AUGMENTED RESEARCH ON DAILY-BASIS IMPROVEMENTS OF WELDING AND NDT ECONOMY IN SHIPYARDS

A Dissertation Presented

by

HUSSAM EL SEIDI, DIPL.-ING., BSC., NAVAL ARCHITECT, IWE, EWE, SFI

Submitted to the Swiss School of Business and Management

in partial fulfillment

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DOCTOR OF BUSINESS ADMINISTRATION (DBA)

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Dedication

To my dear wife Renate, who has encouraged and supported me throughout the DBA journey.

Acknowledgments

I acknowledge the continuous support of my mentor Dr. Giacomo Marzi, who supported me with material and advice at all times, including when he was busy. Without his motivation and encouragement, the dissertation would not have been possible to be carried out with the presented content and quality.

Furthermore, I acknowledge the high quality of the DBA procedures and introductions presented by SSBM as well as the extraordinary structure of the DBA material and milestones.

The DBA has exceeded the research and study targets, and it was evident that DBA could add a considerable amount of learning, joy, and true value to the career.

Thank you for the support of SSBM in achieving this great degree.

ABSTRACT

AUGMENTED RESEARCH ON DAILY-BASIS IMPROVEMENTS OF WELDING AND NDT ECONOMY IN SHIPYARDS

MAY 2021

HUSSAM EL SEIDI

DOCTOR OF BUSINESS ADMINISTRATION

SWISS SCHOOL OF BUSINESS AND MANAGEMENT

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Co-Chair: <If applicable. Co-Chair's Name>

The welding process is expensive and represents a considerable part of the overall process of any shipyard. The shipbuilding welding target is to manufacture a sound hull with no welding defect and as stated by the rules, regulations, and international standards.

The up-to-date information in the shipbuilding and from shipyards have shown the requirement for continuous research in the relevant welding sectors, nondestructive tests, and quality control and assurance during the shipbuilding phase.

Adding new value based on hands-on experience gained in shipyards worldwide and problem areas that occur globally on a day-to-day basis and their smart measures has been considered thoroughly in this dissertation.

Research has demonstrated the definite requirement in considering boosting the proficiency of production in shipyards and the cost-effectiveness. The fusing superiority and nondestructive tests are major factors.

The optimum mutual joining procedures, most common materials and those most commonly applied in shipyards and shipbuilding, and quality control will be summarized—adding

hands-on practical experience gathered in major shipyards—and this will lead to recommendations on how major factors could be better managed on how they could improve the quality, welding, and nondestructive tests economy alike, forming state-of-the-art research.

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LIST OF ABBREVIATIONS

Abbreviation	Description
DNV-GL	Det norske Veritas - Germanischer Lloyd
ABS	American Bureau of Shipping
IACS	International Association of Classification Societies
AWS	American Welding society
ASME	American Society for Mechanical Engineers
ASTM	American Society for Testing Materials
BS	Balanced Scorecard
SAW	Submerged Arc Welding
FSW	Friction Stir Welding
NDT	Nondestructive Testing
VT	Visual Testing
PT	Penetration Testing
MT	Magnetic Particle Testing
UT	Ultrasonic Testing
RT	Radiation Testing
FSW	Friction Stir Welding
GMAT	Gas Metal Arc Welding
SMAW	Shielded Metal Arc Welding
MAG	Metal Active Gas
MIG	Metal Inert Gas
TIG	Tungsten Inert Gas
RSM	Responsibility Sharing Management

Chapter I:

INTRODUCTION

1.1 Introduction

The developments of recent years in shipyards and shipbuilding have shown the requirement for additional research in important sections of the shipyards, mostly the welding procedures, nondestructive tests (NDT), and quality.

New shipbuilding projects have particular circumstances and features, including technical expertise.

Consequently, producing ships is a topic with many factors that may limit the production speed inside the shipyards, hence introducing major cost increases and project delays.

This dissertation will submit state-of-art practical solutions in important and critical production lines in all shipyards; specifically, improvement of the day-to-day welding, material fabrications, and NDT. Additionally, it will propose a thorough framework for managing problems of the welds, materials, and NDT alongside direct solutions through technical and economical improvements, in a method based on hands-on shipbuilding experience in global shipyards.

Recent studies in that domain showed a gap in introducing the operational features of shipyards, including the relevant factors required for improvement of manufacture and cost-effectiveness, such as weld quality and NDT.

The importance of those studies is that works of literature have considered some topics about shipyard welding and NDT procedures. However, the research is insufficient, and consequently, needs for further research were addressed.

By studying along with evaluating the literature reviews and case studies, future research needs, a considerable number of gaps have arisen and have shown a lack of study, and thus a zone of interesting research is considered in the dissertation.

The citations have shed light on several important points on welding, materials, quality, and NDT, such as summaries, similarities and differences, and logical aspects of connections. The critical reviews have led to significant gaps, their further research, and proper solutions, where advice to the shipyards will represent major contributions of this dissertation.

The importance of this topic supports the motivation to conduct additional research on it. The outcome could be extremely valuable to shipyards along with diverse maritime companies dealing with welding, materials, NDT, and welding quality.

A methodology, the comparison of studies and relevant case studies, collected data from yearly shipyard reviews, survey results, and hands-on experience will produce valuable and significant solutions to relevant existing research questions and problems.

The focus is on adding practical solutions based on hands-on experience gained in shipyards worldwide, and problem areas that occur globally on a day-to-day basis and their explanations.

The benefit of this dissertation will be that solutions will be practice oriented. The solutions could be implemented immediately in the practices of welding, materials, and NDT, leading to improved quality and major cost-effectiveness in the shipyards, shipping companies, marine equipment manufacturers, and welding companies.

1.2 Research Problem

The weight of developing the cost-efficient production methods has been calculated and applied by the shipyards, especially in noteworthy areas such as naval architecture.

However, major ship construction along with ship-repair schemes remains face project delays and cost increases outside of budget that could often induce production delays or the loss of important customers, particularly in economically challenging times with low or restricted budgets.

When welding processes, materials, NDT, and weld quality control (QC) are not properly identified during scheduling, conflicts herewith are expected.

Current projects, particularly ship construction and ship-repair projects, are becoming extremely complicated with major challenges, causing severe financial issues concerning project progress.

In welding and NDT—as leading processes in shipyards and the marine environment—shipyard companies need a clearer strategy of how to select the most efficient welding procedure, materials, and NDT.

Recent developments at the shipyard field have concentrated on optimizing the welding processes, so that they are better managed, both technically and economically.

The importance of the investigation topic means that works of literature that were reviewed have considered some topics about shipyard welding and NDT procedures. However, the research is insufficient, and consequently, needs for further examinations are addressed here.

Taken together, this constitutes the motivation for conducting further exploration on this subject matter due to its significance. The outcome could be extremely valuable to shipyards and companies dealing with welding, materials, and NDT, and to welding quality.

The thesis concentrates on adding practical solutions based on hands-on experience gained in shipyards worldwide and problem areas that occur globally on a day-to-day basis and their explanations.

The benefit of the dissertation will be that solutions will be practice oriented. The solutions could be implemented immediately in the process of the welding, materials, and NDT, leading to improved quality and major cost-effectiveness in the shipyards, shipping companies, marine equipment manufacturers, and welding companies.

1.3 Research Purpose

The target of the dissertation will be handling quality problems of welding, materials, NDT, and quality regarding gaps and research questions, improving the implementation to those striving to boost the shipyard's productivity, cost-effectiveness, and competitiveness. This will deliver the outcome of the study.

In particular, the objectives are the following:

1. To deliver a comprehensive review of welding processes, material properties, and NDT methods.

2. To implement a methodology for choosing the best combination of welding, materials, and NDT possibilities to attain the best quality.

3. To review current shipyards and welding companies' practices and research on improvement of the welding processes and welding QC in shipyards and marine, industrial, and welding companies.

4. To demonstrate examples of how shipyards and welding facilities and NDT operations might be more economical in production by identifying the most appropriate welding processes. A comparison between production costs on this should demonstrate the obvious differences,

considering that the above objectives are SMART objectives, where

S means "specific"

M means "measurable"

A means "attainable"

R means "realistic"

T means "time-bound"

1.4 Significance of the Study

The focus of this DBA dissertation is on adding practical solutions based on hands-on experience gained in shipyards worldwide and problem areas that occur globally on a day-to-day basis as well as their explanations.

The benefits of this dissertation will be that solutions will be practice oriented. The solutions could be implemented immediately in the welding process, materials, and NDT, leading to improved quality and major cost proficiency of the following foremost maritime and industry sectors:

Shipyards for ship newbuilding

Shipyards for ship repair

Shipyards for ship conversions

Classification societies

Welding societies

Shipping companies

Marine companies

Welding companies

Material laboratories

Nondestructive testing companies

Any industry concerning welding, materials, and testing

Any companies associated with welding gases

Any company concerning with steel, aluminum, or alloy fabrications

QC and quality assurance (QA) companies

Cost analysis companies

Material labs

Scientific weld methods

Researchers

1.5 Research Purpose and Questions

Objectives are established to find answers to the gaps and research questions in a practical method based on hands-on shipyard experience.

Table 1

Identified Gaps and Research Questions (4.1).

What welding factors decide the quality and processes of welding in shipyards?

4.1.	What welding factors decide the quality/processes of welding in shipyards?
	4.1.1 Why does the choice of the welding process play a considerable role in the welding economy?
	4.1.2. How should the right welding process be chosen in the context of material choice?
	4.1.3 In the case of multiple shifts, how is welding quality assurance supervised?
	4.1.4. What materials could be welded with SAW and FSW? What material thicknesses apply to SAW and FSW? How many restrictions have SAW and FSW shown? How could an NDT plan be synthesized to examine welding quality for SAW and FSW? Which characteristics do SAW and FSW typically have?
	4.1.5. What welding parameters cause what failures? What factors affect the formation of porosity? How feasible is preheating of welding electrodes? What materials need special cleanliness before welding and why? How should the benchmark of defining the rate of deficiencies in the welds be defined? How should the above rate affect the remaining and additional inspections? Why could hot cracks result when welding stainless steel?

4.1. What welding factors decide the quality/processes of welding in shipyards?

4.1.6 What are the acceptance criteria for the HAZ in welded shipbuilding high-tensile steel?

4.1.7.

Which NDT should be chosen for what material?

Why and when is a combination of NDT methods reasonable?

When is a dye penetrant advisable as an NDT method?

What are the limitations of NDT methods?

Table 2

Identified Gaps and Research Questions (4.2).

How DFP could be achieved in shipyard welding operations, leading to competitiveness?

4.2.	How DFP could be achieved in shipyard welding operations, leading to competitiveness?
4.2.1.	How to carry out a welding procedure specification (WPS) and be approved in advance? What factors are required to design a WPS in a shipyard?
4.2.2	Which measurements are acceptable for the throat thickness and leg length?
4.2.3	What design for the welding position should be considered?
4.2.4	How are materials analyzed for weldability given high-strength steels?
4.2.5.	Why do distortions occur in a welded joint and how those could be prevented? How could distortions be better managed in the welding sequence? What welding parameters have a major role on the welding quality when welding steel grade, AH36, Dh36, and E36?
4.2.6.	What factors affect the edge preparation for the weld of low-carbon steel? How does a proper edge preparation contribute to high-quality welding of low-carbon steel?

Chapter II:

LITERATURE REVIEW

2.1 Theoretical Framework

The developments of the previous years in the shipbuilding business have shown the requirement for additional research in important fields among shipyards, mostly the welding procedures, NDT, and their quality and economies.

The purpose of the literature review was to determine what topics had previously been researched and how helpful the results were and eventually find gaps that might be filled by the dissertation. The conclusions of the previous studies have indicated gaps and forthcoming opportunities that are yet to be explored.

The prominence of the study topic derives from the fact that although works of literature cited in the list of mentioned referencing have considered some topics about shipyard procedures, the research is insufficient.

From analysis of works of former literature and case studies, future research needs and a considerable number of gaps have arisen, giving rise to the research questions, described in detail in the problem statement above and systematically addressed in the dissertation.

The citations have shed light on several important points in the form of summaries, relationships, disagreements, and logical aspects of connections. The resulting gaps and their further research will form the significance and benefit from this dissertation.

The methodology includes the comparison of studies and their reviews and relevant case studies and related data collection, collection of data from yearly shipyard reviews and survey results, analysis of those data and own adding valuable hands-on experience. This methodology has produced major solutions to relevant existing questions, main questions, subquestions, and problems.

The literature review aimed to find gaps to demonstrate the necessity of advanced solutions. However, the research concentrates on adding practical solutions based on hands-on experience gained in shipyards worldwide and problem areas occurring globally on a day-to-day basis.

The benefit of the dissertation will be that solutions will be practice oriented. The solutions could be implemented immediately not only in the shipyard processes but on all welding and NDT companies.

Chapter III:

METHODOLOGY

3.1 Overview of Research Methodology

3.1.1 Methodology

The primary research methodology for this dissertation is a well-structured methodology for researching and gathering data for the dissertation, where the following resources might be fully or partly applied:

An examination of research in the disciplines of welding, materials, NDT, and quality.

Revision of case study about welding materials, NDT, and quality.

Review of available materials from the international institute of welding (IIW) or other relevant institutions.

Data from major classification societies' rules.

Data from the international society of classification societies (IACS).

Data from recognized organizations, including EN, ISO, ASW, ASME, and ASTM.

Data from annual shipyard reports and surveys.

Data analysis will follow data gathering.

Own hands-on shipyard global experience as naval architect, principal-surveyor, and executive for ship newbuilding, ship repair, and refitting of all ship types.

Own hands-on experience as weld manager and in welding engineering and supervision in shipyards, and class societies, for ship newbuilding, ship repair, and refitting.

Own hands-on experience as NDT manager for ship newbuilding, and ship repair and refit in shipyards and classification societies.

3.2 Method

A pattern of literature review, progression analysis, state-of-the-art review, history review, and classification.

3.3 Research Design

Depending on the methodology, the design includes a mix of qualitative and quantitative research designs.

3.4 Study Design Scheme and Data Collection Procedures

Table 3

Methodology

NR.	Methodology	Method
1	Research review in the domain of welding, materials, NDT, and quality	Literature review
2	Review of a case study about welding materials, NDT, and quality	Literature review
3	Review of available materials from the IIW or other relevant institutions	Literature review
4	Data from major classification societies rules	Classification
5	Data from the IACS	Classification
6	Data from recognized organizations, including EN, ISO, ASW, ASME, and ASTM.	State-of-the-art review
7	Data from annual shipyards reports and surveys	State-of-the-art review
8	Data analysis will adhere to the collection of data	Process- Analysis
9	Own hands-on shipyard experience as a naval architect, principal-surveyor, and executive for ship newbuilding	History review
10	Own hands-on experience as weld manager of engineering and supervision of shipyards and classification	History review

NR.	Methodology	Method
11	Own hands-on experience as NDT manager for ship newbuilding and ship repair and refitting in shipyards	History review

Chapter IV

Answers to Research Questions

4.1. Cost and Strategic Management of Welding Business

Initially, it is critical to consider what welding factors will be of significance to the welding cost and economy in any shipyard. The significance and value of this dissertation have been proven, including cost reductions for welding, quality improvement, and competitiveness boosts to major shipyards used to research better processes and eventually patent their processes to prevent those from being transferred to competitors in an equivalent field of expertise.

The justifications for patenting are as follows:

Copy prevention

Licensing revenues

Lawsuit prevention

Blocking other companies

Negotiating in a more structured manner

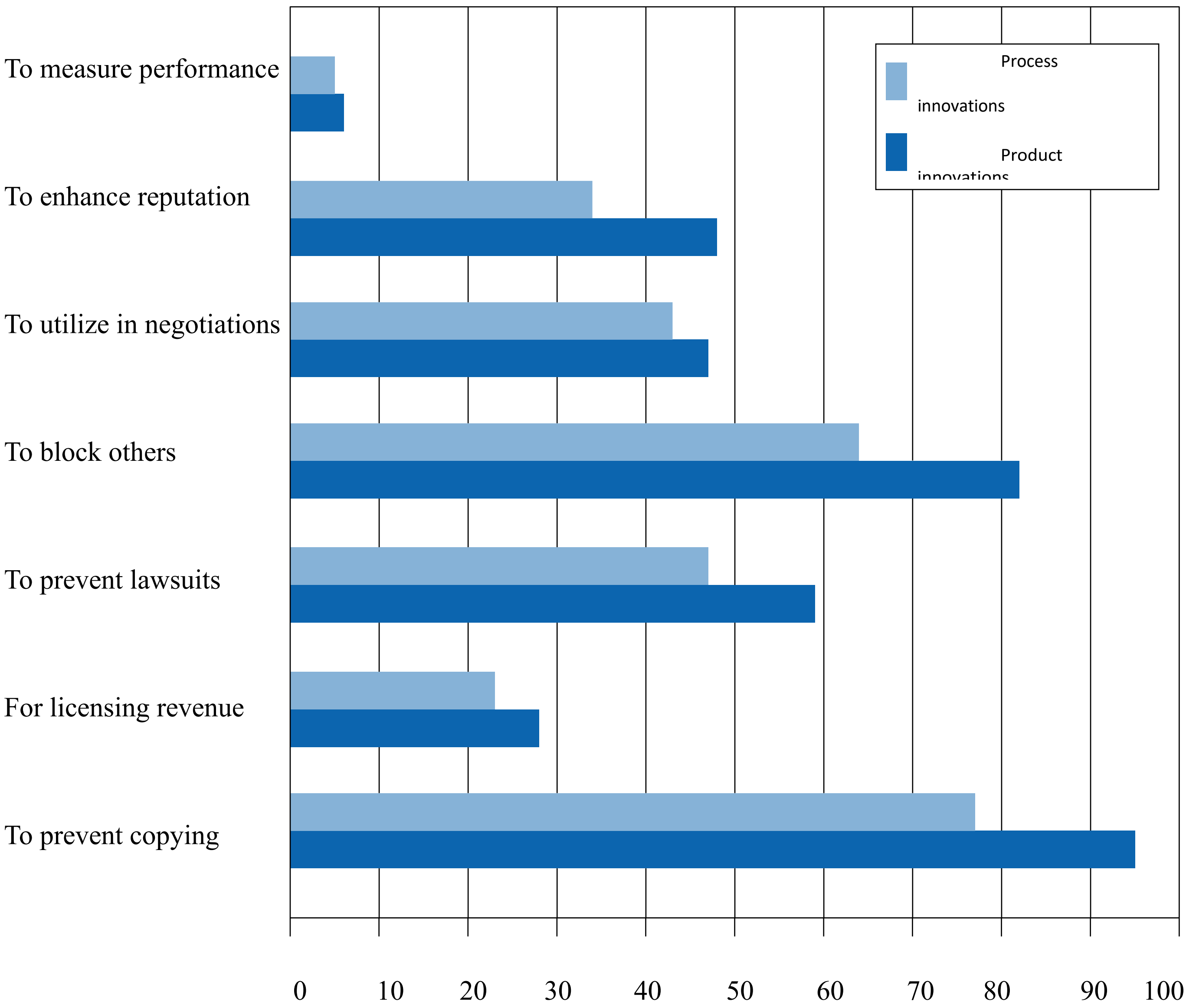
Boosting their image

Assessment of their expertise

The figure below shows incentives for the companies to patent their products. All the above reasons form a requirement for patenting shipyard processes. In weld expertise, it is important to safeguard the welding procedure and innovations since those make the difference in the fabrication cost, competitiveness, and reputability of the shipyards, alike.

Figure 1

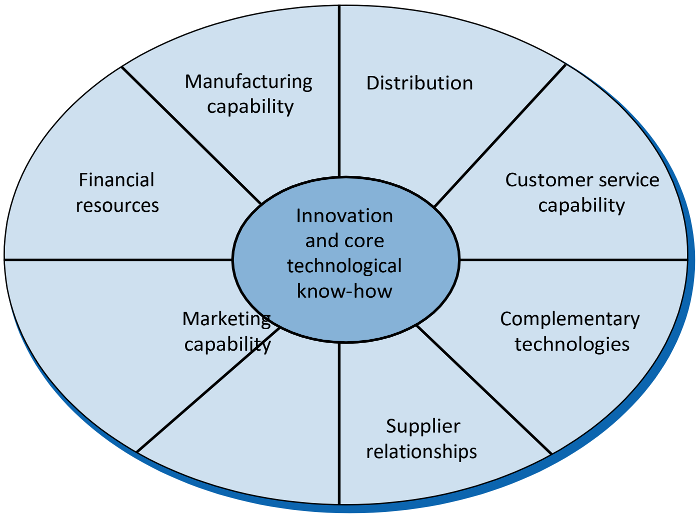
The Reasons for Patenting (Responses by 674 US Companies. Source: Cohen et al. (2000), Grant (2018)



Innovation of products and processes in shipyards requires implementation, including human resources. The ground of expertise in human resources, their motivation, and the management behind them are critical factors in propelling shipyards forward. The design office of a shipyard is key for improving design for production, cost, and quality. These are strategic considerations. Working on designs that cannot be practically fabricated or are extremely difficult and expensive is a waste of resources. There should be no design when not feasible to be economically manufactured. Accordingly, yards are constantly challenged to find new solutions.

Figure 2

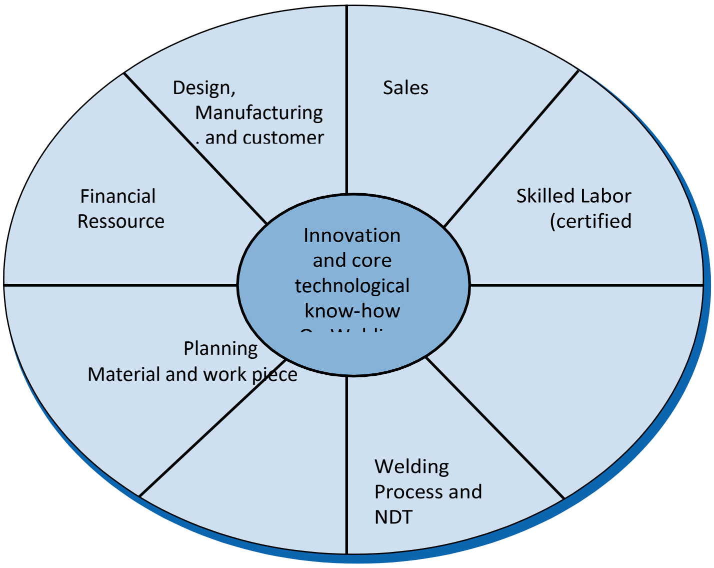
Complementary Resources. Source: Grant (2018)



The above figure also applies to a shipyard at both the design and welding department by adapting relevant factors, demonstrated in the figure below.

Figure 3

Strategic Requirements for an Economical and Efficient Shipyard Operation for Welding Business



In the dissertation, the focus is on developing a strategy for shipyards that includes all previous factors, showing the impact of the strategy on the cost, economy, design, manufacturing, customer service, quality, financial resources, accounting, sales, and marketing. The strategy will prove how efficient planning of skilled labor, choice of materials (workpiece), welding process, and welding machines will directly be significant factors in decreasing overall cost, improving the economy, and hence competitiveness at high welding production quality.

