2005: “Specification and qualification of welding procedures for metallic materials. Welding procedure test. Part 2: Arc welding of aluminium and its alloys” (2005)

[5] ASTM E8/E8M-16: “Standard Test Methods for Tension Testing of Metallic Materials” (2016)

[6] ISO 6892-1:2019: "Metallic materials. Tensile testing. Method of test at room temperature" (2019)

[7] ISO 6892-2:2018: “Metallic materials. Tensile testing. Part 2: Method of test at elevated temperature” (2018)

[8] ISO 6892-3:2015: “Metallic materials. Tensile testing. Part 2: Method of test at low temperature: (2015)

[9] ISO 4136:2012: “Destructive tests on welds in metallic materials. Transverse tensile test” (2012)

[10] ISO 5173:2009: “Destructive tests on welds in metallic materials. Bend tests” (2009)

[11] ISO 9016:2012: “Destructive tests on welds in metallic materials. Impact tests. Test specimen location, notch orientation and examination” (2012)

[12] ISO 148-1:2016: “Metallic materials. Charpy pendulum impact test. Part 1: Test method” (2016)

Erasmus+

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.
ERASMUS + KA2: 2020-1-PL01-KA202-081820