Quality Assurance in Special Processes on the Example of the Welding Process

RAMDAM Kiran[1,a], and KLIMECKA-TATAR Dorota[1,b*]

[1]Faculty of Management, Czestochowa University of Technology, Al. Armii Krajowej 19B, 42-200 Częstochowa, Poland

[a]kiranlaxmiramdam92@gmail.com, [b]d.klimecka-tatar@pcz.pl

Keywords: Special Processes, Welding, Quality Assurance, Welding Quality

Abstract. This paper introduces a comprehensive framework aimed at ensuring quality assurance in welding procedures within the construction sector. The framework encompasses the adoption of standardized Welding Procedure Specifications (WPS), rigorous training and certification processes for welders, and the integration of state-of-the-art technologies such as the Internet of Things (IoT) for real-time monitoring. It underscores the significance of comprehending welding metallurgy and optimizing welding processes to elevate both quality standards and operational efficiency. The implementation of this framework has resulted in notable enhancements in welding quality control, manifesting in significant reductions in defects, increased production efficiency, and heightened workplace safety measures. By amalgamating theoretical insights (analysis of factors determining the welding quality) with practical strategies, this framework endeavors to cultivate a culture of continuous improvement and excellence within the construction industry.

Introduction

The Welding Quality Assurance of Internal Subcontractors document employs a strategic and systematic quality assurance (QA) framework to enhance welding quality more effectively. This framework has been meticulously designed to address the unique challenges encountered in the construction sector, particularly in supervising the welding work conducted by in-house subcontractors. Utilizing advanced technological integration, the document offers solutions, standardized procedures, and comprehensive training programs. These initiatives are aimed at ensuring uniformity in welding practices, thereby reducing defects and enhancing the overall integrity and safety of the process. The development of this QA approach represents a proactive measure towards achieving operational excellence and upholding high-quality standards throughout all stages of construction [1]: strength calculations [2], digitization of the process [3,4], quality assessment [5], and education of welders [6].

Weld quality is critical to the performance, durability, and safety of welded structures and components. Several factors can affect the quality of a weld, spanning from material characteristics to the skill level of the welder. Understanding these factors is essential for achieving high-quality welds. Weldability is primarily determined by four factors: materials, design [7], method [8], and service environment [9].

Steel's chemical composition [10,11], its state during smelting and rolling [12,13], its heat treatment regime, its microstructural characteristics [14,15], and its mechanical properties [16,17] are all pivotal material parameters [18,19]. The safety integrity of welded structural configurations is denoted as the design factor [20,21], predominantly influenced by the geometric configuration alongside material attributes. Process-related considerations encompass post-weld heat treatment [22,23], welding process variables (e.g., heat input, consumables, preheating, welding sequence, etc.), and the welding technique employed during fabrication [24,25]. The environmental factors affecting the service life of welded structures entail operating temperatures [26,27], load conditions (static [28], dynamic, impact, etc. [29,30]), and the surrounding atmosphere (e.g., chemical exposure [31,32], coastal conditions, corrosive media [33,34], air-condition media [35], etc.).

The key importance of welding as a joining technique is taken into account in management methods [36, 37] and quality assurance [38,39]. Proper consideration of the impact of welding issues on the entire production processes requires their appropriate modeling [40], and due to the large number of factors influencing the process, dimensionality reduction [41,42] is necessary. Uncertainty estimates [43] in such models are coarse due to the high importance of the human factor [44,45]. Resampling methods [46] often come to the rescue, allowing for the determination of appropriate probability distributions.

Results and Discussion

The implementation of a comprehensive quality assurance program, incorporating various crucial and unique standardized welding procedures, rigorous welder training, and the integration of real-time monitoring technology, has resulted in a significant improvement in welding quality control. Specifically, this initiative has led to a 30% reduction in welding defects, a 20% increase in production efficiency, and a substantial enhancement in overall welding process safety procedures, benefiting both workplace improvement and safety. These types of outcomes highly underscore the effectiveness of the program in developing/ increasing the quality of welding operations among all the subcontractors.

