European Standard EN ISO 15614-1 versus Requirements of Ship Classification Societies

Haidê Kronbauer Martinelli

Master Thesis

presented in partial fulfillment
of the requirements for the double degree:
"Advanced Master in Naval Architecture" conferred by University of Liege
"Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetics and Propulsion" conferred by Ecole Centrale de Nantes

developed at West Pomeranian University of Technology, Szczecin
in the framework of the

"EMSHIP"
Erasmus Mundus Master Course
In "Integrated Advanced Ship Design"

Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC

Supervisor: Dr. Tadeusz Graczyk, West Pomeranian University of Technology, Szczecin

Reviewer: Prof. Leonard Domnisoru, Galaty Universit (UGAL), Galaty

Szczecin, February 2016

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ABS	American Bureau of Shipping
AC	Alternating current
AWS	American Welding Society
BV	Bureau Veritas
CWB	Canadian Welding Bureau
DC	Direct current
DNV	Det Norske Veritas
DNVGL	Organization under joint between Det Norske Veritas and Germanischer Lloyd
DT	Destructive test
FCAW	Flux cored arc welding
GL	Germanischer Lloyd
GMAW	Gas metal arc welding
HAZ	Heat affected zone
HB	Brinell hardness test unit
HR	Rockwell hardness test unit
HV	Vickers hardness test unit
J-L045	Pipe fixed at 45 degrees downwards welding position
MT	Magnetic particle testing
NDE	Non-destructive examination
NDT	Non-destructive test
PC	Horizontal welding position
PF	Vertical upwards progression welding position
PG	Vertical downwards progression welding position
PT	Penetrant testing
pWPS	Preliminary welding procedure specification
RT	Radiography testing
SAW	Submerged arc welding
SMAW	Shield metal arc welding
UT	Ultrasonic testing

VHT	Impact testing specimen type – Charpy V-notch in heat affected zone through the thickness
VT	Visual testing
VWT	Impact testing specimen type – Charpy V-notch in weld metal through the thickness
WPQR	Welding procedure qualification records
WPS	Welding procedure specification

Declaration of Authorship

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.

I cede copyright of the thesis in favour of the West Pomeranian University of Technology and University of Liège.

Date: *Signature*

"Don´t let your fear of the hazards keep your ship in the harbor. Cast off your lines and sail away."

Gail Lynne Goodwin

ABSTRACT

The shipbuilding industry, from its inception to the present day, had evolved, and following the needs of the industry, classification societies were founded. They, as non-governmental organization, regulate the fabrication of new ships or offshore structures based on their own established codes, rules and standards. As, nowadays, the most widely used joining technique on shipbuilding activities is welding, these welded joints must be certified and ensured that accomplish the quality expected and allow repeatability for the specified material. Consequently, it required qualification of welding procedure which is driven by the rules of a selected Ship Classification Society.

The European Standard EN ISO 15614-1 covers specification and qualification of welding procedure and is specifically applied to metallic material using arc and gas welding process. The entire title of the referred standard, Specification and qualification of welding procedures for metallic material – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys, clearly explicit it is one part of standard series which regulates welding procedure qualification and the method to be performed in this case is welding procedure test.

This standard is used as guidance by Ship Classification Societies to set and establish their technical rules and standards. Due to numerous existence of Classification Societies and being shipbuilding a worldwide activity, shipyards eventually resort to most of them according to the project to be executed. So a great number of Welding Procedure Specification is generated and must be approved. For the welding engineers this is huge time consumed and for the company and/or project is a lot of money spent.

According to all facts, adopting EN ISO 15614-1 as initial reference, a rereading of it is performed to in sequence draw a parallel among the rules associated with Welding Procedure Qualification of different Classification Societies. Resulting, then, on a paper pointing out differences and similarities on which further study could generate a more general document simplifying and shortening the process in terms of approval a new Welding Procedure Specification document.

Key words: Shipbuilding industry, Ship Classification Societies, European Standard EN ISO 15614-1, Welding Procedure Qualification

1. INTRODUCTION

The naval construction activity dates from 3000 BC in accordance with the Archaeological Institute of America. Over the centuries it had been evolved and this evolution took part from the material applied to the construction process, from wood to steel, from rivet to weld, always looking for improvement and development. Along with the progress and consolidation of ship construction activities, following the needs of the industry, classification societies were founded.

As welding is recognized as one of the most widely used joining techniques in manufacturing a ship or offshore structures, being present practically in all the construction phases since pre-assembly to block erection and final outfitting, it could not be neglect by the classification societies which had created codes, rules and standards to regulate it. So, all the welded joints must be certified and ensured that accomplish the quality expected, allowing repeatability for the specified material. This is acceptable through a welding procedure specification qualified according to the rules of a selected ship classification society.

The welding procedure can be qualified by five different methods which each one has their own particular purpose to be applied as well as limitations. Combining with it, the presence of so many different classification societies can make the work of welding engineers somewhat quite hard, once shipbuilding is a worldwide activity and shipyards eventually resort to most of existing ship classification societies according to the project to be executed, generating a great number of welding procedure specification to be approved. In this case, for the welding engineer a huge time consuming and for the company or project a lot of money spent.

To deal with this and aiming to comprehend the process, primarily an analysis were proposed, making a parallel among a standard used as base and the different existent ship classifications societies. The main objective of this study is to point out similarities and differences which may exist evolving EN ISO 15614-1 and the other three ship classification societies selected, being them DNVGL, Bureau Veritas (BV) and American Bureau of Shipping (ABS). Simple, resumed and clear as possible, it could be used as guide for in a further study maybe generate a general document to make the process in terms of approval a new welding procedure specification simpler, shorter and faster.

This study had been organized in sections and subsections, presenting in total seven main sections including acknowledgments and references. Initiating with the introduction, section 1 or actual section, a brief explanation was given within context, relevance of the topic and main purpose of the study. On section two, literature review is done discussing the most relevant subjects as foundation of classification societies, welding procedure specification document, welding procedure qualification record, as well as welding process and typical non-destructive and destructive testing, which could serve as theoretical basis for the next sections.

Section three were defined as the practical part of the study, presenting a summarized writing of the European Standard EN ISO 15614-1, including just the relevant clauses for the analyses presented on section four. Still on the section three a welding procedure qualification record and a welding procedure specification document provided by the company were included, being used as a sample to comprehend and illustrate the referred documents.

On sequence, the analyses of results are presented on section four where the comparison among the European Standard EN ISO 15614-1 and DNVGL, BV and ABS takes part. Just some clauses had been selected to be commented, pointing out similarities and difference which exist in each point. Within the results, the conclusions and discussions covering entire study is done on section five. On this section a recover about the topic is developed giving the final considerations.

2. LITERATURE REVIEW

The current section presents a theoretical discussion related with the proposed topic and evolves a series of subjects which would be relevant to comprehend and proceed with the planned study, being used as reference to develop the next sections.

On subsection 2.1. the foundation of classification societies is briefly discussed describing generally in few words how it started and also presenting the three selected ship classification societies.

The next subsection, 2.2., covers the welding procedure qualification based on the welding procedure test method. A description about the process is done and is shown the welding procedure qualification record and welding procedure specification documents.

The welding process taken in consideration for the analyses is presented on subsection 2.3. with a short introduction about arc welding and more detailed explanation about the flux cored arc welding process, classified as process 136.

The last subsection, 2.4., discourses about the welding test which normally is applied during the qualification process on the weld test piece prepared for that. The welding test is composed by two kinds of tests, non-destructive and destructive. They are described separately, presenting some of the non-destructive test that can be done as well as some of the existing type of destructive tests.

2.1. Classification Societies

Classification societies are non-governmental organization which has as main function regulate the fabrication of new ships and offshore structures based on their own established codes, rules and standards. According to Lagoni (2007) the history of ship classifications societies could be traced back to a London Coffee House, more specifically named Lloyd´s Coffee House, the place for people whose business had to do with shipping in the 17th century.

Everything had started with “Lloyd´s News”, kind of printed information collected by the owner of the coffee house about matters that could be interest or valuable for his clients. Once he had been asked to rectify a statement done criticizing proceedings in Parliament, he preferred to stop publishing the news, after 76 publications of “Lloyd´s News”. This had evolved then to hand-written form and known as “Ships Lists”. The first printed version came in 1726 and is still published today. Passed some years, as affirmed by the same author mentioned previously above, a society of underwriters set the first register titled Register of Shipping. On this register information as, name of vessels, actual and even previous name, owners and masters name, contained also ports involved on the negotiation, the tonnage, crew capacity, port and year of construction and furthermore classification stating the hull condition and equipment.

In 1764 the first book was printed and dated 1764-65-66. After this, as described by Rashid and Kadir (2012), the concept of classification got spread around the world and the ship classification societies started to be founded. In 1828 in Antwerp, Belgium, Bureau Veritas (BV) was founded. In 1862 was time to America Bureau of Shipping (ABS) start its own history in Houston, USA, while Det Norske Veritas (DNV) was originated in 1864 and Germanischer Lloyd (GL) in 1899, nowadays, merged the last two into DNVGL.

2.2. Welding Procedure Qualifications

To be certified and ensured that the welded joints of new ship or offshore structure accomplish the quality and the metallurgical, mechanical and physical properties expected for the specified material, the welding procedures must be qualified. This qualification is a method whereby a welding procedure proves to be adequate to perform welds with required quality and also allows repeatability. Castner (2011) describes, in a general view, the qualification of welding procedures as an important step to assure the quality and performance of any welded component or structure. The author also affirms that qualifications confirm that the welding procedure will meet design requirements and produce welds with the expected quality levels.

These qualifications are completely based on codes, rules and standards provided by the various existing classification societies and organizations that regulate the fabrication of new vessels. And as mentioned by the author cited previously, the qualification is accomplished by preparing, examining, and testing a qualification test weldment as well as documenting the results on a procedure qualification record. So, in other words, qualification follows the step by step established by one of the classification societies which should be selected to certify the new construction, and through comparison between the results achieved with testing technology and the acceptance criteria of the applied standard is possible to obtain the qualification of welding procedure and consequently approval to be used on the production.

The qualification of welding procedure is composed by two documents, the welding procedure specification (WPS) and the welding procedure qualification record (WPQR). The first one, according to American Welding Society (2009) is a document providing the required welding variables for a specific application to assure repeatability by properly trained welders and welding operators. And the second, also defined by the same Organization as a record of welding variables used to produce an acceptable test weldment and the results of tests conducted on the weldment to qualify a welding procedure specification. Another document that is not listed above but is also important to be known is the preliminary welding procedure specification (pWPS) and as its name indicates it is a tentative document writing to perform the weld on the test samples to qualify the welding procedure.
A summarized flowchart illustrating briefly the welding procedure qualification is presented in Figure 1 below.

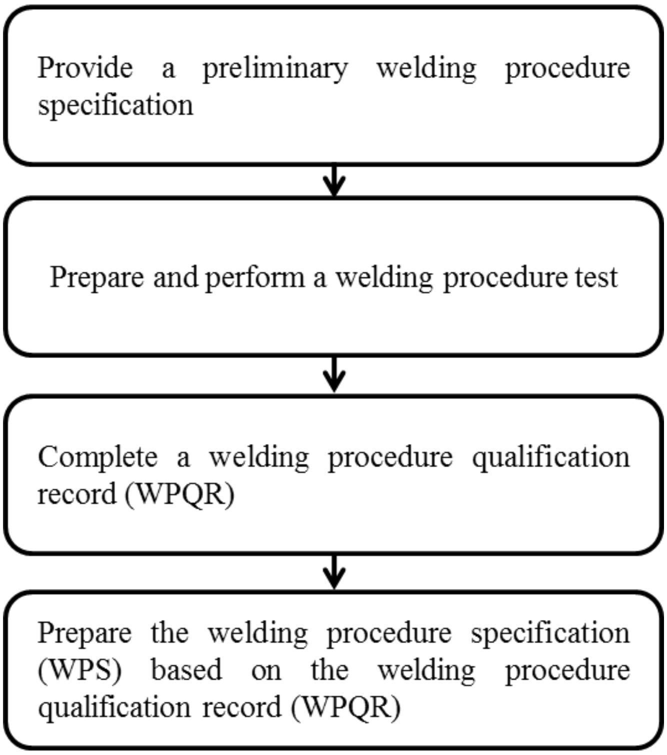


Figure 1: Welding procedure qualification flowchart. Adapted from The British Constructional Steelwork Association Ltd. (2009)

As can be observed, the first activity is preparing a preliminary welding procedure specification. It must be based on the standard to be satisfied and prepared by an experienced person who has knowledge on the process and technique used. It is pointed out by Jeffus (2012). In the sequence, prepare and perform a welding procedure test activity takes part, so at this step the samples are welded, following the procedure of pWPS to test the feasibility of it, and then tested. The cited author advices that the test must be witnessed by an authorized person from an independent testing laboratory, or costumer, or an insurance company or other individual(s) according to the specification given by the selected code or specification. The third activity is to prepare the document welding procedure qualification record reporting on it all the actual welding parameters used and also other significant data obtained on the welding procedure test, including principally the results of the non-destructive and destructive test performed. After all these steps within a positive response from applicable tests, the welding procedure specification is prepared supported by WPQR, identifying the ranges of qualification given in the applicable standard. The process of welding procedure qualification is then finalized. The WPS is documented and can be released to be used in production. In case of failure of the welded samples on the applicable tests, Jeffus (2012) describes that a change on the value parameters of pWPS should be done to make it feasible and the process is executed once again to retest it and analyze if it meet or not the requirements. The process can be repeated as many times as necessary to pass and get the approval. Another point mentioned by him is that once welding procedure had been qualified it can be used for an indefinite period of time or until a more efficient process replace the present one. Regarding the welder who had made the test samples, the author confirms that with the welding procedure qualification the welder will be normally considered qualified and certified in this specific procedure if he still does not have previously qualification for it, and other welders who requires a qualification uses the WPS approved to weld test samples and submit it to inspection according to the applicable requirements. As the WPS the welder´s qualification is considered effective for an unlimited time, unless he is not executing the specific welding process for a certain exceeding quantity of months determined on the related standards.

2.2.1. Welding Procedure Specification (WPS)

As mentioned previously, but in other words, briefly the American Welding Society (2000) defines welding procedure specification (WPS) as a document that provides detailed methods and practices involved in the production of a weldment. Jeffus (2012) terms it in a similar way as a set of written instructions by which a sound weld is made and the CWB Group (2008) complements that a WPS sets broad guidelines for the shop and field welding practice of the fabricator for each anticipated combination of essential variables. In summary, within simple words, it can be described as a recipe used to create an acceptable weld, specifying the parameters and instructing how they are combined. So, the welding procedure specification is a document prepared to provide to welders and welding operator's guidelines to perform welding joints and to achieve its objective the referred document must contain all the detailed parameters and conditions of welding operation.

The parameters or variables presented on WPS can be classified as essential and non-essential variables. According to Hughes (2009) essential variables are those that will affect the mechanical or metallurgical properties of a weldment. Some of them, but not restrict at it, are amperage, voltage, electrode or filler and so on. They are recorded in the WPQR and based on this values the range of approval will be determined and specified on the WPS. A change on these variables, principally changes out of the qualified range, requires a requalification of WPS or even writes a new one, as described by the author and confirmed by Castner (2011). An important point to be noted is depending on the code or standard referred one variable can be denoted as essential which by other will not necessary receive the same classification. On the other hand, non-essential variables are defined as those that do not affect the mechanical or metallurgical properties of a weldment. A change on the non-essential variables does not require necessarily a new procedure qualification, however requires a revision to be made on the WPS to reflect the new range. And as mentioned also by Hughes (2009), unlike essentials variables the non-essential variables are not necessarily required on the WPQR, but they have to be addressed surreally on the WPS, and as previous cited the standard applied will specify it.

Once the WPS list all the variables and parameters specified on the applied standard, the referred one normally does not impose a specific format for this document. As a reference document it is presented on appendix I available from American Welding Society (2009). All these details covered in WPS are described on the following paragraphs.

As general information, on top of the document, name and address of the company, as number, date and revision number of the WPS should be provided. For company name and address must be written complete and if it is used by different projects or products, the applicable project need to be identified. For WPS number each company uses their own methods, but normally is presented consecutive number system and it can identify process, position, groove type and electrode as pointed out by CWB Group (2008). This number must be unique for easy references. The date and revision number indicates the correspondent date and last update made on the document.

As process information, on the sequence, is given welding process as Shield Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Flux Cored Arc Welding (FCAW), and Submerged Arc Welding (SAW) and so on. It should be clearly defined as affirmed by American Welding Society Welding Inspection Handbook (2000) once it is considered an essential variable for most of the standards. Then type of current applied and type of shielding gas.

2.2.2. Welding Procedure Qualification Record (WPQR)

A welding procedure qualification record is shortly defined by DNVGL (2015) as a record which comprises a summary of necessary data needed for the issue of a welding procedure specification (WPS). In a similar way but with different words American Bureau of Shipping (2015) or ABS refers to the WPQR also as welding procedure test record stating that all the welding conditions for test assemblies and test results necessarily need to be recorded on it. Going ahead with the topic, ABS still mentions that apart from the data mentioned above is crucial to do a statement of the results of assessing each test piece, including repeat tests and also the relevant items listed for the WPS.