The two main dissertation subjects and diverse subquestions considered will provide important recommendations and checklists that are beneficial in every shipyard that cares for combining manageable, repeatable high welding quality at a competitive cost. This is what the shipyards and clients are striving for. Introducing below research, calculations, and scores in the dissertation will connect the design and production for welded joints in shipyards. Indicating the significance and advantages of the consequences and recommendations will prove the authenticity of the strategic planning for this business and the dissertation. The significance is to understand the entire essentials for the weld fabrication cost as follows:

- Expenses for welders
- Material cost
- Welding processes
- Weld equipment used
- Cost for a proper welding plan

Consideration is made for the factors required for the welding economy. The key to success is improving them. Thereby, optimum profit for the shipyard can be accomplished. As a principle, weld processing could change the cost factors to be profit factors, if the welding process is well planned and professionally managed.

Figure 4

Cost Distribution Between Welding Wire, Shielding Gas, Energy, Maintenance, and Labor in Semi-Automatic MAG Welding. Source (modified from Stenbacka, 2011, p. 93). Forsström (2016).

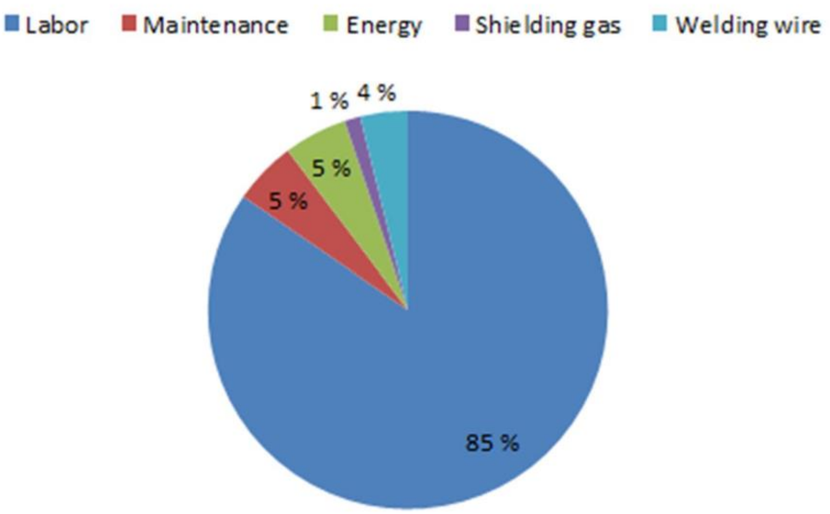


Figure 4 shows an approximate percentage price distribution. However, this is further explained in the subsequent table and figure showing the subdivision under each factor.

The below Table 4 has been created by hands-on experience in several shipyards in different locations worldwide.

Table 4

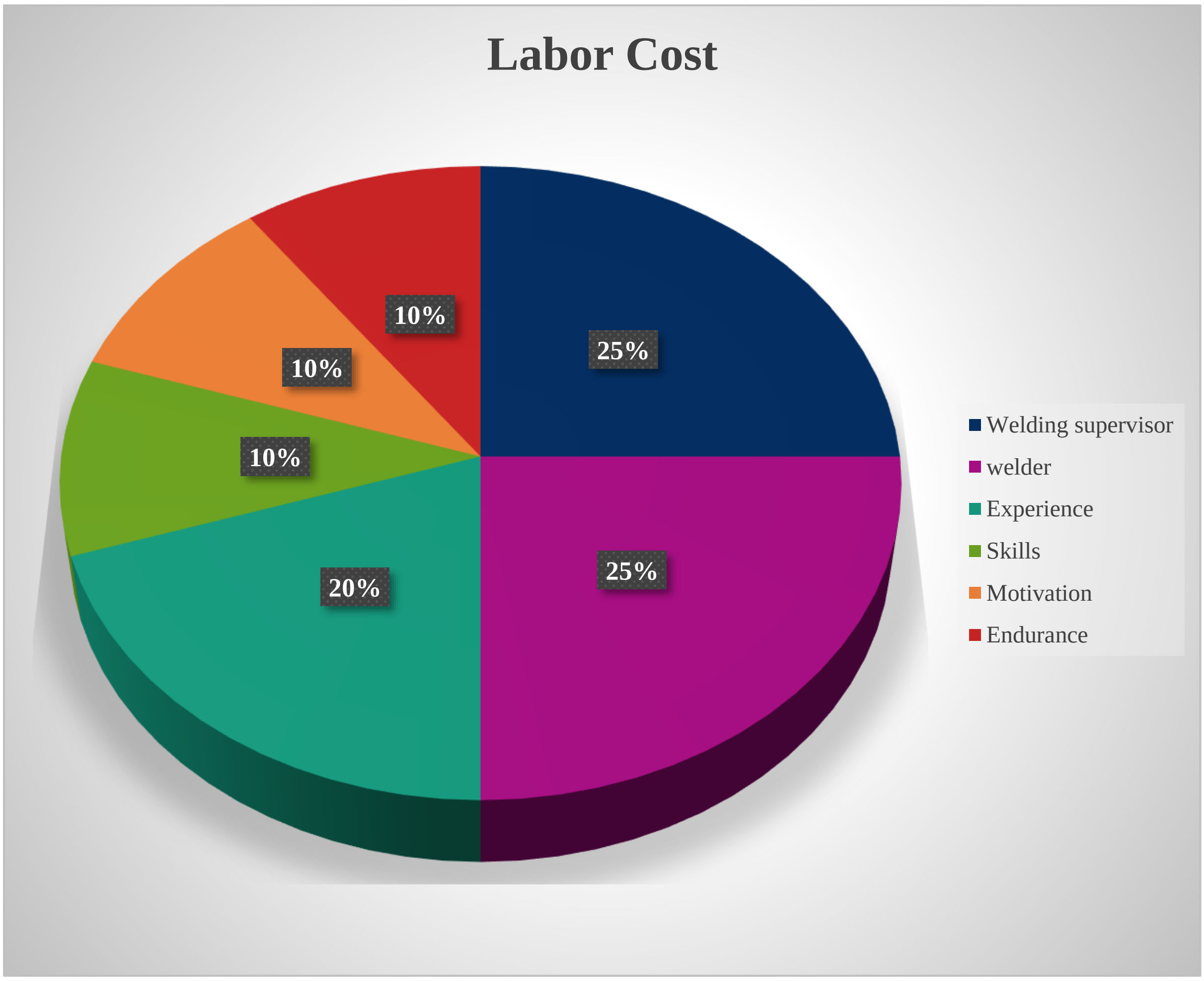
Dynamics that Alter the Weld Production Cost

Dynamics that alter the weld production cost	Labor	Work piece	Process	Machine	Planning
Welding supervisor	25%				
Welder	25%				
Experience	20%				
Skills	10%				
Motivation	10%				
Endurance	10%				
Weldability		20%			
Size		10%			
Weight		10%			
Quantity		10%			
Thickness		20%			
Welding position		10%			
Surface condition		10%			
Location		10%			
Main welding time			20%		
Secondary process time			10%		
Preparation			10%		
Filler metal			10%		
Performance			10%		
Rework			20%		
Application learning			10%		
Safety precautions			10%		
Maintenance				20%	

Dynamics that alter the weld production cost	Labor	Work piece	Process	Machine	Planning
Interest rate				10%	
Handling				10%	
Frequency of use				20%	
Easiness to relocate				10%	
Space required				10%	
Energy consumption				20%	
Quality control					20%
Seam form					5%
Seam arrangement					5%
Material choice					10%
Heat treatment					10%
Choice of process					20%
Access					5%
Welding sequence					5%
NDT					20%

Figure 5

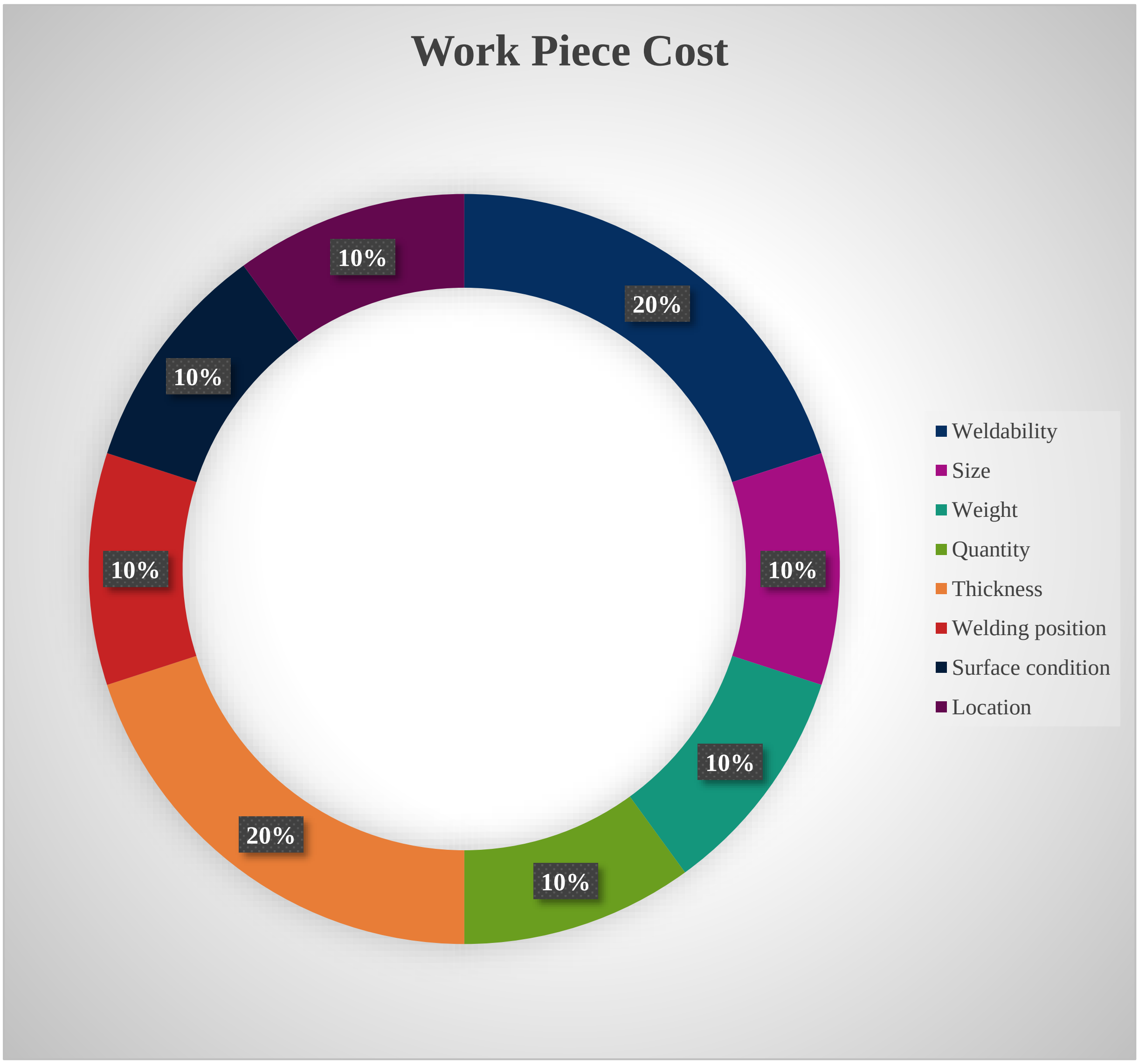
Labor Cost Percentages



This figure shows the subdivision of the workforce expense and cost calculation. It is identifiable that 70% of the price is formed by the welder, the supervisor, and their experience.

Figure 6

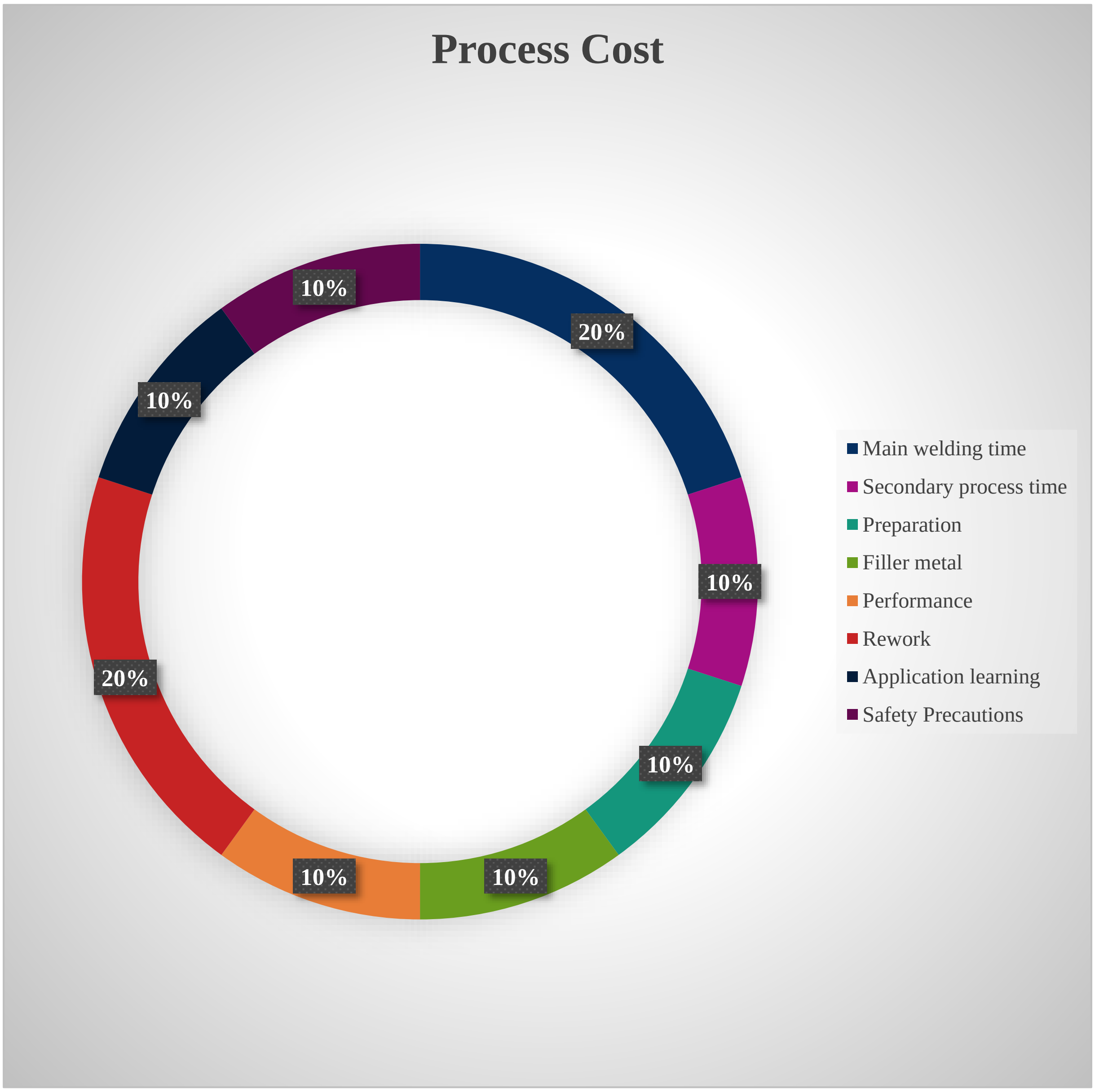
Workpiece Cost Percentages



This figure shows the sharing of the expense of the workpiece. Forty percent of the welding expenses are reliant on the weldability and weld piece thickness.

Figure 7

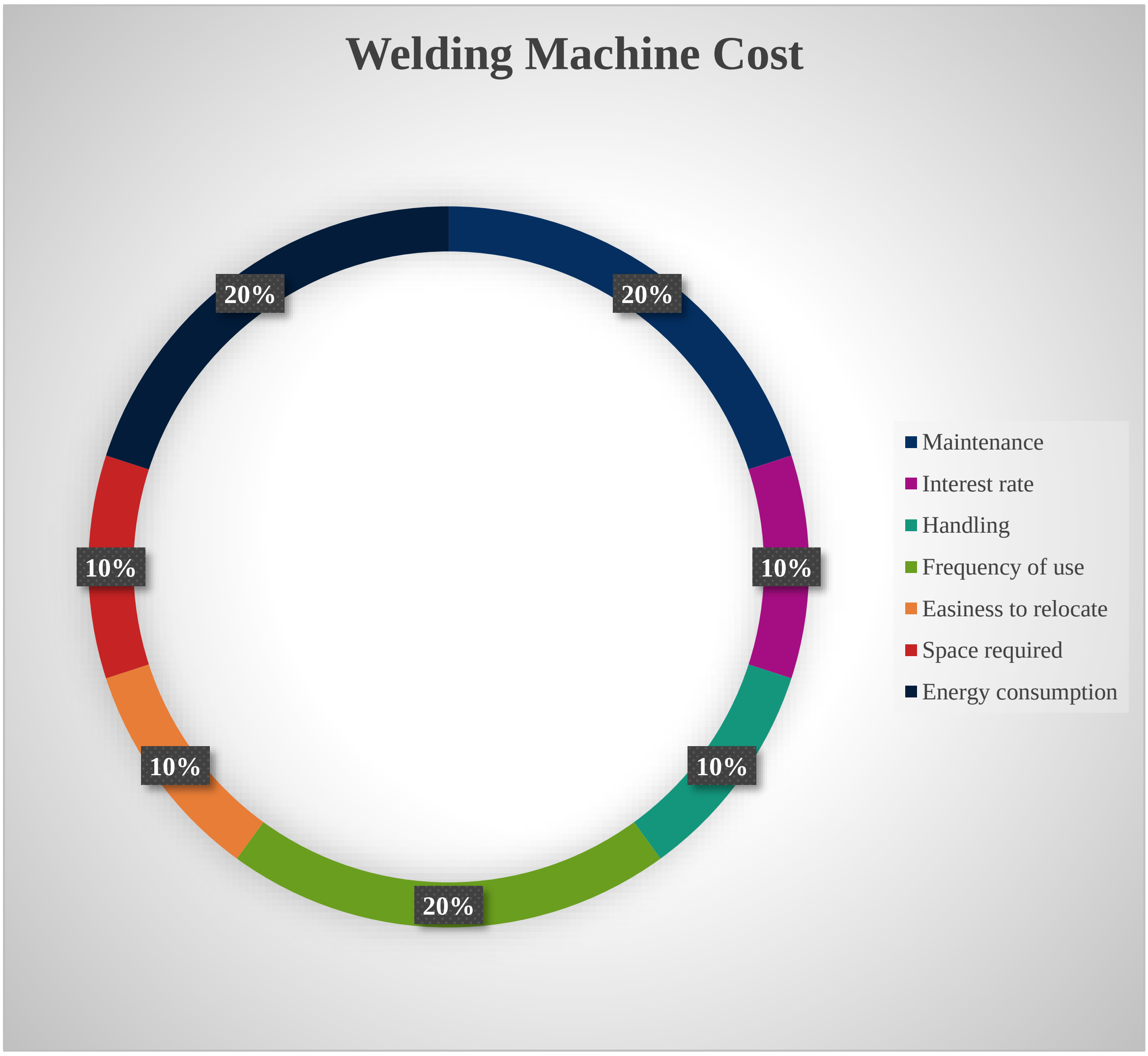
Process Cost Percentages



The main welding time and the provision of welds (edge preparation) build about 40% of the processing welding cost.

Figure 8

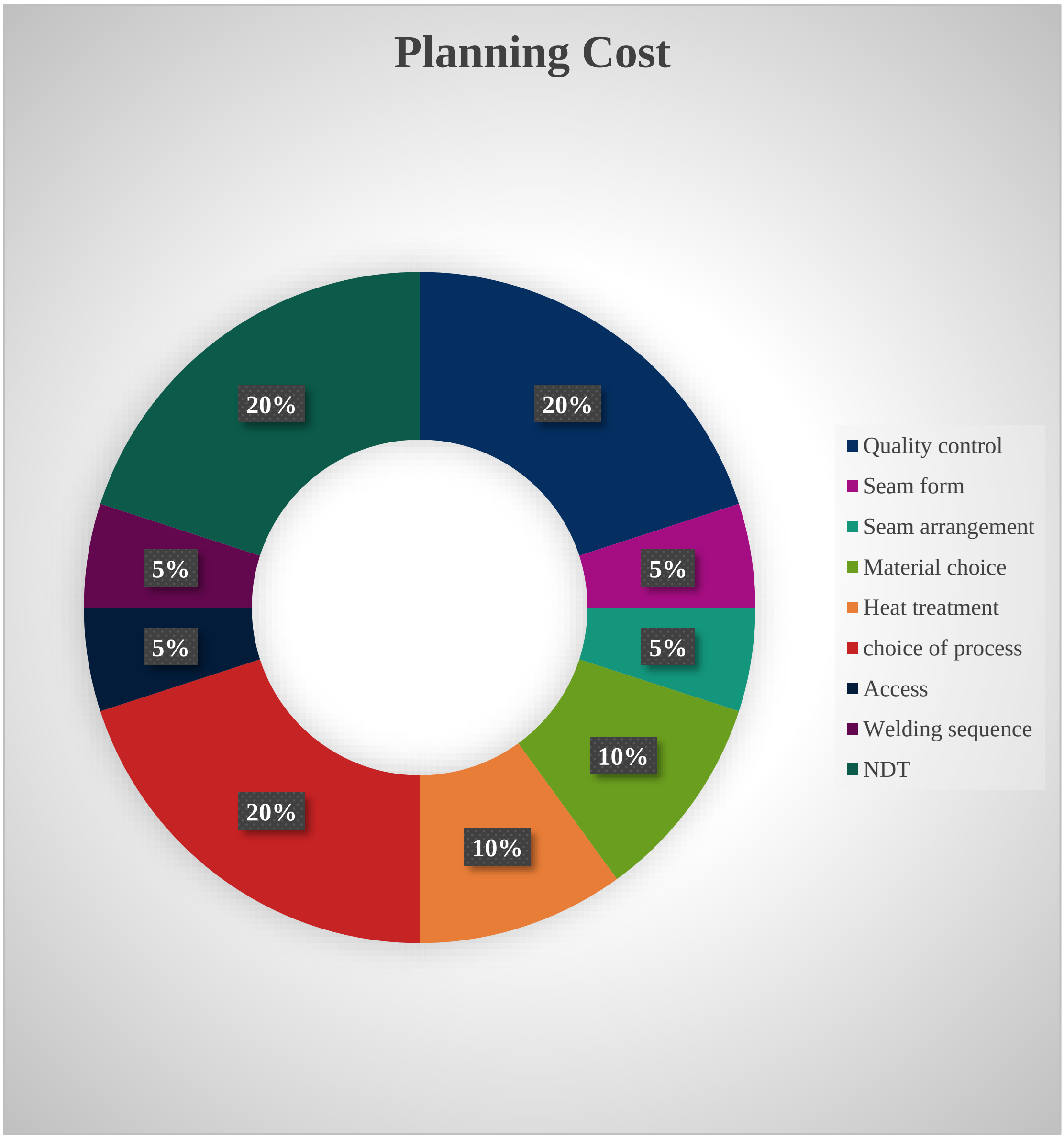
Welding Machine Cost Percentages



The maintenance cost, energy cost, and frequency of machine utilization form 60% of the cost of deployment of the welding device.

