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

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Abstract

Destructive Testing (DT) is a way of determining and evaluating the properties of materials by analyzing the behavior of the objects that are subject to testing. This article focuses on the hardness testing methods as a method of destructive testing used in welding and the normative requirements for these tests.

Introduction

Destructive testing is a testing method that analyzes the point at which a component, asset, or material fails. Destructive testing methods can identify physical properties of a component, like toughness, hardness, flexibility, and strength.

DT methods are commonly used for failure analysis, process validation, materials characterization, and can form a key part of engineering critical assessments.

Destructive testing of welded joints is most commonly used for welding procedure specification approval in accordance to standards as EN ISO 15614-1 [1] (steels) or EN ISO 15614-2 [2] (aluminium and its alloys). Hardness tests for the specification and qualification of welding procedure, in accordance to EN ISO 15614-1, will have to be realized for:

- Butt joint with full penetration,
- T- joint with full penetration
- Branch connection with full penetration
- Fillet welds.

Industries that use destructive testing include:

- Aerospace
- Automotive
- Chemical
- Construction
- Defense
- Electrical Engineering
- Fabrication
- Infrastructure
- Manufacturing
- Oil & Gas
- Petrochemical
- Pipeline
- Power Generation
- Software

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Hardness test

Typically, three types of testing methods are used to measure hardness of metals, as:

- Brinell hardness test,
- Rockwell hardness test,
- Vickers hardness test.

A 10 mm diameter hardened steel or carbide ball usually is used as an indenter in the Brinell hardness test, a diamond or steel cone in the Rockwell hardness test, and a pyramidal shaped diamond indenter in the Vickers hardness test.

Vickers hardness test

Vickers hardness test is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces. The indenter used is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º (Figure 1 a) [3]. The diamond is pressed into the surface of the material at a load. After a dwelt time, the load is removed. And then the size of the residual indent (Fig.1 b) is measured under a calibrated microscope due to the small size of the indent (usually no more than 0.5 mm).

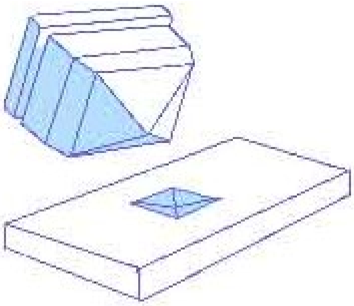

Figure 1 (a) Vickers hardness test

(http://www.hardnesstesters.com/hardness-method-2.htm)

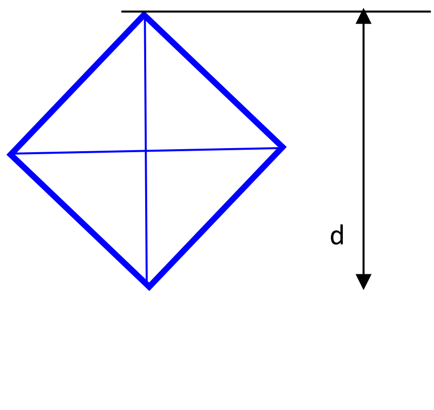

Figure 1(b) the residual indent on the surface

The Vickers number (HV) is calculated by the following formula:

$$HV = 1.854 \cdot \frac{F}{d^2}$$

Where F is the applied load (measured in kilograms-force) and d^2 is the area of the indentation (measured in square millimeters).

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Vickers hardness testing with a load of HV 10 shall be performed in accordance with ISO 9015-1. Hardness measurements shall be taken in the weld, the heat affected zones and the parent metal in order to evaluate the range of hardness values across the welded joint.

For weld thicknesses less than or equal to 5 mm, only one row of indentations shall be made at a depth of up to 2 mm below the upper surface of the welded joint.

For weld thicknesses over 5 mm, one row of indentation from each side shall be made at a depth of up to 2 mm from the surface.

For double sided welds, one additional row of indentations shall be made through the root area. Examples of typical indentation patterns are given in ISO 9015-1.