Resorting again to DNVGL (2015) is possible to describe briefly the welding procedure qualification record document. As mentioned in the standard this document compulsorily needs to record data of the materials, consumables, parameters and every single relevant information as heat treatment used during the welding qualification process as well as the results from non-destructive and destructive tests applied. And still should be documented all the essential variables and all welding parameter in relevant positions for each pass done during the welding qualification process. It is also important to include the manufacturer certificates for base and filler material used in the weld qualification test.

A welding procedure qualification record document can be founded on appendix II and it is the one presented by European Standard EN ISO 15614-1 (2012).

2.3. Welding Process

Welding can be defined as a joining technique resulting on coalescence of two or more different parts. The coalescence is produced by heat and/or pressure with or without filler material. Vural M. describes it as “a material joining process in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat or pressure or both. Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat supplied. In some welding processes, a filler material is added to facilitate coalescence”.

The welding processes can be grouped and subsequently sub-grouped following different technological criteria. By the American Welding Society (ASW) it is firstly grouped in accordance with the manufacturing process, that is, process category, as Fusion Welding or Solid-State Welding, and then sub-grouped in terms of energy source, thermal source, mechanical loading and shielding respectively.

On the shipbuilding industry, the most usable welding process are gas welding, arc welding, laser welding, resistance welding, all them fusion welding process, and few solid-state welding or others are the most usable. Briefly defining, an arc welding is a process which uses electric arc as source of heat to melt and coalescence the working pieces. This arc is formed between an electrode and the metal to be joined.

Eyres and Bruce (2012) explains that “the basic principle of electric arc welding is that a wire or electrode is connected to a source of electrical supply with a return lead to the plate to be welded. If the electrode is brought into contact with the plates an electric current flows in the circuit. By removing the electrode a short distance from the plate, so that the electric current is able to jump the gap, a high-temperature electrical arc is created. This will melt the plate edges and the end of the electrode if this is of the consumable type”.

The process which will be discussed in more details on the further sub-section is flux cored arc welding that is grouped as part of arc welding processes.

2.3.1. Flux Cored Arc Welding (FCAW)

Flux Cored Arc Welding is an arc welding process very similar to Gas Metal Arc Welding. It is semi-automatic or automatic process and as GMAW depends on a gas shield to protect the weld pool from atmospheric contamination. The Hobart Institute of Welding Technology (2012) defines it as “an arc welding process in which the heat for welding is produced by an arc between a continuously fed tubular electrode wire and the work. Shielding is obtained by a flux contained within the tubular electrode wire or by the flux and an externally supplied shielding gas”.

In the same way, Annette (2004) describes FCAW as “a welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure”. As mentioned by the author this process can use an external font to supply gas for shielding and then it is named as Gas-Shielded Flux Cored Arc Welding or does not use extra shield gas that in this case is called Self-Shielded Flux Cored Arc Welding. On Figure 2 below can be observed both process.

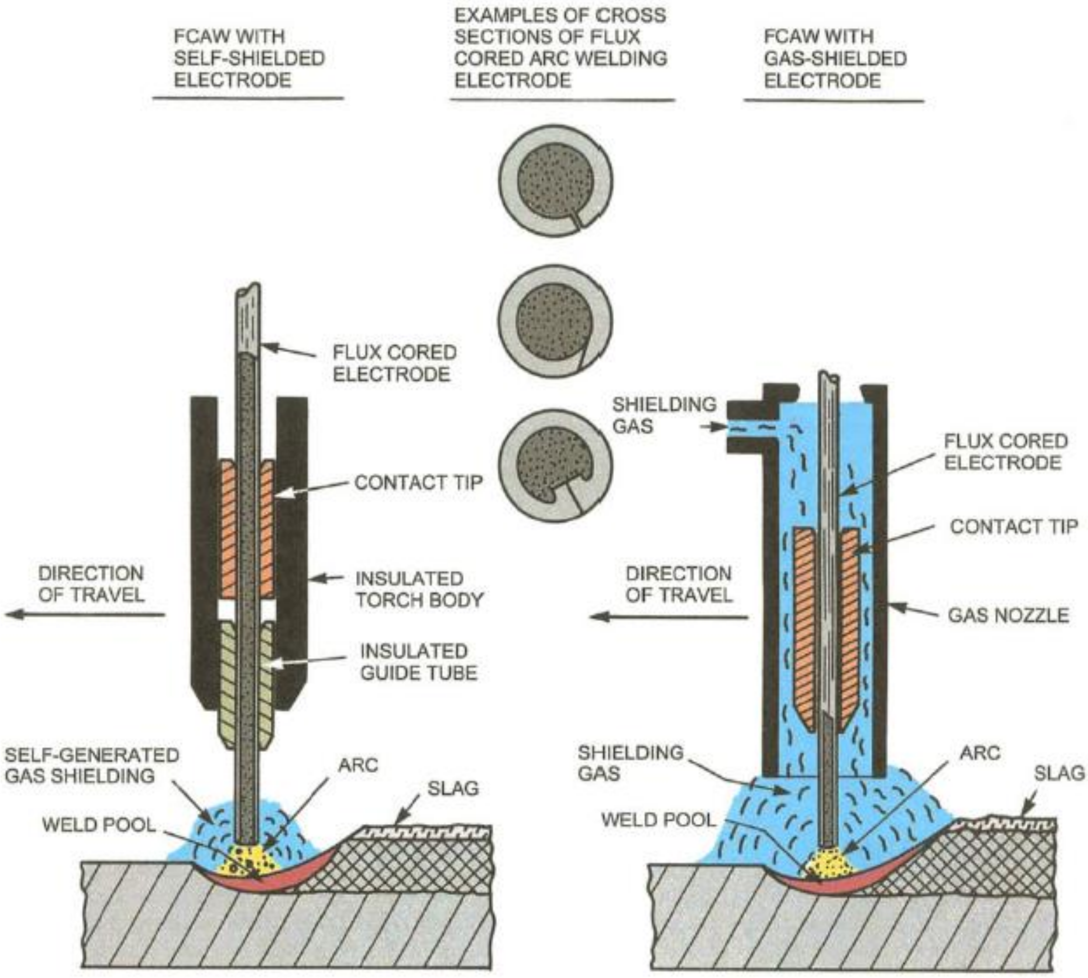


Figure 2: Self-shielded flux cored arc welding and gas-shielded flux cored arc welding. Available from Hobart Institute of Welding Technology (2012).

2.4. Welding Tests

Welding tests are investigations performed on welded joints or bodies to certify its soundness and be sure it is liable to their proposed application. The welding test can be divided into two different types, being them non-destructive test and destructive test. This subsection presents both of them discussing also which type of test are classified as non-destructive or destructive test.

2.4.1. Non Destructive Test (NDT)

Non-destructive test according to Singh (2012) is a general term used to identify all those inspection methods that permit evaluation of materials and welds without destroying them. In a similar way, but using the term non-destructive examination (NDE), the American Welding Society (2009) defines it as the act of determining the suitability of a material or a component for its intended purpose using techniques not affecting its serviceability. More precisely, Jeffus (2012) characterize them as type of tests on welds used to detect surface defects as cracks, arc strikes, undercuts, and lack of penetration. In all, these tests are required to test the weld quality and are previously performed to take place later, in case of specimen approval, the destructive tests.

The tests classified as non-destructive test can be listed as visual inspection (VT), penetrant testing (PT), magnetic particle testing (MT), radiography testing (RT), ultrasonic testing (UT) and others.

2.4.1.1. Visual Inspection (VT)

Visual inspection is commonly the first inspection to be done and as highlighted by Singh (2012) is an important part of the quality control system. As the name proposes it is done by visually looking the external appearance of the weld. Jeffus (2012) express it by affirming that if the weld looks good it passes and the opposite, if it looks bad it is rejected. In case of welding procedure qualification the VT will be done on the weld test piece covering 100% of it before the specimens be prepared to next tests.

According to Halmshaw (1996) for being the first examination in which the weld test piece will be subjected, gross surface defects allow the immediate rejection even before undertake other more expensive test. Some defects as misalignment, weld globules, shrinkage grooves and incorrect grinding are very easily detected. To perform the visual inspection some instruments can be used to assist the test as presented further more in Figure 3. There can be observed a mirror on stern (A), hand magnifying glass (B), illuminated magnifier (C), inspection glass (D) normally fitted with a scale for measurement and a borescope or intrascope with built-in illumination (E).

Regarding to effectiveness of the visual test Hubert Institute of Welding technology (2009) affirms that reliable when correctly applied and insures conformance to a procedure and, more, allows errors to be corrected leading to production of a higher quality weldment at reduced cost.

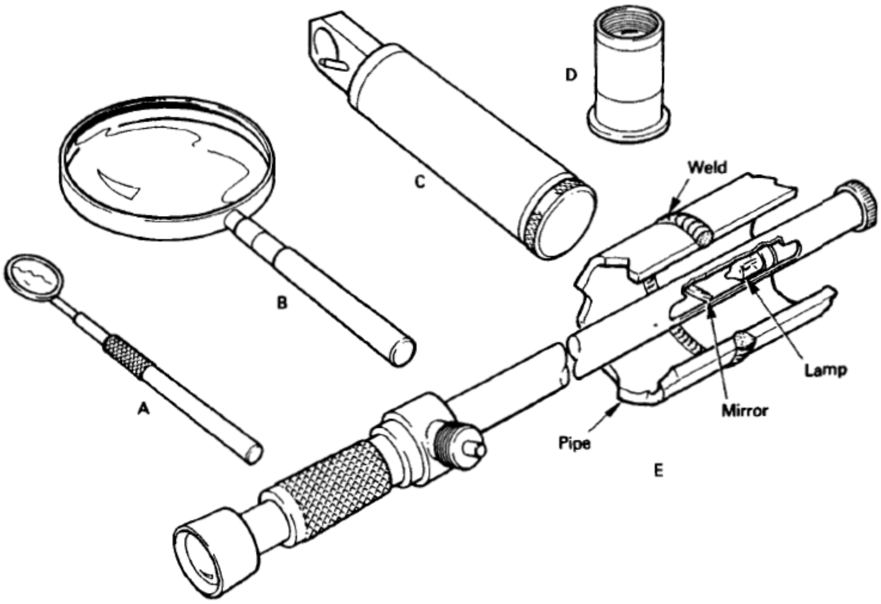


Figure 3: Optical instruments to visual inspection. Available from Halmshaw (1996).

2.4.1.2. Penetrant Testing (PT)

Once the weldment does not present any problem on the visual inspection, the next examinations take place. Penetrant testing and magnetic particle testing has the same purpose, both are applied to identify surface defects as cracks, and their applicability will be driven by the material to be tested. In case of magnetic material rather magnetic particle testing will be used, otherwise penetrant testing will be applied. The Canadian Welding Bureau Group (2006) describes penetrant testing as a versatile method capable of locating cracks, porosity, laps and folds that are open to the surface, confirming also that this is a simple and inexpensive method. Weman (2012) complements saying that it is a method used to reveal discontinuities in the surface of non-porous materials. The basic principle of this test is capillary action as affirmed by Singh (2012) and reinforced by American Welding Society (2009), that is, a dye penetrant liquid is applied on properly cleaned surface and enters by capillary on discontinuities, after removing liquid excess from the surface and applying a developer the penetrated liquid will re-emerge indicating the discontinuity. As observed by Jeffus (2012) there is two types of penetrant testing and they are classified in accordance with the liquid that is applied, as color-contrast and fluorescent. The first one contains a colored dye, commonly red, and shows under white light, once the fluorescent contains more effective fluorescent dye and shows under black light. Anyway the testing process to be followed is the same for both. The Figure 4 below draws the step by step of penetrant testing procedure.

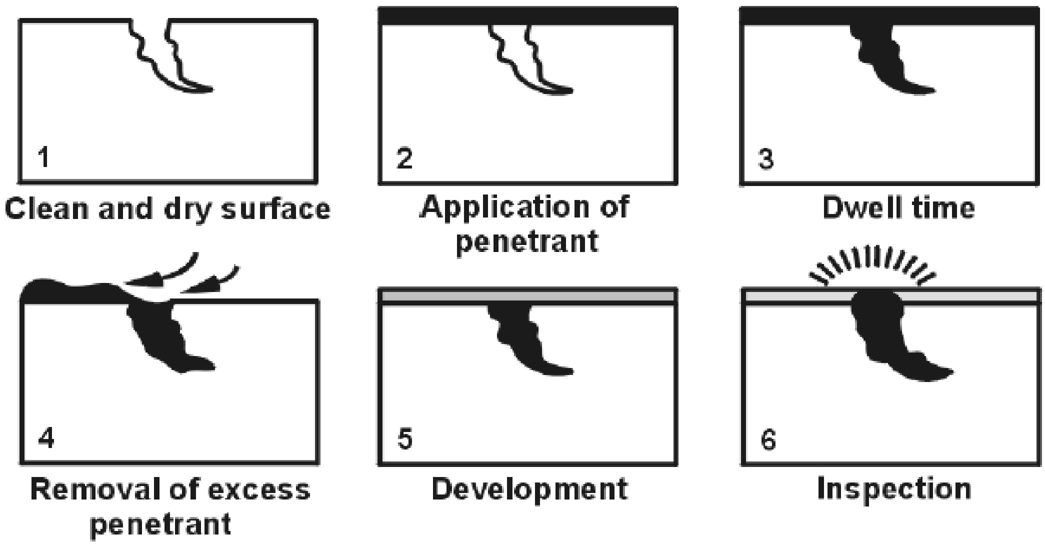


Figure 4: Penetrant testing procedure. Adapted from Canadian Welding Bureau. (2006)

On the first step, the surface to be tested should be prepared which means cleaned, degreased and dried. In sequence, penetrant liquid is applied, in case of color-contrast the colored liquid, if fluorescent, the fluorescent liquid, by spraying, brushing, immersing and so on. A specific waiting time is required then to allow the penetrant liquid gets into discontinuities. On the next step the surface should be cleaned again but now just by removing the excess of penetrant, ensuring that the liquid will be retained in any discontinuities. After it, as step 5 the developer powder is applied to draw the penetrant liquid out to the surface, acting as blotter absorbing the penetrant from the discontinuities revealing these defects. As last step the examination is done, assessing visually under appropriate conditions, depending then on the type of penetrant applied, in case of colored contrast white light or black light in case of fluorescent. As presented on step 6 in Figure 4, the defects are easily defined.

2.4.1.3. Magnetic Particle Testing (MT)

And as mentioned previously, in case of magnetic material specimen is preferred to use magnetic particle inspection to detect openings and even defects buried slightly below the weld surface. The testing method name already indicates the basic principle used which is magnetic field and as presented by Jeffus (2012) makes use of ferromagnetic powder with very fine particles applied to the surface and magnetic field induced by an electric current through or around the probe to be tested. The Canadian Welding Bureau (2012) explains that if the field is interrupted by a discontinuity, as a crack, the field will become distorted at the point, and north and south pole will be formed at each point of material separation, attracting the magnetic particles powder. Figure 5 shows a welding defect identified by magnetic particle inspection.

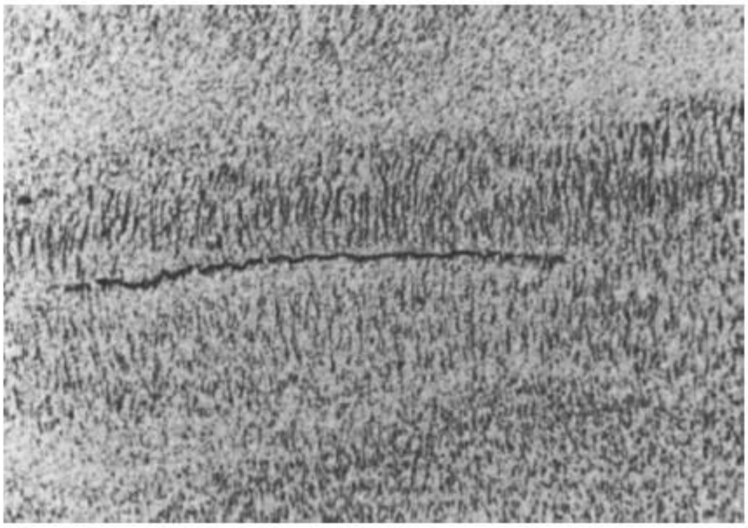


Figure 5: Magnetic particle test indicating longitudinal crack in weld. Available from Halmshaw (1996)

2.4.1.4. Radiography Testing (RT)

Radiography testing, as the tests presented earlier, is also a non-destructive test, but what differs it from the others is its ability to detect internal flaws on the weld. This is confirmed by American Welding Society (2009) which describes it as a method that utilizes radiation to penetrate a weld and reveal information about its internal conditions or, in the words of Canadian Welding Bureau (2006), it is the most commonly used non-destructive method for the detection of sub-surface volumetric discontinuities in welds.

In few words, the basic principle of radiography testing can be explained as radiation passing through the weld to be tested, part of the radiation will be absorbed and this is directly related with thickness and type of material, part will be scattered, and the rest transmitted through less dense medium. All this resultant radiation is recorded then on device as photo-sensitive paper, and as highlighted by Jeffus (2012), defects images measure differences in how the radiation is absorbed as it penetrate the weld. So, how weld absorbs most of radiation, and location where flaws as pore or lack of fusion appears absorbs much less, on the images these regions will show darker spots. But in case of defects that present denser area as tungsten inclusions on TIG welding, it will appear as lighter areas on the recording film. Both cases had been observed by Davies (1992). Some of typical defects detected by radiography testing are presented on sequence in Figure 6, Figure 7 and Figure 8.

