

The need for welding coordination is due to the significant risks of non-compliance with the requirements for welded joints. It is known that the request of coordination standards in welding streamlines the work of ensuring the quality of welding, it is positively perceived by customers and other stakeholders. However, the effect of systemic welding coordination on objective indicators of the quality of welded joints during production requires detailed studying.

The comparative statistical analysis of the effect of systemic welding coordination on the level of welded joints' quality was preceded by the process-oriented development and implementation of a set of procedures for the coordination of welding operations in the production of welded frames. A scheme of interaction and the classification of coordination procedures in welding have been proposed. The procedures were divided into three groups. The first group includes long-term welding quality procedures. The second group is the procedures for ensuring the quality of welding in the execution of a Request (Order, Contract). The third group consists of procedures to ensure and improve the quality of welding a joint. The implementation of regulatory-oriented content of the procedures ensures the admission of personnel with necessary qualifications, the application of appropriate welding equipment, materials, technical documentation, thermal treatment, technical control. All this together ensures that the requirements for the welded joint, the specified thickness of the main metal, the type of a joint and seam, are met.

Data on the quality of welded frames during production were obtained prior to and after the introduction of the international standards of welding coordination. Using the Shewhart charts has shown that ensuring quality by the welding coordination could stabilize the welding process, translating it into a statically manageable state while doubling the proportion of nonconforming units in the sample

Keywords: welding, welding coordination, quality assurance, statistical control, process approach

UDC 621.791.019

DOI: 10.15587/1729-4061.2020.204364

ANALYSIS OF THE INFLUENCE OF THE SYSTEMIC WELDING COORDINATION ON THE QUALITY LEVEL OF JOINTS

O. Haievskiy

PhD, Associate Professor*

E-mail: ggoa@ukr.net

V. Kvasnytskyi

Doctor of Technical Sciences, Professor*

E-mail: kvas69@ukr.net

V. Haievskiy

PhD*

E-mail: v.gaevskiy@kpi.ua

C. Zvorykin

PhD, Associate Professor*

E-mail: constantine.oleg@gmail.com

*Department of Welding Technology

National Technical University of Ukraine

«Igor Sikorsky Kyiv Polytechnic Institute»

Peremohy ave., 37, Kyiv, Ukraine, 03056

Received date 03.06.2020

Accepted date 10.09.2020

Published date 13.10.2020

Copyright © 2020, O. Haievskiy, V. Kvasnytskyi, V. Haievskiy, C. Zvorykin

This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0>)

1. Introduction

Widespread use of welding processes, including the production of potentially dangerous articles, determines the significant risk of violating the requirements for welded joints. This leads to the active development of international standards governing both the welded joints and welding processes and the quality assurance functions by welding engineers and technicians. That renders relevance to the research into the possibilities of comprehensive introduction into welding production of modern procedures to ensure the quality of welding by welding coordination and assess the impact of the system implementation of welding coordination on the level of quality of joints.

2. Literature review and problem statement

Equal strength of the welded metal is the main requirement for welded joints. To determine the strength properties of the metal of a welding seam, it must be destroyed. In this case, we learn the strength properties but lose the welded joint.

The issue is complicated by a significant decrease in the strength characteristics and stresses in the area of the thermal influence of the welded joint [1, 2]. It is impossible or difficult to fully define the properties of a welded joint's metal without its destruction. This makes the welding process a special process and requires a set of mandatory measures aimed at reducing the likelihood of defects and the strength reduction of a welded joint's metal. These measures include both mandatory validation of the welding process and the competence of the personnel involved in welding. At present, the necessary competence is being investigated and ensured not only by welders but also by welding operators, non-destructive control specialists, welding inspectors, and engineers [3–5]. Research is underway into the methods to qualify the welding processes [6–8]. Conventional engineering design and technological ways of ensuring quality are the control over the process regime parameters [9, 10], the optimization of structural solutions [11, 12] for welding products. In modern manufacturing, quality assurance by engineering methods only is impossible. The trend of recent decades has been the use of engineering and organizational

measures to ensure the quality based on the functional approach to management [13–15]. A process approach to quality management [16, 17], based on risk control [18, 19], replaces functional quality assurance models. The critical importance of applying a systematic approach to ensure the quality of welding as a special process has led to the need to standardize key factors influencing the quality of welding seams.

The results of many years of scientific research are summarized in the main international standards for ensuring the quality of welding. These standards include systemic quality assurance requirements, quality assurance requirements for engineers and technicians in the context of welding coordination. At the same time, the requirements for the designation and formation of welding seams, requirements for welding materials, methods, and equipment of technical control in welding, are important. Standardized methods of ensuring the suitability of welding procedures and the methods of ensuring the competence of welding personnel are mandatory for the special process. Existing quality standards can be combined into groups that determine the content of welding coordination [20]. Welding coordination, in turn, is part of the general requirements for the quality of welding (Fig. 1).

Compliance with quality assurance standards is a prerequisite for entering international markets [21, 22]; however, there exist different approaches to meeting these standards [16]. The most effective is a process-oriented system approach to quality management [23, 24]. At the same time, the issue of comprehensive compliance with the regulatory requirements for the quality of welding as a special production process has not been sufficiently studied. Applying a process approach to management requires the development of a structure of coordination procedures in welding that takes into consideration the specificity of regulatory requirements for ensuring the quality of welding.

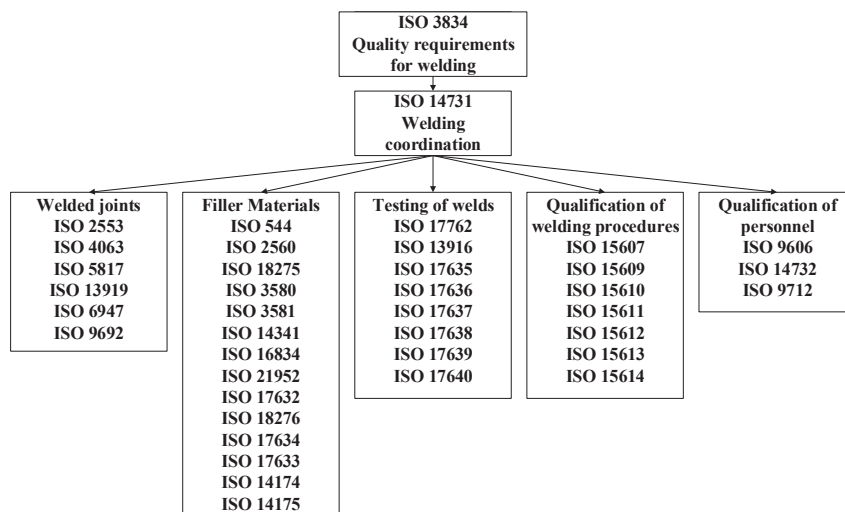


Fig. 1. The structure of international welding quality standards [20]

The positive impact of systemic measures on the quality of welding and products in general as a result of ordering is known. Audit methods evaluated changes related to the implementation of regulatory requirements [25]. Using expert methods, the impact of quality management systems on the company's processes [26] and supply chains [27] was investigated. At the same time, the issue of the impact of the implementation of the set of coordination procedures in welding on the objective indicator of the capability of production to

meet the quality requirements – the quality level of joints – has not been studied in detail. Taking into consideration the variability of quality indicators, studying the effect of systemic welding coordination on the quality level of joints requires the use of statistical methods.

