

STUDIES AND RESEARCH ON THE VISUAL INSPECTION OF WELDED JOINTS

**Elena Valentina STOIAN¹, Maria Cristiana ENESCU^{1*},
Dan UNGUREANU¹, Ivona Camelia PETRE¹, Adrian PICU²**

¹ Valahia University of Târgoviște, Faculty of Materials Engineering and Mechanics, 13 Sinaia Alley, 130004, Târgoviște, Romania

² Doctoral School of Engineering Studies, Valahia University of Targoviste, 13 Sinaia Alley, 130004, Targoviste, Romania

E-mail: cristiana_enescu@yahoo.com

Abstract: The purpose of this paper is to analyse the application of the visual testing (VT) method in assessing the quality of welds made using MIG-MAG (Metal Inert/ Active Gas) and shielded metal arc welding (SMAW) processes, according to the standard SR EN ISO 5817, level B, which represents the most demanding criterion for the acceptance of weld defects. Welding is known to be the fusion of two parts or materials made of metal, metal alloys or polymers. The operation takes place at high temperatures, with or without added material (fusion welding), and the surface layers of atoms are activated in this way, through a controlled energy input. The objective of this paper is to highlight the main visually evident defects, to discuss the possibility of discontinuities developing in welded joints and their acceptable level according to the current standards.

Key words: visual testing, MIG-MAG welding processes, welding defects

1. INTRODUCTION

The welding industry has been heavily criticised in recent decades for being a major consumer of raw materials. This has a negative impact on ecosystem degradation, biodiversity loss and water and soil pollution.

In addition, the consumption of huge amounts of energy needed to transform these raw materials into new metals and alloys is a disadvantage. The emission of greenhouse gases, as well as the generation of waste and fumes, significantly affect human health. This contributes to the global problem of climate change. [1-3]

In addition to these environmental impacts, there is also the economic importance it brings to society. In some countries, such as Spain, this sector accounts for 40% of the country's industrial production. This sector has been influenced by the new guidelines for global sustainable development goals proposed by the United Nations. These propose the transition of industries to sustainable production. [1-5]

Welding is an indispensable manufacturing process that involves joining two or three metals (similar or different) by heating them to a molten state, allowing them to be joined together and solidify into a fixed joint. The use of welding processes is widespread in sectors such as

automotive, railway, shipbuilding, aerospace and civil construction.

The most commonly used welding processes are shielded metal arc welding (SMAW), gas metal arc welding (GMAW), which includes in particular metal inert gas (MIG) and metal active gas (MAG), TIG, also known as gas tungsten arc welding (GTAW), ultrasonic welding (USW), laser beam welding (LBW), friction stir welding (FSW) and electron beam welding (EBW). MIG/MAG, TIG and SMAW processes are the most versatile, economical, generic and commonly used in most of the sectors mentioned above. [2-7]

In addition to environmental considerations, one of the most important factors in product design and welding process planning is the reduction of the production costs. Process optimisation is used to achieve this cost reduction. Process optimisation involves studying the process, including the variables involved (material, energy, personnel) and determining how these can be reduced without compromising the minimum product quality.

One of the most popular options is welding automation. With the use of robotic welding, parameters such as wire feed speed, amperage and shielding gas usage rate can be controlled more efficiently. These costs are often

underestimated. On the other hand, competent preventive maintenance of welding equipment can significantly reduce downtime due to malfunctions. This has already been highlighted by other studies over the past two decades. [6-9]

The economic significance of welding processes in Europe and their economic impact on European industry have been notable for several years now. A decade ago, the term "sustainable production" was defined in the US as the creation of products manufactured using processes that minimise the negative environmental impact; preserve energy and natural resources; are safe for employees, communities and consumers; and are economically sound. [7-11]

Some studies have analysed the economic impact of a welding process and sought methods or tools to reduce costs. Methods have also been developed to support the selection of the most suitable welding process based on economic criteria.

A welded joint is a non-detachable metallic connection between two or more metal elements, made by a welding process, which features mechanical strength and operational safety.

It is clear that the properties of welded joints depend essentially on the physical and chemical processes involved in the formation of the metallic bond. Metallurgical phenomena, the influence of chemical elements and impurities, phase transformations and chemical segregation play a key role in controlling the strength properties of the welded joints. [9-14]

2. VISUAL TESTING (VT)

Visual testing (VT) is one of the most commonly used non-destructive testing (NDT) methods, regulated by the SR EN ISO 17637:2011 standard. According to this standard, visual testing is ideally applied in three phases of the welding process: before welding, to check the geometry of the joints, the preparation of the surfaces, and the correctness of the assembly; during welding, to identify any obvious deviations in the weld bead; after welding, to analyse the integrity and conformity of the weld bead and the heat-affected zone (HAZ), as shown in diagram 1.