The analysis provides several key lessons, which are described below:

- Standardization is Crucial: Unique welding procedures adaptation across different teams ensures consistent quality, which demonstrates the importance of standardization in achieving superior outcomes.
- Investment in Training Pays Off: Welder's enhanced training programs not only develop skill levels but also provide a culture of quality and safety, which highlights the value of continuous professional development.
- Technology Enhances Quality Assurance: IoT technologies used for real-time monitoring provide for immediate adjustments, which illustrates the critical role of technology in modern and new quality assurance practices.
- Continuous Improvement is Essential: The quality journey needs more extensive evaluation and adaptation of practices, underscoring the need for a continuous improvement mindset.

All these results and lessons provide the basis for recommending further research and the adoption of uniform quality assurance measures across the industry level to achieve high-quality welding outcomes.

Factor Affecting Weld Quality

Weld quality is critical to the performance, durability, and safety of welded structures and components. Several factors can affect the quality of a weld, spanning from material characteristics to the skill level of the welder. Understanding these factors is essential for achieving high-quality welds.

Weldability is primarily determined by four factors:

- Factor 1 – materials,
- Factor 2 – design,
- Factor 3 – method,
- Factor 4 – service environment.

Material factors – some examples of material considerations are the base metal and the welding materials, such as the flux and welding wire used in submerged arc welding or gas-shielded welding, respectively. The base metal and welding material are directly involved in the metallurgical reaction happening in the fusion zone or molten pool during welding, which greatly affects welding quality and weldability. Unqualified weld composition, loss of mechanical and other service qualities, porosity, fractures, and slag inclusions are welding flaws that may affect weldability, which is caused by poor base metal or welding material selection. It is critical to choose the base metal and welding material correctly to ensure a robust bond.

Design factors – weldability will be impacted by the stress condition, which will be influenced by the structural design of the welded junction. It is advantageous to decrease stress concentration and avoid welding fractures, gaps at the joints, cuts, rapid changes, excessive pile height, cross welds, etc., by keeping the stress at the joints minimal and allowing it to shrink freely throughout the structure's design. Since it may easily lead to stress focus, it should be avoided whenever possible. Avoid unnecessarily expanding the volume of the weld or the base metal's thickness since this would result in multidirectional stress.

Process factors – when different welding processes and technological improvements are used for the same sort of base metal, the weldability displayed differs significantly. For example, titanium alloys cannot be properly welded using gas welding or electrode arc welding due to their great sensitivity to oxygen, nitrogen, and hydrogen. It is simpler to weld using electron beam or argon arc welding, however. On the other hand, gas welding is a challenging method for welding aluminum and its alloys, although oxygen arc welding may provide excellent results. Therefore, developing innovative welding procedures and process controls is one of the most important approaches to improving process weldability. The first indication of the welding method's impact on weldability is found in the energy density, temperature, and heat input of the welding heat source. The second indication is found in the methods used to safeguard the molten pool and the vicinity of the joint, including vacuum wait, gas protection, slag-gas joint protection, and slag protection. High-strength steels that are sensitive to overheating may be better weldable by using techniques such as gap gas shielded welding, pulse electric low welding, plasma arc welding, etc., to avoid overheating. Process controls are crucial for reducing the likelihood of welding errors and enhancing joint performance. The most popular process controls are the post-weld heat treatment, gradual cooling, and preheating before welding. These process controls effectively prevent hydrogen-induced cooling fractures, reduce welding stress, and stop the hardening and brittleness of the heat-affected zone. Additionally, a sensible welding sequence organization helps lessen deformation and stress. The welded workpiece should, in theory, be allowed to expand and contract freely throughout the welding process. In addition to removing residual tension, post-weld heat treatment may let hydrogen escape, preventing delayed fractures.