3. The aim and objectives of the study

The aim of this study is to determine the impact of a set of regulatory coordination procedures in welding on the production level of welded joints. To achieve the set aim, the following tasks have been solved:

- to identify the list and patterns of the relationship between coordination procedures in welding;
- to determine the planned result and the main content of the regulatory-oriented procedures to ensure the quality of the welding process;
- to apply the regulatory coordination required in welding to ensure quality in the production of a welded article;
- to determine and compare the quality indicators of welded joints before and after the implementation of the system-based coordination approach in welding.

4. The organizational-methodical and statistical methods to ensure the quality of welding in production

The scheme of the interaction of co-ordination procedures in welding was modeled using the basic process model [28, 29] and a data flow diagram [30, 31].

The welding coordination procedures implemented in the study are based on a modern methodology for ensuring the quality of welding [32].

The statistical controllability of the industrial welding process was studied using the Shewhart charts [33, 34].

5. Implemented welding coordination procedures

This chapter reports the results of the process-oriented application of the regulatory welding coordination required to ensure quality in the production of a welded frame. In 2018, based on the decision by the management of ICF «IrKom» (Irpen, Ukraine), a project was initiated to implement the requirements of the international standard ISO 14731 in welding production. The information acquired during the project provides an opportunity to compare the quality levels of welded joints before and after the introduction of quality welding coordination.

The experience of welding coordination projects at Ukrainian enterprises shows that a significant part of ISO 14731 requirements is typically met by enterprises before the start of the implementation projects. Therefore, this chapter focuses on those issues that, for most enterprises that are beginning to meet the requirements of the standard, are relatively new.

5. 1. The scheme of the relationship among the coordination procedures in welding

The activities that are specific and mandatory to ensure and improve the quality of welding are defined by the international standard ISO 14731 «Welding coordination – Tasks and responsibilities» as the task of welding coordination. The standard defines 19 mandatory tasks for ensuring the quality of welding.

An analysis of the welding coordination tasks stated by ISO 14731 shows the need to determine the optimal sequence and frequency of their implementation. The totality of tasks required for welding to ensure and improve the quality of welding determines the set of interconnected coordination procedures in welding (Fig. 2).

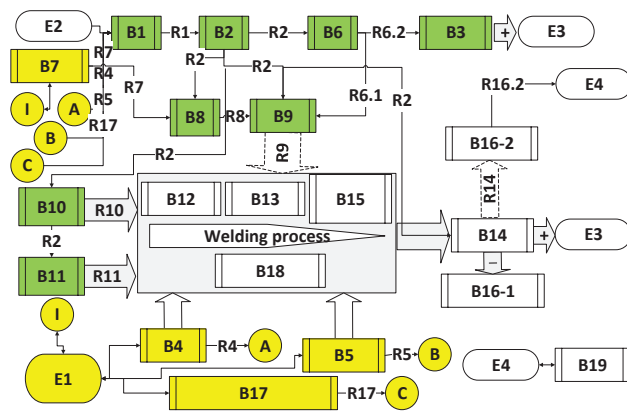


Fig. 2. The relationship between welding coordination procedures

The procedures that determine the actions required to convert the information input into the output are the basis of the system quality assurance [35].

In the diagram (Fig. 2), the procedures are termed and marked in the same way as the welding coordination tasks (B1, B2, etc.):

- B1. Requirement analysis;
- B2. Technical analysis;
- B3. Subcontract;
- B4. Welding staff;
- B5. Equipment;
- B6. Manufacturing planning;
- B7. Assessment of welding procedures;
- B8. Technical requirements for the welding procedure;
- B9. Working instructions;
- B10. Welding materials;
- B11. Basic materials;
- B12. Checks and tests before welding;
- B13. Checks and tests during welding;
- B14. Checks and tests after welding;
- B15. Thermal treatment after welding;
- B16. Inconsistencies and corrective actions;
- B17. Calibration and validation of equipment for measurement, verification, and testing;
- B18. Identification and traceability;
- B19. Records of quality.

The documented results of the procedure (records) are designated as outgoing information flows generated by the relevant procedures (R1; R2; etc.). They also provide information links between the procedures. Documenting the results of procedures (output) reduces the risk of data loss [35].

The description of the information threads is given in the chapters that follow.

- External inputs – outputs:
- E1 – Prospective production plan;
 - E2 – Welding request;
 - E3 – Release – permission to move on to the next stage of the process;
 - E4 – Switching to all welding coordination procedures.
- Internal transitions are marked as A; B; C; I.

In Fig. 2, gray shading corresponds to the main process – the welding process and related material flows.

For the purpose, frequency of execution, and orientation of the results, the welding coordination procedures are divided into three groups:

- long-term welding quality procedures (in the scheme, highlighted in yellow);
- procedures for ensuring the quality of welding in the execution of a Request (in the scheme, highlighted in green);
- procedures to ensure and improve the quality of a welded joint (in the scheme, unshaded).

Given the importance of such a division of procedures in order to establish causal relationships aimed at comprehensive quality assurance, our further study implies the consideration of these groups.

5. 2. The basic content of regulatory oriented procedures to ensure the quality of the welding process

Regulatory-oriented procedures for quality welding coordination have been developed and tested with adaptation to the specificity of a welding plant.

5. 2. 1. Long-term welding quality procedures

Long-term welding quality procedures lay the groundwork and create the conditions necessary to ensure quality in all welding Requests (Orders, Contracts) and welded joints.

The long-term welding quality procedures begin with updating the prospective production plan (Fig. 2). This plan identifies the welding processes, basic and supporting welding equipment, tools, measuring and testing equipment, necessary for the implementation of the enterprise strategy. An up-to-date production plan contains initial data for all long-term welding quality procedures. In particular, the plan formulates conclusions about the planned welded products. Product information makes it possible to determine the main material, the types and sizes of welded parts, the types of joints. Additionally determined is the planned welding technology – the techniques, welding provisions and welding materials, conditions of the formation of a welding joint.

Procedure B4. Welding Staff.

When hiring and conducting periodic qualification tests of welders, the qualifications of welders are provided in accordance with the international standard of ISO 9606. This takes into consideration the features of the welded products planned for production and the planned welding technology.

The competence of welding operators is ensured in accordance with the international standard ISO 14732, based on the features of the welded products planned for production and the welding plants available for use.

In addition to ISO 14731, the procedure should be guided by the following international standards: ISO 9606; ISO 14732; ISO 9712.

Records R4. They contain constantly updated documented data on qualifications and possible admission to work for each welder, welding operator. The records are represented

by the certificates of welders, welding operators, the welders' qualification matrices, tolerance matrices for operators of welding installations, as well as the Welding Procedure Specification (WPS)

The documented data are used to determine the ability to meet the staff qualification requirements set by a Welding Request (Procedure B1 «Requirement Analysis»).

Procedure B5. Equipment.

Newly purchased welding and related equipment are tested before use to meet technical and safety requirements (verification). Welding equipment includes power sources, feed mechanisms, welding installations, etc. Assembly and welding fixtures and accessories, drying chambers, equipment for thermal treatment and heating, holders, personal and collective protective equipment, etc. are related to equipment. After that, the equipment is checked for operability (validation). Only after positive results of verification and validation, the equipment is transferred to production operation according to the Act.

All equipment in production is exposed to periodic maintenance.

In addition to ISO 14731, the procedure should be guided by the following international standards: ISO 17662; ISO 669; ISO 2503; ISO 5172; ISO 5826; ISO 7291; ISO 14114; ISO 15615; ISO 14744.

Records R5. They include welding and related equipment passports, Commissioned Acts, Equipment Registers, Repair and Maintenance Journals.

The documented data are used to determine the availability of the welding and related equipment required to perform a welding Request (Procedure B1. Requirements Analysis).