Figure 9

Planning Cost Percentages



Sixty percent of planning cost depends on the assortment of the welding processes, QC, and NDT.

Excellent Quality Combined with Talented Management

Saving Potentials

The cost for low quality is especially essential for any shipyard project. The shipyard profits result from the expenses (overheads) and the income. The more the revenue and the less the cost, the greater the profit. The cost reduction for the shipyard could mean more profit in connection to less cost for the shipowner.

The cost reduction may be attained via the following:

Excellent weld quality, leading to no or limited rework requirements

Boosting welding speeds

Reduction of no. of welders

Reducing the diameter of weld consumables; specifically, cost reduction

Reducing weld preparation periods

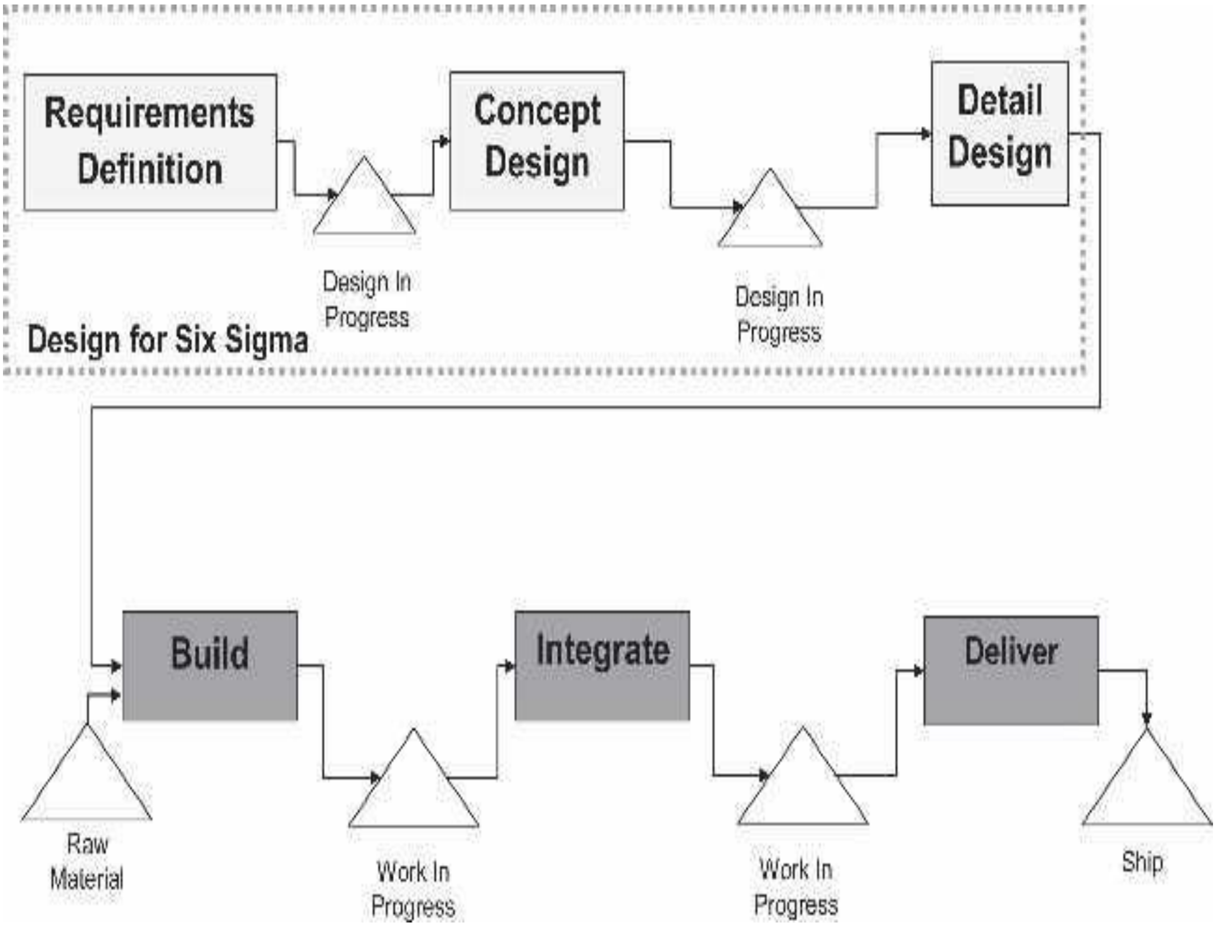
Reducing inspection time for optimum planning

Optimizing the selection of the proper NDT method saves a major portion of the financial plan

Through a proper DFP, WPS, and the correct choice of the welding process, 30–50% cost savings are achievable as displayed in 4.1.1, 4.2.1, and 4.2.2.

Figure 10

Domino Effect of Design. Source: Inozu et al. (2006).



The figure shows the characteristics for knowledge management, lean management, and six-sigma management, and that a quality system is an efficient method of managing the welds. The detailed WPS among the dissertation demonstrates cost savings of about 30%. For these savings, both a high-quality attitude and efficient management are required.

Figure 11

A Continuous Improvement (Philosophy of ISO 9001)

Principle of the Lean-System: Elimination of Non-Value-Added Activities. Principle of the Six-Sigma System: Reduction of Process Variations.

Source: Inozu et al. (2006).

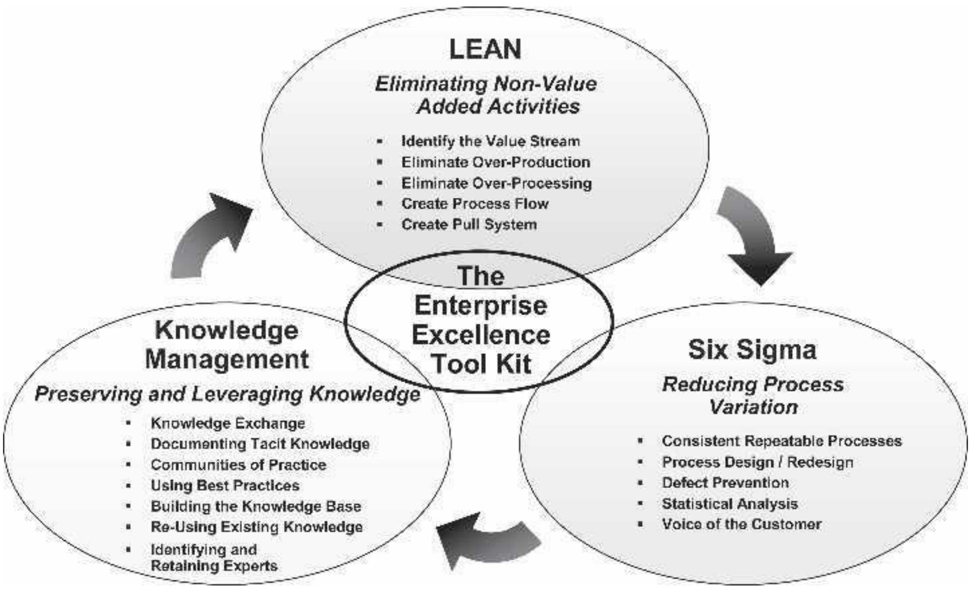


Figure 12

The Overlap of The Lean System and the Six-Sigma System for Quality.

Source: Inozu et al. (2006).

The above figure shows the standpoint of six-sigma and lean system management and quality systems.

Lean management focuses on simplicity and waste elimination. Six-sigma management focuses on perfection and variation elimination. To benefit from both quality philosophies, it is best to integrate them. Significant current discussions are the quality issues and the high costs associated with them. In this dissertation, WPS as a quality checklist and system for welding provides a considerable method of high quality and minimal expense. Cost savings up to 30% may be reached at improved quality.

Strategic Management

When scheduling the company's functions and the procedures reaching the company's targets, the major task is meeting the essential decision about the road map of an organization, developing the training, motivating the team, and developing intelligent procedures to boost the production in the best quality, while monitoring and controlling costs and if required, returning them toward the desired course.

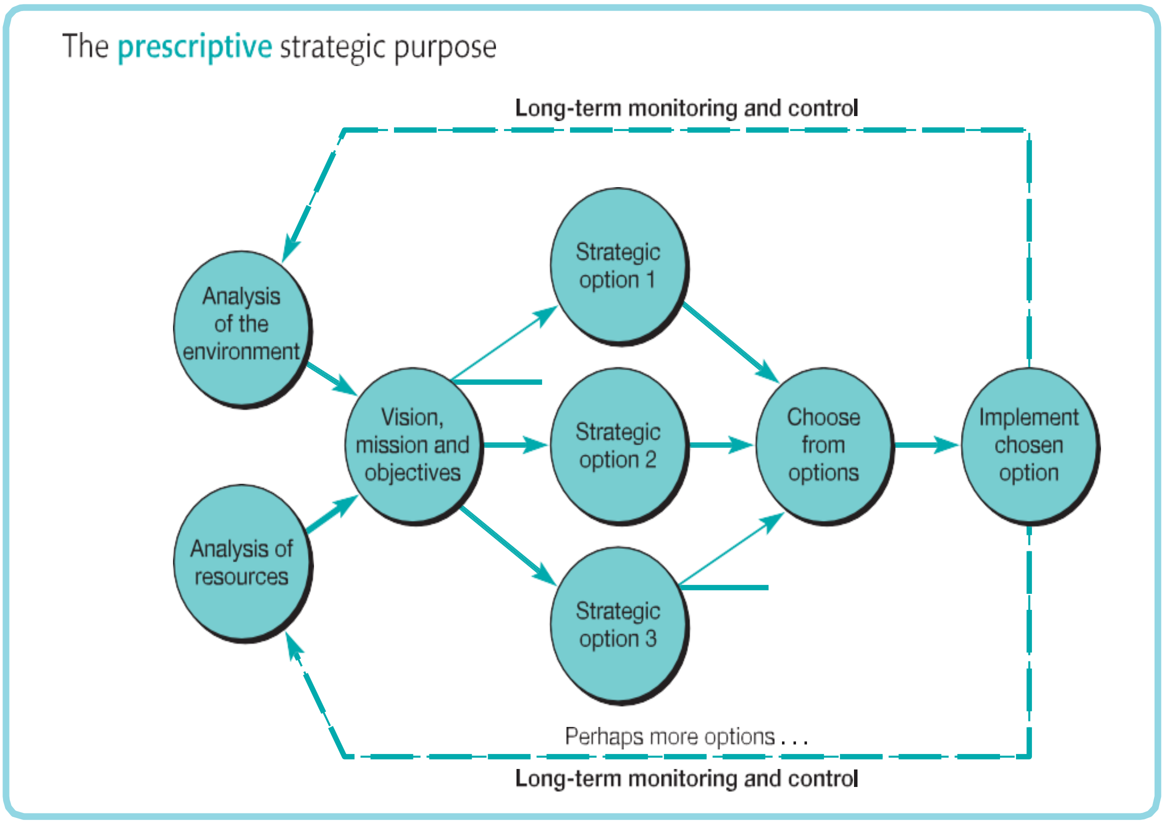
The Prescription Method Concerning Welding Strategy

Any successful shipyard has established visions, missions, and business goals that are the result of strict procedures and a wealth of experience. Welders and materials are required resources.

The fabrication is symbolized by the welding process and testing. Referring to the analysis, demonstrated in this dissertation, major strategic methods to produce welding have been identified. Here, it is about comparing and selecting the best methodology.

Figure 13

The Prescriptive Strategic Purpose. Source: Ritson (2013) and Lynch (2015)



Obtained by long-term monitoring and controls

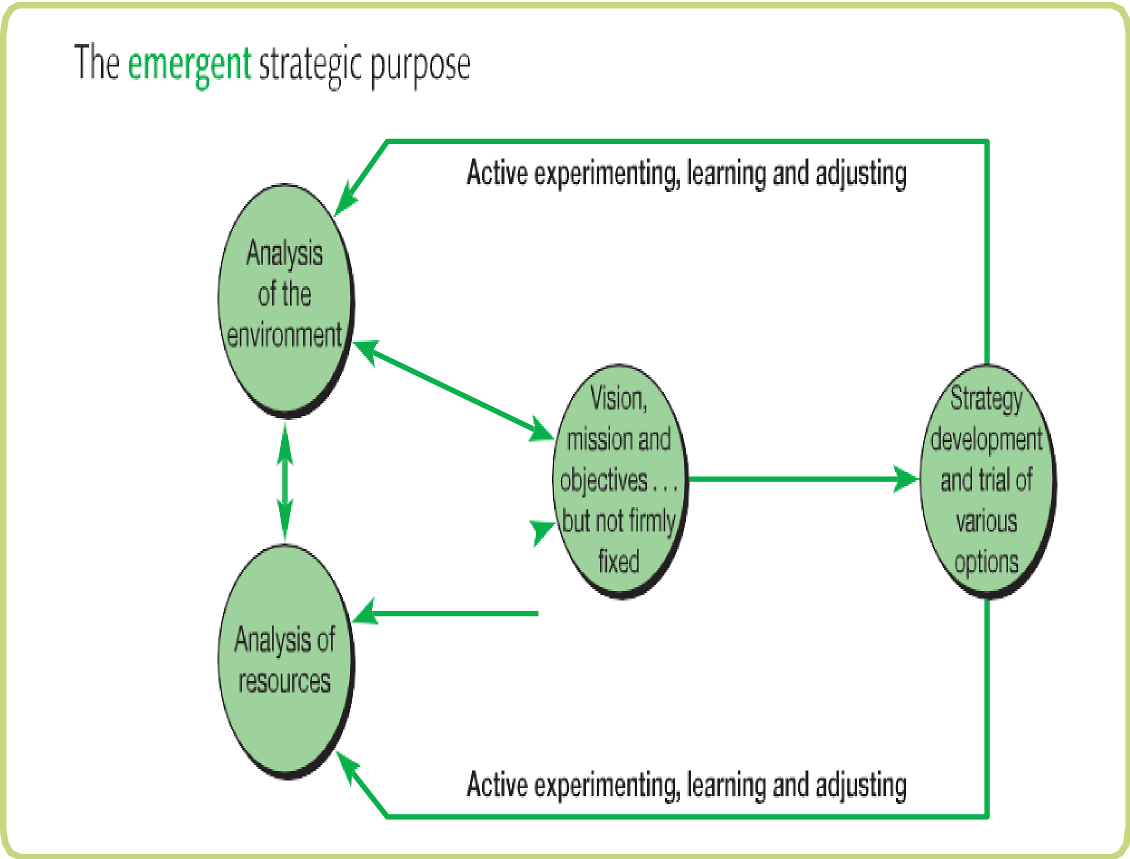
The Emerging Approach of the Strategy of Weld

The difference here contrasted to the former method is that experiments are required. In line with the result of the experiments, a strategic approach to be figured out. The resources are the welders and materials. This is environmentally done by employing the welding process. A proof herewith has been demonstrated in this dissertation under 4.1.1, 4.2.1, and 4.2.2.

Figure 14

The Emergent Strategic Purpose

Source: Lynch (2015).



Obtained by experiments

Competitiveness strategy

This contains the following:

Management of cost-effectiveness

Differences concerning productivity (could be quality, price, or both)

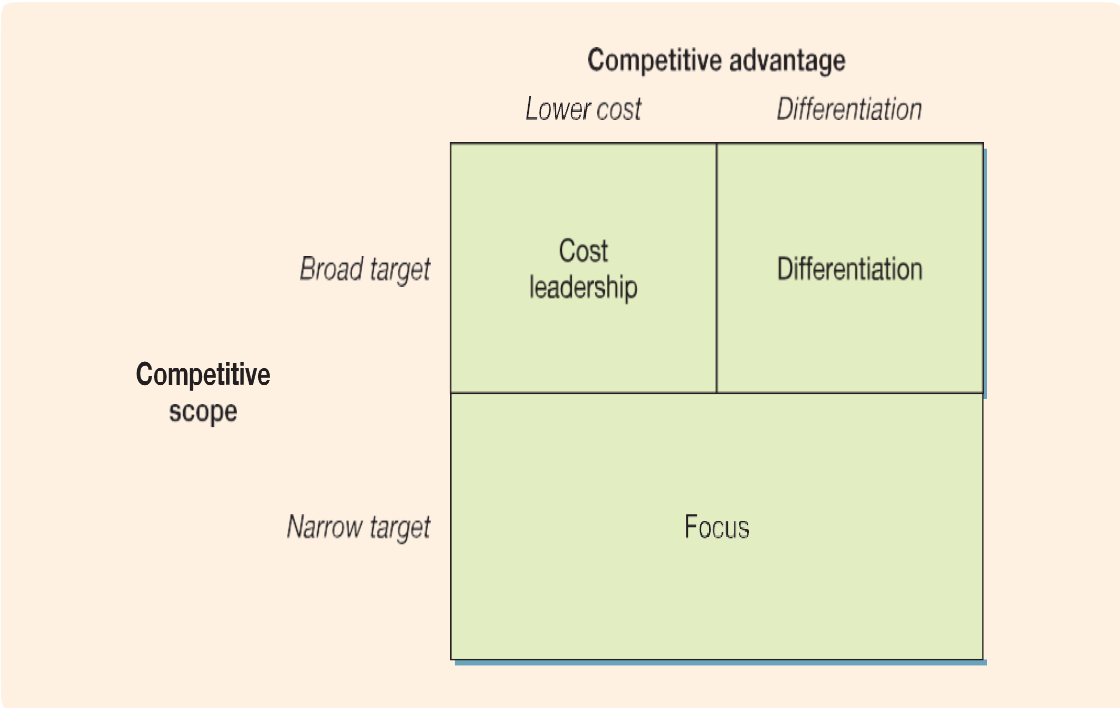
Field of expertise

Both cost leadership (cost savings of 30–50%) and difference barriers through better quality are disclosed in the dissertation. The competitiveness through cost management alongside QC is established in the dissertation in parts 4.1 and 4.2.

Figure 15

Strategy Options

Source: Porter (1985, 1998). Source: Lynch (2015).

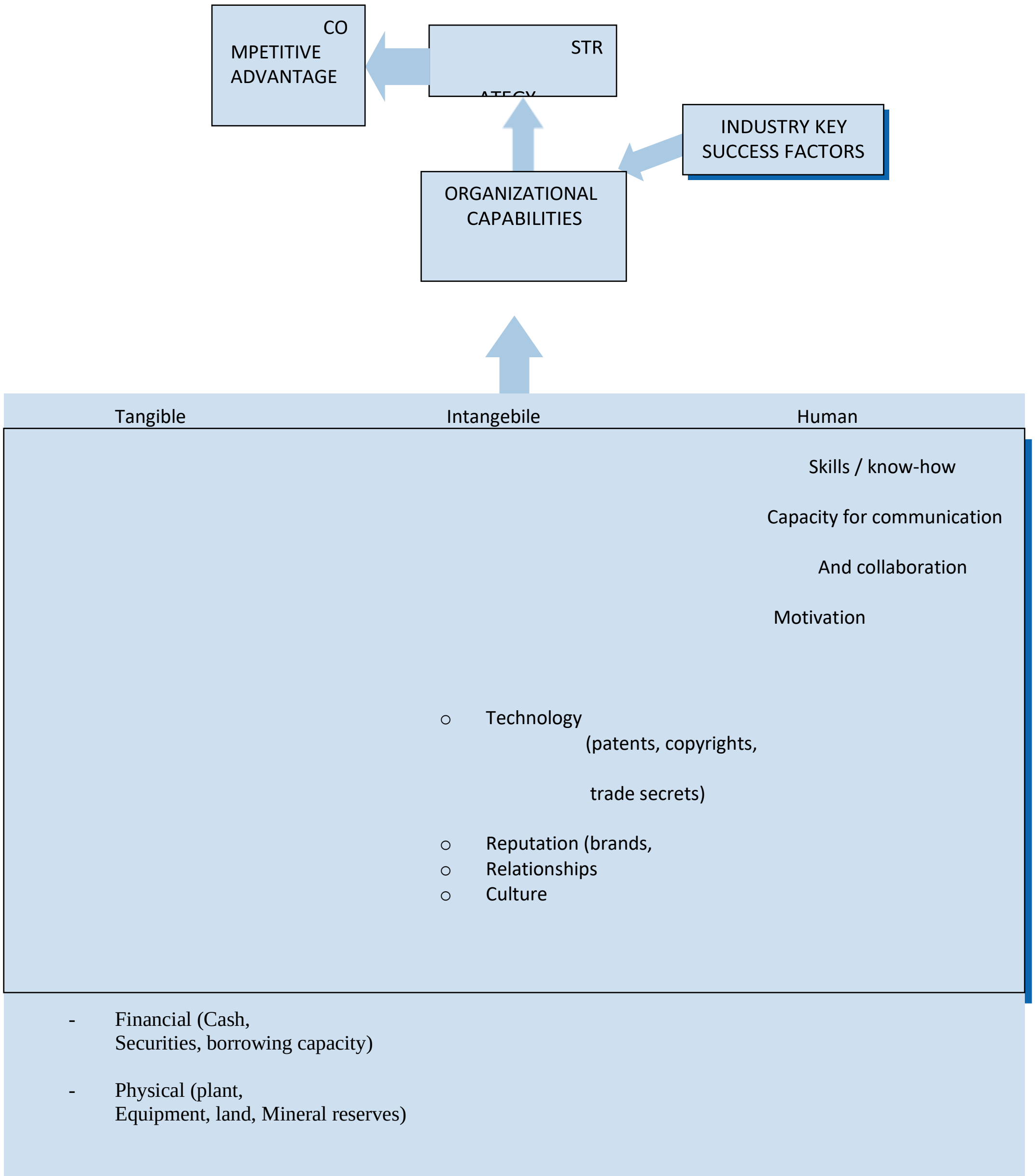


Resource and capability as strategic factors

Strategies are established to fit the company's resources while being capable of all available possibilities. An attractive and innovative product with superior quality and a competitive price is a strategic target for any shipyard.

Figure 16

The Relationships Between Resources, Capabilities, and Competitiveness as Advantages for Businesses. Source: Grant (2018)



Shipyards, ship construction, and ship repairs with related welding technologies combined with their resources, capabilities, and proper competitiveness could propel shipyards to greater leadership and reputation. Diagnostics of performances as achievement components:

In case profits are less than planned, the requirement would be examining the origin of this deficiency and identifying the proper corrective action.