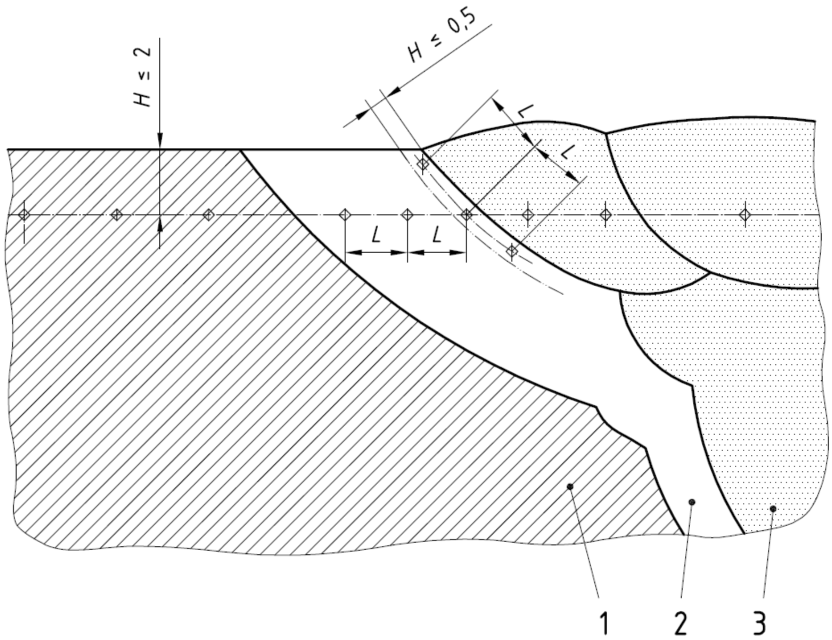
Where more than one welding process is used, each welding process has to be tested by at least one row of indentation.

For each row of indentation at least three individual indentations shall be made in each of the following areas:

— the weld;

— both heat affected zones;

— both parent metals.



1 Parent metal, 2 Heat affected zone(HAZ), 3 Weld metal
Figure 2 — Location of the indentations in butt welds in ferrous metals (excluding austenitic steels) [4]

For the HAZ, the first indentation shall be placed as close to the fusion line as possible. For metals which harden in the HAZ as a result of welding, two additional indentations in the HAZ shall be made

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at a distance u 0,5 mm between the centrepoint of the indentation and the fusion line. For other joint configurations or metals (e.g. austenitic steels) special requirements can be given by the relevant application standard or by agreement between the contracting parties.

Brinell hardness test

In the Brinell hardness test, a hardened steel ball is pressed into the surface of the specimen with the load up to 3000 kilogram. A small load less than 1500 kilogram is applied to relatively soft materials such as aluminum castings and copper alloys. After the load is held for 10 to 15 seconds, the ball will be removed. And a residual round indent is left on the specimen surface. The diameter of the residual indent is measured for calculation of the area of the curved surface of the indention hardness, which is further used to estimate the Brinell hardness as follows:

$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - d^2})}$$

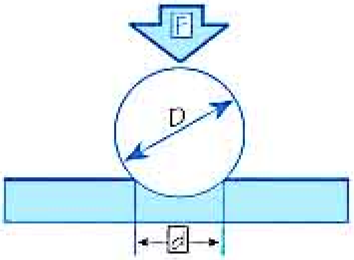

Figure 3(a) Brinell hardness test, D, ball diameter; d = indent diameter; F, load; (http://www.hardnesstesters.com/hardness-method-2.htm)

Because of the large ball diameter the test cannot be used to determine the hardness variations in a welded joint for which the Vickers test is preferred .Very hard metals, over 450BHN may also cause the ball to deform resulting in an inaccurate reading .To overcome this limitation a tungsten carbide ball is used instead of the hardened steel ball but there is also a hardness limit of 600BHN with this indenter [5].

Rockwell Hardness Test

Rockwell hardness values are expressed as a combination of a hardness number and a scale symbol representing the indenter and the minor and major loads .The hardness number is expressed by the symbol HR and the scale designation.

The minor load is used to increase the accuracy of the measurement .The minor load eliminates any backlash effects in the measuring system and breaks through any slight surface roughness.

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The Rockwell hardness test is based on an inverse relationship to the measurement of the additional depth to which an indenter is forced by a heavy total)major (load beyond the depth resulting from a previously applied preliminary)minor (load .Initially a minor load is applied, and a zero datum position is established .The major load is then applied for a specified period and removed, leaving the minor load applied .