Procedure B17. Calibration and Validation of Measurement, Testing and Testing Equipment.

The procedure ensures the suitability of monitoring tools for welding parameters, heating and heat treatment parameters, equipment for non-destructive testing of welded seams and equipment for acceptance testing of welded products. All this equipment undergoes verification and validation, periodic checks, and calibration in accordance with passport requirements, as well as the requirements of the legislation on metrological maintenance and the requirements of the Customers.

In addition to ISO 14731, the procedure should be governed by the following international standard: ISO 17662.

Records R17. They include passports and logs of monitoring and measuring equipment.

The documented data are used to determine the availability of the monitoring and measurement equipment required to perform a welding Request (*Procedure B1. Requirement Analysis*).

Procedure B7. Assessment of Welding Procedures.

All welding procedures required for the manufacture of planned welded products are certified in accordance with the international standard ISO 15607. For each such procedure, Technical requirements for the welding procedure (WPS) are developed, with reference to the Welding Procedure Qualification Record – WPQR. The welding procedure certification confirms that the specified WPS welding technology ensures the formation of a weld of the required sizes and properties at the predefined thickness of the main metal. The welding procedure regulates the technique, parameters of the regime, the position of welding, the preparation of edges, welding materials, running energy, heat treatment, the number and sequence of weld execution.

In addition to ISO 14731, the procedure should be guided by the following international standards: ISO 15607; ISO 15609; ISO 15610; ISO 15611; ISO 15612; ISO 15613; ISO 15614.

Records R7. They include preliminary Technical requirements for the welding procedure, technical requirements for the welding procedure, documents on the qualification of welding procedures.

The documented data are used to determine whether a Request can be fulfilled using certified welding procedures (Procedure B1. Requirements Analysis).

In general, the successful and complete implementation of the long-term quality assurance procedures reviewed is a prerequisite for the follow-up to the welding quality procedures in the fulfillment of a Request (Order, Contract).

5. 2. 2. Procedures for ensuring the quality of welding in the execution of a Request

Procedures for ensuring the quality of welding during the implementation of a Request are launched for the implementation of each Request (Order, Contract) for welding operations. In this case, the original data of the Request are contained in the regulatory documents for the ordered products, the drawings of a welded product. Additional are the requirements for the timing of operations, specific requirements for ensuring the quality of welding, compliance of a welding product, personnel, welding methods used, technical control, acceptance tests, etc.

Procedure B1. Requirement Analysis.

In addition to the Request materials (Order, Contract), the original data for the analysis are contained in the specifications attached to the Request. Personnel qualifications are contained in the competence matrices of the welding staff (*Records R4*). Data on available equipment are available in the registers of available equipment (*Records R5*), logs of monitoring tools and measuring equipment (*Records R17*). The technical requirements for the welding procedure (*Records R7*) give an idea of the available welding technologies.

Each welding Request is analyzed for the completeness of the wording of the requirements for welding, welding requirements. The capability of welding production to meet these requirements is determined. Only those Requests (Orders, Contracts) are accepted for implementation, for which the capability to meet all requirements is confirmed.

Records R1. Agreed Request specifications (Order, Contract). Including the product's drawings and specific requirements for a weld and the conditions for its implementation.

The documented data are used to determine the activities required to ensure the welding quality of the Request (Order, Contract) during the subsequent technical analysis (*Procedure B2. Technical Analysis*).

Procedure B2. Technical Analysis.

The initial data for the technical analysis are contained in the agreed specifications of the Request (*Records R1*). In this case, the basic specification is the drawing of a welded product.

The technical analysis defines the requirements for the main metal – the grade, thickness, diameter for pipes, and the features of the welding capacity of the main metal. The symbols of welds on the drawings, the quality of welds, and the corresponding procurement requirements, welding provisions, preparation of edges for welding are verified. The manufacturability of the product is analyzed – the availability of joints for welding and subsequent non-destructive control, taking into consideration the sequence of welds. If necessary, the technical

analysis identifies additional measures of ensuring the quality of welding, related to the inspection and preparation of welding materials, control of the ferritic phase, removal of residual stresses, heat treatment, treatment of the seam surface, etc.

In addition to ISO 14731, the procedure should be guided by the following international standards: ISO 2553; ISO 4063; ISO 5817; ISO 13919; ISO 6947; ISO 9692.

Records R2. The drawings prepared for production with full designations of welds and technical requirements for welded joints.

The documented data are used:

- in determining the welding procedures required for the manufacture of a product (Procedure B8. Technical requirements for the welding procedure.);
- to ensure the quality of a product in production planning (Procedure B6. Production Planning);
- to explain technical requirements to the direct performers of welding operations (Procedure B9. Working Instructions.);
- in determining the requirements for the supply and handling of welding materials (Procedure B10. Welding materials.);
- in determining the requirements for the supply and handling of basic materials (Procedure B11. Basic Materials).

Procedure B8. Technical requirements for the welding procedure.

The original data are contained in the drawing and include the brand of a material, the thickness, diameter (for a pipe), the welding technique, the position of welding, welding materials.

The procedure implies the identification of an exhaustive list of technical requirements for the welding procedure, completely covering all necessary processes for welding. In the absence of the necessary WPS, appropriate WPS should be developed and properly certified under Procedure B7. Certification of welding procedures.

Records R8. A list of specifications for the welding procedure (WPS) based on a Request.

The documented data are used as a list of specifications for the welding procedure mandatory for the production.

Procedure B6. Production Planning.

The original data are the results of executing Procedure B2. Technical Analysis.

Taking into consideration the specifications for the welding process, the sequence of welds is determined. Specific requirements for the work environment (temperature, humidity, sediment protection, wind and draft protection, etc.) are defined, as well as the necessary means to meet such requirements. Skilled personnel, pre-heating equipment, thermal treatment, pyrometers, non-destructive control, and welding testing equipment are distributed. Forming replacement tasks to perform the Request, taking into consideration the availability of equipment and personnel who have the necessary permits to perform the work.

In deciding whether to transfer part of the welding operation to the subcontract, a set of specifications is developed for the transferable part of the work necessary to ensure quality in subcontracting operations.

Records R6.1. The assembly drawing of the product, which determines the sequence of welds. At the request of the Customer, the Control Plan for the assembly and welding of the product, which is a set of measures to ensure the quality of welding during the implementation of the Request.

The documented data are used for operational production management, dispatching the execution of requests.

Records R6.2. A set of specifications to ensure quality when subcontracting.

The documented data are used as the original requirements when selecting a subcontracting executor.

Procedure B9. Working Instructions.

The original data are contained in the technical documentation prepared in advance for transfer to production during the following procedures: Procedure B2. Technical Analysis; Procedure B8. Technical requirements for the welding procedure; Procedure B6. Manufacturing Planning.

The result of this procedure is to deliver the information contained in the prepared technical documentation to the direct executors in the production and to ensure that this documented information is unconditionally available to performers during the execution of the work.

In addition to drawings and WPS specifications, instructions on equipment setting, visual control, management of non-conforming products, etc. can be transferred to workplaces.

Records R9. A registry of technical documentation used in the workplace based on the Request. It contains information about technical documentation sets that regulate the execution of each Order at each workplace.

The documented data are used for operational production management, to dispatch the execution of requests.

Procedure B3. Subcontract.

The original data are included in the specifications to ensure quality when subcontracting.

The selection of a subcontracting executor is based on his ability to meet the requirements of these specifications.

Records R3. The results of the assessment of the subcontractor's ability to meet quality assurance requirements are recorded in the Subcontractor's Registers and Questionnaires.