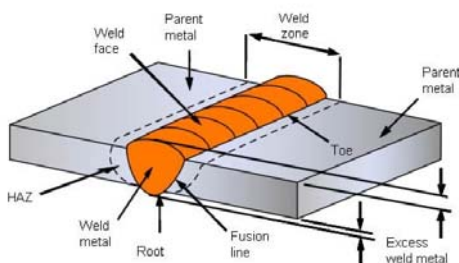


Figure 1. Butt weld diagram

This method allows the observation of surface defects

such as: cracks, porosity, slag inclusions; lack of fusion on the flanks or in the root; non-compliant weld dimensions (overlaps, underpenetration, incorrect transition angle); uneven aesthetic appearance. Despite its simplicity, visual testing requires certain strict conditions: adequate lighting (minimum 500 lux). [11-15]

Perfect cleanliness of the tested surface; adequate visual access to the weld and adjacent areas; standardised optical instruments (magnifying glass, ruler, template, endoscope); qualified personnel, usually certified according to EN ISO 9712 VT level 1 or 2.

Electric arc welding with a consumable electrode in protective atmospheres is a semi-automatic welding process in which the electric arc burns between the base metal and a consumable electrode, the welding wire, which advances mechanically at a constant speed, and a shielding gas is blown around the wire in a circular motion, which can be CO₂, Ar, less commonly He, or a mixture of these gases. [13-19]

The MIG/MAG method is used for welding metals with thicknesses greater than 1.5 mm, using an electrode wire that is automatically fed into the arc, similar to submerged arc welding.

There are two variants, using the same equipment and technology, namely: the MAG process, in which the shielding gas is CO₂, and the MIG process, in which the protection is provided by argon.

The welding stages consist of rigorous preparation of the base material; careful selection of the added material; correct adjustment of the shielding gas; careful adjustment of the wire speed and tension; and precise adherence to the welding angle and travel speed, as shown in Figure 2.



Figure 2. Welding stages

Welding is carried out in the following stages:

selection of electrode quality; determination of welding parameters; preparation, pre-assembly, fixing of structural elements; arc striking; creation of the seam, ensuring the correct position and movements of the

electrode; removal of slag; verification of the quality of the created joint.

Visual testing of the fusion welded joints in metallic materials is carried out as follows: first, an inspection is performed before welding begins, followed by a visual inspection before welding begins, which consists of checking the appearance, shape and dimensions of the joint and the quality of the surfaces to be assembled. Cracks, notches, overlaps, oxidised, dirty or painted surfaces, ridges on the edge, hollows under the edge, wavy profiles, excessive depths, craters and slag crusts are not permitted; checking the cleanliness of the joint surface and adjacent surfaces, cleaning them with a wire brush, by polishing or other mechanical means or with suitable solvents; checking the quality of the temporary tack. The aim is to identify the temporary tack welds;



Figure 3. Visual testing of welded joints

The testing after each layer deposited according to Figure 3 consists of checking the processing of the weld root, ensuring that the edge of the first weld row is cleaned down to the defect-free metal.



Figure 4. Checking the cleaning of slag between layers

Checking that the slag between the layers has been cleaned, paying particular attention to the joint between the deposited metal and the melting surfaces, as shown in Figure 4, and subsequently depositing the next layers can only be carried out after any visible defects have been remedied.



Figure 5. Post-welding testing

Post-welding testing is performed, as shown in Figure 5, after welding is completed and after any repair work by welding, and consists of dimensional inspection of the welded joint (width, height) using a multifunctional caliper.

The cleaning of slag and weld connections is checked by manual or mechanical means. The purpose of this inspection is to ensure thorough cleaning so that no defects remain covered.

The testing of weld penetration, as shown in Figure 6, in the case of single-sided butt-welded joints, is intended to ensure that, along the entire length of the joint, the penetration and any root cavities, perforations or undercuts fall within the acceptance criteria (where possible). The dimensional control of the weld is performed with a caliper, templates and a tape measure.



Figure 6. Examination of weld penetration

The main criterion for classifying defects that occur during welding is the cause of their occurrence. Based on this criterion, there are three main categories of defects, namely design defects, process (technological) defects/discontinuities, and metallurgical defects/discontinuities.