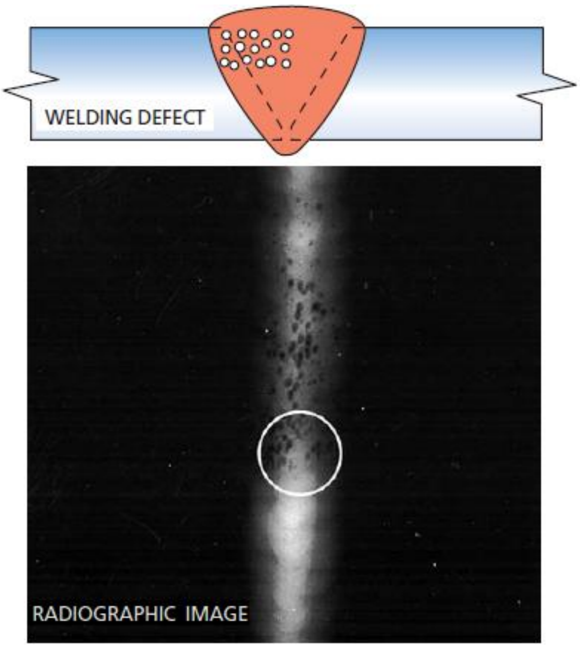


Figure 6: Weld with porosity defect. Adapted from Jeffus. (2012)

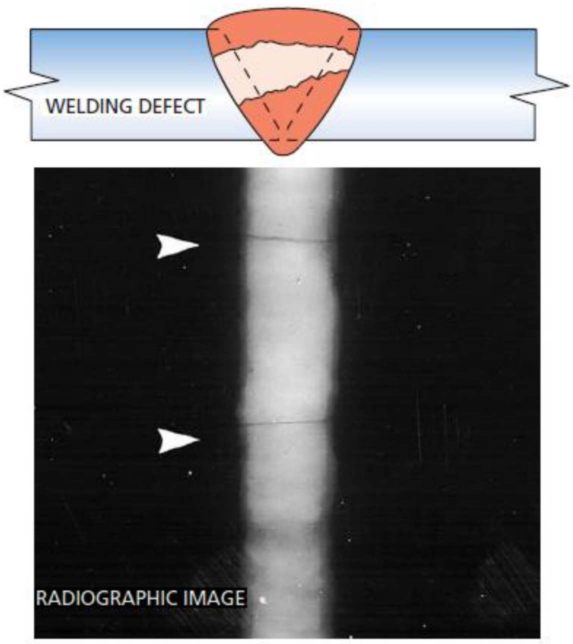


Figure 7: Weld with transverse crack. Adapted from Jeffus. (2012)

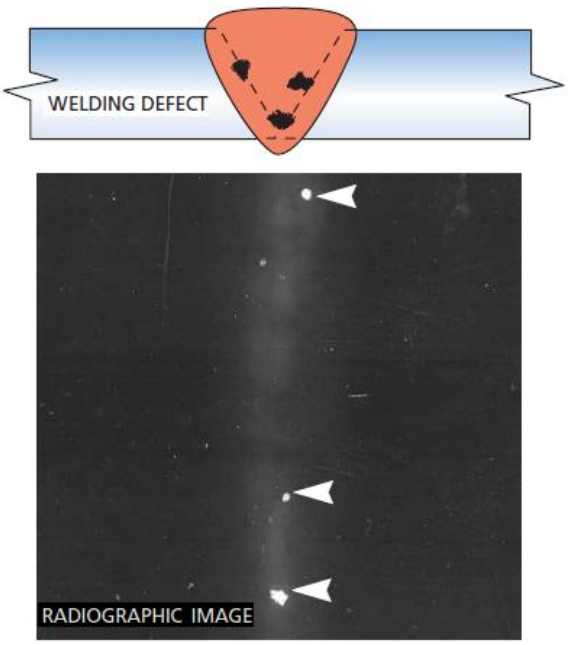


Figure 8: Weld with tungsten inclusion. Adapted from Jeffus. (2012)

As can be observed, and also had been described and explained by the author, on Figure 6 the defect presented on the weld is cluster porosity. The shape of porous are rounded or slightly elongated and they are grouped together, so on the radiography image it is recorded as darker spots randomly spaced. On Figure 7, the weld presents a transverse crack, running across the weld and it is printed on the recording film as a darker density twisting line along the width of the weld. On the last case, Figure 8, the defect is shown as lighter (white) irregular shape spots, once it is tungsten inclusions, or better relating, some bits of tungsten fused, but not melted.

One important point to be noted and still not commented about radiography testing is the disadvantage related with difficult to detect discontinuities which are not placed parallel to the radiation source. Normally only discontinuities that are vertical to the radiation source are recorded on the film. All the authors cited previously agreed among them in this matter. Figure 9 below illustrates it better.

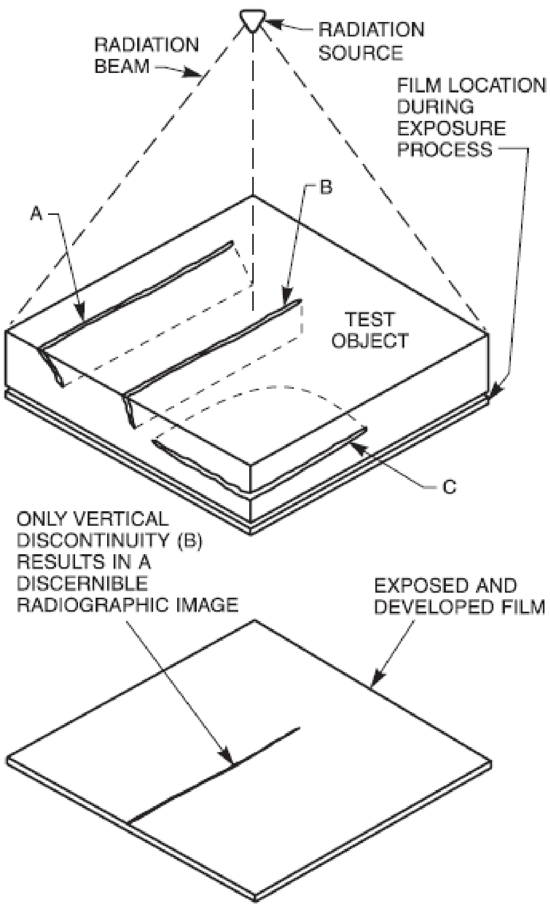


Figure 9: Detection of planar discontinuities at various orientations by radiography. Available from American Welding Society. (2009)

It clearly shows that defects which are not vertically placed, that is, parallel to radiation beam are completed missed. In this case defect named as A and C is not recorded on the developed film, just discontinuity B appears on radiography image. This is then listed as the main limitation of radiography testing.

2.4.1.5. Ultrasonic Testing (UT)

Ultrasonic testing (UT), according to Weman (2012) is most suitable for detecting internal plane discontinuities and requires a good test surface with a restriction on the thickness of the material. It is highlighted by him that the material should have at least 8 mm to the evaluation be reliable. In agreement with the previous definition, Hughes (2009) describes the ultrasonic testing with similar words, stating it as an examination to find internal defects within a weld.

Referring to the execution of UT, or better, to the process in a general way the author cited above presents it in a very simple and brief explanation mentioning that a probe emits sound wave and this transmitted wave passes through the material. Once it finds a defect, part of the wave or all of it reflects back to a receiver in the probe and both the size and the position of the internal discontinuity can be plotted on a graph by an experience operator.

Halmshaw (1996) following the same simplicity used by Hughes (2009) and providing some additional information endorses that commonly ultrasonic flaw detection is performed by moving a probe known as transducer on the surface of the parent material adjacent to the weld and in the same time observing a display on an oscilloscope screen. He also mentions that the probe should be very well coupled to the surface of the metal and to guarantee it a liquid as water, oil, grease, or any one suitable for be used on the material is applied avoiding the possibility of air presence between the probe and the metal. So, after applying this “coupler” to the surface and attaching the probe to the body to be tested a wave is produced passing into the material and it will be reflected back when hitting a flaw. This reflected “signal” is captured by the probe acting at this moment as transceiver. As illustration of the process Figure 10 is presented below and can be observed how is shown the signal on the screen when the wave are reflected by the flaw.

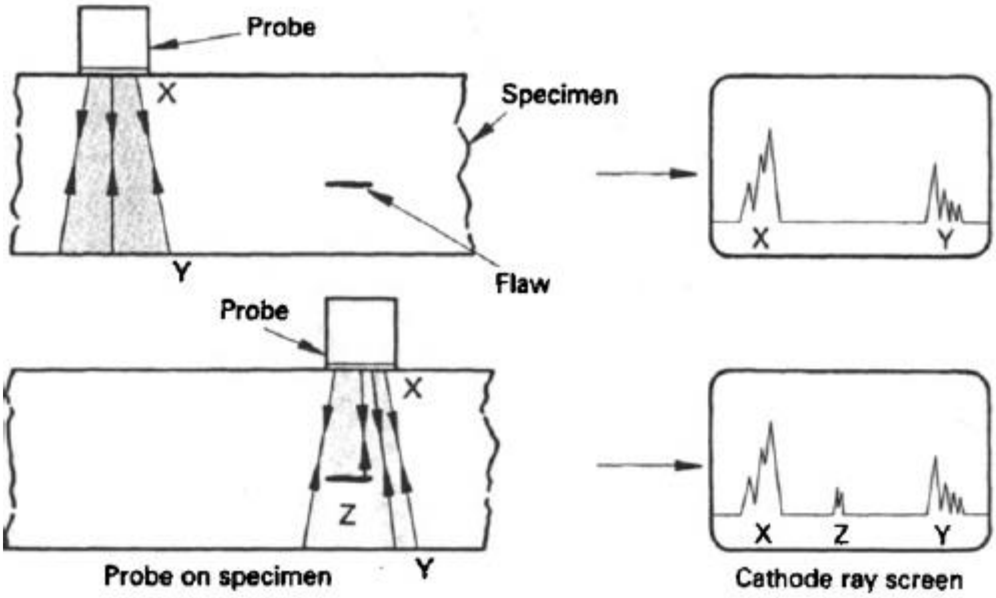


Figure 10: Basic principle of ultrasonic flaw detection. Available from Halmshaw (1996).

2.4.2. Destructive Test (DT)

Destructive test generally as its own title indicates is a specific type of evaluation process on which the specimen is destroyed or that after had been performed turn the body incapable to attend the initial application for what had been designed. In a very similar way Hobart Institute of Welding Technology (2010) defines the destructive test as an evaluation process which takes places during and/or after the destruction of a weld or base metal specimen.

As types of destructive test can be cited tensile, bend, impact, hardness and also etching test. While the four first mentioned are mechanical destructive test, the last one is of chemical type. They are discussed in more details above.

2.4.2.1. Tensile Test

As a basic introduction of tensile test or, in other words, as brief explanation can be written that the main objective of this destructive test is to determine the behavior of the material by pulling it progressively until it fails, that is, reaching the breaking point. According to Hobart Institute of Welding Technology (2010) is one of the most valuable destructive tests once this provides data on strength, ductility and soundness of base metal and weld metal.

When referring to welding procedure qualification normally the tensile test is known as reduced section tensile test. It is described in this way because the test specimens are taken from the welding test piece, usually transverse to the direction of welding, and after there are machined to reach the dimensions specified by the code or standard on which the welding procedure will perform the qualification. When the sample is machined the middle of the specimen in thinner than in the extremities. On Figure 11 is possible to observe the specimen just after been taken from the welding test piece and the specimen after been machined.

Figure 11: Tensile test specimen before and after machined to perform reduced tensile test. Available from Hobart Institute of Welding Technology (2010)

Still according to the Institute referred above, most of the codes or standards determine that the ultimate tensile strength verified in the test must be equal or greater than the minimum of tensile strength specified for the base metal welded.

2.4.2.2. Impact Test

Impact test is another type of destructive test on which specimens will be submitted to a force from a pendulum shock. The elementary principle of it is determined how the material behaves once it has been crashed into an abrupt shock. Referring once more to Hobart Institute of Welding Technology (2010), it states that this type of test presents data to measure the toughness of the material at different temperatures, affirming also that as filler as base metal are evaluated, determining their ability to provide toughness through this specific test.

One of the most used types of impact test is known as Charpy V-notch test, and receives this name exactly because the test specimen is prepared and contains a very precise notch. Some samples are presented on Figure 12. For this test, normally is required a set of specimens

composed by three specimens each set. The specimens are taken transverse to the weld axis and its dimensions are an important parameter to the accuracy of the test. Before to process with the test is really important to mark the specimens necessarily on both sides because after brake it the correspondent pieces still can be matched and evaluated.
The step by step of the test is basically explained according to Hobart Institute of Welding Technology (2010) as firstly the specimen should be cooled and then it will be positioned in a existent fixed support on the base of the machine with the charpy notch centered on the opposite side of where the pendulum will collide against the specimen. The free fall of the pendulum generate the impact force applied on the specimen breaking it. The strength of the material based on the impact is established by measurements of energy absorbed during the fracture of the specimen.

Figure 12: Charpy V-notch test specimen. Available from Hobart Institute of Welding Technology (2010)

2.4.2.3. Bend test

The bend test also known as guided bend test is mentioned by Hobart Institute of Welding Technology (2010) as one of the most popular type of destructive test, once this is a very simple test with a considerable low cost. The main principle of this test is to find the soundness and ductility of the weld metal bending the specimen into a U-form evaluating the bent surface. During bending, the specimen is submitted to tension and compression load on the weld and this can help to determine if the weld metal and base metal are completely fused. The Figure 13 shows same samples of bend test specimens.

Being guided by the previous Welding Institute already mentioned above is possible to define five different types of bend specimen as transverse face bend, transverse root bend, transverse side bend, longitudinal root bend and longitudinal face bend. All of them are tested in very similar way. Referring to transverse face and root, the bend specimen is provided from a perpendicular piece to the weld axis and its thickness is equal to the thickness of test material. While performing the test, the specimen is positioned in the fixture in a way that in case of transverse face bend the face will become convex surface after bend, in the other hand for transverse root bend, the root will become convex.

Figure 13: Bend test sample specimen. Available from Hobart Institute of Welding Technology (2010)

Describing about procedure for the test, is important to mention that before the bend test the reinforcement of the weld should be removed, taking care to not remove the material below the specimen surface and the grinding is required to be parallel to the longitudinal axis of the specimen.

Concerning to longitudinal root and face bend test the specimen is prepared down to the weld axis and the length will be around 152,4mm while the width is the weld width plus 15,88mm. The thickness will be equal to the material thickness or no more than 9,53mm.

About the results, what normally are considered are any discontinuities greater than the acceptable standard or code limit will be rejected.

2.4.2.4. Hardness Test

Hardness according to Hughes (2009) is defined as the material ability to resist indentation on its surface and as mentioned by him among the existing hardness tests the three most used are known as Vickers, Rockwell and Brinell. The basic principle of these tests as described in his guide is based on impress a ball, in this case Brinell or Rockwell test, or a diamond shape, here identified as Vickers or Rockwell, into the material applying a determined load and measuring how large is the indentation getting with this the reading of relative hardness. The Figure 14 presented further illustrates the different cited hardness tests.

The results can be interpreted as smaller is the width harder is the material, or in the other hand, as bigger is the width softer is the material. Normally, as affirmed by the present author, when the hardness test is performed for welding procedure qualification it will be done through the weldment thickness once the hardness levels varies significantly through the thickness. And concerning about test units each type of hardness test has its own units and it is in case of Vickers test HV that means Vickers hardness, in the other hand for Brinell test HB unit representing Brinell hardness and for Rockwell test HR indicating Rockwell hardness test.

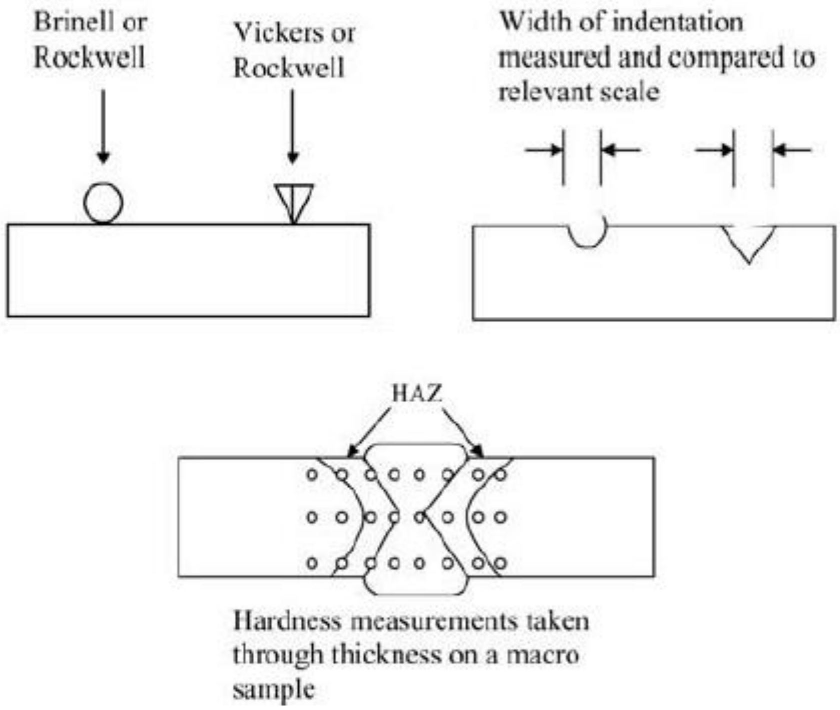


Figure 14: Hardness test. Available from Hughes (2009).