Equation of the profit for certain assets:

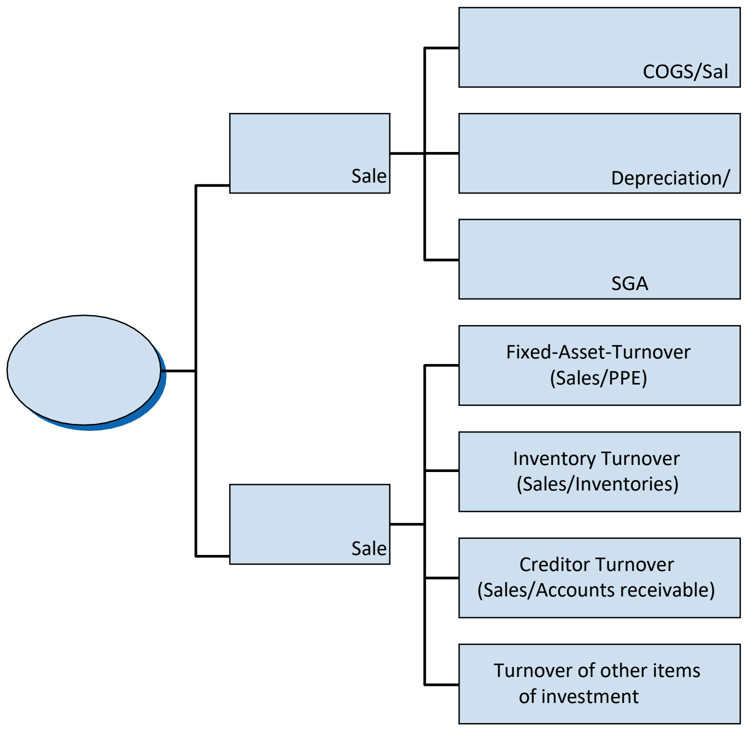
profit/assets = profit/sales × sales/assets.

Utilizing Performance Diagnostic to Achieve Strategic Plans

The figure below demonstrates how the strategy is formed: once nonconformities (NCs) are the consequence of a weak operation, a change-management strategy must be implemented to settle the NCs and increase the success factors of the shipyard business.

Figure 17

Asset Summary. Source: Grant (2018)

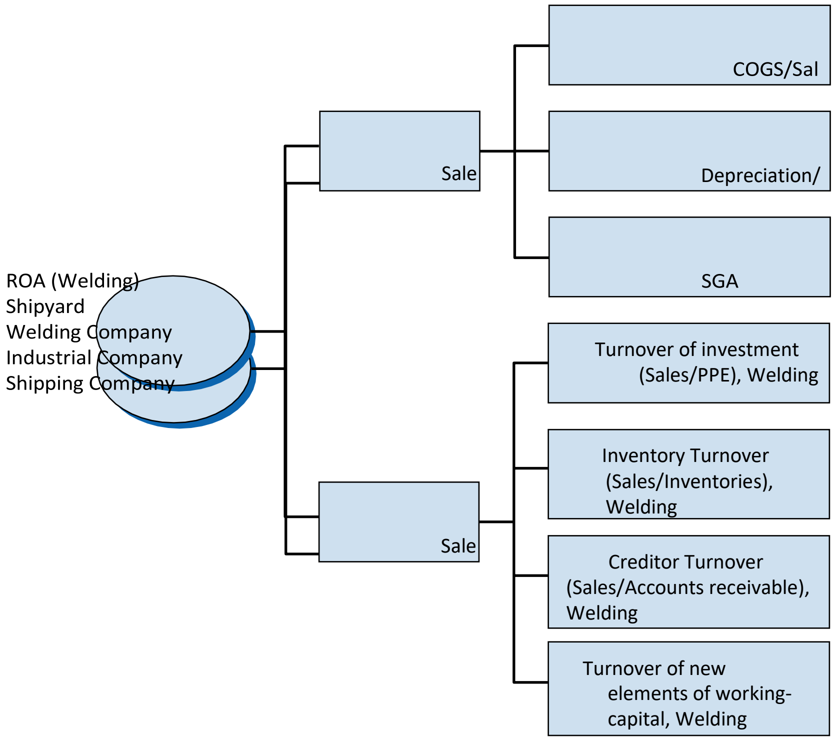


The figure shows the sales margin and sales assets in connection to turnover.

Figure 18

Assets of Welding Process

The figure shows the sales margin and sales assets in connection to turnover for companies producing welded products. Modified from Grant (2018).



In consideration of optimizing the turnover, efficient welding processes are to be implemented as revealed in this dissertation. Production optimizations for welded parts could achieve savings of 50% and more (see 4.1.1 in this dissertation).

Negotiating Capacity of Shipowners

Shipyard profits being conditionally based on the prices paid by shipowners puts shipyards in a difficult position, as the shipowner will negotiate newbuilding or ship repair prices with several shipyards until an acceptable ratio between prices and quality is reached. Shipowners will make every effort to reduce costs. The cost reduction trials by the shipowners are governed by the following:

Resemblance to the expenses of other shipyard facilities for identical quality

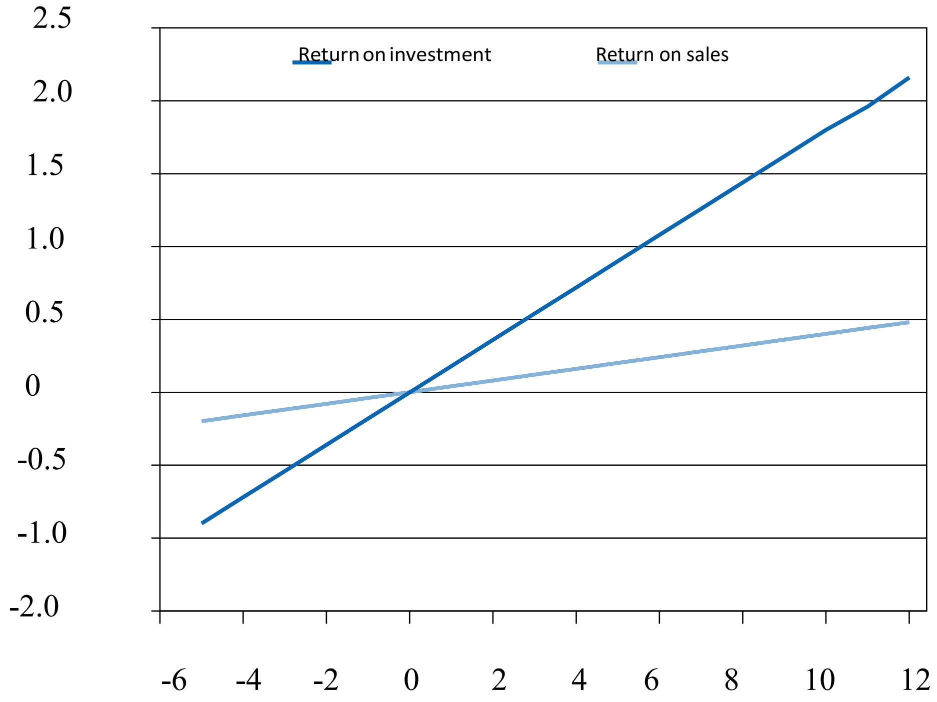
Negotiation skills of the shipowners

A reasonable investment is mandatory to increase profits. The graph below shows that if no money is invested, no profit is achievable. Within the dissertation, it is proved that investment in the welding process (equipment) could save costs of more than 50%.

Figure 19

Rate of market growth (in real terms)

Investment Power on the Profits. Source: Grant (2018)



Advantages of External Competitiveness

Adjustments that arise externally could influence an important shipyard's decision to improve. If those changes are significant and should the yards be inclined to face changes by a solid strategy, competitive advantages could be generated.

The shipyard’s reaction to those changes contains either market expectation or market reaction.

Market Expectation

Shipowners are awaiting effective vessels where continuous new ideas at lower cost are offered, including innovations in layout and production at competitive prices. Therefore, rough confrontations and continuous challenges among the yards result in superior creation at progressively more cost competitiveness, introducing the best method and thereby making a distinction among shipyards.

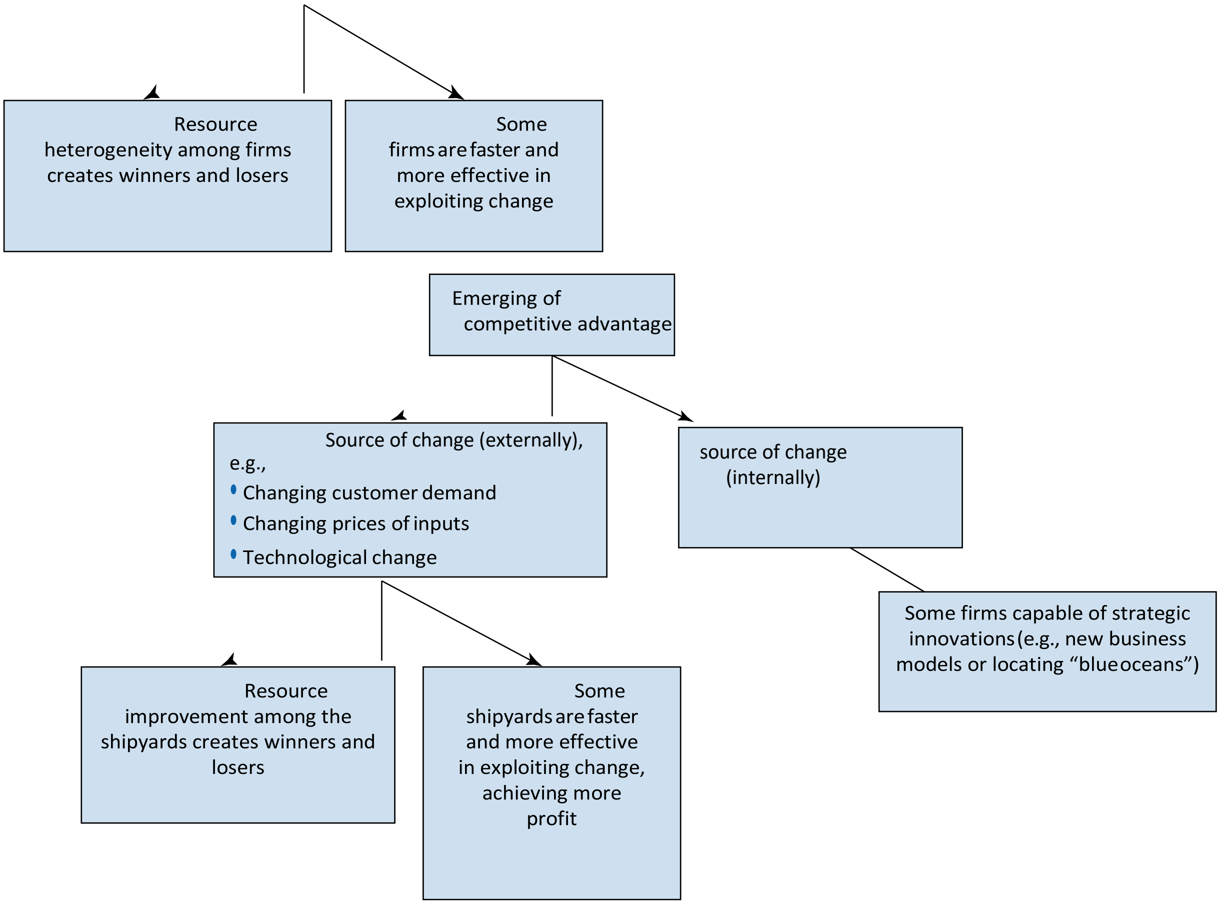
Market Reaction

Since the shipbuilding business has turned out to be challenging to make stable or forecast, it became a significant matter to remain in continuous competition with other shipyards. The shipyard’s directions must develop advanced methods measuring shipbuilding business and the current needs and to acquire quick reaction to the economic situation, being in close contact with the shipowners.

Figure 20

The Emergence of Competing Advantages

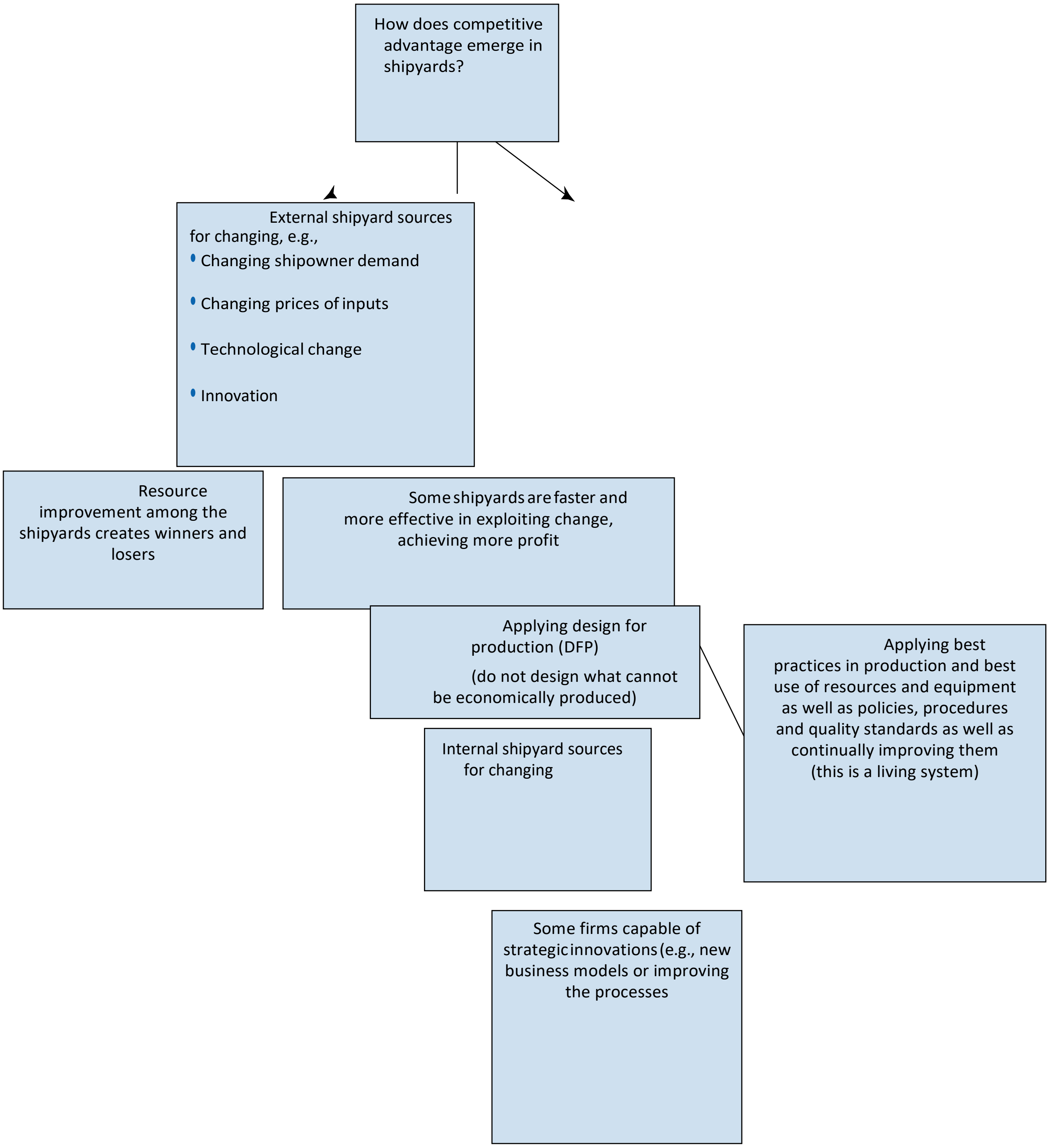
Source: Grant (2018).



The above figure shows the responsibility of resources in producing competitive advantages, internally and externally.

Figure 21

The Competitive Advantages In shipyards



The above figure shows how to achieve competitive advantage subject to the adaption of skills in shipyards—internally and externally—by applying strategies that consider both DFP and excellent methods, policies, procedures, standard of quality, and continual improvement.

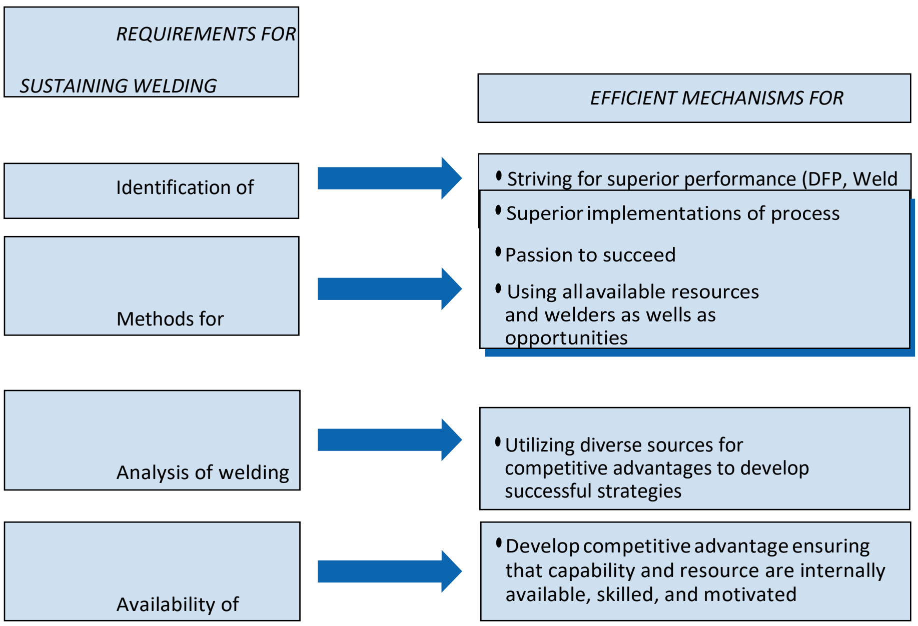
Method for Sustaining the Competitive Advantages

After shipyards have developed competitive advantages, they are surrounded by strong competition from relevant yards. The more the competitive advantages are successful, the less the competitors are ready to face the concern of the innovations. Therefore. the innovation strategies and the innovation practices are patented. The figure below shows the demand for sustaining welding strategies and the associated efficient measures.

Figure 22

Sustaining Competitive Advantages and Measures

Modified from Grant (2018).



Main Costs

This dissertation creates a major contribution to study main expenses and fee structures by demonstrating relevant cost and economical figures in shipbuilding. The study will lead us to evaluate the cost of the weld by determining the welding length. Applying 4.1.1. and 4.1.2 in the dissertation, we can calculate the welding cost. The main expenses implicated in shipbuilding are the following: labor cost (designers and workers), expenditure of welding machines, and the cost of welding consumable materials (filler metal) together with the price of energy. The designers oversee bringing the design to (DFP). Nothing ought to be planned if not feasible to be economically produced. The workforce consists of welders, welding supervisors, NDT applicators, crane drivers, steel/aluminum preparators, shift supervisors, cutting and grinding operators, assembly operators, and preparatory task operators. The welding equipment is the machine used for welding processes like MAG, MIG, SAW, and electrode. The welding consumables are filler metals. Electricity is the main source of energy in shipyards.

Cost structure for shipbuilding:

Major milestones of any shipbuilding project:

Sign of agreement

Initial project

Main drawings

Approval by the relevant classification societies

Production details

Constructing the hull of the ships

Outfitting (pipes, electrical, ship machinery, and ship system)

Sea trial(s)

Issuance of class certificate by the class society

Issuance of the statutory certificates by the class societies or relevant flag states

Delivery to the shipping company

The dissertation has focused on shipyard production given on account of the weld.

Figure 23

Assembly Time Distribution for 20 Stiffeners

Fifty-two percent of expenses are for drop weld.

Source: Leal (2012).

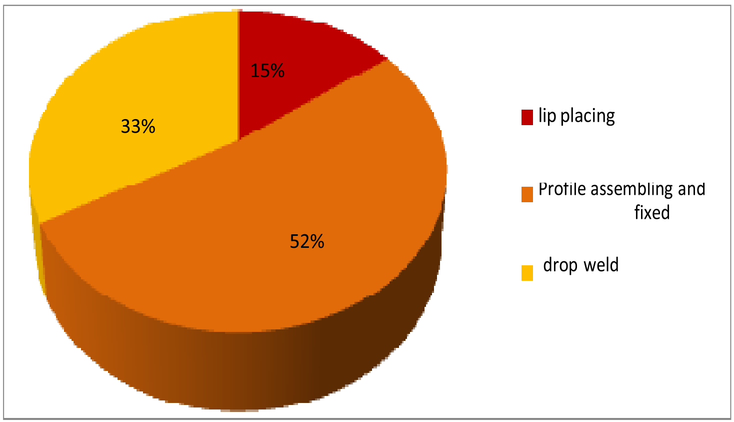


Table 5

Mean Speed of Welds

The SAW is about four times quicker than flux core welding. The economy of welding via SAW proven in 4.1.1 and 4.1.2 and 4.2.1 (Leal, 2012).

Processes	Speeds [meters/hour]
SAW (7 mm thickness)	13.4
Flux core cont. weld	2.8
Robot-flux core automatic cont. weld	20.0
Flux-core man. Discontinuous weld	22.2
Drop weld using coated electrodes	Including assembly
Reinforcement profiles assembly	2.4

Table 6

Block Weights and Related Weld Lengths

The continuous welding lengths are about double of the discontinuous welding lengths (Leal, 2012).

Block	Weight [ton]	Cont. weld length [m]	Discontinuous weld length [m]	Total welding length [m]	No. of profile reinforcements
AC01	15	254	85	339	64
AC02	28.2	592	276	868	112
AC03	22.3	418	328	746	81
AC04	17.3	341	226	566	28
AC07	4.2	103	27	130	21
AC08	17.7	450	105	555	145
AC09	24.3	549	249	799	153
AC10	20.9	513	219	732	84
AC13	22.8	574	298	871	304
AC14	18.9	551	207	758	238
AC15	13.2	350	200	550	174
Total	204.8	4695	2219	6914	1404

The result can be shown by a linear relationship deriving the equations for establishing the relevant weld lengths. The factor λ was calculated. That factor corresponds to dividing the LWHW (multiplication of block's length, width, height, and weight) by the overall weld lengths.

Figure 24

Block Weight vs. Welding Length

Figure Showing the Weights of the Blocks vs.Weld Lengths. Source: Leal (2012).