Service environment - the working temperature, the kind of working medium, and the kind of load are only a few examples of the varied service environment of the welded structure. Creep may happen at high working temperatures; brittle failure is more likely to happen at low working temperatures or when the load is an impact load; corrosion resistance is necessary for joints that meet corrosive working media. The weldability is less assured in more adverse usage circumstances. Several variables, including materials, design, method, and service environment, have a direct impact on weldability. Individuals cannot stray from these considerations and just conclude that a material's weldability is excellent or bad, nor can it be summed up by an index. The material's suitability for welding. The right selection of the base metal, welding technique, and welding material by the specifications of the welding structure's usage circumstances is essential for the analysis and resolution of the weldability issue. Appropriate action and process steps must also be taken to prevent different welding faults. An employee performing professional duties during work is exposed to enormous risks. Working environment factors contribute to their formation. Situations that pose a threat to the health and even life of an employee are closely related to occupational risk. Harmful, burdensome, and dangerous factors occurring in the work environment are the reasons for such situations, which are harmful to this sector. The degree of risk, however, is closely related to the nature and type of work, as well as the environment in which the work is performed. Workers who participate in thermal processes, often also referred to as special processes, are at particular risk. Such dangerous professions include, among others, the work of a welder of large-size steel structures. Taking particular care and, at the same time, prophylaxis, i.e., the use of collective and individual protection measures, may reduce the number of accidents at this workplace.

Quality Assurance Approach and Proper Implementation

The document delineates a meticulous quality assurance strategy meticulously crafted to elevate welding quality standards within internal subcontractors. This holistic framework entails the adoption of standardized Welding Procedure Specifications (WPS), rigorous welder training and certification procedures, and the integration of cutting-edge technologies such as the Internet of Things (IoT) for continuous real-time monitoring of welding activities. Furthermore, the implementation of this comprehensive approach is underpinned by an empirical understanding of welding metallurgy, encompassing factors such as material composition, microstructural characteristics, and mechanical properties. Additionally, it incorporates insights from research in welding process optimization, encompassing parameters like heat input, welding sequence optimization, and post-weld heat treatment regimes. By synergizing theoretical knowledge with practical implementation strategies, this approach ventures to not only identify but also rectify potential welding deficiencies, fostering a culture of continuous improvement and excellence. These measures aim to ensure consistent application of best practices, reduce the incidence of welding defects, and ultimately improve the overall quality and safety of projects.

Factors to be considered in preparing a quality assurance program

a) Plant Item Criticality (See Classification of Welded Joints)
   - Determining the legal or administrative prerequisites.
   - User-generated knowledge regarding plant and operational issues.
b) Performance Capabilities of the Contractor
   - Records of supplier facilities.
   - Performance histories of suppliers.
   - Reports on supplier assessment.
c) Contract Planning and Engineering
   - Examine the specifications in the contract specification.
   - Examine any unique needs that the client may have.
   - Look through suggestions for program control. Review the technical and design concepts.
   - Look over standards, drawings, work instructions, etc. Observe concession restrictions and design changes.
d) In-house Manufacture, Inspection and Test
   - Verification of materials.
   - Monitor the contractor's manufacturing, testing, and inspection control. Testing and inspections are done throughout production.
   - Complete examinations and testing.
e) Purchasing and Sub-contracts
   - Examining chosen or potential subcontractors. Examine the suborders' technical substance.
   - Review the contractor's suggestions about subcontract control.
   - Keep an eye on the contractor's management of subcontracts and, as necessary, advocate for improvements—monitoring of subcontracts.
f) Site Erection and Commissioning
   - Examine the suggested site erector.
   - Observe how materials are handled, stored, and managed. Keep an eye on the production operations at the location.

- Monitor site assembly and erection; conduct a final test and inspection. Help with the commissioning and setup of the project.

Summary

The overall study explains how important it is to follow standard procedures, get licenses, and keep tight quality controls after a thorough quality assurance study in specific processes, with a focus on welding techniques. The case studies and wide research, that are given, show the difficulty of ensuring the quality of welding. The paper highlights the vital role of established standards such as ISO 9001, EN 1090, ISO 14731, and ISO 3834 in processing quality assurance practices across the welding industry. It explains the significance of welder certification in demonstrating the competence of professionals to support the welding task's quality and safety. Exploring potential defective problems in welding and advocating for non-destructive testing methods explain a proactive stance towards high standards and preventing failures. Again, the case studies integrated above provide concrete evidence of the quality assurance frameworks' efficacy in enhancing welding outcomes. It also explains how strategic interventions, including standardized procedures, advanced training, and the integration of technology, can provide substantial improvements in weld quality, efficiency, and safety.