2.4.2.5. Etching Test (Macro or micro examination)

In a brief description about etching test can be write that the main principle of this test is to cut a specimen transverse to the weld axis and apply an etching solution, inspecting then the exposed surface. As mentioned by Hobart Institute of Welding Technology (2010) it is a very good method to test the soundness of the weld metal and also the metallurgical structure generated by the weld. On this test the weld structure in contrast with the base metal is defined, clearly presenting the weld, heat affected zone and base metal. Figure 15 shows an etched welding surface specimen.

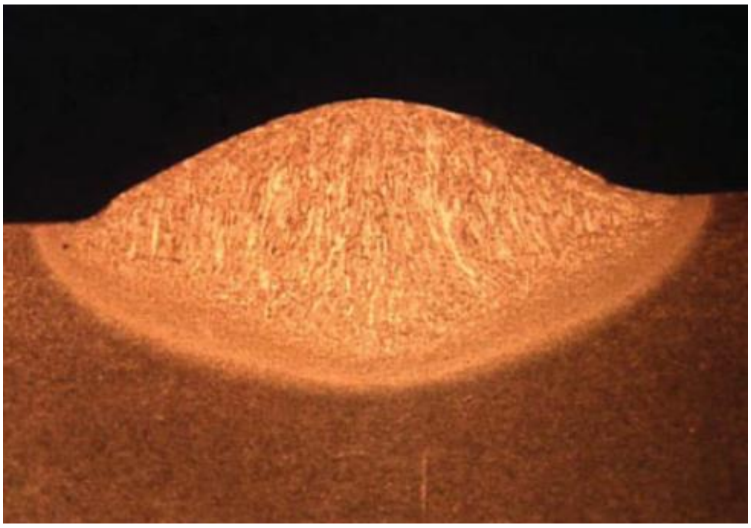


Figure 15: Etched welding surface specimen. Available from Hobart Institute of Welding Technology (2010)

The etching test can be of two different types, macro or micro etch test. Normally the macro etch is applied to qualify fillet weld procedures and also welders. On the macro etch test the specimen is cut transverse to weld axis and prepared grounding smooth. The solution used to etch the surface depends on the material type and in case of carbon steel a mixture of ammonium persulphate and water can used. The etch starts as soon as the solution is applied. This test is named as macro because while inspecting the etched surface no magnification is used or if so, the magnification will be less than ten times. Observing the etched surface imperfections as cracks, porosity, incomplete fusion, slag inclusions or lack of penetration can be evaluated.

Regarding to micro etch test, while macro does not apply magnification, the micro is the opposite and has been named micro exactly because uses a microscope with magnification greater than ten times. The preparation of specimen is quite similar with the macro described above, but with a special care concerning to the ground and polish of the surface. It should be prepared as mirror finish to remove all scratches. For the micro test, in case of carbon steel the etching solution normally used is composed by 5% nitric acid in methyl alcohol. The main purpose is to analyze some characteristics as grain size, carbon content and ferrite content.

3. WELDING PROCEDURE SPECIFICATION AND WELDING PROCEDURE QUALIFICATION RECORDS ON PRACTICE

For knowledge and alignment, it is important to draw attention to the existence of five different methods to qualify a welding procedure, being them methods based on welding procedure test, tested welding consumables, previous welding experience, standard welding procedure and pre-production welding test. Each one has their own particular purpose to be applied as well as limitations. This is better described on the standard used as reference, EN ISO 15607:2003 Specification and Qualification of Welding Procedures for Metallic Materials – General Rules.

The analyses and discussions presented on this study will be focused on the first listed method, which is, the one based on welding procedure test. As mentioned on EN ISO 15607, this is a method that can be constantly applied, essentially when the properties of the material on both, weld and heat affected zone, are critical for the required applications. The restriction given by this method is naturally related with the procedure test, which shall correspond adequately to the joint geometry, restraint and accessibility of the actual welds.

So, to develop the proposed study, firstly, a reduced interpretation of DIN EN ISO 15614-1:2012-06 had been done and this can be found on next subsection 3.1. The European Standard had been adopted as initial reference and it will be used as principal guideline for the further analyses and comparisons with the other application standards, once it is the most comprehensive and normally used also as main base by the application standards. The rereading is entitled reduced because it covers solely the clauses related with the type of joint which is object of the current study, the butt weld joints on steel plates.

On sequence, subsection 3.2 describes and presents a welding procedure qualification record document provided by the company to serve as sample in order to provide familiarization with it. The applied WPQR is the one used as base to develop the welding procedure specification presented on the following subsection 3.3. Consequently, and as mentioned, subsection 3.3 presents and briefly expose the WPS document provide by the company with the same purpose as presented on subsection 3.2 for the WPQR.

3.1. DIN EN ISO 15614-1:2012-06: A Brief Rereading of the Standard

The discussed European Standard EN ISO 15614-1:2012-06 titled Specification and qualification of welding procedures for metallic material – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys clearly identifies that it is just the first one of a standard series which specifies how a preliminary welding procedure specification is qualified by welding procedure tests. Each part of the series is directly related with the applied welding process for metallic material, and in total this series 15614 is composed by thirteen parts which cover welding process as arc welding, gas welding, electron beam welding, laser beam welding and resistance welding and so on. As part 1 is the one directed to arc and gas welding, it is the one selected to be analyzed on the present investigation. The current case applies flux cored arc welding (process136) as welding process on a butt weld joint type. Only the clauses relevant to the study are presented further.

3.1.1. Clause 1: Scope

The first clause of the referred standard exposes and delimits comprehensiveness and applicability of it, specifying how a preliminary welding procedure specification is qualified by the welding procedure test method. It also defines the conditions under which the tests of the welding procedure should be performed and further the range of qualification in which the welding procedure would still be applicable. As mentioned on EN ISO 15614-1:2012-6 the range of variables is listed in clause 8.

When referring to additional tests it may be required by application standards, in this case, by requirements of ship classification societies.

As the title of the document itself clearly presents, this standard applies to arc and gas welding of steels as well as to arc welding of nickel and nickel alloys in all product forms, covering including ship and offshore structure constructions, in all mentioned welding methods.

It is important to point out that the process 136 – tubular-cored metal arc welding with active gas shield is among the processes classified as arc welding in accordance with EN ISO 4063.

3.1.2. Clause 6: Test Piece

6.1 General

A standardized test piece should be prepared in accordance with clause 6.2, discussed further, and it will represent the welded joint to which the welding procedure will relate in production. If the joint geometry requirements do not represent the standardized test piece as presented in this standard, then another standard, more specifically, EN ISO 15613 shall be applied.

6.2 Shape and dimensions of test pieces

Referring to dimensions, or better defining, length and number of test pieces to be prepared, the instruction is to provide an amount which allows all required tests to be done. If additional tests are required, including re-testing specimens or extra tests, then more test pieces may be prepared.

Regarding to thickness of material, and mentioning here solely plates that is the material applied under the welding procedure specification analyzes, it shall have the same thickness *t* for both parts of the plates to be joined.

Once the application standard, here indicated as requirements of ship classification societies, necessarily ask for the direction of plate rolling, this need to be marked on test piece in case of impact test be performed involving Heat Affected Zone (HAZ).

Again, as the object of study is restricted to butt joint type in plates with full penetration, the shape of the test pieces and minimum acceptable dimensions shall follow the instructions given in sequence.

6.2.1 Butt joint in plate with full penetration

According to Figure 16 below, following shape and dimensions, the test piece shall be prepared.

The nomenclature presented and dimensions are listed previously on sequence:

- 1 is joint preparation and fit-up as detailed in the preliminary Welding Procedure Specification (pWPS).
- a is minimum value equal to 150 mm
- b is minimum value equal to 350 mm
- t is the material thickness

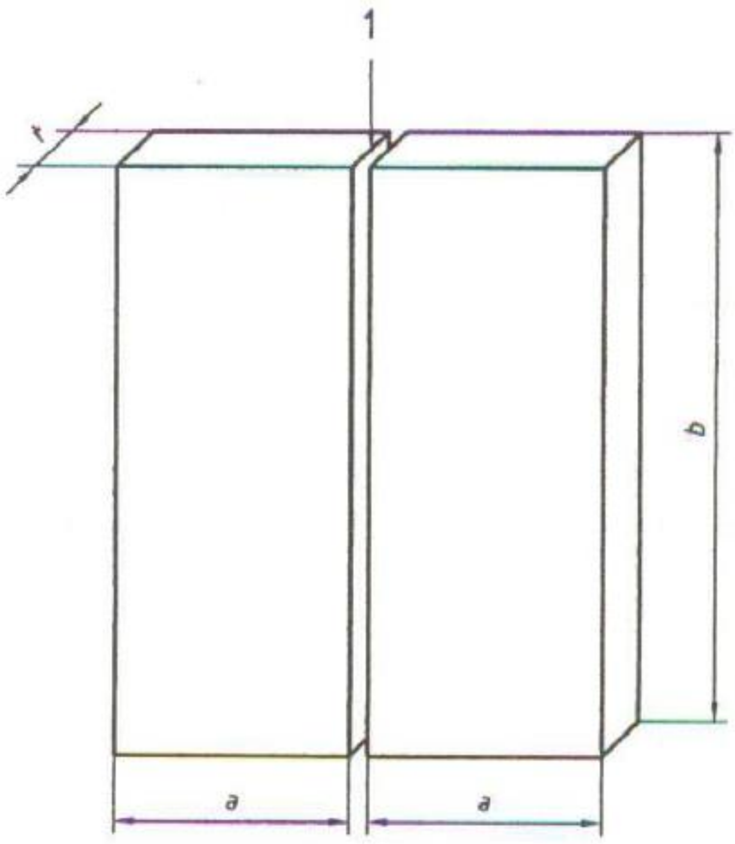


Figure 16: Test piece for a butt joint in plate with full penetration. Available from DIN EN ISO 15614-1:2012-06

6.3 Welding of test pieces

As the welding of test pieces is the main element, or in other words, the subject which will be tested to develop further the welding procedure specification from a preliminary welding procedure specification (pWPS), the test pieces must be prepared and welded following this pWPS and simulating the welding conditions on production which they would be subjected to on reality.

When referring to welding position and limits for slope angle, other standard need to be applied, this is EN ISO 6947.

It is important to be aware in case of tack weld, if on production site it will be assimilated or fused into the permanent joint, it also mandatory to be present in the test piece.

All the process of welding and testing the test pieces necessary need to be done under presence of examiner or examining body.

3.1.3. Clause 7: Examination and Testing

7.1 Extent of testing

Non-destructive testing (NDT) and destructive testing (DT) are performed and the requirements to be attended are listed on table 1.

In case of additional tests, requirements of ship classification society can specify it, asking for tests as longitudinal weld tensile test, all weld metal bend test, corrosion tests, chemical analysis, micro examination, delta ferrite examination, and cruciform test.

Table 1: Examination and testing of the test pieces. Adaptation from DIN EN ISO 15614-1:2012-06

Test Piece	Type of test	Extent of testing	Footnote
Butt joint with full penetration – Figure 16	Visual	100%	-
	Radiography or ultrasonic	100%	a
	Surface crack detection	100%	b
	Transverse tensile test	2 specimens	-
	Transverse bend test	4 specimens	c
	Impact test	2 sets	d
	Hardness test	Required	e
	Macroscopic examination	1 specimen	-

a Ultrasonic testing shall not be used for t < 8 mm and not for material groups 8, 10, 41 to 48.

b Penetrant testing or magnetic particle testing. For non-magnetic materials, penetrant testing.

c For bend tests, see 7.4.3

d 1 set in the weld metal and 1 set in the HAZ for materials ≥ 12 mm thick and having specified impact properties. Requirements of ship classification society may require impact testing below 12 mm thick. The testing temperature shall be chosen by the manufacturer with regard to the application or application standard but need not be lower than the parent metal specification. For additional tests see 7.4.5.

e Not required for parent metals: sub-group 1.1, and groups 8, 41 to 48.

7.2 Location and taking of test specimens

According to the weld joint type, the test specimens necessary need to follow what present in a specific figure. As already mentioned before, in this case butt joint type in plate with full penetration, so Figure 17 is the appropriate one and can be observed further.

First, all the non-destructive tests should be performed on the weld testing piece and just if has passed according to the criteria the test specimens are taken.
As alert, the test specimens can be taken from locations avoiding areas with imperfections since the imperfections are within the acceptance limits for the NDT methods used.

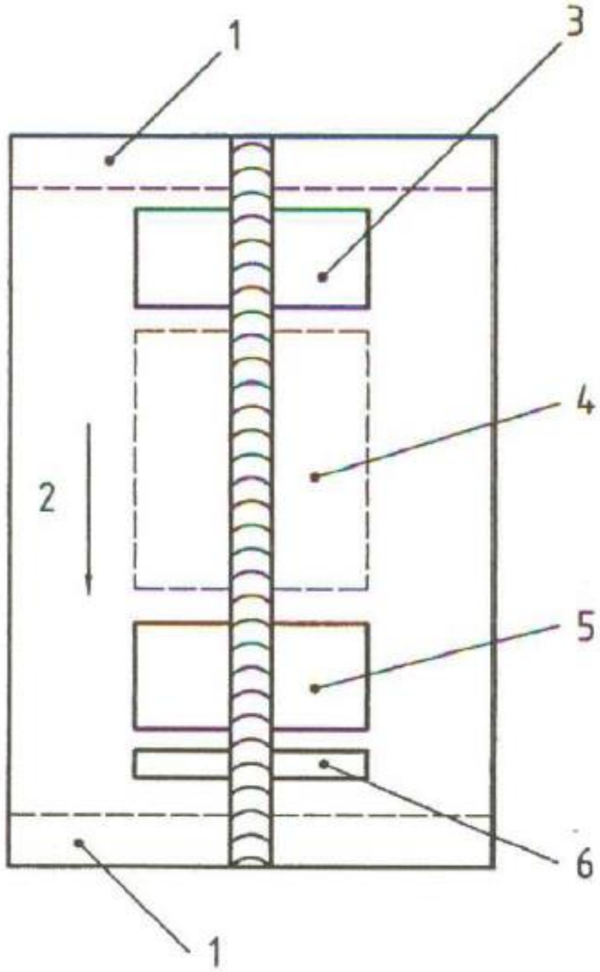


Figure 17: Location of test specimens for a butt joint in plate. Available from DIN EN ISO 15614-1:2012-06

The meaning of each number shown on Figure 17 is described as:

- 1 is the discard of 25 mm
- 2 indicates the welding direction
- 3 represents area for:
  - 1 tensile test specimen;
  - Bend test specimens.
- 4 is area for:
  - Impact and additional test specimens if required.
- 5 is area for:

- 1 tensile test specimen;
- Bend test specimens.

- 6 is area for:
  - 1 macro test specimen;
  - 1 hardness test specimen.

And as note the Figure 17 is not to scale.

7.3 Non-destructive testing

Considering all non-destructive test as mentioned on clause 7.1 and table 1, they shall be performed on the weld test piece before then cutting the test specimens and if post-weld heat treatment is required it also should be done before complete the non-destructive tests.

In case of materials that are predisposed to hydrogen induced cracking and where no post heating or no post-weld heat treatment is indicated, the delay of non-destructive testing should be considered.

Each non-destructive test should be performed in accordance with their own specific standards and following the criteria presented in table1.

7.4 Destructive testing

7.4.2 Transverse tensile test

Knowing the type of joint relevant for the study, as cited before butt joint, the specimens and testing shall be in accordance with EN 895.

In relation to the results, the tensile strength of the test specimen must be bigger than the corresponding specified minimum value for the parent metal unless it had been specified before performs the test.

In case of dissimilar parent metal the tensile strength must be higher than the minimum value specified for the lowest tensile strength of the parent material.

7.4.3 Bend test

Following the same reasoning related to the type of joint, that is butt weld, the specimens and testing shall be in accordance with EN 910.

If the plate thickness is smaller than 12mm (< 12 mm), two root and two face bend test specimens would be tested. In case of equal or higher thickness of 12 mm four side bend specimens are suggested.

In case of dissimilar metal joints or heterogeneous butt joint in plates, one root and one face longitudinal bend test specimen is permitted to be used, rather than four transverse bend tests. The inner roller dimension shall be 4t and the bending angle 180^0 for parent metal with elongation A ≥ 20%. The presented formula shall be used in case of A < 20%.

$$d = \frac{(100\ x\ t_s)}{A} - t_s$$

where

d is the diameter of the inner roller

t_s is the thickness of the bend test specimen

A is the minimum tensile elongation required by the material specification

The acceptance criterion is not revealing any one single flaw higher than 3 mm in any direction on the specimens. Flaws that appear on the corner of test specimen during the test can be overlooked in the evaluation.

7.4.4 Macroscopic examination

To perform the macroscopic test, EN 1321 should be followed to preparing and etching on one side the test specimen to visibly show fusion line, the heated affected zone (HAZ) and weld passes.

This examination shall contain unaffected parent metal and be recorded by at least one macro-reproduction per welding procedure test.

On clause 7.5 is presented the acceptance levels referred to the macroscopic examination.

7.4.5 Impact testing

Regarding to location of specimens and temperature of testing the presented standard shall be followed, already in respect with dimensions and testing EN 875 shall be referred.