3. EXPERIMENTAL PART

The base material used was S235JR general-purpose carbon steel, standardised according to EN 10025-2:2019, which is one of the most widely used materials in welded metal constructions due to its excellent ratio between mechanical properties, welding behaviour and manufacturing costs.

According to the technical data sheet of the fume extractor and the aforementioned European standard, the chemical composition of S235JR steel is presented in Table 1.

Table 1 . Chemical composition of S235JR steel

Element	Maximum content (%)
Carbon (C)	0.17
Manganese (Mn)	1.4
Phosphorus (P)	0.035
Sulphur (S)	0.035
Silicon (Si)	0.5

This composition guarantees good weldability without the need to preheat the material for thicknesses less than 20 mm and without the risk of forming a brittle martensitic structure in the heat-affected zone (HAZ).

The materials used in the work were delivered in the form of hot-rolled sheet metal with the following characteristics: plate dimensions: 300 mm x 150 mm, thickness: 6 mm, straight edges, no seams, degreased and lightly sandblasted surface before welding.

The following consumables, compatible with S235JR steel, were used in the two welding processes applied:

For shielded metal arc welding (SMAW I 111): E6013 rutile electrodes, diameter 2.5 mm Classification according to AWS A5.1: E6013; Classification according to EN ISO 2560-A: E 42 0 R 11; Welding current: 80-100 A (DC+); Advantage: stable arc, removable slag, aesthetic weld bead.

For MIG-MAG welding (135): G3Si1 type copper-coated solid wire, diameter 1 mm; classification according to EN ISO 14341: G3Si1 (ER70S-6); protection: CO₂ active gas (99.5% purity); Feed speed: 5-8 m/min; Arc voltage: 18-22 V; Advantage: high productivity, clean weld, less slag.

Equipment and materials used

Base material: S235JR steel sheet, thickness 6 mm, hot rolled.

Welding processes applied: SMAW (111): rutile electrode E6013, diameter 2.5 mm; and MIG-MAG (135): solid wire G3Si1, diameter 1 mm, CO₂ protection.

The equipment used was: SMAW welding inverter: 90-110 A; Semi-automatic MIG-MAG: 120-140 A, voltage 18-22 V, wire speed 5-7 m/min; Portable lighting source (2: 500 lux); 10x optical magnifier, millimetre ruler, welding template.

The height of the bead was measured on 8 samples, according to **Table 2**.

Table 2 . Dimensions of the weld bead height

Bead	a[mm]
1	4
2	3.9
3	4.1
4	3.8
5	4.2

Of the 8 weld beads made (4 using the MIG-MAG process and 4 using the SMAW process), only 5 were considered compliant with level B (according to Table 2) following visual testing, and 3 were considered non-compliant, requiring repair or redone.

These results highlight the differences in behaviour of each process and their sensitivity to variations in welding parameters or improper material preparation.

Visual testing of the welds was performed in accordance with SR EN ISO 17637, under the following conditions: artificial lighting 500 lux, measured with a lux meter; observation distance: 600-800 mm; 10x optical magnifier for detailed inspections; templates and rulers for measuring the bead dimensions.

For each bead, the following were checked: continuity and visual appearance (aesthetic appearance, uniformity); actual dimensions compared to the designed ones; presence of surface defects (porosity, lack of fusion, overlaps, spatter); compliance with the tolerances imposed by level B of the SR EN ISO 5817 standard.

The welds made using the MIG-MAG process generally had a very good aesthetic appearance, with a continuous weld line, consistent dimensions and smooth transitions between the added metal and the base material. However, the following defects were identified in 1 out of 4 welds:

Isolated porosity: small holes, 0.3 mm in size, appearing mainly in the initial areas of the bead. Possible causes were: local contamination (oil, moisture, oxides); insufficient gas protection (side air flow); short arc interruptions.

Incomplete crater closure: on a weld, the end was not completely filled, creating a depression where cracks can occur. Cause: premature arc shutdown without final filling (lack of crater filling).

Metal spatter: visible around the weld bead, but in small numbers and isolated. These frequently occur at too high current or at arc voltages > 22 V, especially in combination with pure CO₂ gas.

Welds made using the SMAW process (with E6013 electrodes) showed greater variability, specific to manual work, and the visual appearance was influenced by: electric arc stability; electrode angle; travel speed.