Procedure B10. Welding Materials.

The original data are the symbols of welds on a drawing with the requirements of the product designer for welding materials.

The additive and protective welding materials are selected taking into consideration the compatibility and requirements of the designer to the materials. Requirements for the supply of welding materials, the acceptance of welding materials, the necessary accompanying documents, the conditions for storage and maintenance of welding materials are defined and implemented.

In addition to ISO 14731, the procedure should be guided by the following international standards: ISO 544; ISO 2560; ISO 18275; ISO 3580; ISO 3581; ISO 14341; ISO 16834; ISO 21952; ISO 17632; ISO 18276; ISO 17634; ISO 17633; ISO 14174; ISO 14175.

Records R10. A request for the supply of welding materials under the Request, quality passports (certificates) for welding materials, logs of handling the welding materials in a warehouse.

The documented data are used to ensure the quality of the welding materials during production.

Procedure B11. Basic Materials.

The original data are the requirements of the designer to the main metal, specified in the drawings.

Taking into consideration the features of the welding capacity of the main metal, additional requirements for delivery terms, acceptance, marking, storage, the documented quality of the main material are defined and implemented. The source data for traceability of the main material in welding are provided.

In addition to ISO 14731, the procedure should be guided by the following international standard: ISO 15608.

Records R11. A request for the supply of basic materials under the Request, quality passports (certificates) on basic materials, logs of handling the basic materials in a warehouse.

The documented data are used to ensure the quality of basic materials during production.

5.2.3. Procedures to ensure and improve the quality of welding of a joint

A mandatory condition and source of the raw data for the implementation of the procedures to ensure and improve the quality of the welding of a joint is the complete and successful implementation of the procedures for ensuring the quality of welding for the Request.

The procedures to ensure and improve the quality of a welding joint accompany and ensure the quality of welding of each joint.

The source data for all procedures to ensure and improve the quality of joint welding are contained in the Technical Documentation in accordance with R9 «Register of technical documentation used in the workplace on the Request».

Procedure B12. Checks and tests before welding.

The original data are contained in the full technical documentation for the making a welding joint in accordance with R9 «Registry of technical documentation used in the workplace on the Request».

Only welders and operators of welding plants with a valid certificate and appropriate permit are eligible to make a welded joint.

Welded joints are made only if there are appropriate and up-to-date technical requirements for the welding procedure.

All the main metal and welding materials submitted to the assembly and welding site are checked so that the brand in the accompanying documents meet the requirements of the drawing.

The preparation of edges (shape and sizes) of welded joints should meet the requirements of the drawing and WPS.

The gap and preparation of the joint for welding during assembly, the use of clamps, and the execution of seizures are monitored.

The implementation of special measures aimed at reducing stresses and deformations, ensuring perpendicularity, axial alignment, the flatness of parts, etc. is monitored.

Records R12. Product checklist – Welding preparation section.

The performed checks and tests before welding are documented in the journal of welding operations or in a Product control sheet – Welding Preparation Section.

The documented data are used to confirm the execution of all measures necessary to ensure the quality of activities immediately prior to welding.

Procedure B13. Checks and tests during welding.

The original data are contained in the full technical documentation for making a welding joint in accordance with R9 «Registry of technical documentation used in the workplace on the Request».

Checks and tests during welding ensure compliance with the technical requirements for the welding procedure, while:

- constant monitoring and monitoring of welding regime parameters is carried out;
- the predefined pre-heating temperature is maintained, as well as the temperature before each run;
- the rollers are cleaned and the shape of the rollers is controlled, as well as the layers of a welded joint's metal;
- the formation of the back of the joint is controlled;

- the preset execution order of welds is ensured;
- the planned cleaning is carried out, as well as drying (calcination), protection from external influences, reuse of welding materials;
- the stipulated deformation control is executed;
- intermediate inspections are carried out by external inspections and measurements of size.

Records R13. A product checklist – the Welding Section.

Performed actions on inspection and testing during welding are documented in the control sheet of the product – The Welding Section.

The documented data are used to confirm the execution of all activities necessary to ensure the quality of welding.

Procedure B15. Thermal treatment after welding.

The implied thermal treatment after welding is carried out. In addition to ISO 14731, the procedure should be guided by the following international standard: ISO 17663.

Records R15. A product's control sheet – the Thermal Treatment Section.

Data on the time of the start of heat treatment after welding, the actual thermal cycle, the equipment and materials used, are documented.

Procedure B18. Identification and Traceability.

Identification is carried out – the designations that make it possible to distinguish:

- the drawings transferred to production, the assembly and welding control plan, the specifications to ensure quality in subcontracting work;
- technical documentation forms used in the production;
- the locations of welds in the product;
- procedures and non-destructive control personnel;
- welding materials;
- the main material;
- places of correction (reporting to compliance, corrections);
- places to install temporary devices.

There is traceability – the ability to trace in production to restore history, origin, application.

For each welding joint, made by a fully mechanized or automated installation, its ID and operator's ID are documented who executed welding in accordance with an appropriate permit. This ensures that the welded joint is traceable until the automatic welding and operator are installed.

For each welded joint, made by a welder, the welder's ID is documented, in accordance with his permit. This ensures that the welded joint is traceable to the welder.

For each welded joint, the Technical Requirements' ID for the welding procedure that is performed is documented. This ensures that the welded joint is traceable to the technical requirements for the welding procedure.

Identification simplifies the use of materials, documentation, equipment for the purpose. This allows the staff to perform operations in accordance with the permit.

Traceability makes it possible to confirm the performance of basic measures to ensure the quality of welds and to determine the causes of detectable discrepancies.

Records R18. Identifiers in the drawings and control sheets of the product.

They contain consolidated data on the identifiers used in the execution of the Request.

Procedure B14. Checks and tests after welding.

The original data are R2 technical requirements for welded joints.

All welded joints are exposed to external inspection. This controls the shape, size, external defects of the welded joint.

If specifications require it, welded joints are subjected to non-destructive or destructive tests.

The protocols of processing after welding (thermal treatment, aging) are analyzed.

The implementation of the B14 procedure makes it possible to further use (release) of the welded joints with confirmed compliance. The non-compliant welded joints undergo the B16-1 Procedure *Inconsistencies* and Corrective Actions.

In addition to ISO 14731, the procedure should be guided by the following international standards: ISO 13916; ISO 17635; ISO 17636; ISO 17637; ISO 17638; ISO 17639; ISO 17640.

Records R14. A product checklist – the Technical Control Section.

The actions on verification and testing performed after welding are documented in the product's control sheet – Technical Control Section.

The documented data are used to confirm that welds meet the requirements.

Procedure B16-1. Inconsistencies and Corrective Actions.

The initial data are the R14 results of technical control of the product, data on the identified inconsistencies in the requirements.

The procedure is performed to correct inconsistencies.

If a section of the joint that does not meet the requirements is found to deviate from the size of the product, this section (product) is identified and isolated.

Depending on the inconsistency, the necessary correction is made – bringing to compliance.

Further use of a welded joint (product) for the purpose is possible only after the technical control of the correction effectiveness.

Records R16-1. Non-conforming product management sheet.

The nature and location of the discrepancy are documented, the actions taken for correction, the results of the re-examination of the welding section (product) after the correction.

Procedure B16-2. Inconsistencies and Corrective Actions.

The initial data are the R14 results of technical control of products, data on the identified non-compliance with requirements throughout production.

The procedure is performed to prevent the recurrence of inconsistencies and reduce their overall level.

Data on the nature, localization, time, and frequency of inconsistencies during the production period are analyzed. Inconsistencies of greatest importance and priority actions to address the causes of their occurrence are identified.