Impact test can be performed with different types of test specimen and its selection depends on which part of the weld will be tested. In case of weld metal, specimen type VWT shall be adopted that means: V - charpy V-notch, W - notch in weld metal and T - notch through the thickness. On the other hand for HAZ, specimen type VHT is the one to be adopted and means: V - charpy V-notch, H - notch in heat affected zone T notch through the thickness. The quantity of specimen is determined as from each specified location, weld metal or HAZ, each set must be composed of three specimens.

Concerning about the exactly location for the charpy V notch, in case of weld metal this notch will be located at the weld centerline and on HAZ it needs to be at 1 mm to 2 mm from the fusion line. The V charpy notch on the specimen shall be made with maximum 2 mm below parent metal surface and positioned transverse to the weld.

Depending on the thickness of the material the number of sets should be increased. Included in this case, materials that are ticker than 50 mm, two additional sets of specimens shall be taken, one more set from the weld metal and one more from the HAZ. It is open two options for the one from HAZ, it can be at mid thickness or in the root area of the weld.

The acceptable value for the energy absorbed is based on the appropriate parent material standard if the requirements of ship classification societies do not modify it. To be approved on Impact testing the average value from the three specimens is the comparable value and it shall meet the specified requirements. From the three specimens of each set only 1 is allowed to have a value lower than the minimum average value specified but also not less than 70% of that value.

In case of welding different material, the impact test compulsorily needs to be performed on specimens from HAZ of each parent metal.

Concerning about several welding process being qualified with a single test piece, the specimens for impact test will be taken from location, weld metal and HAZ, of each process.

7.4.6 Hardness testing

For the hardness testing as Vickers hardness testing with a load of HV10, the standard EN 1043-1 is the one to be followed.

The hardness values are measured mandatorily on the three different regions, which includes weld, heat affected zone and parent material, for the purpose of evaluating the hardness range across the welded joint.

The material thickness determines how many rows of indentations are requested for the hardness test. If the material thickness is less or equal to 5 mm, one row of indentations is requested with maximum depth of 2 mm from upper surface of welded joint. In the case of the material thickness be higher than 5 mm, then 2 rows of indentations need to be done with maximum depth of 2 mm each one, one from the upper surface of the weld and the other from the lower surface. In case of double side welds, fillet and T-butt welds, one more row of indentations is required positioned through the root area.

For each row, at least 3 individuals indentations are made in each area, it means, at least three indentations on the weld, three on both heat affected zone, being the first one closer as possible of the fusion line and three on both parent metals.

The Table 2 gives the requirements to be matched by the hardness test. For the groups not presented there, as group 6 (non-heat treated), 7, 10 and 11 and any dissimilar metal need to be specified before perform the test.

Table 2: Permitted maximum hardness values (HV 10). Available from DIN EN ISO 15614-1. (2012)

Steel groups CR ISO 15608	Non-heat treated	Heat treated
1[a], 2	380	320
3[b]	450	380
4, 5	380	320
6	-	350
9.1 9.2 9.2	350 450 450	300 350 350
a If hardness tests are required. b For steels with min R_{eH} > 890 N/mm^2 special values shall be specified.		

7.5 Acceptance levels

The acceptance level is driven by quality level B in ISO 5817. It means that the welding procedure will be qualified if presented imperfections are bounded inside the specified limits.

In case of imperfections type as excess convexity, excess throat thickness and excessive penetration and incorrect weld toe then level C is acceptable to be applied.

Regarding to angular misalignment, it is specified that is not applicable for welding procedure test and in case of undercut it is mandatory to be equal or smaller than 5 mm.

On a note, it is pointed out the standard EN 12062 which presents the correlation regarding to quality levels of ISO 5817 and acceptance criteria of different non-destructive test techniques.

7.6 Re-testing

In case of the test piece does not comply one of the requirements for visual examination or NDT indicated in clause 7.5, one more test piece compulsorily need to be welded and be submitted to the same examination. If this extra test piece fails again, the welding procedure test has failed and cannot be approved.

Regarding to failure on destructive testing, in case of any specimens does not comply with the requirements presented on clause 7.4 due to weld imperfections, then two more test specimens mandatorily need to be tested for each one that has failed initially. Reiterating, the new specimen will be subjected to the same test as the initial specimen has failed. This extra specimen can be taken from the same test piece in case of sufficient material otherwise a new test piece need to be welded. In case of one of the additional specimens fails again the welding procedure test has failed.

Concerning about tensile test, if the specimen does not match the requirements given on clause 7.4.2, two more specimens necessarily need to be obtained for each specimen that failed and both must satisfy the requirements indicated on the clause cited previously.

Referring to hardness test, in case of any hardness value located in different test zones is higher than the values presented on Table 2 then an extra hardness test is required. It can be done in the same specimen but on the opposite side or in the same surface but after satisfactorily grinded. As criteria any of extra hardness values are acceptable to be higher than the maximum hardness values from the table presented previously.

Closing the discussion on re-testing, the charpy impact test would be performed again in case of results from a set of three specimens do not satisfy the requirements but obeying the fact of just one value being lower than 70%. If only one value is lower than 70% than three extra specimens necessarily need to be taken. The results will be computed as following: an average value involving the previous results and the values of three additional specimens will be considered and it compulsorily cannot be lesser than the required average.

3.1.4. Clause 8: Range of Qualification

When discussing about range of qualification it is important to point out that in case of changes outside of the specified ranges, a new welding procedure test is required.

8.2 Related to the manufacturer

Once the manufacturer has qualified a pWPS applying welding procedure test method following this existent standard, the WPS is suitable to weld on site or in workshops since the welding is performed under similar technical and quality control of the producer.

8.3 Related to the parent material

8.3.1 Parent material grouping

As the number of welding procedure test could be high just by the method itself, aiming and being capable to reduce it the material are grouped following ISO/TR 15608.

If the parent material or parent material combination is not covered by grouping system then a separated welding procedure qualification is required.

In case of parent material makes part of two groups or sub-groups, the lower group or sub-group necessarily is the one to be considered.

Reminding that if a permanent backing material is used on the welding process it compulsorily needs to be considered as parent material considering the approval group or sub-group.

8.3.1.1 Steels

As the object of this analysis is limited to steel material, only the clause related to it is assumed relevant and consequently is the one presented here. So further in Table 3 the ranges of qualification for steels can be observed.

Table 3: Range of qualification for steel groups and sub-groups. Available from DIN EN ISO 15614-1. (2012)

Material (sub-) group of test piece	Range of qualification
1 - 1	1[a] – 1
2 - 2	2[a] – 2, 1 - 1, 2[a] – 1
3 - 3	3[a] – 3, 1 - 1, 2 – 1, 2 - 2, 3[a] - 1, 3[a] –2
4 - 4	4[b] – 4, 4[b] - 1, 4[b] - 2
5 - 5	5[b] – 5, 5[b] - 1, 5[b] - 2
6 - 6	6[b] – 6, 6[b] - 1, 6[b] – 2
7 - 7	7[c] – 7
7 - 3	7[c] – 3, 7[c] - 1, 7[c] – 2
7 - 2	7[c] - 2[a], 7[c] – 1
8 - 8	A1) 8[b] – 8 (A1
8 - 6	8[c] - 6[b], 8[c] - 1, 8[c] - 2, 8[c] – 4
8 - 5	8[c] - 5[b], 8[c] - 1, 8[c] - 2, 8[c] - 4, 8[c] - 6.1, 8[c] - 6.2
8 - 3	8[c] - 3[a], 8[c] - 1, 8[c] – 2
8 - 2	8[c] - 2[a], 8[c] – 1
9 - 9	9[b] – 9
10 -10	10[b] – 10
10 - 8	10[b] - 8[c]
10 - 6	10[b] - 6[b], 10[b] - 1, 10[b] - 2, 10[b] – 4
10 - 5	10[b] - 5[b], 10[b] - 1, 10[b] - 2, 10[b] - 4, 10[b] - 6.1, 10[b] - 6.2
10 -3	10[b] - 3[a], 10[b] - 1, 10[b] – 2
10 -2	10[b] - 2[a], 10[b] – 1
11 -11	11[b] - 11, 11[b] – 1

[a] Covers the equal or lower specified yield strength steels of the same group

[b] Covers steels in the same sub-group and any lower sub-group within the same group

[c] Covers steels in the same sub-group

8.3.2 Material thickness

8.3.2.1 General

Once the qualification is requested for a unique process, the thickness *t* necessarily needs to be adopted for a butt joint type as the parent material thickness.

And when concerning to multi-process qualification, the recorded thickness influence of each single process would be used as reference for the range of qualification for separately welding process.

8.3.2.2 Range of qualification for butt joint

Mentioning about exclusively the range of qualification for butt joint, it is described that a welding procedure test qualified on thickness *t* would necessarily include qualification for thickness in accordance with the ranges shown in Table 4 below. The dimensions are in millimeters.

Table 4: Range of qualification for butt welds material thickness and weld deposit thickness. Available from DIN EN ISO 15614-1. (2012)

Thickness of test piece *t*	Range of qualification	
	Single run	Multi-run
$t \leq 3$	0,7*t* to 1,3*t*	0,7*t* to 2*t*
$3 < t \leq 12$	0,5*t* (3 min.) to 1,3*t* [a]	3 to 2*t* [a]
$12 < t \leq 100$	0,5*t* to 1,1*t*	0,5*t* to 2*t*
$t > 100$	Not applicable	50 to 2*t*
[a] when impact requirements are specified the upper limit of qualification is 12 mm unless impact testing has been performed.		

8.4 Common to all welding procedures

8.4.1 Welding processes

The qualification of welding procedure needs to be done separately for each degree of mechanization of the process and is not allowed to change the means of implementation (Manual, partly mechanized, fully mechanized and automatic).

Once the qualification is applied for a specific welding process, this is, the one used in the welding procedure test, it is acceptable and valid solely to that one.

The qualification of multi-process procedure can be done in two ways, or separated welding procedure tests for each welding process or as a multi-process procedure test. This qualification is only valid for the process sequence performed during the multi-process procedure test.

8.4.2 Welding positions

Concerning to the position that is performed the welding on the test piece, it is mentioned that excluding PG and J-L045 position any other that is used to weld the test piece gives the qualification for all positions. In specific for PG and J-L045 position a distinct welding procedure test is compulsorily required.

Still related with all position qualification, in case of impact and/or hardness test be required then the specification is to take for the impact test the weld in the highest heat input position and in the other hand for hardness take the weld from the lowest heat input position. Following it the range of qualification will comprehend all positions. But if impact test is not required neither hardness then any welding position qualifies for welding in all positions. Describing as example, and fitting exactly for the butt joint type in a plate the highest heat input position is usually PF and the opposite, lowest one in PC position.

If different positions qualification is required, then it is necessary to have two test pieces in different welding positions to fulfill both hardness and impact requests. In cases which requires qualification for all positions the two test pieces necessarily needs to be submitted to full visual examination and non-destructive testing.

Specifically to material of group 10, equally hardness test and impact test must be done taking lowest and highest heat input positions.

8.4.3 Type of joint/weld

For type of joint, the qualification range necessarily needs to be as performed and described in the welding procedure test but also liable to limitations presented in other clauses and moreover:

a. In case of butt welds it qualifies both full and partial penetration for butt and fillet welds.
b. When the weld is done from one side without using backing it qualifies welds that are done from both sides and still welds with backing.
c. Also when the weld is done using backing it qualifies welds that are done from both sides.
d. In case of weld that is done from both sides without gouging then it qualifies welds done from both sides with gouging.
e. When a multi-run deposit is used it is not allowed to change it for a single run neither in the contrary situation for a specified process.

Note that the terms mentioned above are just part of the ones presented on the original standard, but is the ones which could be relevant for the analysis.

8.4.4 Filler material designation

Referring to range of qualification for filler material it can be covered by other filler materials since they present similar mechanical properties, equal type of covering core or flux, equal nominal composition and still equal or lower hydrogen content relating to the terms in the suitable European Standard for the filled material mentioned.

8.4.5 Filler material, make (manufacturer and trade name)

Referring to filler material producer, in cases of impact testing is requested for processes that include process 136, the qualification range is limited solely to that specific producer applied in the procedure test.

Moreover, it is acceptable to change the specific filler material producer to other one with equal compulsory part of the description when an extra test piece is welded. In this case, the test piece must be welded applying identical welding parameters as the original test and it is necessary to test just the weld metal impact test specimens.

Important to advice that, this facility cannot be used to solid wire and rods which presents the same applicability and nominal chemical compositions.

8.4.6 Filler material size

Concerning to size of filler material, it can be changed certifying that the criteria of clause 8.4.8 are fulfilled.

8.4.7 Type of current

Respecting to range of qualification for type of current it is qualified exactly to polarity and type of current applied in the welding procedure test, independently of being alternating current (AC), direct current (DC) or pulsed current.

8.4.8 Heat input

For heat input qualification range, once impact test is required, the upper limit of heat input is limited and eligible in 25% higher than the heat input applied during welding the test piece.

In the other hand, if hardness test is required, then the lower limit of heat input will be limited to 25% lower than the heat input used in welding test piece.

To calculate the heat input the standard EN 1011-1 must be referred.

Closing the heat input range of qualification, in case of welding procedure test subject at high and also low heat input level, then the heat input that is within the interval will be qualified too.

8.4.9 Preheat temperature

In case of preheat temperature is prerequisite then the lower limit of qualification will be the nominal preheat temperature used at the start of welding the test piece.

8.4.10 Interpass temperature

Regarding to interpass temperature, the range of qualification is bounded on the upper limit of the highest interpass temperature during welding of the test piece in the welding procedure test.

8.4.11 Post-heating for hydrogen release

If post-heating is required due hydrogen release then temperature and duration of it necessarily cannot be reduced. The post-heating must not be omitted however can be added.

8.4.12 Post-weld heat-treatment

The range of qualification for post-weld heat treatment is strict in a way that add or neglect it is not acceptable. If not specified, the temperature range certified will be the holding temperature applied on the welding procedure test $\pm 20°C$.

8.4.13 Initial heat treatment

Once initial heat treatment is required, a change on its conditions before the welding of precipitation hardenable materials is not allowed.

8.5 Specific to processes

8.5.2 Processes 131, 135, 136 and 137

Criteria specific to processes, in the particular study process 136, is described within three sub-clauses as presented further.

8.5.2.1 Regarding to shielding gas, the qualification approved is limited to the symbol of the gas as referred on ISO 14175. But, still the content of CO_2 mandatorily cannot exceed 10% of the one applied to qualify the procedure test. Moreover the shielding gases not cited by ISO 14175 will be limited to the nominal composition subjected in the test.

8.5.2.2 Related to wire system, the qualification is acceptable strictly just to the wire system which the welding test piece had been done. This means if a single-wire system had been used then the qualification is just valid for single-wire system and the same in case of multiple-wire system.

8.5.2.3 In case of solid and metal cored wires, the method of metal transfer is limited in a ways as if the qualification had been done applying short circuiting transfer then it will be valid just for short circuiting transfer, but in other hand, if the qualification had been

3.1.5. Clause 9: Welding Procedure Qualification Record (WPQR)

Performing the welding procedure test, as historical or kind of data base, a welding procedure qualification record (WPQR) is generated. The WPQR is a document that states all the results of evaluation of each test piece and in case of re-testing, this is recorded too hereby. It also necessarily needs to include the relevant items listed for the WPS according to the relevant part of prEN ISO 15609, and still, in the same way, details of any features that according to the requirements of clause 7 would not be accepted.

Presenting the WPQR describing the welding procedure test piece results without any refused features or unacceptable results, it will be validated, in other words, qualified. This compulsorily needs to be signed and dated by the representative person, in this case examiner or the examining body.

It is crucially important to use a WPQR format, once this enable to record details for the welding procedure and all the test results assisting easily then an uniform presentation and valuation of the data.

3.2. Welding Procedure Qualification Records: The Applied Sample

As presented and discussed previously, the Welding Procedure Qualification Records (WPQR) is a document generated to assess all the important or relevant information used or obtained during the welding procedure test. Furthermore, analyzing the given flowchart of qualification of welding procedure specification by the welding procedure test method on sub-section 2.2, it is simple to recognize that the WPQR is just one step before and, even more, the base to prepare and consolidate the WPS, or in other words the last document before finally have a WPS.

Based on this, in the current sub-section is exposed the WPQR format taken as guide for familiarity with the document and, if necessary, further analyses. Moreover, it is the one that generates the WPS presented in the next sub-section. It is appropriate to inform that this is one layout among others normally used by the company and is specifically provided by DNV-GL classification society. Within it is all the data related to welding procedure test taken as reference to perform the proposed study, but the most relevant information at the moment are those related to the material applied, type of joint, welding process and so on, once the analyses which will be done is restricted to butt weld on steel plates using flux cored arc welding process.

This document is composed by two pages. In the first one, all the information regarding to the welding of the test piece is given. On top right side is specified the number of manufacturer´s welding procedure, this number is linked later with the specific WPS. By confidential reason the manufacturer name is omitted. It is also possible to observe the joint preparation and welding sequence applied on the welding test piece as well as every welding parameters correspondent to each welding pass used during the welding process. In case, a steel plate of 12mm had been used and six welding pass had been done. Closing the first page, on lower part of it the special requirements and others relevant information take part.

In the second page are all the results and recorded information related with the non-destructive and destructive test that the specimens had been submitted to. As non-destructive test, ultrasonic examination and magnetic particle testing are performed. And regarding to destructive tests results, it had been record for tensile, bend, impact and hardness test. Macro examination also had been done and the correspondent number of report is mentioned.