Frequently observed defects were:

Lateral overlap: deposition of the added metal over the surface of the material without fusion, occurring especially at the beginning of the welding. Cause: too low travel speed and incorrect inclination angle.

Lack of sidewall fusion: visually detected at the lower edge of the bead. Probable cause: too low current (below 90 A) or poor contact between the electrode and the material.

Retained slag: dark or bluish areas on the surface of the bead. Possible causes: incomplete cleaning after the first layer; uncontrolled vertical position; overlapping of layers; no intermediate cleaning.

Analysing the values of the parameters recorded during the experiment, the following trends were highlighted, according to Table 3:

Table 3. Welding parameters

Parameter	Observed behaviour
MIG-MAG current >140A	Increased spatter, risk of excessive penetration
SMAW current <90A	Frequent lack of fusion
Low feed speed (MIG-MAG)	Excessive bead thickening
CO ₂ gas <10L/min	Porosity in the initial bead area

Table 4. Identification of welding defects

Sample no.	Process	Defect type	ISO 6520-1 code	Size [mm]	Action
1	MIG-MAG	Porosity	2011	0.3	A
2	MIG-MAG	Final crater	1004	Depth	R
3	SMAW	Overlap	5012	Width 2	R
4	SMAW	Fusion gap	4011	1.2	R
5	SMAW	No defect	-	-	A

A= accepted; R = rejected

Interpretation of the results in Table 4 highlights that the MIG-MAG procedure offers more consistent visual quality, but is sensitive to gas and finishing parameters. On the other hand, the SMAW procedure is more prone to human error, but can produce compliant welds if performed with care and experience.

Visual testing proved effective in: quickly identifying execution defects; determining their technological sources; making decisions regarding the acceptance, rejection or repair of welds.

The MIG-MAG process produced welds with more consistent visual quality, but is sensitive to variations in gas shielding and arc parameters. Isolated porosity and spatter were identified at high current and voltage values.

The SMAW process produced welds that were more variable in appearance, depending on the operator's experience. The main defects identified were overlaps and lack of fusion - caused by insufficient current and poor manual technique.

The SR EN ISO 5817 standard, level B, imposes strict requirements, and non-compliant welds must be remedied. Of the 8 welds analysed, only 5 were compliant without additional intervention.

4. RESULTS AND DISCUSSIONS

The study demonstrated that visual testing is a fundamental method in weld quality control, providing rapid and relevant information about the correct or incorrect execution of a weld.

The weld bead produced by MIG-MAG had a uniform appearance, but at too high a feed rate, isolated porosities were identified, classified as level B.

The SMAW weld showed overlaps at the ends and spatter, probably caused by excessive current and oscillating electrode handling.

Welding defects gradually reduce the load-bearing capacity of the welded joint, and the defective area expands over time if not repaired, which can lead to the destruction of the welded part and its scrapping.

5. CONCLUSIONS

To identify surface or shallow defects, as well as in the case of thin products, the following methods are used: direct visual inspection or inspection with a magnifying glass, liquid penetrant testing, and magnetic particle testing.

Deep defects on massive structures can be detected using the following methods: ultrasonic testing and radiographic testing.

Visual inspection is the most commonly used method and allows the detection of the following types of defects: superficial cracks, microcracks, geometric defects (excessive elevation, excessive convexity, root leaks, excessive penetration, burns, misalignments, deviations from flatness, incomplete joint filling, spatter, craters, etc.).

Eliminating design defects during the welding process involves a series of preventive and corrective measures. The elimination of process and technological defects during metal welding can be achieved through a combination of preventive and corrective measures.

Metallurgical defects such as cracks, fissures, lamellar disintegration, segregation and fish eyes can have a significant impact on the quality and integrity of welded joints in metallic materials.

To minimise these defects, it is essential to pay close attention to the welding process, material selection and quality control.

Visual testing of fusion welded joints in metallic materials plays a crucial role in ensuring their quality and structural integrity.

Visual testing allows for the identification of visible defects such as cracks, porosity, craters, spatter, and inclusions. These defects can significantly affect the performance of the joints.

Visual inspection helps to assess the uniformity and consistency of joints, ensuring that the weld meets technical specifications and design requirements.

The testing can highlight problems related to the welding technique used, such as excessive welding speed or insufficient temperature, which can lead to defects.

Visual inspection allows the evaluation of the adhesion between the base material and the weld material, which is essential for ensuring a solid joint.

Visual examination is a quick and effective method of quality control during the production process, helping to prevent subsequent failures.