For such inconsistencies, the reasons for the occurrence are determined, measures are determined and implemented to eliminate such causes, the effectiveness of the measures taken, corrective actions, is assessed.

Effective activities become a daily practice of action and can lead to changes in any of the procedures adopted.

Records R16-2. A sheet of data collection for the period. Pareto's diagram for the period. A sheet of corrective actions for the period.

It documents step by step data on the corrective actions carried out during the production period.

Procedure B19. Quality Records.

The procedure for maintaining, storing, and ensuring the availability of all previously listed quality records, both in paper and electronic form, is determined.

The procedure is part of all procedures and ensures that the information in the quality records is available.

Records R19. Acts of transferring records to third parties, acts of destruction of records.

Data on the transfer of records to third-party organizations, including on-demand, subcontract, storage, as well as the destruction of expired records and records are documented.

5.3. Applying the regulatory required welding coordination to ensure quality in the production of a welded frame

Manufacturing, used here as an example of welding coordination procedures, specializes in the fabrication of agricultural equipment. Including frame seeders, plows, cultivators. The main welding technique is mechanized welding in protective active gases (135). The products are made of carbon-based structural steels with a fluidity limit of up to 275 MPa (subgroup 1.1) using FM1 additive materials for unalloyed fine-grained steels. A pipe (T) with an external diameter of $D=20-25$ mm and a rolled profile with a wall thickness of 2–4 mm are used. Products require both butt (BW) and fillet (FW) welded joints. The use of equipment, positioners allows welding mainly in convenient positions PA, PB but there are positions of welding PC, PF. Butt welds (BW) are made as one-sided (ss) without backing (nb). The welding production basically has the personnel, equipment, tooling, infrastructure necessary to fulfill the long-term production plan.

The invariability of the product range has allowed a comparative assessment (before and after the implementation) of the impact of systemic welding coordination on the quality of welded joints.

Request 24/ZW129-18 was fulfilled under the conditions of systemic welding coordination. In accordance with this Request, it was necessary to weld the transmission elements to the frames (8 joints per frame). The order volume is 420 frames. Running time is 25 working shifts.

The basic content of the quality assurance system in welding in the fulfillment of Request 24/ZW129-18 is related to the results of the relevant procedures and is given below:

1. Welding requirements are established and agreed with the designer:

A1=z3<135/ISO5817-B/ISO6947-PB/ISO9692-3.1.2/
ISO14341-A: G 42 3 M21 3Si1.

2. WPS-135-09-PBF-3.2-PB-3.0 (Table 1) were selected from the company's technical requirements for the welding procedure as they meet previously established requirements for welded joints.

3. In order to fulfill Request 24/ZW129-18, the heated welding warehouse was used to keep the minimum required solid-section welding wire (purchased from a manufacturer's official dealers) with a diameter of 1.2 mm, ESAB OK 12.51, corresponding to ISO 14341-A: G 42 3 M21 3Si1. The warehouses are equipped with thermometers/hygrometers, twice a day the readings of temperature and humidity in the warehouse were recorded in the warehouse log. It also recorded all the movements of welding wire with traceability to shipments.

4. To fulfill Request 24/ZW129-18, the racks in closed premises store the minimum required stock of the profile of steel PNH84020-88: St3W.

5. To work on Request 24/ZW129-18, only the welders with valid confirmed qualifications were involved: 135 T BW FM1 S s3,0 D32 PF ss nb.

6. According to Request 24/ZW129-18, all products were accompanied by a sheet (Table 2) with the registration of the technical control results.

Table 1

Welding procedure specifications (WPS)

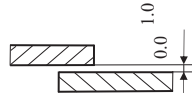
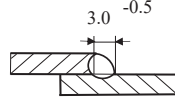
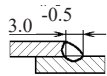
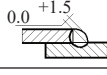
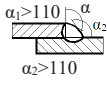
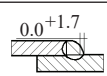
Welding procedure specifications: WPS-135-09-PBF-3.1.2-PB-3.0				Preparation and cleaning method: Guillotine scissors			
WPQR No. PQR-135-EG01/12.07.2018				Parent material designation: Sub-group 1.1 PNH84020-88: St3W			
Manufacturer: MP ICF «IrKom»				Material's thickness (mm): 3.0			
Type of joint and weld: P FW				Welding position: PB			
Joint design				Welding sequence			
							
Welding parameters							
Run	Welding process	Size of filler material, mm	Welding current, A	Arc voltage, V	Polarity	Speed, mm/min	Heat input, kcal/mm
1	135	1.2	150	20	DC+	470	0.09
Filler material designation and make: EN ISO 14341-A: G 42 3 M21 3Si1ESAB OK 12.51				Designation of gas – shielding: ISO 14175 – M21 (18 %CO ₂ 72 % Ar)			
Heating temperature: N/A				Gas Flow Rate – Shielding: 17 l/min			

Table 2

Product checklist – Technical Control Section

Request		24/ZW129-18							
Frame No.		171-ZW/129-18							
Work shift		3.2							
Limitations ISO5817-B		Control point location – ZW-129-334-C							
		A1-No. 1	A1-No. 2	A1-No. 3	A1-No. 4	A1-No. 5	A1-No. 6	A1-No. 7	A1-No. 8
z – leg length		Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
503 –excessive convexity		Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
505 – incorrect weld toe		Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
512 – excessive asymmetry of fillet weld		Ok	Ok	Ok	512-A1/4-117-24	Ok	Ok	Ok	Ok
Other inconsistencies with requirements ISO5817-B		5012-A1/1-117-24	Ok	Ok	Ok	Ok	Ok	Ok	Ok

All the discrepancies identified were corrected.

7. Every week, the results of technical control on Request 24/ZW129-18 were consolidated per shifts (Table 3) in a summary table. Critical inconsistencies were corrected every week.

List of data collection over a week

Request	24/ZW129-18						
Week No.	3						
Identified inconsistencies	Work shift						
	3.1	3.2	3.3	3.4	3.5	Total	
z – leg length	0	0	0	0	1	1	
503 – excessive convexity	0	0	1	0	0	1	
505 – incorrect weld toe	0	0	0	0	0	0	
512 –excessive asymmetry of fillet weld	1	1	0	0	1	3	
5012 – intermittent undercut	1	1	0	0	0	2	
Total inconsistencies per shift	2	2	1	0	2	7	
Total checked per shift	112	120	112	104	120	576	

5. 4. The level of quality of welded joints before and after the introduction of welding coordination

The universal indicator of the level of inconsistencies or the level of quality of welded joints [37–39] is the *p*-proportion of non-conforming units within the sample. The proportion of non-conforming units in the sample is defined as the ratio of *x*, the number of identified non-conforming units, to *n*, the number of units tested in the sample or the sample size:

$$p = \frac{x}{n} \tag{1}$$

When fulfilling Request 24/ZW129-18, the sample size *n_i* was defined as the total number of welded joints tested over the *i*-th shift (Table 3: total checked per shift). The number of detected non-conforming units over the *i*-th shift (*x_i*) was determined as the number of inconsistencies per shift (Table 3). The proportion of non-conforming units in the sample *p_i* was calculated according to formula (1).

The summarized data on the number of discrepancies identified in the implementation of Request 24/W129-18 are given in Table 4. Request 24/ZW129-18 was in fact executed in 28 working shifts (versus 25 shifts planned).