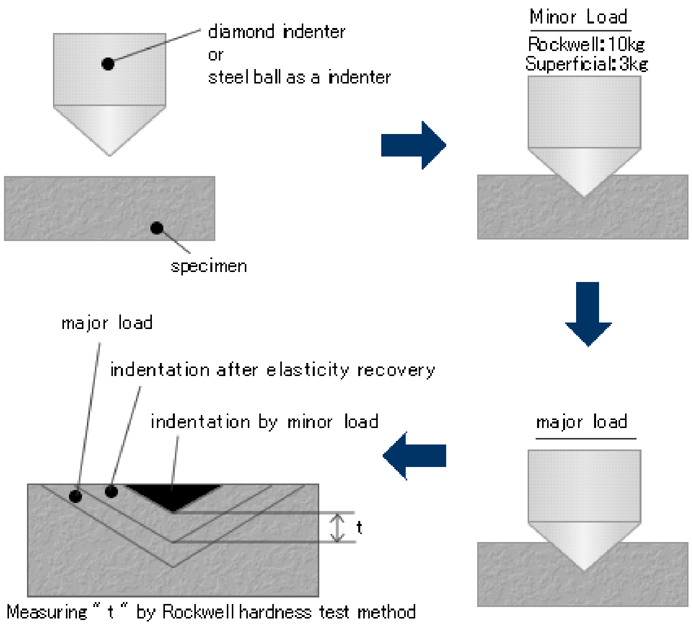

Figure 4 Rockwell hardness test

The resulting Rockwell number represents the difference in depth from the zero datum position as a result of the application of the major load .The entire procedure requires as little as a few seconds up to 15 for plastics.

The degree of surface roughness that can be tolerated depends on the force levels to be applied .A finish ground surface is usually sufficient for the Rockwell C scale and for the Rockwell ball scales that apply a force of at least 980.7 N)100 kgf .(In general, lighter test forces require better surface finishes . For the superficial scales that use a total force of 147.1 N)15 kgf(, a polished surface is usually required.

Hardness measurements on the different scales

Hardness can be measured on the macro-, micro- or nano- scale according to the forces applied and the displacements obtained. The macro-hardness (bulk hardness) measurement is carried out under the load greater than 1000gf. And the indent usually is visible to the naked eye. Most microhardness testing is typically performed on the smooth samples that have been metallographically mounted and polished. The applied load typically ranges from 15 to 1000 gf. As a result, the indentation is so small that it must be measured with a microscope. Microhardness is used to evaluate the hardness of different microconstituents within a structure due to small size of the indent. Nano-indentation testing is used to measure the hardness via using a very small indentation load and via measuring the depth of the indention. Nano-indentation is extensively applied to nanoscale materials such as ultra-thin films, and to soft matters such as biological cells.

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Correlation of hardness with yield strength

Hardness represents the resistance of materials to deformation. It is well known that hardness is correlated with tensile strength of materials in tension, while resistance to deformation is dependent on modulus of elasticity.

Empirically, the yield strength value of steels is about 1/3 of the hardness. An approximate relationship between the hardness and the tensile strength of steel is expressed by,

$$\text{Tensile strength (MPa)} = \begin{cases} 3.55HB & (HB \le 175) \\ 3.38HB & (HB > 175) \end{cases}$$

Where HB is the Brinnell Hardness of the material measured with a standard indenter at the load of 3000 kgf.

Conclusion

The aim of this paper was to inform readers about the use of one of the destructive testing methods used in evaluating the welded joints and base materials. The method may seem as relatively simple but they have to be performed in an authorized laboratory, according to the requirements of EN ISO 17025 and such laboratories have to use properly trained and thus competent personnel.

References

[1] ISO 15614-1: "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)
[2] ISO 15614-2: "Specification and qualification of welding procedures for metallic materials. Welding procedure test. Part 2: Arc welding of aluminium and its alloys" (2005)
[3] http://www.hardnesstesters.com/hardness-method-2.htm
[4] University of Jordan – Hardness test theory course
[5] EN ISO 9015-1: "Destructive tests on welds in metallic materials – Hardness

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