Early identification of defects through visual inspection can reduce repair and maintenance costs by preventing costly failures in service.

In conclusion, visual testing of welded joints is an essential step in the quality assurance process, helping to improve the reliability and durability of metal structures.

These defects in design can lead to a variety of problems in the welding process, including defects in joints, structural weakening, and failures during use.

A careful and well-planned design is essential to minimise the risks associated with these defects.

REFERENCES:

- [1] Kou, S. (2003) *Welding Metallurgy*. 2nd Edition, John Wiley & Sons, Inc., Hoboken, New Jersey, 17-20.
- [2] Puchoicela, J. (1998) Control of Distortion of Wed Steel Structures. *Welding Journal*, **77**, 49-52.
- [3] Ueji, R., Fujii, H., Cui, L., Nishiokioka, A., Kunishige, K. and Nogi, K. (2006) Friction Stir Welding of Ultrafine Grained Plain Low-Carbon Steel Formed by the Martensite Process. *Materials Science and Engineering: A*, **423**, 324-330. <http://dx.doi.org/10.1016/j.msea.2006.02.038>
- [4] Gery, H., Long, P. and Maropoulos, E. (2005) Effects of Welding Speed, Energy Input and Heat Source Distribution on Temperature Variations in Butt Joint Welding. *Journal of Material Processing Technology*, **167**, 393-401. <http://dx.doi.org/10.1016/j.jmatprotec.2005.06.018>
- [5] Muthupandi, V., Srinivasan, P., Bala, S.K. and Sundaresan, S. (2003) Effect of Weld Metal Chemistry and Heat Input on the Structure and Properties of Duplex Stainless-Steel Welds. *Materials Science and Engineering: A*, **358**, 9-16. [http://dx.doi.org/10.1016/S0921-5093\(03\)00077-7](http://dx.doi.org/10.1016/S0921-5093(03)00077-7)
- [6] AWS Welding Handbook, Volume 2, Eighth edition, 1995, pp 157 – 190
- [7] Henson B.K., 'Practical applications of orbital tube and pipe welding', AMI internal publication, 2011.
- [8] Widgery D.J., 'Mechanised welding of pipelines', Svetssaren No.1, 2005, pp 23- 26.
- [9] Yapp D., Blackman S.A., 'Recent developments in high productivity pipeline welding'. *Journal of the Brazilian Society of Mech.Sci. &Eng.*, Volume XXVI No.1, January – March 2004, pp 89 -98.
- [10] J. O. A. Morales, O. Piamba, The corrosion resistance of Carnes R.W., Hudson R.S, and Nichols S.P., 'Advances in homopolar welding of API linepipe for deepwater applications'. *Joining and welding for the Oil and Gas Industry*, Proceedings, International Conference, London, UK, 1997.
- [11] Blackman S.A, Dorling D.V., 'Technology advancements push pipeline welding technology'. *Welding Journal*, Volume 79, number 8, August 2000, pp 39 - 44.
- [12] Dunkerton S.B, Johansen A., Frich S.; 'Radial friction welding for offshore pipelines. *AWS Welding Journal*, Volume 66, Number 7, July 1987, p 41
- [13] Thomy C, Seefeld T., Vollertsen F., Vietz E. 'Application of fibre laser to pipeline girth welding'. *AWS Welding Journal*, Volume 85, Number 7, July 2006, pp 30 – 33
- [14] C. J. Hellier, *Handbook of Nondestructive Evaluation*, The McGraw-Hill Publishing Company, Inc.
- Hill Companies, Inc. 2001, ISBN: 13: 978-0071777148
- [15]. Judi E. See, *Visual Inspection: A Review of the Literature*, SANDIA REPORT SAND, 2012, code: 2012-8590*.
- [16] Robert A Smith, *Non-Destructive Testing (NDT) – Guidance Document: An Introduction to NDT Common Methods*, 2015, Document code: AA050*.
- [17] R. Halmshaw, *Introduction to nondistructive testing of welded joints*, Abington Publishing, 1996, ISBN: 10: 1-85573-314-5.
- [18] K. Uchino, *Advanced Piezoelectric Materials, The development of piezoelectric materials and the new perspective*, Woodhead Publishing, 2010, ISBN 9781845695347.
- [19] P. Dineva, D. Gross, R. Müller, T. Rangelov, *Dynamic Fracture of Piezoelectric Materials*, Springer International Publishing, 2014, ISBN 13: 9783319378138.