The welding procedure qualification record used as sample can be found as appendix III.

3.3. Welding Procedure Specification: The developed Document

With the WPQR in hand, properly dated and signed by examiner or, even, by an examination body, the welding procedure specification (WPS) will be written. As mentioned in the previous sub-section, the WPQR described there and presented in appendix IV is the document used to develop the current WPS which will be discussed here in the same way and with the same purpose as for the WPQR in the sub-section before. Or in other words, it will serve to illustrate and give the opportunity to get familiar within this kind of document. The format shown on appendix III is the standard document developed and generally used by the company, being in this case according to DNV rules for ships – DNV OS-C401.

This WPS is one page document and contains all the information required to proceed with the specific welding process, including also the range of qualification in which it still can be valid and usable, as well as some step by step instructions to the welders how to prepare carefully the joint and maintain it clean along whole process. On the top right side of the document page is possible to observe the number which the WPS had been register on, this number normally is a sequential number that follows the company quality standard. Just below it, the numbers of WPQR´s which support the WPS are given. And as in the WPQR, here the company name or manufacturer had been preserved too.

Still regarding to the upper part of the document, it is presented the welding process 136 – flux cored arc weld, the welding position vertical-up (PF) and type of joint as butt weld on both sides without backing. In sequence, the base material properties are shown including the range of thickness that the WPS could be applied and just below it the information corresponding to welding consumables as filler material and their specific characteristics, size, producer and so on, and gas flow description.

In the middle of the page is the information referring to special requirements and the instructions for the welders cited before. As special requirements, contain pre-heating and interpass temperature as well as type of pass and also information about gouging. It is given a sketch pointing out thickness of plate, gap, and opening angle and so on and moreover the welding sequence, showing all the passes to be done during the welding process. And to close the WPS, on the bottom part of it, the welding parameters which should be used by each pass of welding with their respective range of applicability. As the WPQR, the WPS is also dated and signed, but in this document beyond dated and signed by the examiner or surveyor of classification society is also dated and signed by person who had prepared the document as a responsible welding engineer.

4. ANALYSES OF RESULTS

After reading, analyzing and interpreting the standard EN ISO 15614-1:2012-6, comprehending the process of welding procedure qualification based on welding procedure test method and getting familiar with welding procedure qualification record and welding procedure specification documents applied by the manufacturer, the next decision was concerning to selecting the correspondents requirements of ship classification societies to perform the analyses. Based on two different criteria related with the frequency in which each of the standards of ship classification societies were adopted by the company and then selecting another classification society which does not make part of European Union, the three classification societies, object of the analyses, had been selected.

First the most commonly used by the company DNVGL with the standard DNVGL-OS-C401 entitle Fabrication and testing of offshore structures. Then, one rarely applied by the company Bureau Veritas (BV) with a rule note NR 426 named Construction survey of steel structures of offshore units and installations. And the last, a classification society originally outside of Europe, American Bureau of Shipping (ABS) with Rules for Material and Welding – Part 2 – APPENDIX 9 – Welding Procedure Qualification Tests of Steels for Hull Construction and Marine Structures. For the purpose of summarizing and simplifying they will be referred here respectively as A, B and C.

Initially, the general interest was to point out similarities and principally differences among the document adopted as base, EN ISO 15614-1, and the requirements of ship classification societies evolving entire documents, but as this could generate a massive and extensive analyses the study had been focused in some specific clauses as presented further by sub-sections.

4.1. Shape and Dimensions of Test Pieces

Regarding to shape and dimensions of test pieces, specifically for the joint type selected, butt welds on plate, observing the Figure 18 and Figure 19, together with

Table **5**, it is easy to conclude that there is not difference among requirements of ship classification societies and European Standard. What can be noticed is that in the European Standard the type of welding process for the minimum dimensions is not specified.

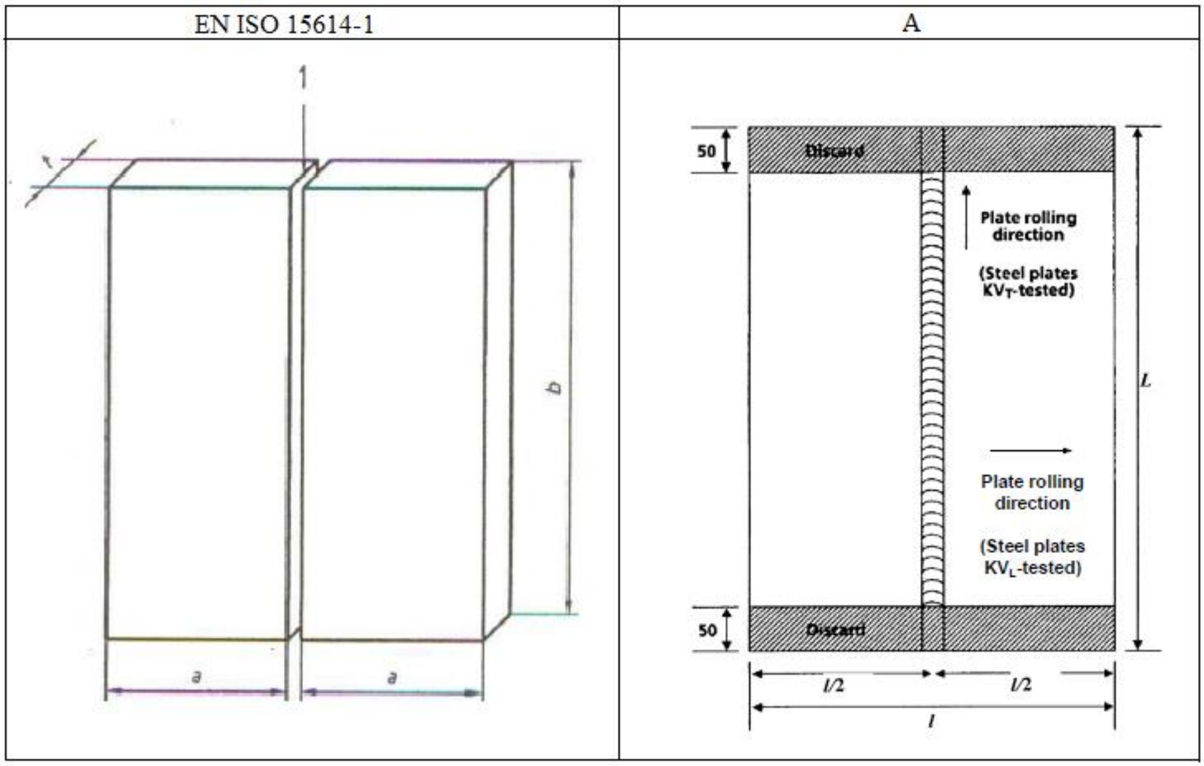


Figure 18: EN ISO 15614-1 vs DNVGL: Test piece dimensions comparison.

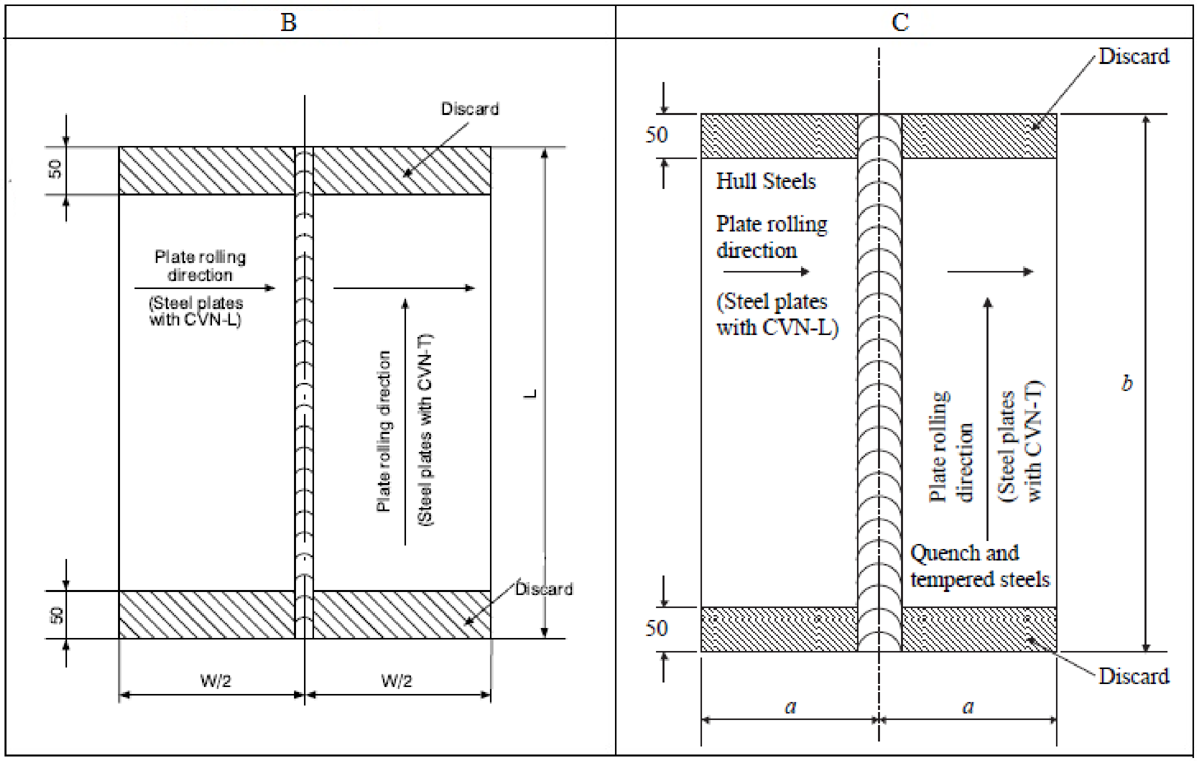


Figure 19: BV vs ABS: Location and taking of test specimens.

Table 5: Comparison table related to dimensions of test pieces.

Welding process	A		B		C	
	Dimensions		Dimensions		Dimensions	
	l (min)	L (min)	W* (min)	L *(min)	a* (min)	b* (min)
manual/semi-automatic	300	350	150	350	150	350
automatic	400	1000	200	1000	200	1000
Note: * Width and length are related with tickeness, being L=6t and W/2=3t for manual/semi automatic welding and W/2=4t for automatic welding						

Another point that can be highlighted is while classification society B and C link the dimensions of test piece with thickness of material, the classification society A as the European Standard EN ISO 15614-1 do not mention it.

4.2. Extend of Testing

Analyzing about the tests to be performed on weld test piece with butt weld type and full penetration, specifically for non-destructive test requirements as compiled on Table 6 below, all referred classification societies are in accordance with the European Standard used as base.

Table 6: Comparison table related to extent of testing of non-destructive test.

Type of test	Extent of testing			
	EN ISO 15614-1	A	B	C
Visual	100%	100%	100%	100%
Radiographic or ultrasonic	100%	100%	100%	100%
Penetrant testing or magnetic particle	100%	100%	100%	100%

All of them agree that 100% of non-destructive test need to be done, but just EN ISO 15614-1 relate a commentary regarding to ultrasonic test reminding that for this type of test the material thickness must be higher than 8mm and it is not applicable also to material groups 8, 10, 41 to 48.

For destructive tests, in summary the requirements of EN ISO 15614-1 and also of ship classification societies are presented in the Table 7. As can be observed almost all of them follow the same quantity of specimens for all the required tests, differing just in case of impact test and longitudinal tensile test. For impact test while EN ISO 15614-1 requires 2 sets, DNVGL represented by letter A requires 4 sets and Bureau Veritas (B) in agreement with American Bureau of Shipping (C) require 3 sets. On the longitudinal tensile test, European Standard and DNVGL do not mention it and BV and ABS require it in case the filler material is not approved respectively by BV and ABS, in other words if the filler material are not approved by BV then a longitudinal tensile test will be required as well as for ABS requirements.

Table 7: Comparison table related to extent of testing of destructive test.

Type of test	Extent of testing			
	EN ISO 15614-1	A	B	C
Transverse tensile test	2 specimens	2 specimens	2 specimens	2 specimens
Transverse bend test	4 specimens	4 specimens	4 specimens	4 specimens
Impact test	2 sets	4 sets	3 sets	3 sets
Hardness test	required	required	1* specimen	required
Macroscopic examination	1 specimen	1 specimen	1 specimen	1 specimen
Longitudinal tensile test	-	-	1* specimen	1* specimen

Some other concerns are important to be reported as the specific notes or requirements given by classification societies, including also the European Standard. On EN ISO 15614-1 is relevant to state that for the impact test one set is located on weld metal and one set in the Heat Affected Zone but this request is valid only for material with thickness equal or higher than 12mm. On DNVGL standard the particular requirement mentioned is related to transverse bend test, which in case of material thickness equal or higher than 12mm as option four side bend specimens can be tested replacing the two root and two face bend specimens. And closing the present discussion, on BV rules beyond the longitudinal tensile test already mentioned above, the hardness test also has a specific statement and it is related with type of material, that is, in case of high strength steels with minimum specified yield strength equal or higher than 355N/mm^2 the hardness test is required.

4.3. Location and taking of test specimens

Observing the Figure 20 and Figure 21, it is easy to recognize and understand part of what had been described on the previous sub-section concerning to extend of testing. It is shown clearly by each classification society the location on the test piece to take all the specimens. The most notable difference is in the dimension of the discard. While on EN ISO 15614-1 determines 25mm discard on both sides of the welded test piece the three other standards propose 50mm discard on both sides.

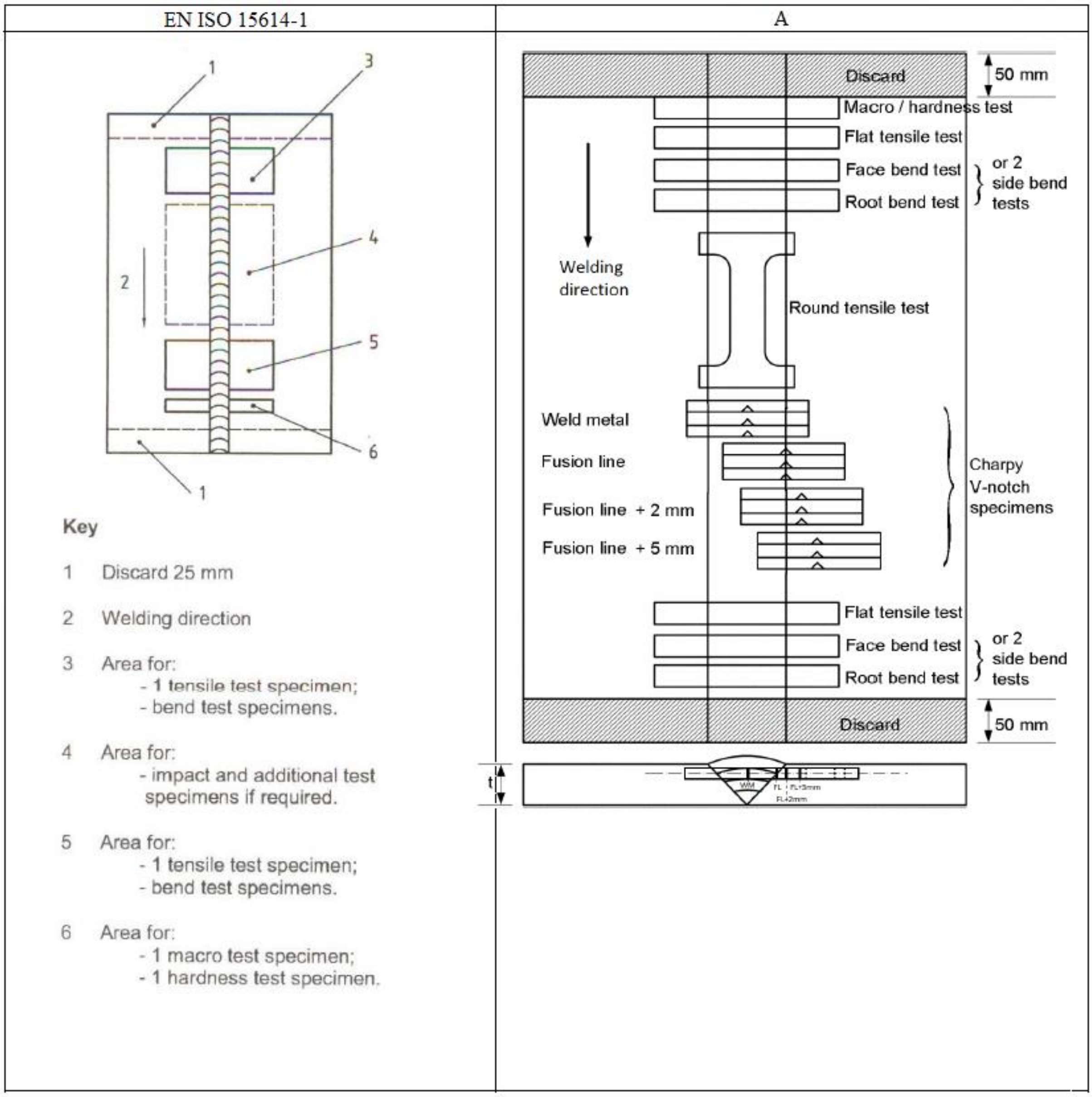


Figure 20: EN ISO 15614-1 vs DNVGL: Location and taking of test specimens.