To determine the statistical controllability of the welding process, a proportion *p*-chart was used as the type of a Shewhart chart. The state of statistical control over the process is desirable and indicates sufficient reliability, predictability, and stability of the welding process [40]. To build a Shewhart chart, Table 4 was used to calculate the location of the central line, the upper and lower control boundaries. The sample volumes *n_i*, determined by the number of welded joints made and checked during a shift, differed from the average value *n* by no more than 10 %, which made it possible to use the *p*-chart of shares with the calculated rectilinear control boundaries [41].

frames, seven criteria for the influence of specific causes should be used [30].

Criterion 1 «exit point for the control limit» (its manifestation is possible only at the upper limit) – no influence of special causes was found.

Criterion 2 «two points out of three points» – no effect of special causes was found. Based on this criterion, the influence of special causes manifests itself by three consecutive points on one side of the central line, two of which are in zone A or beyond. In our case, the manifestation of the criterion is possible only along the upper limit.

Criterion 3 «four points out of five points» – no effect of special causes was found. Based on this criterion, the influence of special causes manifests itself by five consecutive points on one side of the central line, four of which are in zone B or further. In our case, the manifestation of the criterion is possible only at the upper limit.

Table 4

The number of identified inconsistencies – Request 24/ZW129-18

Work shift (<i>i</i>)	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5
The number of non-conforming units (<i>x_i</i>)	4	2	5	2	1	2	6	2	0	2
Sample size (<i>n_i</i>)	112	120	128	120	120	112	120	120	128	120
The proportion of non-conforming units (<i>p_i</i>)	0.033	0.017	0.042	0.017	0.008	0.017	0.05	0.017	0	0.017
Work shift (<i>i</i>)	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5
The number of non-conforming units (<i>x_i</i>)	3	2	1	0	2	1	1	2	5	2
Sample size (<i>n_i</i>)	112	120	128	120	120	112	120	112	120	128
The proportion of non-conforming units (<i>p_i</i>)	0.025	0.017	0.008	0	0.017	0.008	0.008	0.017	0.042	0.017
Work shift (<i>i</i>)	5.1	5.2	5.3	5.4	5.5	6.1	6.2	6.3	–	–
The number of non-conforming units (<i>x_i</i>)	2	1	4	2	6	3	1	1	–	–
Sample size (<i>n_i</i>)	120	120	120	120	128	128	120	112	–	–
The proportion of non-conforming units (<i>p_i</i>)	0.017	0.008	0.033	0.017	0.05	0.025	0.008	0.008	–	–

The central line of the *p*-chart of shares was calculated as follows:

$$CL_p = \bar{p} = \sum_i \frac{x_i}{n_i} \tag{2}$$

The upper control boundary of the *p*-chart of shares was calculated as follows:

$$UCL_p = \bar{p} + 3 * \sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}} \tag{3}$$

The lower control boundary of the *p*-chart of shares was calculated as follows:

$$LCL_p = \bar{p} - 3 * \sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}} \tag{4}$$

The Shewhart *p*-chart, based on the data on the implementation of Request 24/ZW129-18, is shown in Fig. 3. Only the upper control limit (*UCL_p*) is valid on the control chart. There is no lower control limit because the calculation produced a negative value *LCL_p*=-0.018. At the bottom, the control chart is limited to zero in the share of non-conforming units in the sample. The control chart field from the central line to the upper control limit is divided into three zones equal in length: A; B; C.

Using a control chart, the welding process is tested for the impact of special causes. Since the control chart field recorded data from consistently produced and verified

Criterion 4 «nine points» – no effect of special causes was found. Based on this criterion, the influence of special causes manifests itself by nine consecutive points on one side of the central line.

Criterion 5 «six points» – no effect of special causes was found. According to this criterion, the influence of special causes manifests itself as six consecutive points, arranged in an ascending or descending way (trend).

Criterion 6 «fourteen points» – no effect of special causes was found. According to this criterion, the influence of special causes manifests itself as fourteen consecutive points, arranged alternately up and down.

Criterion 7 «fifteen points» – no effect of special causes was found. Based on this criterion, the influence of special causes manifests itself as fifteen consecutive points located in zone C.

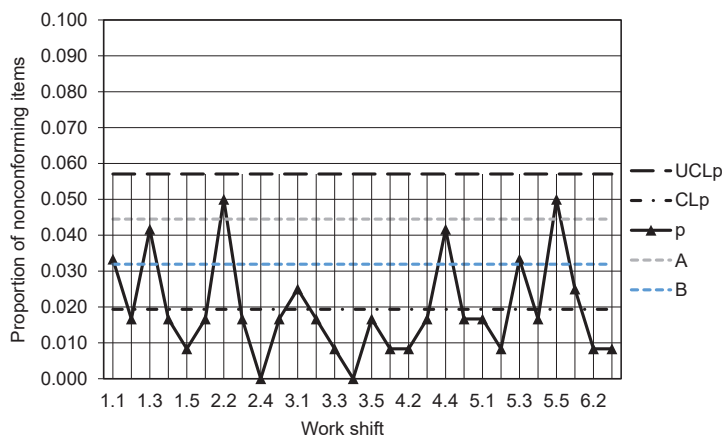


Fig. 3. Shewhart chart on Order 24/ZW129-18 (ISO 14731 welding coordination)

The general conclusion is that the impact of specific causes has not been found. In the execution of Request 24/ZW129-18, the welding process was in a state of statistical controllability

with the process-characteristic statistically sound level of the quality of welded joints $p^*=0.019$ of the proportion of nonconforming units in the sample.

A comparative assessment of the impact of systemic welding coordination on the level of the quality of the joints was carried out. The level of joints' quality obtained prior to the introduction of ISO 14731 requirements for the Request, similar to the requirements for welding joints and welding technology in Request 24/ZW129-18, was used. Fig. 4 shows the Shewhart p -chart, built on welding data without system coordination according to the ISO 14731 requirements.

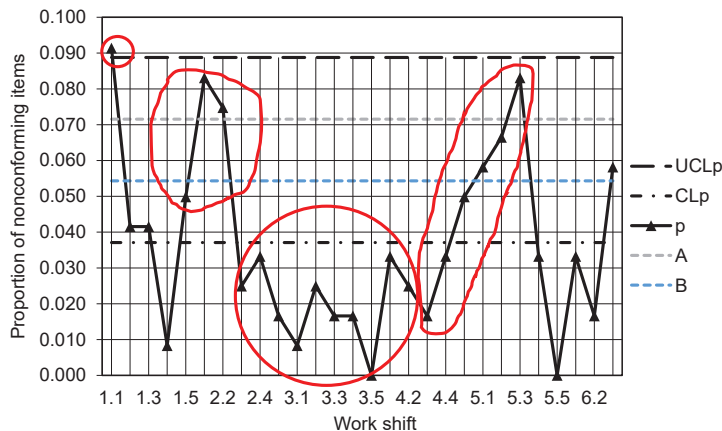


Fig. 4. Shewhart chart without system-coordinated welding

We shall identify shifts during which, in the absence of systemic coordination of operations, the welding process was influenced by special reasons. Use the same seven criteria for the influence of special causes.

Criterion 1 «exit point over the control boundary» (the manifestation is possible only at the upper limit) – the effect of a particular cause during a shift 1. 1.

Criterion 2 «two points out of three points» – the effect of a special cause during shifts 1. 5; 2. 1; 2. 2.

Criterion 3 «four points out of five points» – no effect of special causes was found.

Criterion 4 «nine points» – the effect of a special cause was during shifts 2. 3; 2. 4; 2. 5; 3. 1; 3. 2; 3. 3; 3. 4; 3. 5; 4. 1.

Criterion 5 «six points» – the effect of a special cause during shifts 4. 3; 4. 4; 4. 5; 5. 1; 5. 2; 5. 3.