Weld Lengths (m)

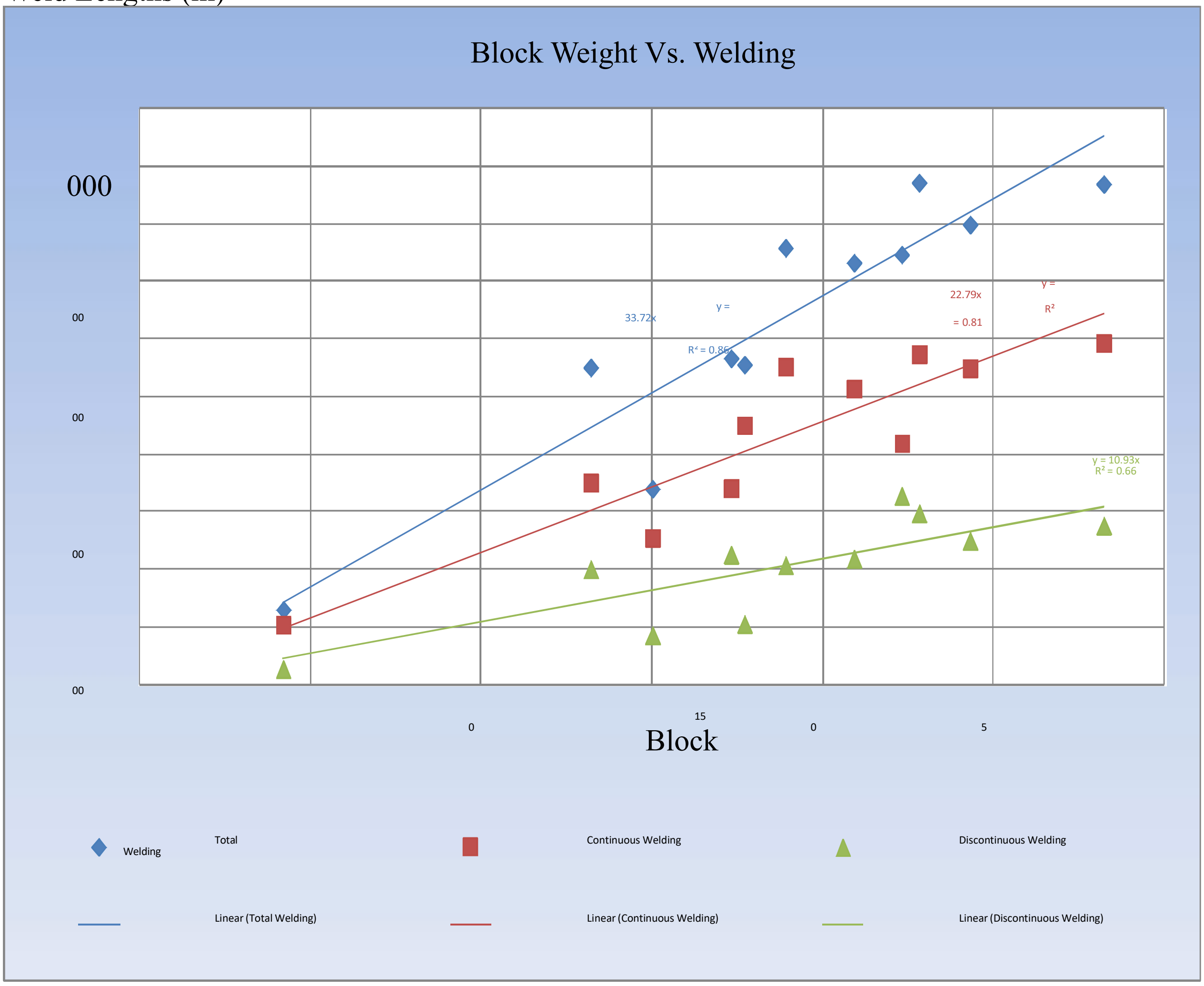


Table 7

Main Block Dimensions

Source: Leal (2012).

Block	Length [m]	Width [m]	Height [m]	Weight [t]	LxWxHxW	Weld length [m]	λ Factor
AC01	5.9	7	2.5	15	1548.75	339	4.6
AC02	8.6	15	2.5	28.2	9094.5	868	10.5
AC03	10.2	15	2.5	22.3	8529.75	746	11.4
AC04	10	15	2.5	17.3	6487.5	567	11.4
AC07	5.9	2.9	2.5	4.2	179.655	130	1.4
AC08	9.9	15	2.5	17.7	6571.125	555	11.8
AC09	10.2	15	2.5	24.3	9294.75	798	11.6
AC10	10	15	2.5	20.9	7837.5	732	10.7
AC13	11.6	15	2.5	22.8	9918	872	11.4
AC14	9.9	15	2.5	18.9	7016.625	758	9.3
AC15	6.2	15	2.5	13.2	3069	550	5.6
Average							11.0

The welding lengths could now be estimated. Since the fabrication expense of 1 m welding is known, refer to 4.1.1., calculating the fee of welding became tangible. Using the right welding procedures, reaching, and exceeding 50% of welding expense can be saved.

Table 8

Flux-Core Wiring Reel expenditure. Source: Leal (2012).

	Flux-Core Wiring Expenditure			
Block	Butt joint Welding (kg)	Continuous fillet joint (kg)	Discontinuous fillet joint (kg)	Number of reels (16 kg)
AC01	7.34	143.51	12.80	11
AC02	34.52	313.89	41.38	25
AC03	40.90	201.86	49.15	19
AC04	39.80	156.60	33.83	15
AC07	8.19	51.91	4.07	5
AC08	28.35	235.86	15.76	18
AC09	39.90	281.65	37.41	23
AC10	39.80	260.03	32.78	21
AC13	34.65	302.61	44.63	24
AC14	39.70	283.07	31.01	23
AC15	25.93	179.16	29.98	15
TOTAL	339.08	2410.17	332.80	199

As declared in this dissertation, discontinuous fillet joints are to be operated when in compliance with the classification rules. When equated to the weights of the uninterrupted fillet joints, the actual percentage in weight of filler metal of the discontinuous fillet joints is only 13.80%. As a result, only 13.80 of the budgets will be applicable (considerable saving factor).

It appears that the truly relevant factor is labor costs, applied welding process, and the testing of the welds. To get acceptable test results, skilled welders are required.

Shipyards found out the importance of welding economical aspects including by which means they influence the production efficiency and competitiveness alike. see cost implications depending on the process used in 4.1.1 and 4.1.2 and 4.2.1. Shipbuilding productivity could achieve major profits by considering DFP (design for production) which is described in detail in 4.2 in this dissertation. The modernization and competencies of the yard’s design office could add a significant profit margin by involving skilled designers with shipbuilding experience (see resource and capability section in this dissertation).

Recommendations

The dissertation presents a method for reducing welding costs by using estimating factors for establishing the weld lengths and estimating the welding cost (see also 4.1.1, 4.1.2, and 4.2.1). It connects the DFP and the welding processes alongside clearly indicating how to design to be efficiently produced via lean production that avoids wastage in all categories. Depending on plan approval being considered by the classification society, all efforts are vital to augment the ship design; specifically, not only designing a drawing that fulfills the rules but also important saving factors.

Competitive intelligence

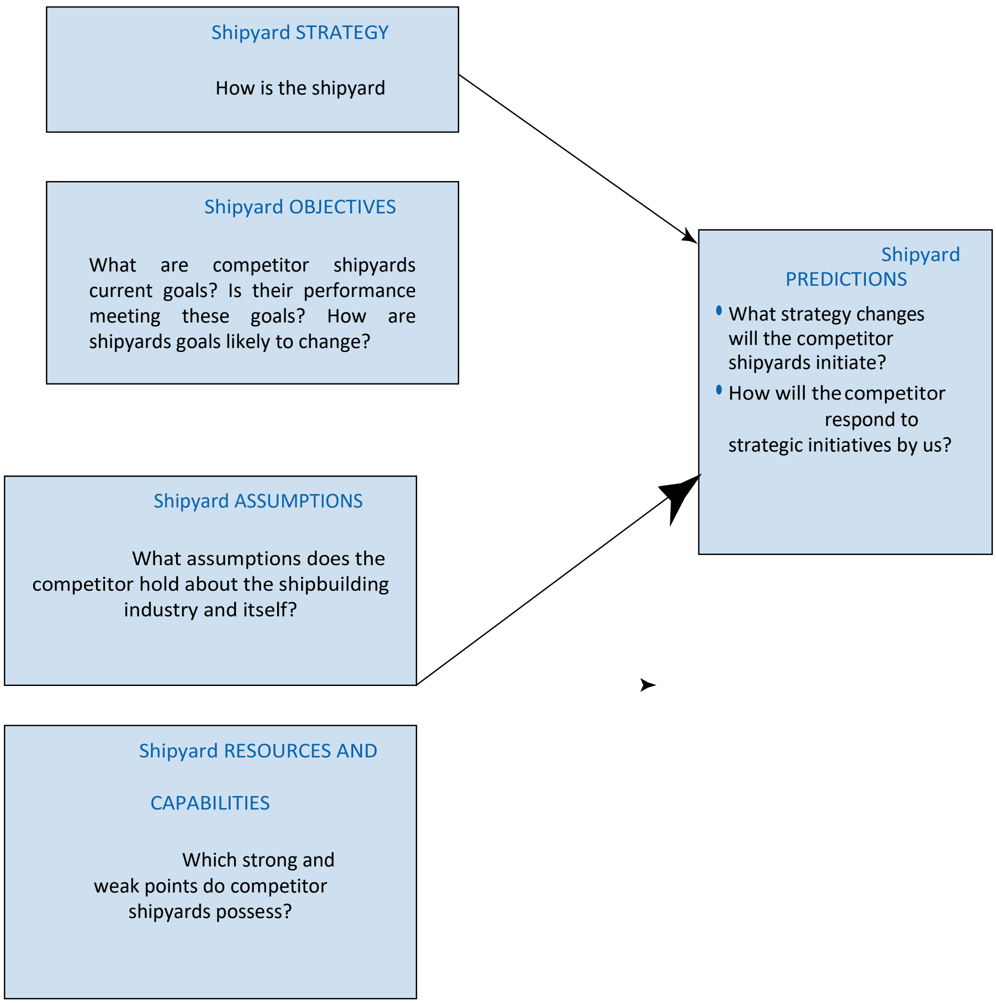
This consists of obtaining and assessing data concerning other shipyards. It encompasses four principles:

- Identifying the competitor
- Forecasting the strategy of other shipyards
- Predicting how other shipyards behave
- Reacting quickly to the competitor’s approach

The innovations of the welding practices and welding processes require confidential treatment by the shipyards for reasons that were indicated earlier in this dissertation.

Figure 25

Analysis of Competitors Adapted for Shipyard's Business. Modified from Grant (2018)



Organization Capability of Shipyards

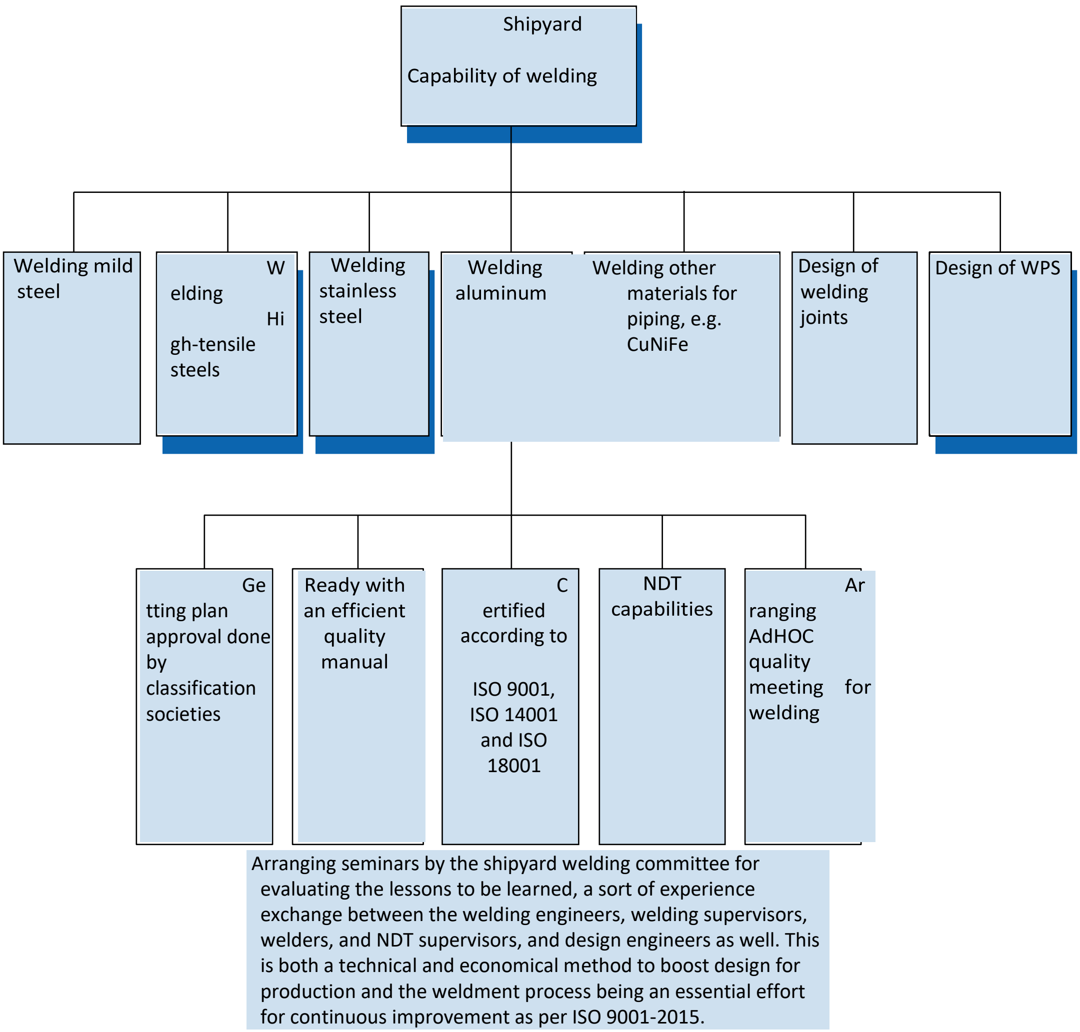
The figure below shows the shipyard welding capability.

For most shipyards, lean production, talents of yard employees, plan and schedule,

total quality management (TQM), process management, and continual improvement as per ISO 9001 principles are major components of economic performance and profit of the shipyards.

Figure 26

Organizational Capability of Shipyards. Modified from Grant (2018)



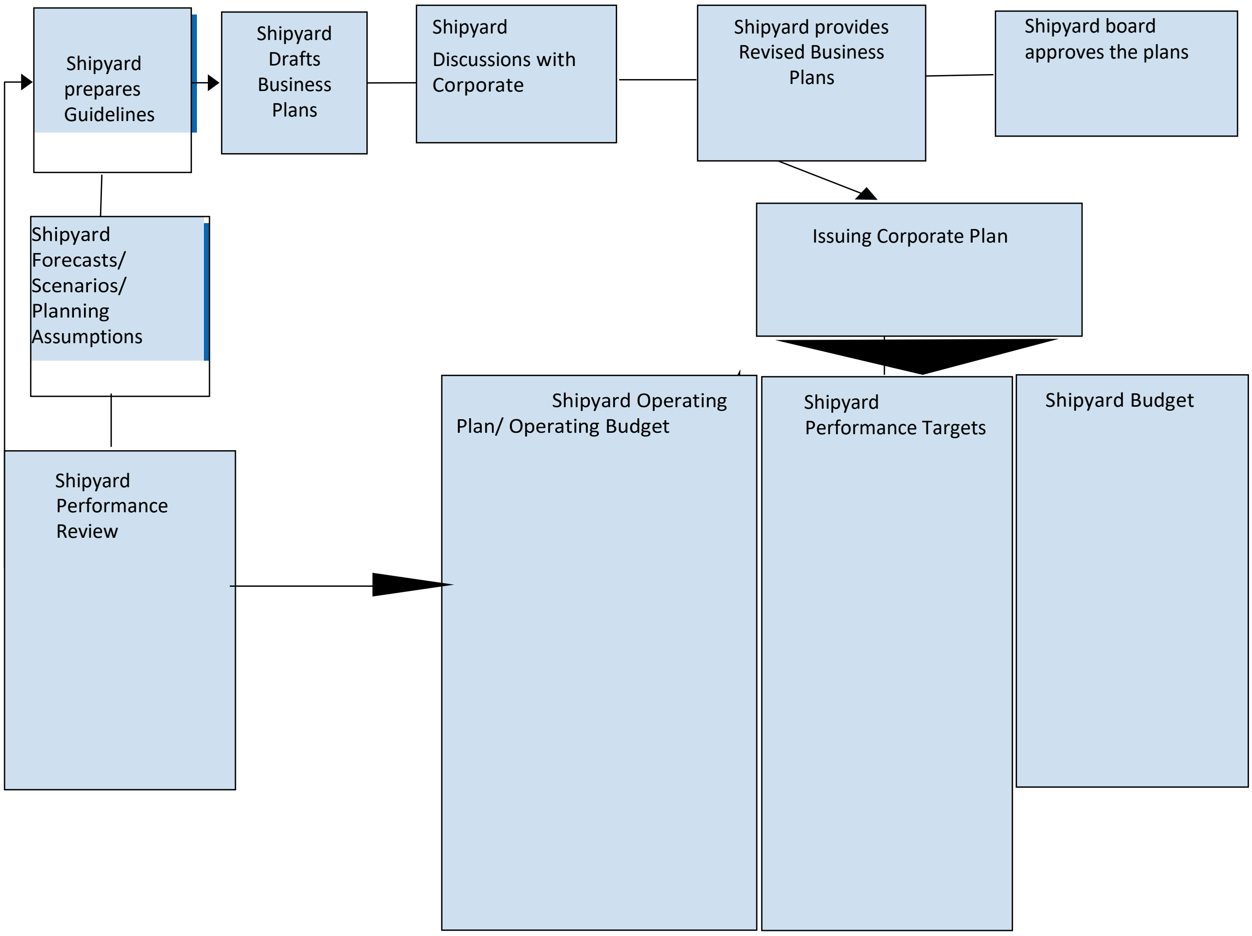
Achieving the above organization for proper, efficient, and economical welding results and better budget planning proves the necessity for shipyards, considering that strategy is a living process aligned with ISO 9001-2015 standards.

Strategic Planning

All reputable shipyards conduct annual strategy planning. The strategy is signed by the management and cascades to the department heads, who in turn transmit the strategy to their employees, explaining and evaluating the strategy with them. Key performance indicators (KPIs) are then created by the unit heads with a weighing system and each employee will have a tailor-made KPI. Matching the corresponding KPIs, the employees will be under assessment on an annual basis.

Figure 27

Annual Strategic Planning. Modified from Grant (2018).



In major shipyards, strategic planning involves a system to cascade down the yards' strategy.

This contains the following:

Developing the guidelines, forecasts, and assumptions:

The strategic planning department will also provide an area for improvements to unit heads. Especially, in times where there is less demand on a particular ship type, the shipyard must be capable of building another ship type or initiating another relevant business, such as ship repair or constructing any form of steel construction, even including production of the design drawings for another shipyard.

Business Plans

The shipyard departments must develop proper strategic planning that is subject to approval by top management.

- The corporate plan:

Upon agreement on the above, a corporate plan is established to accomplish the strategy set for the shipyard. A corporate plan must be approved by the management.

- Capital budget:

Capital budget is well-defined as the link between the assets in the shipyard and its strategy.

The endorsement of the capital budget occurs. The decision is prepared by the top management who approves what budgets. For example, what will a department manager approve and what will be approved by higher management in the yard, from what sums and onwards, the approval to be endorsed by the executive board.

- Plan of operating and performance's goals:

The strategy planning will require a strategy plan and several performance goals. The performance goals are the following:

- Financial increase in sales, financial limits, and financial returns for the investment
- Inventories, rate of deficiency, and number of lately opened sites for the shipyard

Considering the optimization of the marketing and sales of the yard yearly (e.g. no. of ships to be constructed, type and ship size, keeping existing customers, and achieving new customers), targets are established for an economical shipyard annual and strategic plan.

The main research questions are as follows:

4.1 What welding factors decide the quality and processes of welding in shipyards?

4.2 How could DFP be achieved in shipyard welding operations leading to competitiveness?

Each main research question will answer important subquestions in the dissertation.

4.1 Main research question:

This dissertation handles significant welding-specific factors that will directly affect the welding process cost and thus the total production cost. First, selection of the proper welding process is considered, including in what manner it influences the welding cost. Two famous welding processes are considered in detail. The welding processing coupled with the materials utilized are also considered, alongside the various welding schedules at daytime and nighttime, concentrating on the typical characteristics of multiple shifts.

This research assesses the difference between the two famous welding processes, explaining what materials could be welded with each and what material thicknesses are applicable, including the restrictions when using each material, what NDT may be applied in each case, and what characteristic the welding processes will have.

Since edge preparation is a major factor in the welding practices, the dissertation considers details of typical edge preparation figures that facilitate high-quality weld, including by which means it could contribute to cost savings. Handling surface cleanliness focuses on necessary precautions and the consequence if neglected neglecting it. Welding of grade-A steel is considered because this represents common steel used in shipbuilding. The dissertation considers the implication of the NDT selection for different material groups. Additionally, it will also be clarified when a sequence of NDT methods could be necessary, sometimes even essential. The best NDT methods are considered with their characteristics and limits.

4.1 Main research question

What welding factors decide the quality and processes of welding in shipyards?

Subquestions

4.1.1 Why does the choice of the welding process play a considerable role in the welding economy?

4.1.2. How should the right welding process be chosen in the context of material choice?

4.1.3 In the case of multiple shifts, how is welding quality assurance supervised?

4.1.4.

What materials could be welded with SAW and FSW?

What material thicknesses apply to SAW and FSW?

How many restrictions have SAW and FSW shown?

How could an NDT plan be synthesized to examine welding quality for SAW and FSW?

Which characteristics do SAW and FSW typically have?

4.1.5.

What welding parameters cause what failures?

What factors affect the formation of porosity?

How feasible is preheating of welding electrodes?

What materials need special cleanliness before welding and why?

How should the benchmark of defining the rate of deficiencies in the welds be defined?

How should the above rate affect the remaining and additional inspections?

Why could hot cracks result when welding stainless steel?

4.1.6 What are the acceptance criteria for the HAZ in welded shipbuilding high-tensile steel?

4.1.7.

Which NDT should be chosen for what material?

Why and when is a combination of NDT methods reasonable?

When is a dye penetrant advisable as an NDT method?

What are the limitations of NDT methods?

Subquestions

4.1.1

Why does the choice of the welding process play a considerable role in the welding economy?

This study provides an excellent opportunity to gain a better understanding of welding processes versus cost (economy).

The processes of shield-metal arc-welding (SMAW) and gas-metal arc-welding (GMAW)—electrode—will be launched, supported by a comparison of which process is more economical.

SMAW welding process:

SMAW involves hand welding using electrodes. The heat is generated by an electrical arc. The light arc is induced once the electrode has touched the joint being welded, and the electrode will then melt and fill the gap (filler metal).

For shielded electrodes, the shielding has the following main features:

1- Filler metal and workpiece are separated from atmospheric influences

2- Through the addition of substances included in the electrode shielding, the mechanical properties are improved

3- The grain size in the workpiece is finer

4- Clean welding surfaces will result upon removing the slag

Advantages:

Welds are of good quality.

Different materials can be welded.

Various thicknesses can be welded.

The price of the welding device is affordable.

The welding device is portable for easy handling at the shipyard and inside the ship.

Different positions can be welded.

Suitable for enclosed space of the ship; for example, in tanks.

Disadvantages:

The overall cost for the welding is more than GMAW (see 4.1.1 and 4.1.2).