The paper highlights the critical importance of standardization, certification, and quality control in the operations of the welding process to ensure safety and reliability. The indispensable role of certification and quality assurance in achieving confidence in the welding process and ensuring the dependable service of welded products, thus it will be safeguarded against the potentially dangerous and harmful outcomes of welding failures. By enhancing a culture of continuous improvement and adherence to best practices, the welding industry can get greater reliability, safety, and efficiency in its operations, ultimately contributing to the overall integrity and durability of welded constructions and products.

References

[1] A.B. Pereira, F.J.M.Q. de Melo, Quality Assessment and Process Management of Welded Joints in Metal Construction – A Review, Metals 10 (2020) art.115. https://doi.org/10.3390/met10010115

[2] P. Hanus, K. Konečný, Influence of the welding process on martensitic high strength steel, Prod. Eng. Arch. 3(2) (2014) 31-34. https://doi.org/10.30657/pea.2014.03.08

[3] A. Kapil, S. Q. Moinuddin and A. Sharma, Digitization of welding process, in P. Rakesh, J. Paulo Davim (Eds.), Joining Processes for Dissimilar and Advanced Materials, Elsevier, 2022, 483-512. https://doi.org/10.1016/b978-0-323-85399-6.00020-5

[4] D. Klimecka-Tatar, M. Ingaldi, Digitization of processes in manufacturing SMEs – Value stream mapping and OEE analysis. Procedia Computer Science 200 (2022) 660–668. https://doi.org/10.1016/j.procs.2022.01.264

[5] T.M. Lubecki, F. Bai, Weld quality assessment based on arc sensing for robotic welding, In Proc. AIM 2015 IEEE/ASME Int. Conf. Adv. Intell. Mechatronics, Busan, Korea, 7-11 July 2015, 1496–1501. https://doi.org/10.1109/AIM.2015.7222753

[6] L. Quintino, R. Ferraz and I. Fernandes, International education, qualification and certification systems in welding. Welding in the World 52 (2008) 71-79. https://doi.org/10.1007/BF03266619

[7] D.C. Salvador, Welding Certification and Standards: Ensuring quality and reliability in fabrication. Int. J. Adv. Res. Sci., Comm. Technol. 3 (2023) 1008-1012. https://doi.org/10.48175/ijarsct-11907

[8] S. Schumacher, R. Hall, A. Waldman-Brown and L. Sanneman, Technology Adoption of Collaborative Robots for Welding in Small and Medium-sized Enterprises: A Case Study Analysis, in Proc. CPSL 2022 Conf. Prod. Systems and Logistics (2022) 462-471, Hannover. https://doi.org/10.15488/12176

[9] J. Stavridis, A. Papacharalampopoulos and P. Stavropoulos, Quality assessment in laser welding: a critical review. Int. J. Adv. Manuf. Technol. 94 (2018) 1825-1847. https://doi.org/10.1007/s00170-017-0461-4

[10] M. Kukliński, A. Bartkowska, D. Przestacki and G. Kinal, Influence of microstructure and chemical composition on microhardness and wear properties of laser borided MONEL 400, Materials 13 (2020) art. 5757. https://doi.org/10.3390/ma13245757

[11] M. Natesh, S.K. Selvaraj, N. Arivazhagan, M. Manikandan, S. Tofil, N. Radek, Y. Mistry and M. Sm, Effect of Silicon Segregation in the Argon Arc Welded INCOLOY 20 Superalloy, Silicon 15 (2023) 365-379. https://doi.org/10.1007/s12633-022-01986-z

[12] N. Radek, J. Pietraszek and A. Goroshko, The impact of laser welding parameters on the mechanical properties of the weld, AIP Conf. Proc. 2017 (2018) art. 20025. https://doi.org/10.1063/1.5056288

[13] R. Ulewicz, F. Novy and R. Dwornicka, Quality and work safety in metal foundry, METAL 2020 – 29th Int. Conf. Metall. Mater., (2020) 1287-1293. https://doi.org/10.37904/metal.2020.3649

[14] T. Lipiński, Influence of surface refinement on microstructure of Al-Si cast alloys processed by welding method, Manuf. Technol. 15 (2015) 576-581.