Criterion 6 «fourteen points» – no effect of special causes was found.

Criterion 7 «fifteen points» – no effect of special causes was found.

The general finding is that the effect of special causes was found for 19 of the 28 points mapped on the Shewhart p -chart field. This clearly shows the state of statistical uncontrollability of the welding process under study in the absence of systemic coordination of welding operations. At the same time, due to the instability of the welding process, it is not possible to determine a statistically reasonable level of quality. However, the estimated average of the proportion of nonconforming units in the sample is $p=0.037$, which is twice the corresponding statistically reasonable value when fulfilling Request 24/ZW129-18.

Thus, the systematic implementation of welding coordination procedures stabilizes the welding process, leads it to a state of statistical controllability, and reduces the proportion of nonconforming units in the sample by 2 times.

6. Discussion of the results of analyzing the effect of systemic welding coordination on the level of quality of welded joints

Comparing the level of the quality of welded joints before and after the introduction of the system approach to welding coordination (Fig. 3, 4) shows a significant improvement in performance indicators. In the absence of systemic coordination of welding, the estimated average of the proportion of nonconforming units in the sample was $p=0.037$ (Fig. 4). At the same time, in 19 samples out of 28 samples, the welding process was in a statistically unmanageable state. The systemic implementation during the fulfillment of Request 24/ZW129-18 of the required procedures for the coordination of welding operations (Tables 1–4) has led to an improvement in the quality level. The average value of the proportion of nonconforming units in the sample was reduced to $p=0.019$ and the welding process moved to a statistically manageable state (Fig. 3). Stabilizing the welding process while reducing the proportion of nonconforming units in the sample can be explained by the implementation of the regulatory-oriented procedures B1–B19 for welding coordination. The systematic character of the welding coordination is ensured by the interconnection of the procedures under the verified scheme (Fig. 2). The systemic coordination of welding operation ensures constant monitoring of the main sources of variability in the quality indicators of welded joints.

A comprehensive solution for the systemic coordination of welding in production has been proposed. In this case, we have defined the main content of the coordination procedures, the pattern of their relationship, and proposed the application of statistical control over the welding process using the Shewhart p -chart. Our findings show a statistically sound improvement in the welding process as a result of the proposed solutions.

The main merit of the study is that objective data from production was analyzed using the methods of statistical process control. This allowed us to build on objective criteria for assessing the effectiveness of the implementation of coordination of welding. Conventionally, such analysis was carried out through production audits [25] and the results were based on the method of expert estimates [26]. The method used here minimizes subjectivity in conclusions.

A significant limitation of this study is its orientation to ensure quality when welding by melting. The proposed and tested procedures for the coordination of welding operations do not take into consideration the specificity of other welding techniques, including the widely used techniques of contact, point, seam, diffusion welding.

Some caveats of this study include restrictions on the number of objects for the implementation of the proposed systemic welding coordination and the number of samples for statistical analysis. Expanding the base of welding industries that use a systematic approach to welding coordination could eliminate these shortcomings in the future.

This study may be advanced through the construction of mathematical models that determine the contribution of coordination procedures in welding in the formation of the level of quality of a welded joint. Simulation using production experiment planning techniques can be hampered by the actual production capabilities regarding the regulation

and maintenance at the predefined level of the procedure as a factor in the experiment. Therefore, in the first stage, the simulation could be carried out using regression analysis methods.

7. Conclusions

1. A scheme of the interconnection of coordination procedures in welding has been proposed and verified, which makes it possible to systematically meet the ISO 14731 requirements for the quality of welding. The scheme establishes the optimal sequence of procedures and information links between them.

2. It has been shown that it is important to distinguish between three groups of quality-assurance procedures in welding. The first group includes long-term procedures for ensuring the quality of welding. The second group includes procedures for ensuring the quality of welding in the execution of a Request (Order, Contract). The third group includes procedures to ensure and improve the quality of a welded joint.

3. We have proposed and tested under welding production conditions a variant of embedding a set of standardized requirements for welding processes into quality assurance procedures by welding coordination. The statistical analysis of data on the level of the quality of welded joints in production before and after the introduction of systemic welding coordination has been carried out.

4. The Shewhart charts were applied to perform a statistical analysis of empirical data acquired during production on the proportions of nonconforming units in the sample, characterizing the quality level of joints when executing systemic welding coordination and without such. It has been demonstrated that systemic compliance with the ISO 14731 requirements makes it possible to attain a statistically managed state of the welding process while reducing the proportion of non-conforming units in half.

8. Acknowledgments

The involved companies (Agro-Soyuz Corporation, ICF «IrKom») are acknowledged for informational support.

References

- Slyvinsky, O., Chvertko, Y., Bisyk, S. (2019). Effect of welding heat input on heat-affected zone softening in quenched and tempered armor steels. *High Temperature Material Processes An International Quarterly of High-Technology Plasma Processes*, 23 (3), 239–253. doi: <https://doi.org/10.1615/hightempmatproc.2019031690>
- Prokhorenko, V. M., Prokhorenko, D. V., Zvorykin, C. O., Hainutdinov, S. F. (2019). Kinetics of strains during single-pass fusion welding of a symmetrical butt joint. *Technological Systems*, 3 (88), 87–98. doi: <https://doi.org/10.29010/88.11>
- Fukuda, S. (1998). Engineering Accreditation. *Journal of the Japan Welding Society*, 67 (3), 237–239. doi: <https://doi.org/10.2207/qjwjs1943.67.237>
- Harasawa, H. (2010). Education and Certification System of Welding Engineers in Japan and Overseas Activities. *Journal of the Japan Welding Society*, 79 (1), 49–57. doi: <https://doi.org/10.2207/jjws.79.49>
- Quintino, L., Fernandes, I., Miranda, R. M. (2012). Impact of the Qualification of Personnel in the Manufacturing Industry. *Welding in the World*, 56 (7-8), 130–137. doi: <https://doi.org/10.1007/bf03321373>
- Hirata, Y. (2016). Sustainable Evolution of Welding and Joining Technology. *Journal of the Japan Welding Society*, 85 (1), 5–11. doi: <https://doi.org/10.2207/jjws.85.5>
- Harasawa, H. (2008). Planning and Management of Welding Procedure. *Journal of the Japan Welding Society*, 77 (6), 582–595. doi: <https://doi.org/10.2207/jjws.77.582>
- Omata, K. (2012). Standards of Welding Procedure. *Journal of the Japan Welding Society*, 81 (5), 443–445. doi: <https://doi.org/10.2207/jjws.81.443>
- Babkin, A. S., Chang, Y., Babkin, I. A. (2017). Identification welding parameters using complex criteria of quality. *China Welding (English Edition)*, 26 (4), 1–9. doi: <https://doi.org/10.12073/j.cw.20170922001>
- Darmadi, D. B., Abdillah, F. N., Raharjo, R. (2019). Controlling the pressure force to obtain a better quality of aluminum 6061 friction stir welded joint. *Eastern-European Journal of Enterprise Technologies*, 3 (1 (99)), 6–10. doi: <https://doi.org/10.15587/1729-4061.2019.159286>
- Davydovs'kyi, L. S., Bisyk, S. P., Chepkov, I. B., Vas'kivs'kyi, M. I., Katok, O. A., Slyvins'kyi, O. A. (2019). Alternatives of Energy Absorption Element Design Parameters for an Armored Combat Vehicle Seat Under Explosive Loading. *Strength of Materials*, 51 (6), 900–907. doi: <https://doi.org/10.1007/s11223-020-00140-7>
- Dragan, S. V., Kvasnitsky, V. V., Romanchuk, N. P., Solonichenko, Yu. V., Goloborodko, Zh. G. (2004). Technological processes of welding and cutting in shipbuilding of Ukraine (Review). *Automatic Welding*, 8, 3–6. Available at: <https://patonpublishinghouse.com/as/pdf/2004/as200408all.pdf>
- Harasawa, H. (2012). Quality Assurance and Quality Management. *Journal of the Japan Welding Society*, 81 (5), 434–436. doi: <https://doi.org/10.2207/jjws.81.434>
- Otsuka, H., Minoda, Y., Nagayama, K. (2013). Quality Assurance of Welded Steel of Tokyo Sky Tree. *Journal of the Japan Welding Society*, 82 (4), 252–257. doi: <https://doi.org/10.2207/jjws.82.252>
- Matsuyama, K. (2015). Trend of Standardization Works on Resistance Spot Welding of High and Ultra-High Strength Steel Sheets. *Journal of the Japan Welding Society*, 84 (6), 462–466. doi: <https://doi.org/10.2207/jjws.84.462>