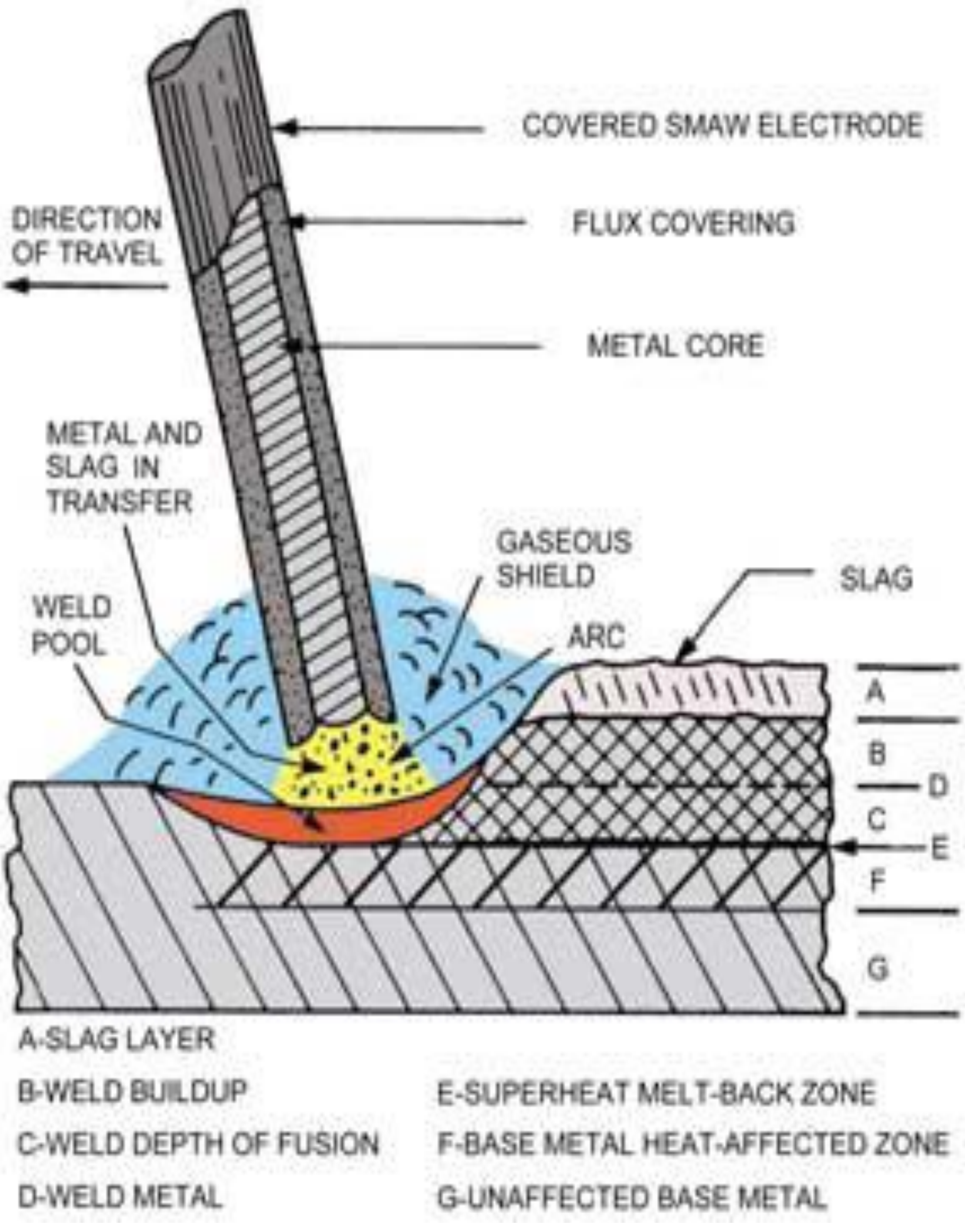
Slag inclusions that may exist in the welds will be identified during NDT.

It could require more NDT and additional welding inspections.

Skilled, certified welders are essential.

Figure 28

A Schematic Representation of Shield-Metal Arc-Welding. Source: Kielhorn et al. (1999), W. H. (LeTourneau U., Adonyi, Y. (LeTourneau U., Holdren, R. L. (Edison W. I., Horrocks, R. C. (Springfield & C. C., & Nissley, N. E. (The O. S. U. (1991)., A. W. S. (1999).



GMAW welding process:

GMAW is a frequent process in shipyards, where a light arc is produced. This melts the workpiece. GMAW could use an active or an inert gas as shielding gas.

Applying active-based-gas:

Metal-active-gas (MAG) arc-welding—for welding of ferritic materials (steels).

Applying inert-based-gas:

Metal-inert-gas (MIG) arc-welding—for welding of nonferritic materials (aluminum).

The benefits of GMAW:

Welding various positions

Increased depositions rate of the weld

Time of welding sums about half compared to shielded electrodes

Increased welding speed

Limited or no distortion could be attained

Excellent quality of welding

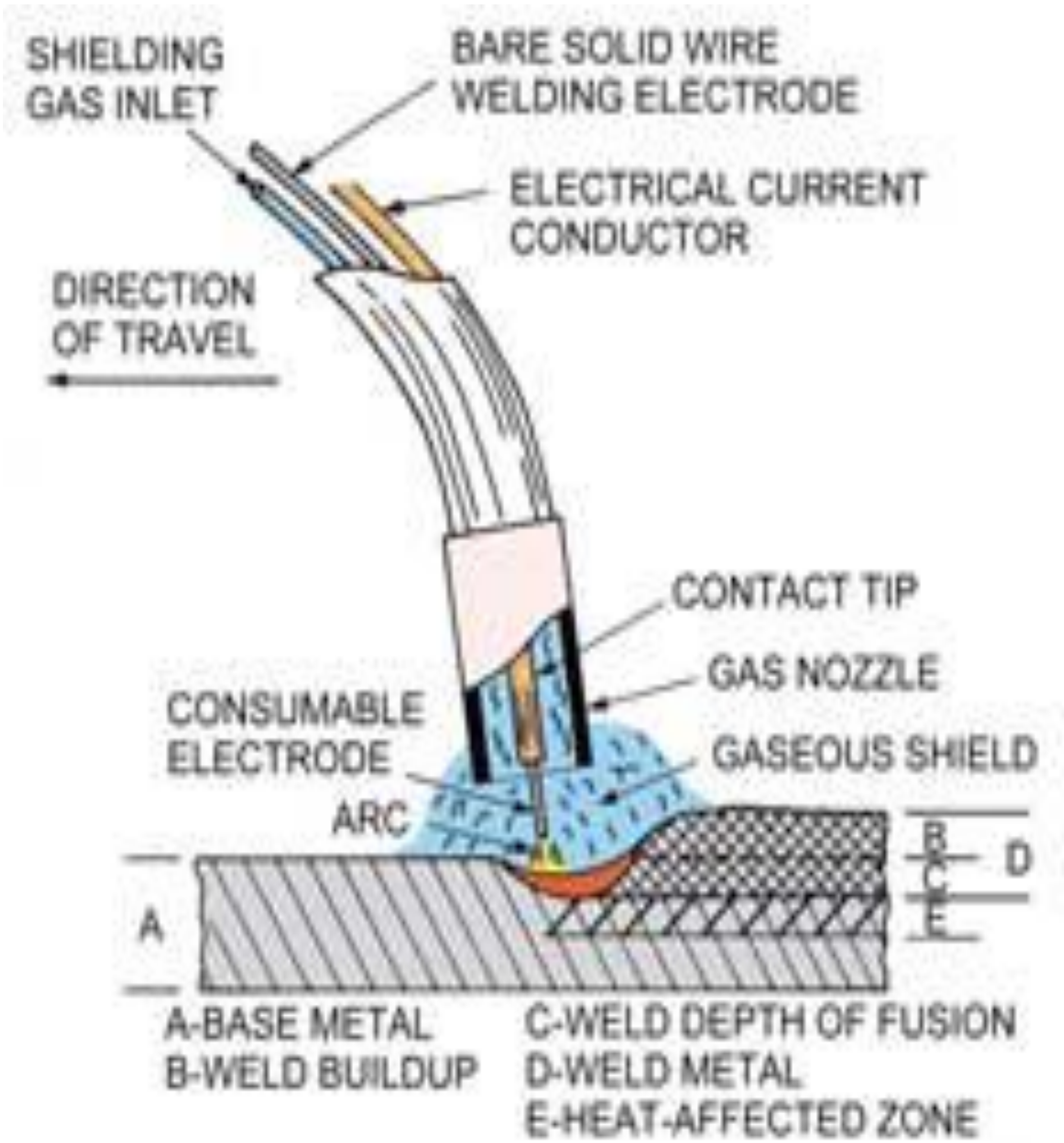
The disadvantages are the following:

Sophisticated device compared to SMAW, requiring a proper implementation.

Skilled, trained, certified welders necessary.

Figure 29

Schematic Representation of Gas-Metal Arc-Welding. Sources: Kielhorn et al. (1999) (LeTourneau U., Adonyi, Y. (LeTourneau U., Holdren, R. L. (Edison W. I., Horrocks, R. C. (Springfield & C. C., & Nissley, N. E. (The O. S. U. (1991)., A. W. S. (1999)



This practical cost calculation explains how important selecting the welding processes could significantly reduce the economy of welding.

In this comparison, welding using SMAW—electrode—will be linked to the welding with GMAW—MAG/MIG. Thus, the wire diameter in both cases will be 1.2 mm.

Welding type: fillet weld.

Throat thickness is 4–5 mm.

Both welding processes are common in shipyards worldwide.

The indicated rates are actual market prices.

SMAW specification:

Electrode dimensions:

Length	= 350 mm
Wire diameter	= 1.2 mm
Weight/electrode	= 34.60 g
Price	= 1.0 euro/Electrode
Filling weight	= 200 g/m
Required no. of electrodes	= 6 electrodes
Price of required electrodes	= 6 euro/m

Welding speed = 6 electrodes × 2 min/electrode = 12 min/m

Labor rate	= 60 euro/hr
Labor price	= 12 euro/m
Total cost	= 18 euro/m

Manufacturer: Boehler Rutil/Basic Electrode

GMAW specification:

Wire diameter	= 1.2 mm
Filling weight	= 200 g/m
Price of filler metal	= 20 euro/kg
Price of filler metal/m	= 4 euro/m
Consumption	= 50 g/min
Price	= 4 min/m
Labor cost /m	= 4 euro/min
Total cost	= 8 euro/m

Manufacturer of MTC MAG/MIG wire

Table 9

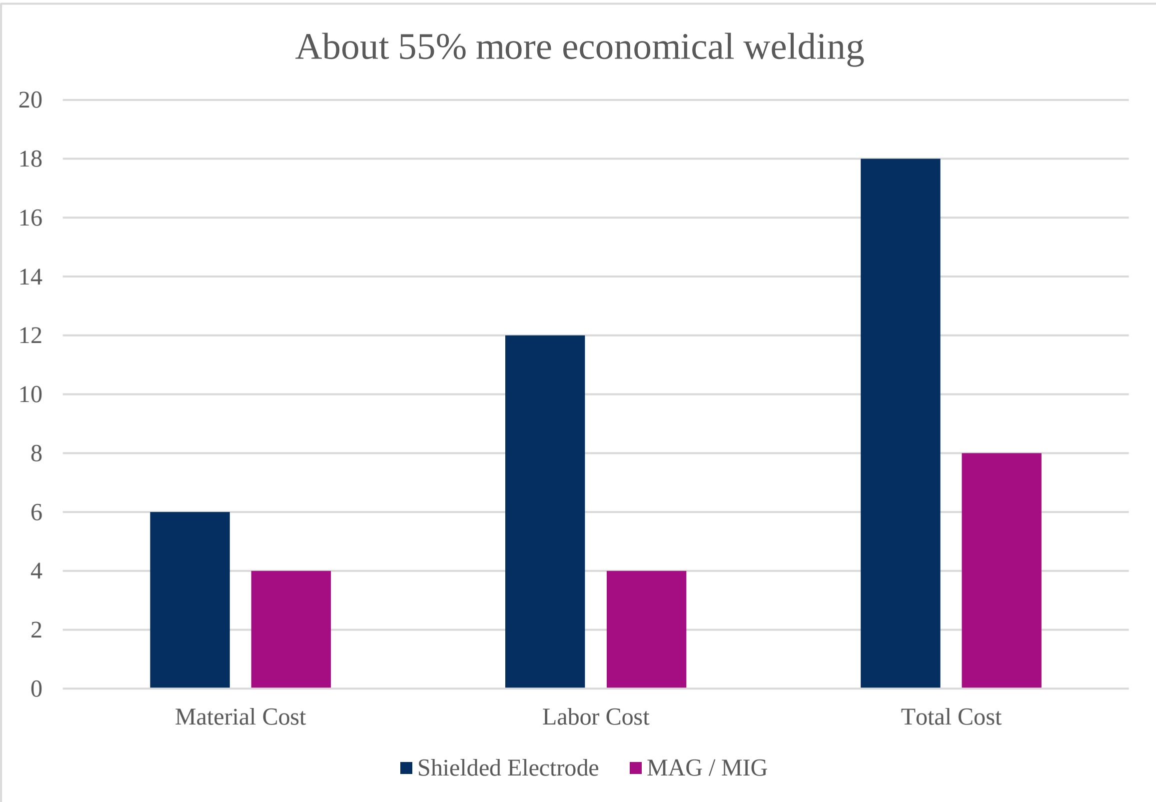
Welding cost of electrode vs. MAG/MIG

Welding cost/m (euro)	Shielded electrode	MAG/MIG
Total cost/m	18	8
Material cost/m	6	4
Labor cost/m	12	4

Figure 30

That Just via a Proper Choice of Welding Process, About 55% of Welding Cost Can Be Saved

Cost in euro/m



Cost in euro/m

Figure 31

How Economical it is to Apply MAG as a Welding Process. In Comparison to Manual Electrode Welding, 55% of Welding Cost Can Be Saved.

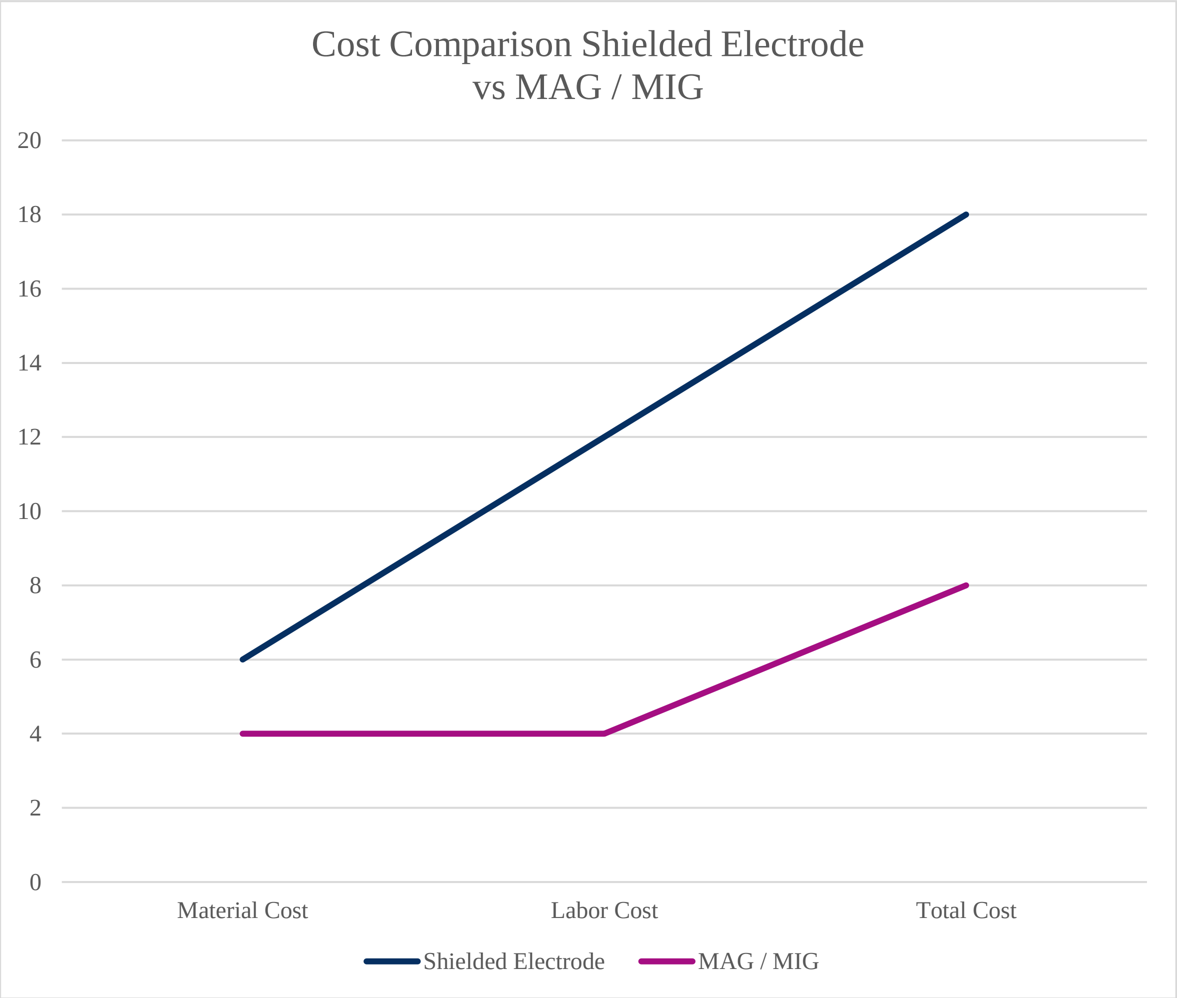


Figure 32

The Material Cost is Doubled when Applying Electrode Welding

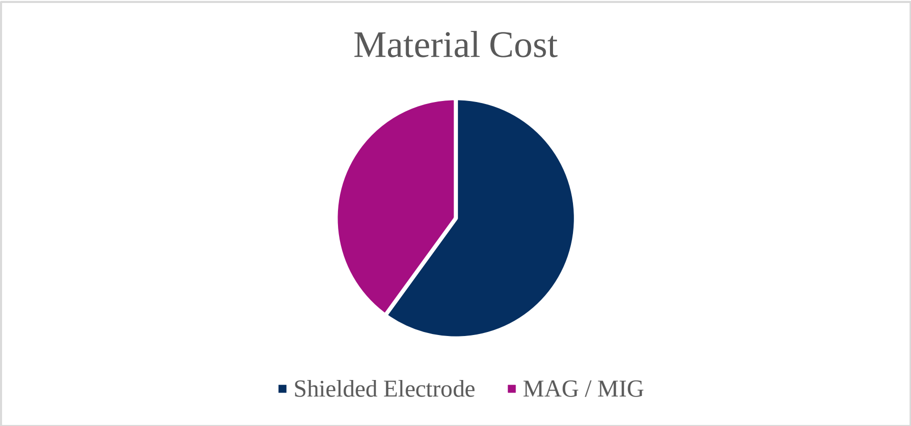


Figure 33

The Labor Cost is Tripled when Using Electrode Welding

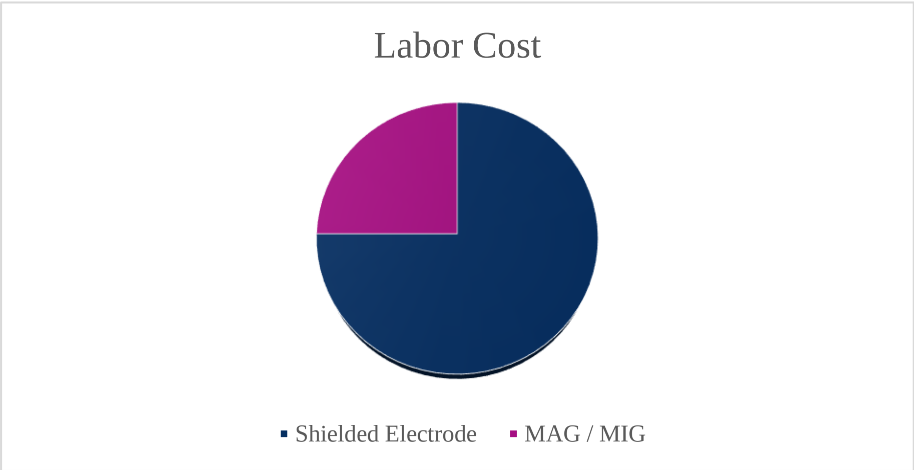
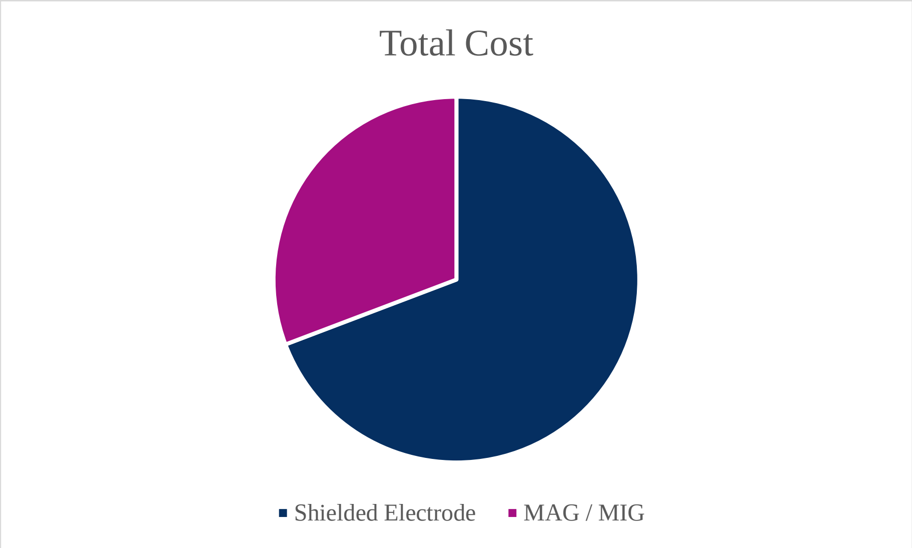


Figure 34

Total Cost is Double when Using Electrode Welding



By comparing the above results, proper choice of welding processes could save more than 50% of the product cost: in the above case, a 55% saving. Since the MAG/MIG process happens on a daily basis, it is vital to contemplate the right welding process and to support the process using MAG/MIG. Another significant issue with the uneconomical usage of the electrode may become even more costly. It is observed in practical use that electrodes often are not used completely; specifically, depending on workmanship, consumption of electrodes might only be partial, and the remainder is thrown away, leading to even more losses as part of the fabrication cost. Electrodes that are only used until half their length remains cost double the filler-metal cost since they are unnecessarily dissipated. The wastages of the yards also increase as well.

The costs of the welding processes can be optimized by doing the following:

Correctly choosing the welding process

QC of the welding consumables

QC of welding processes

It is clear how cost reserves are reachable in a shipyard by considering the right welding processes and welding consumables. Subresearch question 4.1.2 considers relationships among the welding process and material selection.

4.1.2

How should the right welding process be chosen in the context of material choice? First, the material must be chosen. Considering this, the assortment of welding processes will follow. Most metallic materials utilized in ship hull material are mainly steel and aluminum of different grades.

Steel (ferritic) weld:

MAG (GMAW) is a very frequently used welding process at shipyards.

Submerged arc welding (SAW) is very frequently used in welding steel. However, welded plating are straight plates. Furthermore, the minimum thickness of plates is usually 10 mm.

Aluminum weld:

MIG/GMAW: Universally used welding process for aluminum welds in shipyards.

Stainless steel weld:

Tungsten inert gas (TIG) could be implemented.

Piping (stainless steel/CuNiFe) weld:

TIG is a suitable welding process.

For all-purpose welds:

SMAW with or without electrode shields is deployable for various materials, including ferritic steels, stainless steels, aluminum, and alloys.

Regarding flexibility in restricted spaces, SMAW (manual electrodes) may be preferable depending on accessibility; specifically, inside enclosed spaces in the hull construction. A proper DFP concept should consider adequate space for proper welding along with a focus on welding accomplished in a cost-effectively manner (GMAW).