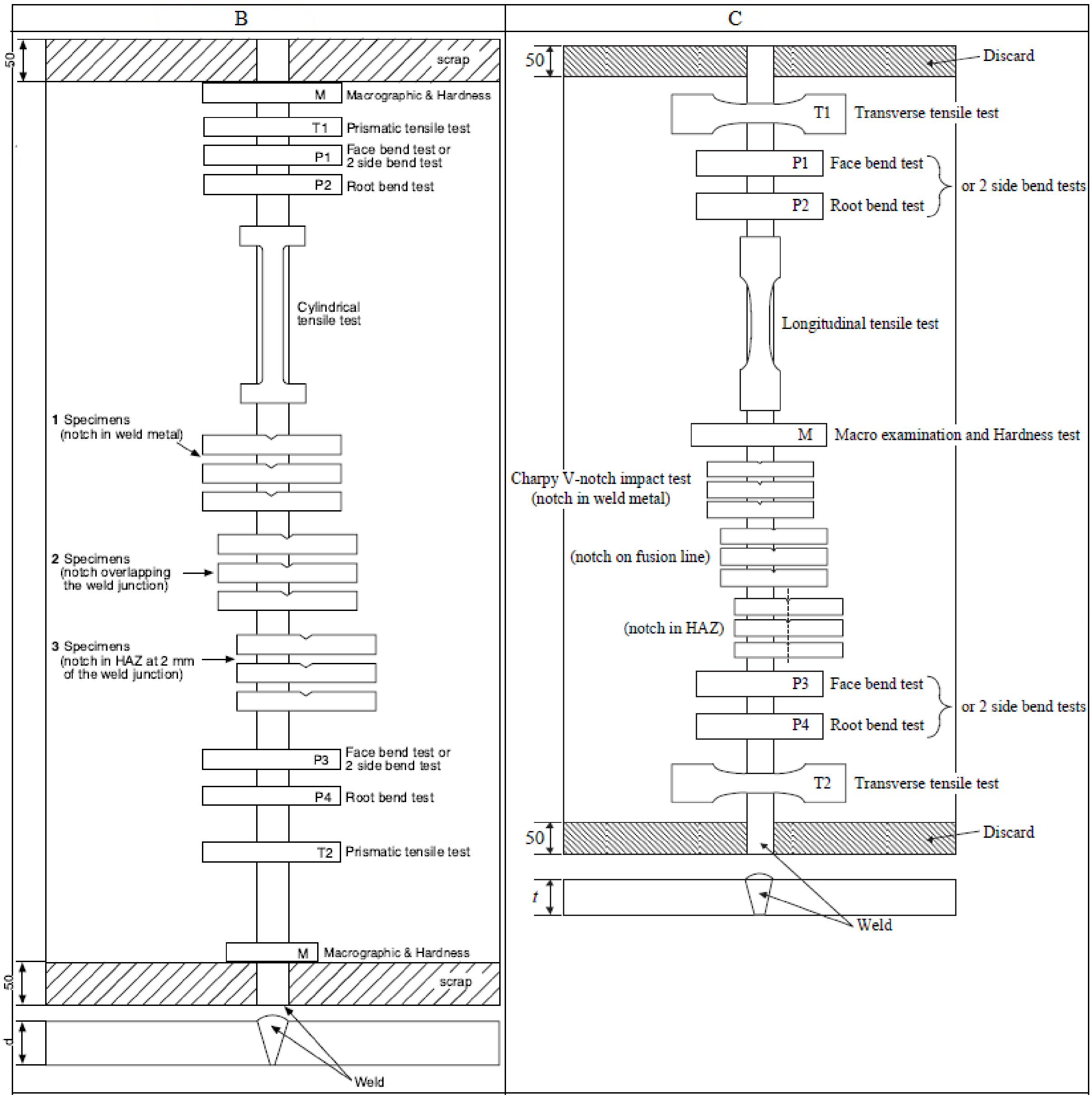


Figure 21: BV vs ABS: Location and taking of test specimens.

It is also convenient to emphasize the small differences, even in case of repetition. In this case, for DNVGL the 4 sets of specimens on charpy V-nocth impact test, which one set the V-notch will be located on the weld material, one set on the fusion line and the two others will be located on HAZ, being one 2mm away from the fusion line and other 5mm. Another different point to highlight, but now regarding to ABS rule is the location of specimen for macro and hardness test. While this is located close to the ends of the welded test piece on the others standards, on ABS it is proposed to be located on the middle of the welded test piece.

4.4. Range of Qualification – Related to Material Thickness

Making now the parallel among the standards concerning to range of qualification related to material thickness by the Table 8 shown ahead it is correct to affirm that EN ISO 15614-1 is less restricted than the others when concerning about welding with a single run, offering a larger interval for the welds performed in a unique pass, and similar with the others when referring to multi-run welds. Still discoursing about European Standard, is relevant to mention that for the restriction $3 < t \leq 12$ the upper limit of qualification will be 12mm if impact testing had not been performed.

Table 8: EN ISO 15614-1 vs requirements of ship classification societies: range of qualification related to material thickness.

	EN ISO 15614-1		A	
	Range of qualification		Range of qualification	
Thickness of test piece *t*	Single run	Multi-run	Single run or single run from both sides	Multi-run
$t \leq 3$	$0{,}7t$ to $1{,}3t$	$0{,}7t$ to $2t$	-	-
$3 < t \leq 12$	$0{,}5t$ (3min) to $1{,}3t$*	3 to 2t*	$0{,}7t$ to $1{,}1t$	3 to 2t
$12 < t \leq 100$	$0{,}5t$ to $1{,}1t$	$0{,}5t$ to $2t$	$0{,}7t$ to $1{,}1t$	$0{,}5t$ to $2t$ (max. 150)
$t > 100$	not applicable	50 to $2t$	not applicable	$0{,}5t$ to $2t$

	B		C	
	Range of qualification		Range of qualification	
Thickness of test piece *t*	Single run or single run from both sides	Multi-run	Single run or single run from both sides	Multi-run
$t \leq 3$	-	-	-	-
$3 < t \leq 12$	$0{,}7t$ to $1{,}1t$	3 to 2t	$0{,}7t$ to $1{,}1t$	3 to 2t
$12 < t \leq 100$	$0{,}7t$ to $1{,}1t$*	$0{,}5t$ to $2t$ (max. 150)	$0{,}7t$ to $1{,}1t$*	$0{,}5t$ to $2t$ (> 150)*
$t > 100$	-	-	-	-

Dimensions in millimeters

Another point that can be concluded from the Table 8 above is regarding to very thin plates, in case where thickness is equal or lower than 3mm just EN ISO 15614-1 mentioned it, the others standards do not give any information about. And almost in the same way for great thickness, when it is higher than 100mm EN ISO 15614-1 states that for single run it is not applicable, but for multi-run the range could be from 50mm to 2 times de tested thickness. Following the European Standard, DNVGL affirms the same while BV and ABS do not provide information.

Regarding to particular information contained in each specific rule or standard of the analyzed classification societies about the range of qualification related to material thickness, there are still other points that can be discussed. In case of DNVGL standard, it limits for the vertical downward welding position the maximum thickness qualification in 1,0 time thickness and in the same way for high heat input processes greater than 5kJ/mm, the upper limit range will be 1,0 time thickness. Apart of this, is still possible to conclude that DNVGL standard is closely to European Standard in this clause too.

As DNVGL, BV rule also limit the range of qualification to 1,0 time thickness on single run weld when the high heat input process is higher than 50kJ/cm, in case of welded test piece thickness is higher than 12mm and smaller or equal to 100mm ($12 < t \leq 100$). And more, BV also restrict the upper limit range in case of multi-run maximum 150mm for test piece thickness between $12 < t \leq 100$, in the same way as DNVGL.

Closing the sub-section, the analyses of particularity given by ABS that can be highlighted regarding to this clause it is also related to the upper limit range as discussed above for BV, with a difference that here ABS rule accept upper limit higher than 150mm but with a restriction as to be subject to special consideration, which are not mentioned at this point.

5. CONCLUSIONS AND DISCUSSIONS

Along this study, focused on the proposed topic and following the main purpose of it, firstly a literature review was done, serving as reference and supporting the next step. So, after expose the theoretical basis, a practical part was established through a summarized interpretation of the European Standard, EN ISO 15614-1, and presentation of a developed welding procedure qualification record and welding procedure specification documents. On sequence, the parallel among the different ship classification societies selected and the European Standard could be done. The analyses of results were collected and presented contrasting four chosen clauses.

As the main objective of these analyses was to point out similarities and differences that could exist among the studied objects, it can clearly be noticed that had been achieved on section four, even if the previous expectation was to have more numerous and significant differences than similarities, which was in fact the opposite as observed on the mentioned section. Due to this, the most reasonable affirmative to be done is that the rules, codes or standards compared here are consistent regarding to qualifying a welding procedure through the welding procedure test method.

And still concerning to the presented results, another remark that can be done in the same circumstance is that the ship classification societies are more conservative than EN ISO 15614-1. This can be seen as in the range of qualification for test piece material thickness, $3 < t \leq 12$ and $12 < t \leq 100$, both single run weld, as in the number of specimens required for impact test, or, furthermore, in the dimension of discard that is minimum 50mm to all three consulted classification societies while to European Standard the minimum size could be 25mm.

Discoursing about difficulties faced along the development of this current study, what can be related is inexperience or, better, few experience on interpreting rules together with double meaning misunderstanding, which required an extra time to ready, and re-ready carefully clause by clause of, primarily, EN ISO 15614-1 and then each one of the three requirements of ship classification societies. Making it a bit more complex, add the necessity to check time by time other standards referred on the ones that were objects of analyses.

To close the section, before suggesting further studies, justifying it with the obtained results, it is important to highlight that once the comparison was restricted a few clauses, two facts could had contributed to outcomes, being them, first the short extend of the analyses and second the selection of clauses that was made. So, based on this, can be registered here as suggestion for next investigations, a deeper or more detailed analysis evolving any single clause of each addressed standard or, still as previously suggested, if possible to use the current document as guide to develop a general document in order to make the process in terms of approval a new welding procedure specification simpler, shorter and faster.

6. ACKNOWLEDGMENTS

First of all, I would like to present my thanks to my family, the most valuable treasure in my life, and who had supported me even from the other side of the ocean in another one of my dreams, in special my mother Inez Kronbauer Martinelli who did not measure efforts to be personally present with me for at least a month per semester. Sincerely thanks to my sisters Haline, Heveline and Lizandra Kronbauer Martinelli who had given me support by hundred late night phone calls and instant messages.

Not less important and representing Crist Shipyard enterprise I direct my gratitude to Mr. Tadeusz Waszkiewicz for the opportunity to be part of his team along my internship period and even more for the solicitude, attention and shared experience. I am in the same way grateful to Edyta Kułaga-Dorsz who provided me help and support day by day through guidance, advices and intellectual suggestions, being essential to the development of this study.

And to express my last thanks related with the graduation, it is more than necessary to mention my appreciation to all the professors in general, from the first to the third semester, from Liège University, Ecole Centrale de Nantes and West Pomeranian University of Technology who had gave us beyond the knowledge their precious time too. My special thanks to Prof. Tadeusz Graczyk who had encouraged me to maintain the topic in addition to conducted me during my master thesis development.

This thesis was developed in the frame of the European Master Course in "Integrated Advanced Ship Design" named "EMSHIP" for "European Education in Advanced Ship Design", Ref.: 159652-1-2009-1-BE-ERA MUNDUS-EMMC.

7. REFERENCES

American Bureau of Shipping, 2015. *Rules for materials and welding.* American Bureau of Shipping, Houston

American Welding Society Committee on Definitions and Symbols , 2009. *Standard welding terms and definitions*. American Welding Society, 12th Edition, p. 47-57.

American Welding Society Committee on Methods of Inspection , 2000. *Welding Inspection Handbook*. American Welding Society, 3th Edition, p. 65-80.

Annette O'B., 2004. *Welding handbook: Welding processes, part 1*. American Welding Society, 9th Edition, Vol. 2, pp. 53-394

British Constructional Steelwork Association, 2009. *Typical Welding Procedure Specifications for Structural Steelwork.* No. 50/09. London: The British Constructional Steelwork Association Ltd.

Bureau Veritas, 2006. *Construction survey of steel structures of offshore units and installations.* Rule note NR 426 DT R01 E, Paris

Canadian Welding Bureau, 2006. *Welding for design engineers.* CWB Group, Mississauga

Castner, H.R., 2011. Qualification of Welding Procedures and Personnel. *In*: Lienert, T.J., Babu, S.S., Siewert, T.A. et al, ed. *Welding Fundamentals and Processes, Vol.06A*. Ohio: ASM International, 260–265.

Davies, A.C., 1992. *The science and practice of welding, Vol.1*. 10th edition. Cambridge: Cambridge University Press.

DNVGL, 2015. *Fabrication and testing of offshore structures.* DNVGL-OS-C401. DNVGL AS

DIN EN ISO 15614-1, 2012. *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys.* European Committee for Standardization

Eyres D.J., Bruce G.J., 2012. *Ship Construction*. 7th Edition. Oxford: Butterworth-Heinemann.

Halmshaw, R., 1996. *Introduction to the Non-Destructive Testing of Welded Joints*. 2nd Edition. Cambridge: Abington Publishing.

Hobart Institute of Welding Technology, 2010. *Destructive Testing Methods*. EW-512-5 Training Workbook, 1th Edition, pp.1-48

Hobart Institute of Welding Technology, 2012. *Flux Cored Arc Welding*, EW-492 Technical Guide, 3th Edition, pp.1

Hughes, S., 2009. *A Quick Guide to Welding and Weld Inspection*. 1st Edition. Cambridge: Woodhead Publishing Limited.

Jeffus, L., 2012. *Welding: Principles and Applications*. 7th edition. New York: Delmar.

Kadir, O.A, Rashid, N.A.A., 2012. The Role of a Classification Society in the Shipbuilding and Ship Repair Industries. *Jurutera*, February 2012, p. 14-16.

Lagoni, N., 2007. *The Liability of Classification Societies*. Thesis (PhD). University of Hamburg.

Singh R., 2012. *Applied welding engineering: processes, codes and standards*. 1st Edition. Oxford: Butterworth Heinemann.

Weman K., 2012. *Welding processes handbook.* 2nd Edition. Cambridge: Woodhead Publishing Limited.

APPENDIXES

Appendix I

SAMPLE WELDING PROCEDURE SPECIFICATION (WPS)
for SAW, SMAW, GMAW, GTAW, FCAW

Company ____________________ Approved by ____________________
(Signature Required)
WPS No. ____________________ Date ____________________
WPS Revision No. ____________________ Rev. Date ____________________
Supporting PQR Nos. ____________________
Welding Process(es) ____________________ Type(s) ____________________
(Manual, Semiautomatic, Automatic, Robotic, Mechanized)

Joints (see 4.13.1)

Joint Type ____________________
Backing ____________________
Backing Material (Type) ____________________
Groove Angle ____________________
Root Opening Radius: U ☐ J ☐
Root Face ____________________
Backgouging: Yes ☐ No ☐
Backgouging Method ____________________

Joint Details

Sketches, production drawings, welding symbols, or written description should show the general arrangement of the parts to be welded. Where applicable, the root details of the weld groove may be specified.

Base Metals (see 4.13.2)

M-No. __________ Group No. __________ or to M-No. __________ Group No. __________
Specification Type and Grade ____________________ to Specification Type and Grade ____________________
Thickness Range of Base Metal: Groove __________ Fillet __________
Deposited Metal: Groove __________ Fillet __________
Pipe Diameter Range: Groove __________ Fillet __________
Other ____________________

Filler Metals (see 4.13.3)

Filler Metal F-No. ____________________ Other ____________________
AWS Classification ____________________ AWS Specification ____________________
Weld Metal Analysis A-No. ____________________ Other ____________________
Filler Metal Size ____________________ Electrode Flux (Class) ____________________
Weld Metal Thickness ____________________ Flux Trade Name ____________________
Consumable Insert ____________________ Other ____________________

Positions (see 4.13.4)

Position(s) of Groove ____________________
Position(s) of Fillet ____________________
Weld Progression ____________________

PWHT (see 4.13.6)

Temperature ____________________
Time ____________________

Preheat (see 4.13.5)

Preheat Temperature (Min.) ____________________
Preheat Maintenance ____________________
Interpass Temperature (Max.) ____________________
Continuous of Special Heating or Maintenance:
____

Shielding (see 4.13.7)

	Torch Shielding	Root Shielding	Trailing	Environmental Shielding
Gas(es)				
Composition				
Flow Rate				

Electrical Characteristics (see 4.13.8)

Current Type/Polarity ______________________________
Pulsing: Yes ☐ No ☐
Current (Range) ______________________________
Voltage (Range) ______________________________
Wire Feed Speed (Range) ______________________________
Tungsten Electrode Size/Type ______________________________
Pulsing Parameters ______________________________
Transfer Mode ______________________________
Other ______________________________
____
____

Other Variables (see 4.13.9)

Cup or Nozzle Size ______________________________
Collet Body ☐ or Glass Lens ☐
Cleaning Method ______________________________
Technique: Stringer ☐ or Weave Bead ☐
Cleaning Method ______________________________
Number of Electrodes ______________________________
Single ☐ or Multipass ☐
Contact Tip to Work Distance ______________________________
Other ______________________________
____
____

Welding Parameters

Layers	Process	Filler Metal		Electrical			Travel Speed Range
		Class	Diameter	Type and Polarity	Current Range	Voltage Range	

We, the undersigned, certify that the statements in this record are correct and the test welds were prepared, welded, and tested in accordance with the requirements of AWS B2.1/B2.1M, (__________), *Specification for Welding Procedure and Performance Qualification.* (year)

Manufacturer or Contractor ______________________________

Date ______________ By______________ (Please Print) ______________ (Signature Required)

Appendix II

Welding procedure qualification - Test certificate

Manufacturer's WPQR No.:
Manufacturer :
Address :
Code/Testing Standard :
Date of Welding :

Examiner or examining body
Reference No. :

Range of qualification

Welding Process(es) :
Type of joint and weld:
Parent material group(s) and sub group(s):
Parent Material Thickness (mm) :
Weld Metal Thickness (mm) :
Throat Thickness (mm)
Single run/Multi run:
Outside Pipe Diameter (mm) :
Filler Material Designation:
Filler Material Make:
Filler Material Size
Designation of Shielding Gas/Flux :
Designation of Backing Gas:
Type of Welding Current and Polarity:
Mode of Metal Transfer:

Heat Input:
Welding Positions :
Preheat Temperature:
Interpass Temperature:
Post-Heating :
Post-Weld Heat-Treatment:
Other Information (see also 8.5) :

Certified that test welds prepared, welded and tested satisfactorily in accordance with the requirements of the code/testing standard indicated above.