16. Takechi, S. (2008). Knowledge Management in Manufacturing. *Journal of the Japan Welding Society*, 77 (1), 55–59. doi: <https://doi.org/10.2207/jjws.77.55>
17. Ueyama, T. (2017). 2016 Industrial Trend. *Journal of the Japan Welding Society*, 86 (5), 343–343. doi: <https://doi.org/10.2207/jjws.86.343>
18. Shackleton, D. N. (2006). Reducing Failure Risk in Welded Components. *Welding in the World*, 50 (9-10), 92–97. doi: <https://doi.org/10.1007/bf03263449>
19. LaPlante, W. (2011). How to assure quality in outsourced welded products. *Welding Journal*, 90 (10), 42–46. Available at: <https://www.researchgate.net/publication/293774882>
20. Haievskiy, O. A., Haievskiy, V. O. (2017). *Koordynatsiya zvarivvalnykh robot. Kyiv: Tsentr uchbovoi literatury*, 168. Available at: http://pdf.lib.vntu.edu.ua/books/2017/koordynatsiy_zvarivvalnyh_robot.pdf
21. Walker, R. H., Johnson, L. W. (2009). Signaling intrinsic service quality and value via accreditation and certification. *Managing Service Quality: An International Journal*, 19(1), 85–105. doi: <https://doi.org/10.1108/09604520910926827>
22. Björk, T., Samuelsson, J., Marquis, G. (2008). The Need for a Weld Quality System for Fatigue Loaded Structures. *Welding in the World*, 52, 34–46. doi: <https://doi.org/10.1007/BF03266615>
23. Aikawa, T. (2001). An outline of iso 9001:2000 requirements and the point of building a management system. *Journal of the Japan Welding Society*, 70 (7), 701–706. doi: https://doi.org/10.2207/qjws1943.70.7_701
24. Wada, H. (2008). Management system of welding quality. *Journal of the Japan Welding Society*, 77 (3), 248–253. doi: <https://doi.org/10.2207/jjws.77.248>
25. Ericson Öberg, A. (2018). From standard change to implemented assessment. *Welding in the World*, 62, 941–946. doi: <https://doi.org/10.1007/s40194-018-0622-6>
26. Zimon, D. (2016). Influence of Quality Management System on Improving Processes in Small and Medium-Sized Organizations. *Quality – Access to Success*, 17 (150), 61–64. Available at: https://www.researchgate.net/publication/298072272_Influence_of_quality_management_system_on_improving_processes_in_small_and_medium-sized_organizations
27. Zimon, D. (2017). The impact of quality management systems on the effectiveness of food supply chains. *TEM Journal*, 6 (4), 693–698. doi: <https://doi.org/10.18421/TEM64-07>
28. Xie, Q., Yang, Y., Li, X., Zhao, N. (2007). Basic model study on efficiency evaluation in collaborative design work process. *Frontiers of Mechanical Engineering in China*, 2 (3), 344–349. doi: <https://doi.org/10.1007/s11465-007-0060-4>
29. Dekoulou, P., Iacovidou, M., Antonaras, A. (2018). Developing a university CSR framework using stakeholder approach. *World Review of Entrepreneurship, Management and Sustainable Development*, 14 (1/2), 43. doi: <https://doi.org/10.1504/wremsd.2018.10009040>
30. Li, Q., Chen, Y.-L. (2009). Data Flow Diagram. *Modeling and Analysis of Enterprise and Information Systems*, 85–97. doi: https://doi.org/10.1007/978-3-540-89556-5_4
31. Abed Thamer, K. (2020). Development of cognitive approach to the organization of business processes in virtual machine-building enterprises within Industry 4.0. *Eastern-European Journal of Enterprise Technologies*, 1 (2 (103)), 14–23. doi: <https://doi.org/10.15587/1729-4061.2020.196371>
32. Quintino, L., Ferraz, R., Fernandes, I. (2008). International Education, Qualification and Certification Systems in Welding. *Welding in the World*, 52 (1-2), 71–79. doi: <https://doi.org/10.1007/bf03266619>
33. Matsuyama, K. (2014). Quality Management Technologies for Resisyance Spot Welding. *Journal of the Japan Welding Society*, 83 (8), 602–615. doi: <https://doi.org/10.2207/jjws.83.602>
34. Kang, C. W., Kvam, P. H.. (2012). Shewhart control charts. *Basic Statistical Tools for Improving Quality*, 97–124. doi: <https://doi.org/10.1002/9781118491751.ch5>
35. Grigor'ev, A. V., Kuzenkova, T. V., Solomina, I. N. (2010). Issledovanie sostoyaniya sistemy obespecheniya kachestva produktsii na poligraficheskom predpriyatii. *Eastern-European Journal of Enterprise Technologies*, 6 (8 (48)), 40–44. Available at: <http://journals.uran.ua/eejet/article/view/5764/5197>
36. Lazko, I. V. (2013). Analysis and estimation accompanying risk of the provision quality to design product. *Eastern-European Journal of Enterprise Technologies*, 2 (10 (62)), 4–7. Available at: <http://journals.uran.ua/eejet/article/view/12596/10475>
37. Tanaka, M. (1968). Theoretical study of Statistical Quality Control in Welding Fabrication. *Journal of the Japan Welding Society*, 37 (8), 771–780. doi: <https://doi.org/10.2207/qjws1943.37.771>
38. Senthil Kumar, G., Natarajan, U., Veerarajan, T., Ananthan, S. S. (2014). Quality Level Assessment for Imperfections in GMAW. *Welding Journal*, 93 (3), 85–97. Available at: https://www.researchgate.net/publication/286610792_Quality_Level_Assessment_for_Imperfections_in_GMAW
39. Haievskiy, V. O., Haievskiy, O. A., Zvorykin, C. O. (2018). Investigations of weld seam width variability during shielding gas mixture arc welding. *Technological Systems*, 82/1, 70–73. doi: <https://doi.org/10.29010/082.9>
40. Stenberg, T., Barsoum, Z., Åstrand, E., Öberg, A. E., Schneider, C., Hedegård, J. (2017). Quality control and assurance in fabrication of welded structures subjected to fatigue loading. *Welding in the World*, 61 (5), 1003–1015. doi: <https://doi.org/10.1007/s40194-017-0490-5>
41. Wu, C. S. (2011). Recent Progress and Trend in Sensing and Monitoring GMAW and PAW Processes in China. *Journal of the Japan Welding Society*, 80 (1), 44–51. doi: <https://doi.org/10.2207/jjws.80.44>