The study offers significant insights into class societies in charge of classifying the ships.

Referring to the above tables, the welding processes will include the following factors for approval by the classification society:

The materials are to be certified and procured with the chemical and mechanical properties required by the classification societies' rules

Approved WPS, with class approval

Approved welders (valid welder certificates)

- Approved NDT operators (valid certification required)

Heat treatment sheets

Considering the above data, a connection of material requirements, welding process requirements, and quality requirements have been generated.

The quality documentation is subject matter to collection to be evaluated and maintained on file as a reference.

This research examines the impacts of selecting the materials on the welding procedure and hence on the total welding production cost. In the context of subquestions 4.1.1 and 4.1.2, there are noteworthy facts that help a shipyard realize how important costs could be optimized by selecting the accurate welding processes for certain materials, and in case of diverse possibilities, which one prioritizes the superlative choice to meet mutually procedural and economic targets.

For steels, different welding processes have been discovered. Common processes at the shipyard have been compared. MAG is a cost-effective welding process and the most utilized in steel shipyards. For shipyards that build or repair aluminum ships, MIG is a commonly utilized process. MAG and MIG are similar—the differences are the protection gases being used: MAG uses an active shield gas, where MIG uses an inert protection gas. Therefore, cost might be saved by precisely choosing the welding process, introducing a significant cost saving that can boost the competitiveness of the shipyards toward other shipyards, locally or globally.

Regardless of the processing used, focusing on high quality is a critical cost-cutting factor. Accordingly, high quality is a major cost factor, but it may cause significant cost reserves for shipyards and shipowners. High-quality production is not developed optionally but is rather a necessity and a challenge for all yards.

Considering research subquestion 4.1.3, efforts will be generated to indicate which quality issues have been considered.

4.1.3

In the case of multiple shifts, how is welding QA supervised?

Considering 4.1.7 of the dissertation, welding defects could critically influence the budget for any ship construction. Rework, retesting of the welding is a direct cost component to the yards and the shipowner that required thorough QC and QA.

Therefore, total QC management systems have been introduced to all major shipyards. A quality department is established, and the head of quality must be independent in their role to fulfill the quality requirements. Therefore, the head of quality reports directly to the CEO or general manager, without referring to other departments of the yard.

Since MAG/MIG welding processing requires more skilled welders than the manual electrode process, the focus is on including a proper QC on the welders, particularly during the night shift, if welding should continue during that time. Extended attention is placed on the welding quality on the day shift. However, the attention might be reduced or absent during the night shift. Thus, it is key to observe the welders and welding processes during the night shift as well.

Welding positions referring to ISO, ASME/AWS:

(PA), (1G), (1F): Position for flat welding.

(PB), (2F): Fillet weld horizontal welding position.

(PC), (2G): Butt weld horizontal welding position.

(PD), (4F): Overhead welding fillet weld position (to be reduced as much as possible).

(PE), (4G): Butt weld overhead position of the weld (to be fundamentally decreased).

(PF), (3G): Up fillet welding position

(PG), (3G): Down fillet welding position.

(5G), (PH): For a pipe butt weld, vertical up welding position.

(5G), (PH): For a piping butt weld, vertical down welding position.

(6G), (H-L045): Position for welding on an inclined plane (for testing purposes)

(6G), (J-L045): Position for down welding (for testing purposes)

Table 10

Checklist "Welding Subcontractors" in Shipyards

Nr.	Subcontractor requirements	Remarks
1	Certified materials from an IACS society	Heat number to be counter-checked to the Cert.
2	Approved WPS	Approval by classification societies
3	Welder certificates	Valid welder certificates for all tasks
4	Approved Welders, Position A	1G/1F
5	Approved Welders, Position B	2F
6	Approved Welders, Position C	2 G
7	Approved Welders, Position D	4F
8	Approved Welders, Position E	4G
9	Approved Welders, Position F	3G-Uphill
10	Approved Welders, Position G	3G-Downhill
11	Approved Welders, Position H	5 G-Uphill
12	Approved Welders, Position J	5 G-Downhill
13	Approved Welders, Position H-L045	6 G-Uphill
14	Approved Welders, Position J-L045	6 G-Downhill
15	Certified NDT operators	NDT operator certificate to be verified
16	PT	Dye penetrant testing
17	MT	Magnetic-particle testing
18	UT	Ultrasonic testing
19	RT	Radiation testing
20	EC	Eddy current testing
21	Material, welder, and NDT certificates	Forwarding to QC of the shipyard
22	Safety gear	Suits, helms, gloves, and goggles.

23	Quality control	Both at daytime and at night shift (if applicable).
22	Random, additional NDT	At locations where normally no findings are observed

Being realized from above, a shipyard must only consider welds together with NDT subcontractors that fully fulfill the ship class requirements and take into consideration the international standards, including the standard of the shipyard.

The checklist to be merged in the quality manual of the yard and must be circulated to the welding and NDT subcontractors. Certifications and documentation to be forwarded to the QC department of the shipyard for the appropriate project.
A typical important issue that arises when deploying subcontractors is the QC during shipbuilding and ship repair, particularly at nighttime. From experience, it happens that QC on welding is active during the daytime only. At nighttime, insufficient QC or even no QC might apply. The issue is that experienced welders will be utilized during the daytime, in the regular work time of the shipyard. At nighttime, less skilled welders may be deployed during the night shift, leaving a gap in quality. If there is no control at nighttime, considerable weld failures might apply. When performing visual inspections and NDT, all noncomplying welds will be rejected and redone, causing a considerable loss in manhours and labor cost.

Considering the NDT must consider locations that were welded at nighttime, including those locations that are usually not facing welding failures during the same welding during the daytime. Shipyards must reach competitiveness through extraordinary and successful ship deliveries, both using own labor or subcontractor labor.

Establishing the prominence of the subject, 3.1.1, 3.1.2, and 3.1.3 are connected and relevant cost factors that require a close look and care to avoid costly losses in the welding process. Certain welding processes, though interesting, are not economical in shipbuilding and are thus to be avoided due to extremely expensive welding machine direct costs, explained in detail under subquestion 4.1.4.

4.1.4

What materials could be welded with SAW and FSW?

What material thicknesses apply to SAW and FSW?

How many restrictions have SAW and FSW shown?

How could an NDT plan be synthesized to examine the welding quality for SAW and FSW?

Which characteristics do SAW and FSW typically have?

Submerged-arc-welding (SAW):

SAW is a common welding process in most reputable shipyards. The induced light arc melts the material, filling the welding gap. The light arc is flux-covered. Therefore, the light arc cannot be seen. SAW can be utilized in welding materials of various grades such as low and high-alloyed steel plus stainless steel and other alloys. The SAW can be computerized and may include a tandem so that parallel welding can occur.

Due to the absence of the light arc, a spotlight moves along the welding and shows the presence of the light arc.

The welding quality of SAW is excellent. However, material thicknesses below 6 mm are difficult for welding by SAW for the reason of excessive heat inputs, which may cause distortions. The range of material thickness between 6 and 9 mm may give high weld quality, provided the SAW welding factors have been adjusted properly. Material thicknesses with 10 mm and onwards are usually professionally managed by SAW, and the weld seams look straight, and those seem excellent in shape after removing the slag.

Another feature of SAW is that the light arc is protected by flux and is thus invisible to the operator. To solve this, an LED lamp hangs over the flux and moves with the welding. This spotlight has the normal contrast of the light. Welders must be very experienced to monitor the spotlight to follow the continuity of the welding path.

In locations, where SAW is applied outside the welding hall, directly in the sun, even the spotlight would be problematic to observe.

Suggestions to solve this issue include either of the following:

Providing a second lamp to get an improved sight

Amending the contrast of the spotlight (for example red or green)

The flux can be applied several times instead of discarding it following a single use. This requires well-trained welders for SAW and better QC on the applications. Flat is the most advantageous welding position, since ensuring full weld control. Upon weld completion, the slag will be removed easily, and an excellent weld seam will result, free of weld spatters and with an extremely smooth appearance.

Figure 35

A Schematic of SAW. Source: Kielhorn et al. (1999). , W. H. (LeTourneau U., Adonyi, Y. (LeTourneau U., Holdren, R. L. (Edison W. I., Horrocks, R. C. (Springfield & C. C., & Nissley, N. E. (The O. S. U. (1991)., A. W. S. (1999)

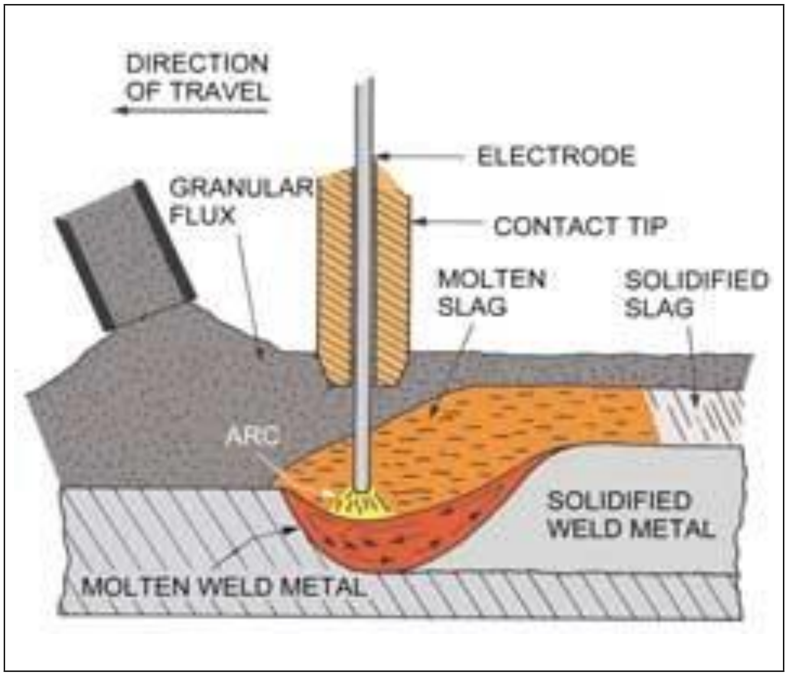
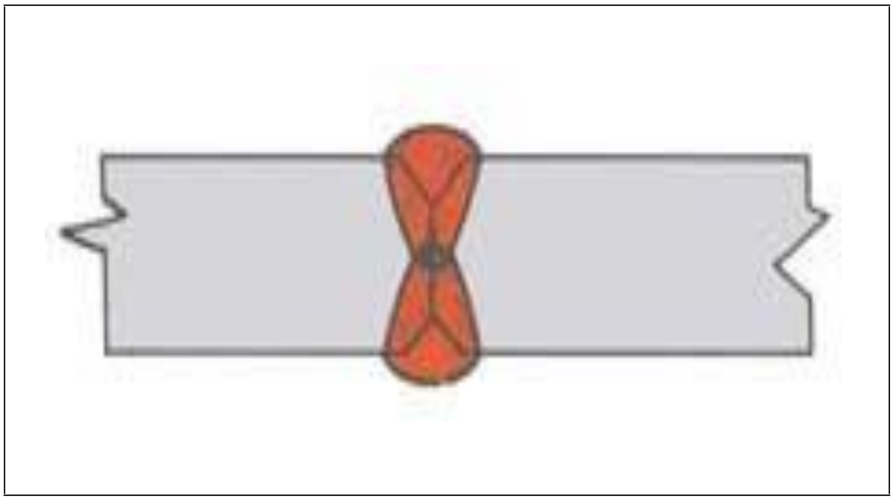


Figure 36

A Joint With Thick Root Face Produced by SAW. Source: Kielhorn et al. (1999), W. H. (LeTourneau U., Adonyi, Y. (LeTourneau U., Holdren, R. L. (Edison W. I., Horrocks, R. C. (Springfield & C. C., & Nissley, N. E. (The O. S. U. (1991)., A. W. S. (1999).



Friction stir welding (FSW) represents a modern welding technique for aluminum and aluminum alloys, in supplement to magnesium and copper alloys. A rotating tool at 450–500 °C melts the material partially, resultant in the welding.

Advantages:

- Dedicated to welding aluminum
- The welds do not need rotation
- No need for protection gases
- High-quality weld
- Excellent HAZ

Disadvantages:

- Only a limited number of materials
- Expensive direct machine costs when welding steel (not economical).

Figure 37

Friction Stir-Welding Tool and System Setup. Source: Taheri et al. (2019)

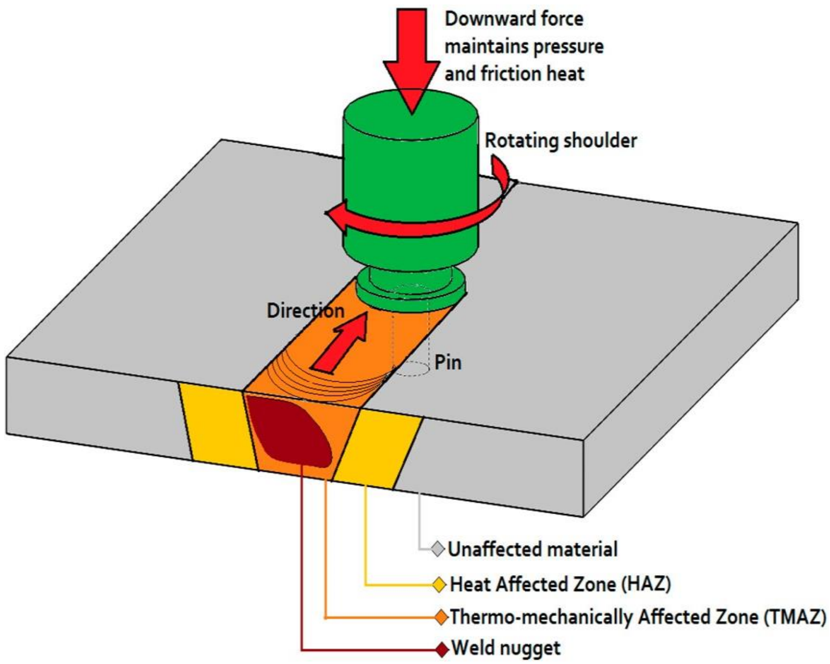


Figure 38

A Schematic of Friction Stir-Welding. Source: Kielhorn et al. (1999), W. H. (LeTourneau U., Adonyi, Y. (LeTourneau U., Holdren, R. L. (Edison W. I., Horrocks, R. C. (Springfield & C. C., & Nissley, N. E. (The O. S. U. (1991), A. W. S. (1999)

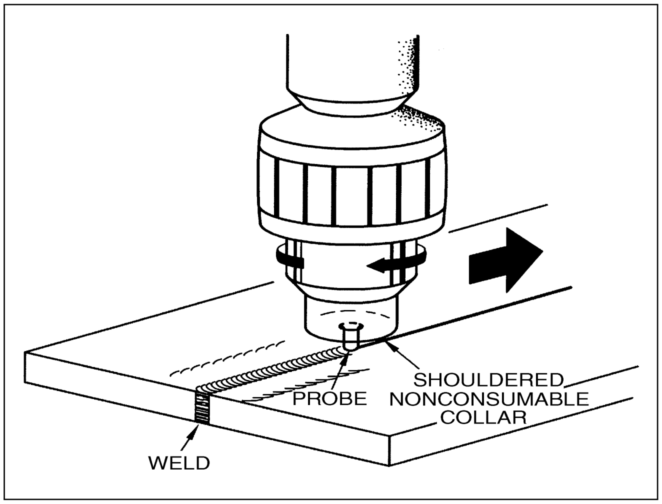


Table 11

Global Parameters for Economic Assessment. Source: Toumpis et al. (2014)

Parameter	Unit	Value
Useful economic life	[a]	8
Welding meters per year	[m]	60,000
Material	-	DH36
Detail	-	Butt weld
Plate length	[m]	10
Plate field length	[m]	30
Typical plate thicknesses	[mm]	5–15

The mean speed of welding of SAW is 40% higher than FSW, but the plates are usually welded with two passes (double-sided welding) to prevent flaws in the roots. Thus, the duration of processing is 2.6 times higher than the FSW. FSW offers about a 20% cost decrease via one go, due to good root qualities.

Table 12

Economic Assessment Results. *Source: Toumpis et al. (2014)*

	SAW	FSW
Number of passes	2	1
Pass/capping pass	Yes	No
Average welding speed	575 mm/min	400 mm/min
Primary processing time	1,800 h	2,500 h
Auxiliary process time	3,000 h	1,200 h
Investment costs machinery	830,000 €	500,000 €
Machine hourly rate	31 €	20 €
Machine direct costs	139 €	1,805 €
Overhead and personal costs	41 €	41 €
Production costs per meter	11 €	80 €
Production costs per hour	136 €	1,307 €
Total production time	~ 4,800 h	~3,700 h

The labor and other costs are equivalent for both welding processes but the machine direct costs in FSW are about 13 times higher compared to SAW. The welding cost proved not to be economical for steel welds.

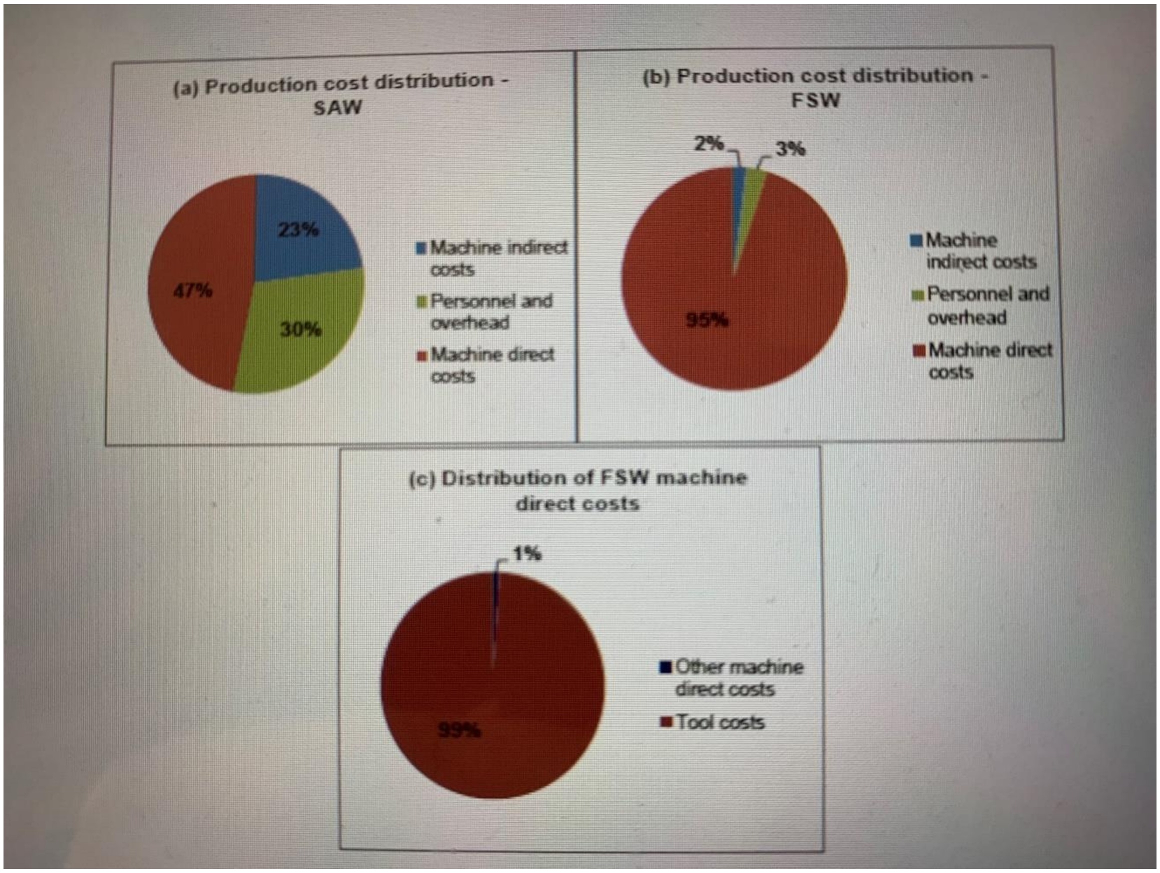


Figure 39

Distribution of Production costs for (a) SAW; (b) FSW; and (c) FSW Machine Direct Costs. Source: Toumpis et al. (2014)

The main problem with FSW is the machine direct expense. Thus, manufacturing is noneconomical for commercial use. The machine's direct cost of utilizing the SAW is about 47% (less than half of FSW). The main value of the SAW tandem method is in greater production and less expenditure.

Table 13

Cost Comparison of SAW (single, tandem) and Friction Stir-Welding

Cost comparison	SAW (single machine)	SAW (tandem)	FSW
Number of passes	2	4	1
Pass/capping pass	Yes	Yes	No
Average welding speed	575 mm/min	1,150 mm/min	400 mm/min
Primary processing time	1,800 h	2,500 h	2,500 h
Auxiliary process time	3,000 h	3,000 h	1,200 h
Investment costs machinery	830,000 €	1.200,000 €	500,000 €
Machine hourly rate	31 €	62 €	20 €
Machine direct costs	139 €	278 €	1.805 €
Overhead and personal costs	41 €	82 €	41 €
Production costs per meter	11 €	22 €	80 €
Production costs per hour	136 €	204 €	1.307,00 €
Total production time	~4,800 h	~5,500 h	~3,700 h

Since the SAW process could be activated by a tandem system, where costs can be even further optimized. The production hourly cost for FSW is roughly 10 times greater than a single SAW and about 6.4 times more than a parallel tandem SAW. However, the fabrication of welding is almost doubled in parallel tandem SAW. The expansion of the investment of the tandem SAW from 830,000 euro to 1,200,000 euro is negligible when correlated to the machine direct charge of the FSW. FSW is considerably expensive compared to SAW.

Thus, SAW is commonly applied in shipyards, limited to low-alloy steel.

A comparison between NDT possibilities for SAW and FSW is as follows.

Typical NDT possibilities for materials welded by SAW:

If mild steel: Either PT or MT is utilized for spotting surface cracks.

For other welding deficiencies: RT or UT

A pattern of above is also likely as might be appropriate.

If stainless steel is used:

PT is utilized for spotting cracks directly connected to the surfaces.

RT or UT is utilized to verify other welding defects.

Typical NDT possibilities for materials welded by FSW:

Typically, PT for surface crack detection for nonferrite material. In the case of ferrite materials, MT is utilized. For detection of other welding discontinuities, RT or UT may be utilized. A mix of PT/RT or PT/UT could be beneficial depending on predicted welding deficiencies. The NDT methods are explained in detail in 4.1.7.