....	....	....
Location	Date of issue	Examiner or examining body Name, date and signature

Record of weld test

Location :
Manufacturer's pWPS No:
Manufacturer's WPQR No:
Manufacturer :
Welder's Name :
Mode of Metal Transfer :
Joint Type and Weld:
Weld Preparation Details (Sketch)* :

Examiner or examining body :
Method of Preparation and Cleaning :
Parent Material Specification :
Material Thickness (mm) :
Outside Pipe Diameter (mm) :
Welding Position :

Joint Design	Welding Sequences

Welding Details

Run	Welding Process	Size of Filler Material	Current A	Voltage V	Type of current/ Polarity	Wire Feed Speed	Travel Speed*	Heat input*	Metal transfer

Filler Material Designation and Make :
Any Special Baking or Drying :
Gas/Flux : shielding
backing :
Gas Flow Rate – Shielding :
Backing :
Tungsten Electrode Type/Size :
Details of Back Gouging/Backing :
Preheat Temperature :

Other information* e.g.:
Weaving (maximum width of run) :
Oscillation : amplitude, frequency, dwell time
Pulse welding details :
Distance contact tube/ workpiece:
Plasma welding details :
Torch angle :

Interpass Temperature :
Post-Heating :
Post-Weld Heat Treatment :
(Time, Temperature, Method :
Heating and Cooling Rates*) :

....

Manufacturer
Name, date and signature

Examiner or examining body
Name, date and signature

* If required

Test results

Manufacturer's WPQR No:
Visual:
Penetrant/Magnetic Particle*
Tensile Tests

Examiner or examining body
Reference No.
Radiography* :
Ultrasonic* :
Temperature :

Type/No.	Re N/mm^2	Rm N/mm^2	A % on	Z %	Fracture Location	Remarks
Requirement						

Bend Tests

Former Diameter :

Type/No.	Bend Angle	Elongation*	Results

Macroscopic Examination ::

Impact Test* Type : Size : Requirement :

Notch Location/Direction	Temp. °C	Values 1	2	3	Average	Remarks

Hardness Test* (Type/Load)
Parent Metal :
HAZ :
Weld metal :

Location of Measurements (Sketch*)

Other Tests :
Remarks :
Tests Carried out in accordance with the requirements of :
Laboratory Report Reference No. :
Test results were acceptable/not acceptable
(Delete as appropriate)
Test carried out in the presence of :

* If required

....

Examiner or examining body
Name, date and signature

Appendix III

WELDING PROCEDURE QUALIFICATION TEST

According to (code, standard)

DNV-OS-C401

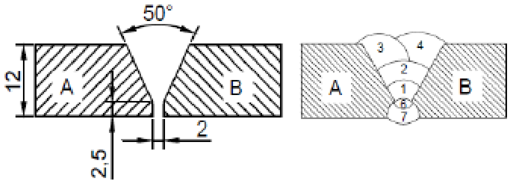
Manufacturer's welding procedure No. **O/136/12/E36N/BF/bs/2015**

Manufacturer **xxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxx** Place and date **Gdynia, 13-11-2014**

Purchaser's spec. No. **-** Project **-**

Requirements beyond code/standard **DNV-OS-C401**

Joint preparation and welding sequence (Sketch).
State rolling direction, if applicable



BASE MATERIAL SPECIFICATION AND GROUPING
A,B=12mm NVE-36(+N); Gr. 1.2 acc. to PN-CR ISO 15608:2002;
Heat No.: 580307/283131-1

Grade	C, %	C eq %
NVE-36	**0,14**	**0,40**

Grade	C, %	C eq %
NVE-36	**0,14**	**0,40**

If applicable, the following C eq based on ladle analysis is to be calculated:

$$Ceq = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Cu+Ni}{15} \%$$

Welding process(es) **136** Welding position **3G (PF)** Single-/double sided welding **bs nb**

WELDING CONSUMABLES:

Index	Consumable(s), trade name	Code designation
A	**OUTERSHIELD 71M-H GRADE: III Y40 (H5)**	**EN ISO 17632-A: T46 2 P C 1 H5**
B	**-**	**-**
C	**-**	**-**

WELDING PARAMETERS

Pass No.	Index	Diam. mm	Gas composition	Gas L/min	Current polarity	Amps	Volts	Travel speed mm/min	Wire feed mm/min	Heat input kJ/mm
1	**A**	**1,2**	**C1**	**19**	**DC+**	**133**	**21,4**	**90,6**		**1,51**
2	**A**	**1,2**	**C1**	**19**	**DC+**	**177**	**22,4**	**142,8**		**1,33**
3	**A**	**1,2**	**C1**	**19**	**DC+**	**168**	**22,4**	**231,6**		**0,78**
4	**A**	**1,2**	**C1**	**19**	**DC+**	**176**	**22,4**	**180,0**		**1,05**
5	**gouging**	**-**	**-**	**-**	**-**	**-**	**-**	**-**		**-**
6	**A**	**1,2**	**C1**	**19**	**DC+**	**172**	**22,3**	**266,4**		**0,69**
7	**A**	**1,2**	**C1**	**19**	**DC+**	**180**	**22,2**	**165,6**		**1,16**

Other information (weaving, backing, groove preparation, gouging, grinding, etc.):
Groove preparation:Flame cutting,Gringing is allowed to clean the surface, Gouging.Weld tests were done at plates with shop primers PPG CoatingsEurope B.V. Protective&MarineCoatings SigmaWeld 199dry film thickness to 20 [µm].

SPECIAL REQUIREMENTS: Preheat min. **40°C** Interpass max **125°C** PWHT **N/A°C** Time **N/A Hr(s)**

Heating/cooling rate **N/A** Baking of electrodes **N/A** Others **N/A**

WELDING CARRIED OUT BY **xxxxxx xxxxxx** TEST PIECE MARKED **"04" 136 PF bs**

EXTENT OF APPROVAL: Base material(s) **A ÷ NV E36** Positions: **3G (PF)**

Plate /wall thickness **BW: 3 ÷ 24 mm** Diam. **>500 mm** Other limitations

bs nb; FW: a = 3 ÷ 24 mm; 3F (PF)

We certify that the statements in this record are correct and that the test weld was prepared, welded and heat treated in accordance with the specified Code/Standard and/or purchaser's requirements.

Manufacturer's signature and stamp

DNV GL's survey station and surveyor's signature

xxxxxxxx xxxxx

If any person suffers loss or damage which is proven to have been caused by any negligent act or omission of the Society, then the Society shall pay compensation to such person for his proven direct loss or damage. However, the compensation shall not exceed an amount equal to ten times the fee charged for the service in question. The maximum compensation shall never exceed USD 2 million.
In this provision the "Society" shall mean DNV GL AS as well as all its direct and indirect owners, affiliates, subsidiaries, directors, officers, employees, agents and any other person or entity acting on behalf of DNV GL AS.

NON-DESTRUCTIVE TESTING

1. Radiographic testing

Procedure ref. -	Acceptance criteria -	Result -	
Film type -	Screens -	IQI -	
KV -	mAmin. -	Sensitivity -%	Density -

2. Ultrasonic examination

Procedure ref. **NVT/UT-2**	Acceptance criteria **PN-EN ISO 11666; level 2**	Result **ACC / Pozytywny**

3. Other examination Type: **Magnetic particle examination - wet method** **Report No.: nvt/MT/1371/14**

Procedure ref. **NVT/MT-5**	Acceptance criteria **PN-EN ISO 23278; level 2x**	Result **ACC / Pozytywny**

Place and date Laboratory signature and stamp	Reveiwed by **Janusz Stęchły**

MECHANICAL TESTING (According to **DNV-OS-C401** **Report No. TNL/048/2014**)

1. Tensile tests Specified R_{eH} Specified Rm: **490 ÷ 630 MPa**

Test No.	Dim (mm)	Area (mm²)	Yield load (kN)	ReH (N/mm²)	U.T. load (kN)	Rm (N/mm²)	A, % on	Remarks
4-1	**24,70 x 11,50**	**284**	**-**	**-**	**156,3**	**550**	**-**	
4-2	**24,80 x 11,25**	**279**	**-**	**-**	**156,5**	**561**	**-**	

2. Bend tests Specified **180** degr. Former diameter **40 mm**

Type and dimensions	Results	Type and dimensions	Results
4-1; SBB; 10 x 12	**ACC / Pozytywny**		
4-2; SBB; 10 x 12	**ACC / Pozytywny**		
4-3; SBB; 10 x 12	**ACC / Pozytywny**		
4-4; SBB; 10 x 12	**ACC / Pozytywny**		

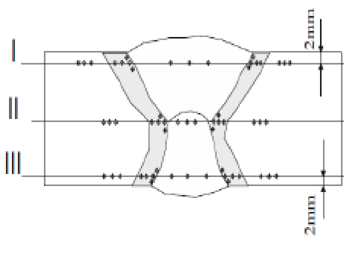
3. Impact tests Type: **KV2 7,5** Size: **10 x 7,5 mm - 5/6 KVT** Requirement: **Minimum (5/6) 20J**

Notch Location/Direction	Temp. °C	Values, J 1	2	3	Average J	Remarks
VWT 0/1 / Transverse - 5/6KVT	**-40**	**37,3**	**58,8**	**67,7**	**54,6**	**- Impact energy requirement**
VHT 0/1 / Transverse - 5/6KVT	**-40**	**30,4**	**28,4**	**34,3**	**31,0**	**for sub-size speciments:**
VHT 2/1 / Transverse - 5/6KVT	**-40**	**39,2**	**39,2**	**39,2**	**39,2**	**10 x 7,5 mm - 5/6 KV;**
VHT 5/1 / Transverse - 5/6KVT	**-40**	**23,5**	**22,6**	**34,3**	**26,8**	**- 10 x 10mm KVT 24J * 5/6 =**
						= 10 x 7,5 mm KVT 20J

4. Macro examination **No weld defects were observed, see report No. TNL/048/2014**

5. Hardness test Specified type if test::

Sketch showing indentations



BM	Hardness	HAZ	Hardness	WM	Hardness	HAZ	Hardness	BM	Hardness
I	**160**	**I**	**177**	**I**	**204**	**I**	**247,245,244**	**I**	**150**
I	**154**	**I**	**192**	**I**	**201**	**I**	**222**	**I**	**156**
I	**155**	**I**	**229,212,227**	**I**	**199**	**I**	**192**	**I**	**156**
II	**152**	**II**	**166**	**II**	**190**	**II**	**202,197,200**	**II**	**160**
II	**156**	**II**	**181**	**II**	**187**	**II**	**198**	**II**	**166**
II	**160**	**II**	**195,194,192**	**II**	**194**	**II**	**191**	**II**	**154**
III	**162**	**III**	**173**	**III**	**208**	**III**	**210,219,195**	**III**	**162**
III	**156**	**III**	**198**	**III**	**212**	**III**	**171**	**III**	**166**
III	**159**	**III**	**221,215,218**	**III**	**205**	**III**	**162**	**III**	**158**

6. Other tests Type and results:

Place Laboratory signature and stamp	Date	Reviewed by **XXXXXXXXX XXXXXXXX**

We hereby certify that by virtue of the information given on page 1 of this form and the laboratory test results given above, this welding procedure meets the Code/Standard and/or purchaser's specification, and that within the limitations given in the Code/Standard and/or purchaser˝s specification by our signature is approved for welding on said product.	Place Date Surveyor **XXXXXXX XXXXXX**

Appendix IV

Wytwórca/Manufacturer	**WPS** *Instrukcja technologiczna spawania/* *Welding procedure specification*	*Nr WPS/WPS No:* **136/12/E36N/BF/bs** *Nr WPQR/WPQR No* **O/136/12/E36N/BF/bs/2015** **S/136/12/E36N/BF/bs/2015**

Metoda spawania/ Welding process	**136**	*Pozycja spawania/ Welding position*	**PF**	*Typ złącza/ Joint type:*	**BW bs nb**

MATERIAŁY PODSTAWOWE/BASE MATERIALS

Gatunek/Grade: **(A;B): A(+N) ÷ NVE-36(+N)**	*Grupa/Group:* **1.2 (PN-CR ISO 15608)**	*Grubość/Thickness:* **t = 6 ÷ 24 mm**

MATERIAŁY DODATKOWE/WELDING CONSUMABLES

Spoiwo (średnica, marka, klasyfikacja)/Filler material (diam, trade name, classification) **Ø1,2 OUTERSHIELD 71M-H** PN-EN ISO 17632-A: T46 2 P C 1 H5	*Rodzaj gazu, przepływ/Description of gas, flow* **C1 (100% CO_2)** **17÷21 l/min** PN-EN ISO 14175 *Dysza gazowa / Gas nozzle:* **MB 15**

SPECJALNE WYMAGANIA/SPECIAL REQUIREMENTS

Podgrzewanie wstępne/Preheating: **Min. 40°C**

Temperatura międzyściegowa/Interpass temperature: **Max. 125°C**

Podkładka/Backing **Nie dotyczy / NA**

Rodzaj ściegu/Bead kind: **Ściegi zakosowe / Weave beads**

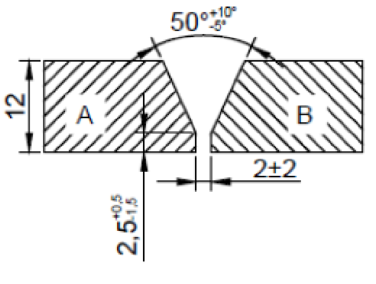
Żłobienie/Gouging: **Elektro-powietrzne**
Arc- air gouging

Wolny wylot/Stick out: **15 ÷ 20 mm**

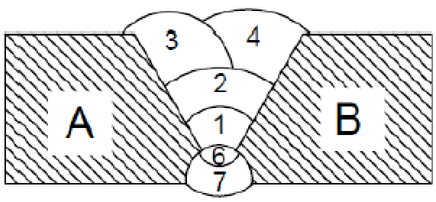
Przygotowanie,czyszczenie, UWAGI/

1. **Cięcie plazmowe, szlifowanie.**
   Plasma cutting, grinding.
1. **Po cięciu termicznym powierzchnie rowka szlifować.**
   Grind groove surfaces after thermal cutting.
2. **Łuk zajarzyć w rowku spawalniczym.**
   Strick the arc in the weld groove.
3. **Poszczególne warstwy dokładnie oczyścić.**
   Clean carefully all beads.
4. **Początek następnego ściegu cofnąć względem końca poprzedniego ściegu o min. 30 mm.**
   The start of succesive weld bead move back min. 30 mm from the end of previous bead.
5. **Po żłobkowaniu szlifować w celu usunięcia warstwy nawęglonej.**
   Excavated area shall be grind to ensure removal of carbon enriched area.groove.

Przygotowanie złącza/Joint preparation



Kolejność układania ściegów/Welding sequences



Sczepianie/Tacking

Metoda/Method: **136**
Mat.dodatkowy/Consumables: **Ø1,2 OUTERSHIELD 71M-H**
Długość sczepu/Lenght: **25 ÷ 50 mm**
Liczba warstw/No of runs: **1**
Spoin na metr/Tacks per meter: **2 ÷ 4**

PARAMETRY SPAWANIA/WELDING PARAMETERS

Nr ściegu/ Pass No	*Rodzaj prądu/ Type of current*	*Natężenie/ Amperage [A]*	*Napięcie/ Voltage [V]*	*Prędkość podawania drutu/ Wire feed [m/min]*	*Prędkość spawania/ Welding speed [mm/min]*	*Energia liniowa/ Heat input [kJ/mm]*
1	**DC+**	**125 ÷ 140**	**19,5 ÷ 22,5**	**-**	**84 ÷ 97**	**1,21 ÷ 1,80**
2; 6	**DC+**	**165 ÷ 185**	**20,5 ÷ 23,5**	**-**	**190 ÷ 219**	**0,74 ÷ 1,10**
3 ÷ 4; 7	**DC+**	**165 ÷ 185**	**20,5 ÷ 23,5**	**-**	**179 ÷ 206**	**0,79 ÷ 1,17**

WPS zgodny z normą / WPS according to: DNV Rules for Ships, DNV OS-C401

Opracował/Compiled by	*Zatwierdził/Approved by*
………………………………………………………………..	………………………………………………………………..
Podpis i data/Date and signature	*Podpis i data/Date and signature*