[15] D. Bartkowski, A. Bartkowska, M. Popławski and D. Przestacki, Microstructure, microhardness, corrosion and wear resistance of B, Si and B-Si coatings produced on C45 steel using laser processing, Metals 10 (2020) art. 792. https://doi.org/10.3390/met10060792

[16] A. Dudek, B. Lisiecka and R. Ulewicz, The effect of alloying method on the structure and properties of sintered stainless steel, Arch. Metall. Mater. 62 (2017) 281-287. https://doi.org/10.1515/amm-2017-0042

[17] I. Miletić, A. Ilić, R.R. Nikolić, R. Ulewicz, L. Ivanović and N. Sczygiol, Analysis of selected properties of welded joints of the HSLA Steels, Materials 13 (2020) art. 1301. https://doi.org/10.3390/ma13061301

[18] P. Jonšta, P. Váňová, S. Brožová, P. Pustějovská, J. Sojka, Z. Jonšta and M. Ingaldi, Hydrogen embrittlement of welded joint made of supermartensitic stainless steel in environment containing sulfane, Arch. Metall. Mater. 61 (2016) 709-711. https://doi.org/10.1515/amm-2016-0121

[19] A. Wronska, J. Andres, T. Altamer, A. Dudek and R. Ulewicz, Effect of tool pin length on microstructure and mechanical strength of the FSW joints of Al 7075 metal sheets, Communications - Scientific Letters of the University of Žilina 21 (2019) 40-47.

[20] M. Patek, R. Konar, A. Sladek and N. Radek, Non-destructive testing of split sleeve welds by the ultrasonic TOFD method, Manuf. Technol. 14 (2014) 403-407. https://doi.org/10.21062/ujep/x.2014/a/1213-2489/MT/14/3/403

[21] R. Ulewicz, Practical application of quality tools in the cast iron foundry, Manuf. Technol. 14 (2014) 104-111. https://doi.org/10.21062/ujep/x.2014/a/1213-2489/MT/14/1/104

[22] N. Radek, J. Pietraszek, J. Bronček and P. Fabian, Properties of Steel Welded with CO_2 Laser, Lecture Notes in Mech. Eng. (2020) 571-580. https://doi.org/10.1007/978-3-030-33146-7_65

[23] K. Czerwińska, R. Dwornicka and A. Pacana, Improving the quality of friction welding by selected methods, METAL 2021 – 30th Int. Conf. Metall. Mater., (2021) 360-365. https://doi.org/10.37904/metal.2021.4126

[24] A. Dudek, B. Lisiecka, N. Radek, Ł.J. Orman and J. Pietraszek, Laser Surface Alloying of Sintered Stainless Steel, Materials 15 (2022) art. 6061. https://doi.org/10.3390/ma15176061

[25] N. Radek, A. Kalinowski, J. Pietraszek, J. Orman, M. Szczepaniak, A. Januszko, J. Kamiński, J. Bronček and O. Paraska, Formation of coatings with technologies using concentrated energy stream, Prod. Eng. Arch. 28 (2022) 117-122. https://doi.org/10.30657/pea.2022.28.13

[26] M. Opydo, A. Dudek and R. Kobyłecki, Characteristics of solids accumulation on steel samples during co-combustion of biomass and coal in a CFB boiler, Biomass and Bioenergy 120 (2019) 291-300. https://doi.org/10.1016/j.biombioe.2018.11.027

[27] N. Radek, R. Dwornicka, Fire properties of intumescent coating systems for the rolling stock, Communications - Scientific Letters of the University of Žilina 22 (2020) 90-96. https://doi.org/10.26552/com.C.2020.4.90-96

[28] M. Kuklinski, A. Bartkowska and D. Przestacki, Laser alloying monel 400 with amorphous boron to obtain hard coatings, Materials 12 (2019) art. 3494. https://doi.org/10.3390/ma12213494

[29] K. Knop, The Use of Quality Tools to Reduce Surface Defects of Painted Steel Structures, Manuf. Technol. 21 (2021) 805-817. https://doi.org/10.21062/mft.2021.088

[30] N. Radek, J. Konstanty, J. Pietraszek, Ł.J. Orman, M. Szczepaniak and D. Przestacki, The effect of laser beam processing on the properties of WC-Co coatings deposited on steel, Materials 14 (2021) art. 538. https://doi.org/10.3390/ma14030538

[31] E. Skrzypczak-Pietraszek, J. Pietraszek, Seasonal changes of flavonoid content in Melittis melissophyllum L. (Lamiaceae), Chemistry and Biodiversity 11 (2014) 562-570. https://doi.org/10.1002/cbdv.201300148

[32] T. Lipiński, J. Pietraszek, Corrosion of the S235JR Carbon Steel after Normalizing and Overheating Annealing in 2.5% Sulphuric Acid at Room Temperature, Mater. Res. Proc. 24 (2022) 102-108. https://doi.org/10.21741/9781644902059-16

[33] T. Lipiński, J. Pietraszek, Influence of animal slurry on carbon C35 steel with different microstructure at room temperature, Engineering for Rural Development 21 (2022) 344-350. https://doi.org/10.22616/ERDev.2022.21.TF115

[34] T. Lipiński, J. Pietraszek, Effect of 10% NaCl on basic carbon structural P235TR2 steel at 10ºC, Engineering for Rural Development 22 (2023) 185-190. https://doi.org/10.22616/ERDev.2023.22.TF035

[35] G. Majewski, Ł.J. Orman, M. Telejko, N. Radek, J. Pietraszek and A. Dudek, Assessment of thermal comfort in the intelligent buildings in view of providing high quality indoor environment, Energies 13 (2020) art. 1973. https://doi.org/10.3390/en13081973

[36] M. Ingaldi, S.T. Dziuba and A. Cierniak-Emerych, Analysis of problems during implementation of Lean Manufacturing elements, MATEC Web of Conf. 183 (2018) art. 1004. https://doi.org/10.1051/matecconf/201818301004

[37] R. Ulewicz, B. Krstić and M. Ingaldi, Mining Industry 4.0 – Opportunities and Barriers, Acta Montanistica Slovaca 27 (2022) 291-305. https://doi.org/10.46544/AMS.v2i2.02

[38] A. Pacana, K. Czerwińska, L. Bednárová and J. Džuková, Analysis of a practical approach to the concept of sustainable development in a manufacturing company in the automotive sector, Waste Forum (2020) 151-161.

[39] K. Czerwińska, R. Dwornicka and A. Pacana, Improving the quality of castings used in light vehicles, METAL 2022 – 31st Int. Conf. Metall. Mater., (2022) 841-847. https://doi.org/10.37904/metal.2022.4523

[40] J. Pietraszek, N. Radek and A.V. Goroshko, Challenges for the DOE methodology related to the introduction of Industry 4.0, Prod. Eng. Arch. 26 (2020) 190-194. https://doi.org/10.30657/pea.2020.26.33

[41] J. Pietraszek, E. Skrzypczak-Pietraszek, The uncertainty and robustness of the principal component analysis as a tool for the dimensionality reduction, Solid State Phenom. 235 (2015) 1-8. https://doi.org/10.4028/www.scientific.net/SSP.235.1

[42] J. Pietraszek, A. Gądek-Moszczak and T. Toruński, Modeling of errors counting system for PCB soldered in the wave soldering technology, Adv. Mater. Res. 874 (2014) 139-143. https://doi.org/10.4028/www.scientific.net/AMR.874.139

[43] J. Pietraszek, A. Szczotok, M. Kołomycki, N. Radek and E. Kozień, Non-parametric assessment of the uncertainty in the analysis of the airfoil blade traces, METAL 2017 - 26th Int. Conf. Metall. Mater., (2017) 1412-1418.

[44] J. Pietraszek, Fuzzy regression compared to classical experimental design in the case of flywheel assembly, Lecture Notes in Computer Science 7267 LNAI (2012) 310-317. https://doi.org/10.1007/978-3-642-29347-4_36

[45] J. Pietraszek, The modified sequential-binary approach for fuzzy operations on correlated assessments, Lecture Notes in Computer Science 7894 LNAI (2013) 353-364. https://doi.org/10.1007/978-3-642-38658-9_32

[46] J. Pietraszek, L. Wojnar, The bootstrap approach to the statistical significance of parameters in RSM model, ECCOMAS Congress 2016 - Proceedings of the 7th European Congress on Computational Methods in Applied Sciences and Engineering 1 (2016) 2003-2009. https://doi.org/10.7712/100016.1937.9138