Table 14

A Comparison Between SAW and FSW for Shipbuilding

	SAW			FSW		
Item/Comparison	Yes	No	Range	Yes	No	Range
Flux particles	x				x	
Light arc visible		x		x		
Welding steel	x			Only low alloy		
Welding alu alloys		x		x		
Weld pos. PA, 1 G and 1F	x			x		
Weld pos. PC, 2 G	x			x (restricted)		
Weld PE, 4G		x			x	
Electrode diameter			1.5–6 mm			Probe (5–6 mm)
Thickness of welds			6–30 mm			1.5–30 mm
Current			High			Low
Cooling rate			Low			High
Heat affected zone			Wide			Thin
Welding form			Single or tandem			Single
Smoke or fumes		x		x		
Width of weld			Wide			Less wide
Importance			Very widely used			Less used
Weld quality			High			High

Influencing factors to the welding cost are explored in 4.1.1, 4.1.2, 4.1.3, and 4.1.4. The controlling of welding expense depends on a considerable number of factors, including materials, welding process, welding consumables, QC, and NDT. The emphasis is on thoroughly considering how to select all of the above factors and determining what will fit in the welding process and how costs can be reduced while maintaining consistently high quality. The task is to manage the cost without compromise on quality.

4.1.5

Which welding parameters cause which failures?

Which factors affect the formation of porosity?

Why could hot cracks result when welding stainless steel?

How considerable is preheating of welding electrodes?

What materials need special cleanliness before welding and why?

How should the benchmark of defining the rate of deficiencies in the welds be defined?

How should the above rate affect the remaining and additional inspections?

In this segment of the dissertation, significant welding parameters and their influence on welding testing and quality are considered. Consequently, the economy of the welds is discussed. Thus, a logical connection to research main questions 4.1 and 4.2 is maintained.

Main Welding Parameters

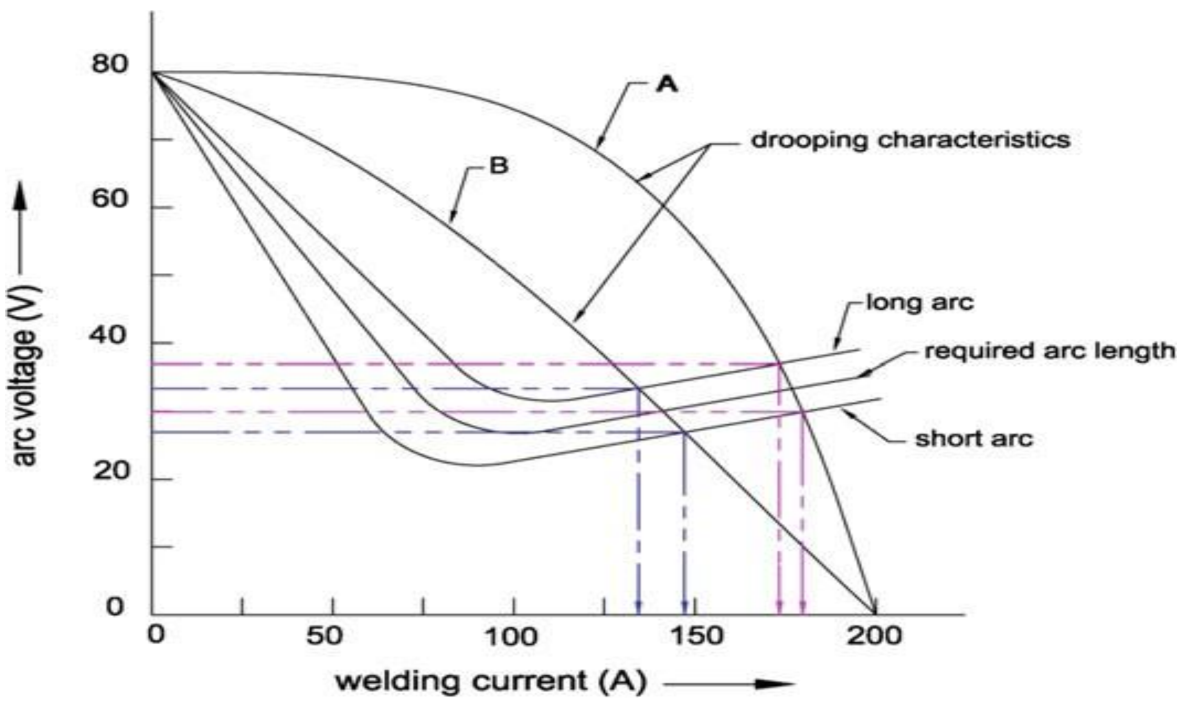
- Welding current (DC or AC).
- Light arc voltage.
- Speed of weld.
- Electrode speeds.
- Electrode diameter.
- Orienting the electrode.
- Electrode polarity.
- Contents of shield gas.

Constant Current Source

The constant current source achieves an almost stable current when the voltage changes.

Figure 40

Typical Volt-Ampere Characteristics of a Constant Current Power Source. Source: Mandal (2017).

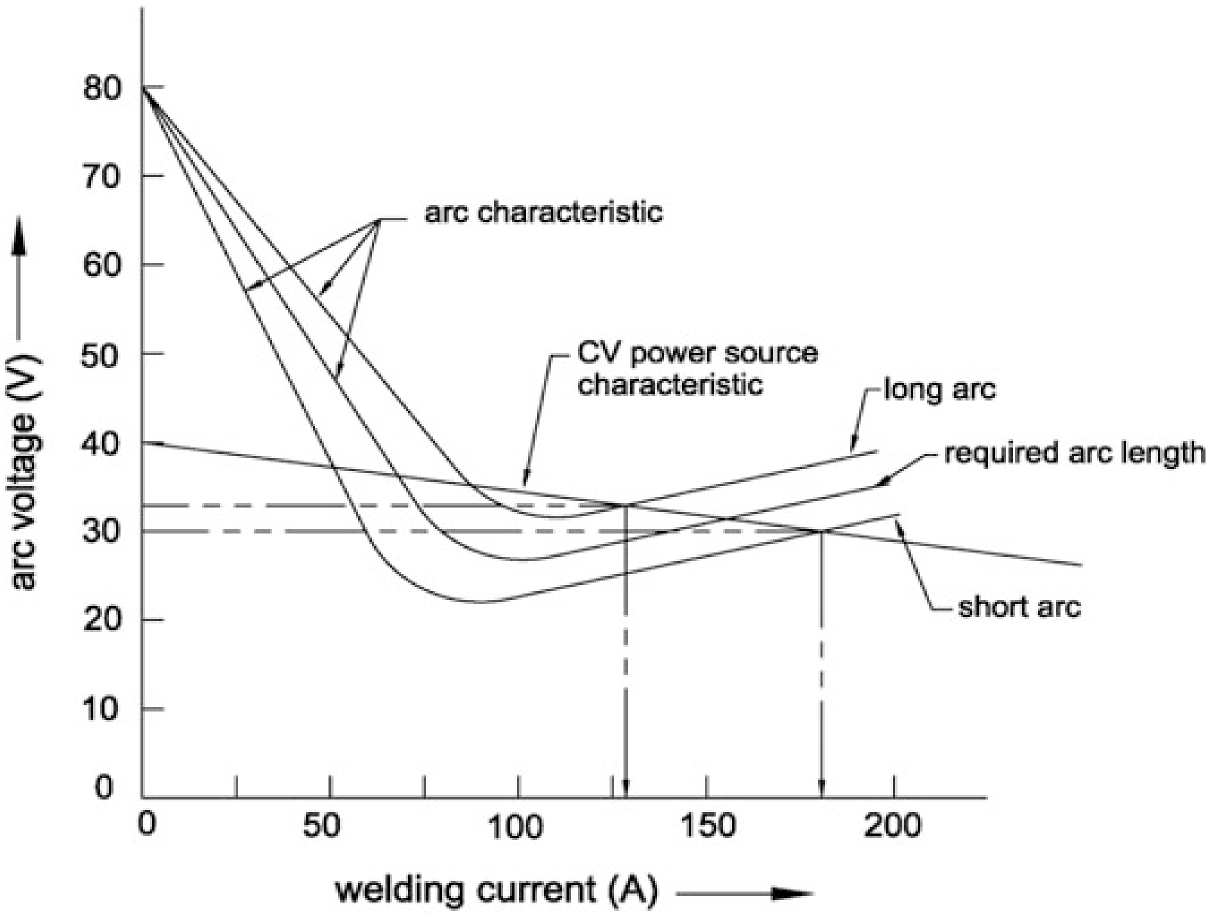


Constant Voltage Source

The constant voltage source achieves an almost stable voltage when the current changes.

Figure 41

Typical Volt-Ampere Characteristics of a Constant Voltage Power Source Source: Mandal (2017)



Light Arc voltage

It ranges from 17 to 40 V and influences the light arc lengths. The length of the light arc is the distance between the light arc's longest point and the welded piece.

It is critical to control the voltage of the light arc and hence light arc length to avoid the following:

Formation of welding spatters

Formation of porosity

Formation of the undercut

Improper deposition

Improper arc direction

Improper arc intensity

Short circuit caused by the change of voltage

Those defects must be removed inducing excessive uneconomical rework and retesting and a loss of quality.

Figure 42

The System of Open-Circuit Voltage and Arc Voltage. Source: Mandal (2017)

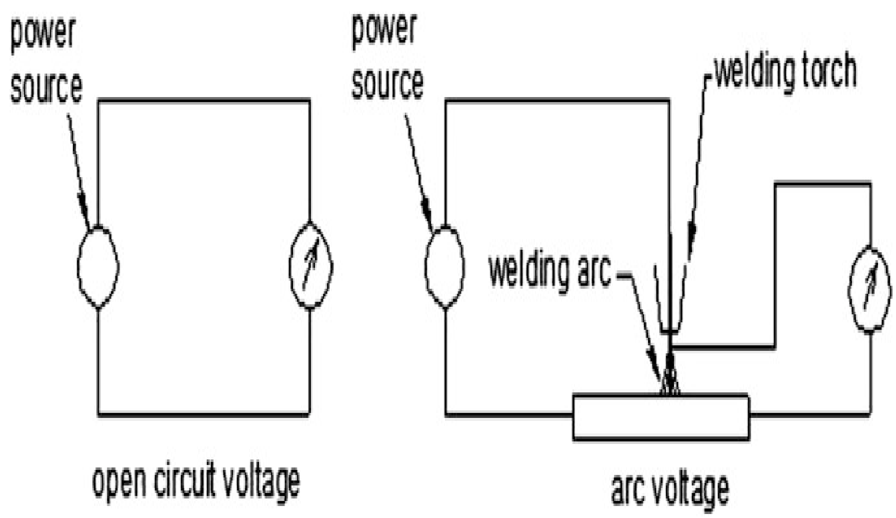
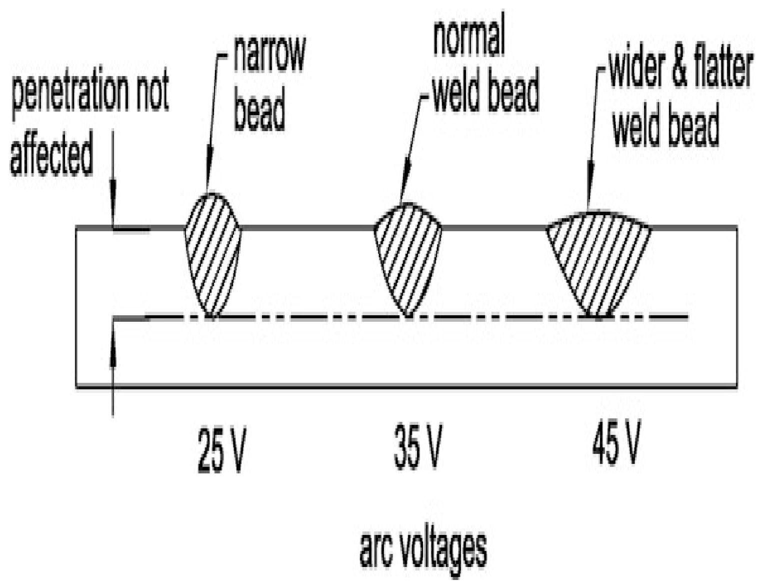


Figure 43

The Effect of Arc Voltage Variations on Welding Bead and Fusion Zone Shape. Source: Mandal (2017)



Speed of Weld

It is essential to manage the welding speed since it influences the welding time and consequently the cost. Problems with increased welding speed include the following:

- Reduction of heat input
- Reduced deposition rate
- Increase of undercut

Increase in porosity.

- Improper welding surface

Problem with decreased welding speed:

- Increased deposition (filler metal)
- Increased heat input
- Increased slag formation (inclusions)
- Increased HAZ
- Increased distortion

Electrode speeds:

For automatic welding, when increasing electrode speed, the current increases automatically. Since applied current only ranges within limits, the electrode speed must consequently also be monitored.

The problem associated with increased speed of electrode:

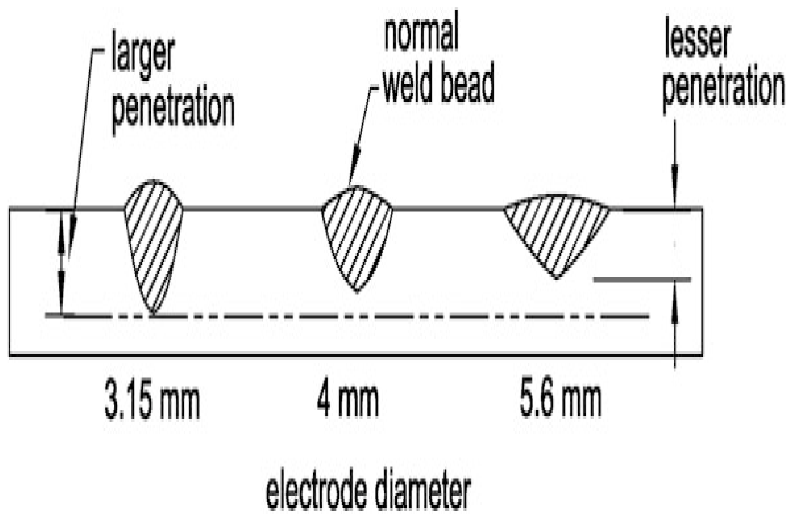
Higher deposition (risk of distortion)

Diameter of Electrode

This has a major impact on the depths of penetrations. For wide root gaps, thicker electrodes must be utilized. In the event of normal gaps, thinner electrodes must be utilized, otherwise the risk of distortion.

Figure 44

Effect of Electrode Size on Welding Bead Shape and Penetration. Source: Mandal (2017)



Orientation of the Electrode

The angle of electrode orientation will influence the shapes of welds. Forehand and backhand techniques are selectable by welders. Typically, an angle of 10–20 degrees is used.

Forehand technique (push angle) has the following characteristics:

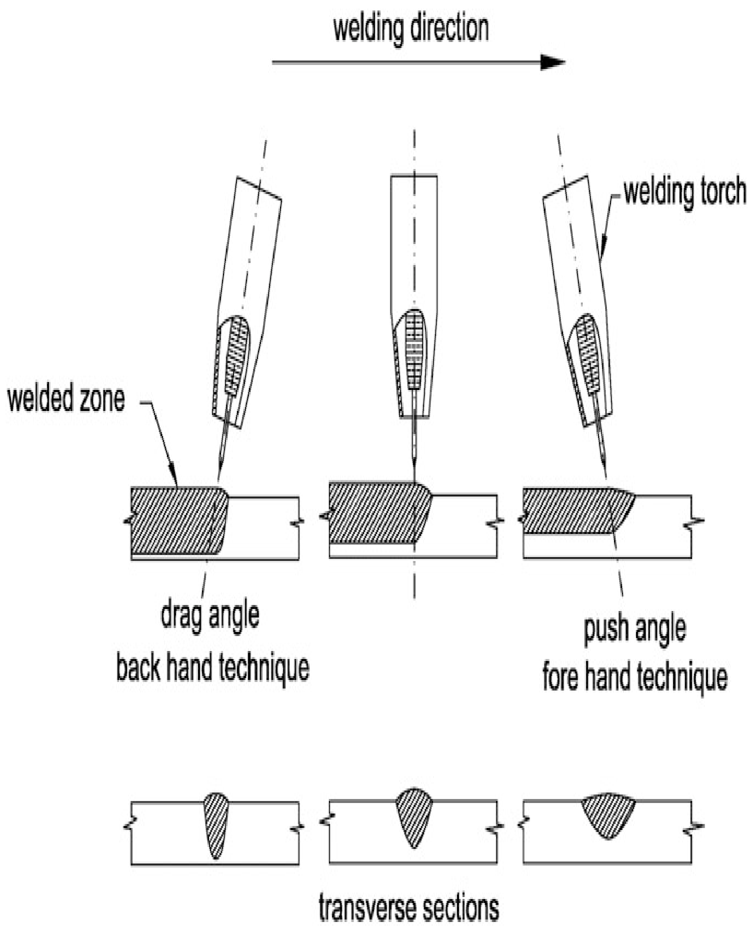
- Decreasedpenetration
- Wider weld
- Increased spatters
- Some distraction in the view due to moving the hand of the welder

The backhand technique (drag angle) has the following characteristics**:**

- Increased penetration
- Narrower, more controlled seams
- Reduced spatters
- Reduced light arc length
- Some distraction due to the placement of the welding torch

Figure 45

The Effect of Electrode Orientation on Bead Shape and Weld Penetration. Source: Mandal (2017)



The Polarity of Electrode

This issue does not apply when welding with the alternative current. However, when using direct current, polarity adjustment is vital for producing fusion.

It matters whether electrodes will act as the anode or the cathode. For steel welds, electrodes will be positively charged.

The composition of shielding (protection) gas:

The protective gas has a fundamental task of shielding the light arc and the weld out of atmospheric influences. Should air enter the melted weld, porosity will arise in the welding. Rejection of welding or rework may be the outcome.

Advantages of shield gas:

- Forming plasma-gas
- Stabilizing the light arc
- Smoothly transferring metal drops out of electrodes or wires to the welding gap or groove

When using GMAW in shipyards, the shield gas is typically CO_2, argon, or both in varying percentages reliant on the materials. CO_2 is applicable for steel welding. Welding aluminum requires argon. Other shield gas is available, reliant on the utilized material besides the required penetration. A helium mixture could likewise be used, reliant on the utilized material and required penetration.

After the essential parameters of the welds have been thoroughly explained, efforts must be spent discussing how wrongly adjusted parameters will cause severe welding defects, deficiencies, or discontinuities, which will cause severe problems both technically and economically, delaying project delivery. Particularly now, weld quality in hull construction is at the central emphasis of the shipowner, the owner representative, and QC and management of the yard.

4.1.5 connects implementation of WPS detailed in 4.2.1

In part 4.1.7, all relevant NDT methods to explore welding defects are considered in full detail.

Defects of Weld:

Weld defects vary in type, form, size, and location. All reputable shipyards strive for sound welding for ship hulls with no deficiencies and according to the rules of the involved class society. The weld calculations at the design department of the shipyard, the developed welding procedures, and the welder skills and those of welding supervisors will play a substantial role in determining the weld quality.

Welding deficiencies can be summarized as follows:

Lack of penetration:

Figures a through c demonstrate cases of lacking penetrations.

Penetration of filler metals through the entire material thickness is insufficient.

No sufficient penetration in weld seams.

No sufficient penetration in the fillet weld.

Penetration depth must be monitored at all times by following approved WPS. The current, voltage, heat input, and welding speed are major parameters to avoid insufficient penetration.

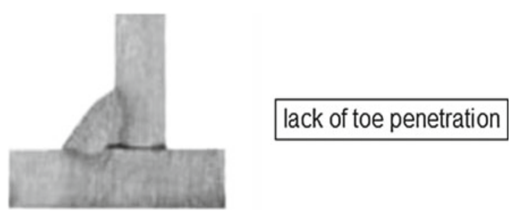
Figure 46

A, b, c: Examples of Insufficient Penetration. Source: Mandal (2017)

a-

b-

c-



Lack of Fusion

If the filler metal did not melt enough or does not fill the entire welding gap, a lack of fusion is present. The welding skills, welding speeds, and sizes of welding gaps play major roles in this concern and must be controlled during the whole welding process.

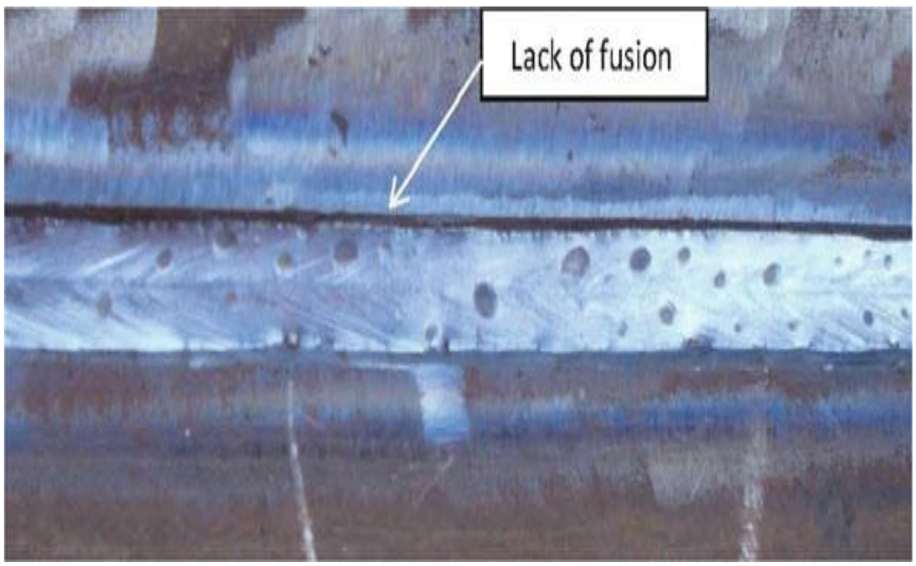


Figure 47

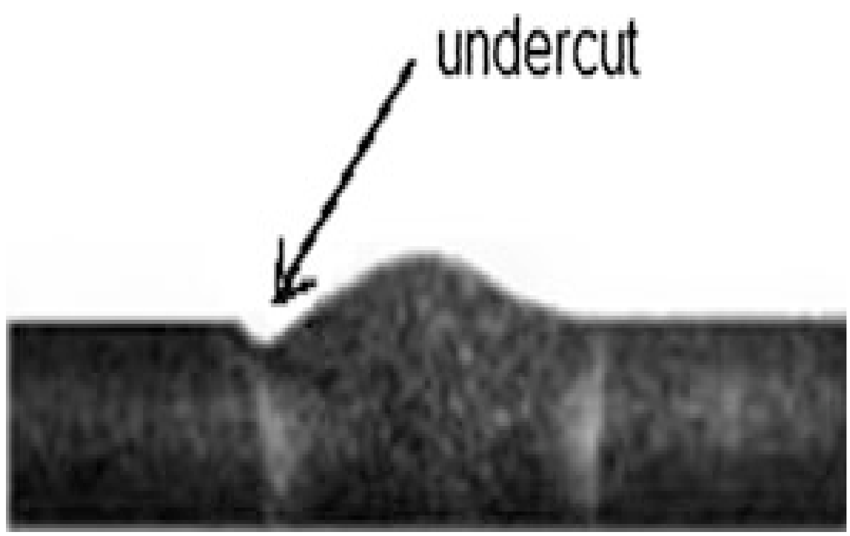
A Typical Example of Lack of Fusion. Source: Mandal (2017).

Undercut

This is principally initiated by excessive welding speeds caused by an improper parameter for the light arc voltage (and hence current) in butt joints. This defect occurs at the corner of welds. Weld speed in WPS must be maintained to avoid this problem.

Figure 48

A Typical Example of Undercut. Source: Mandal (2017)



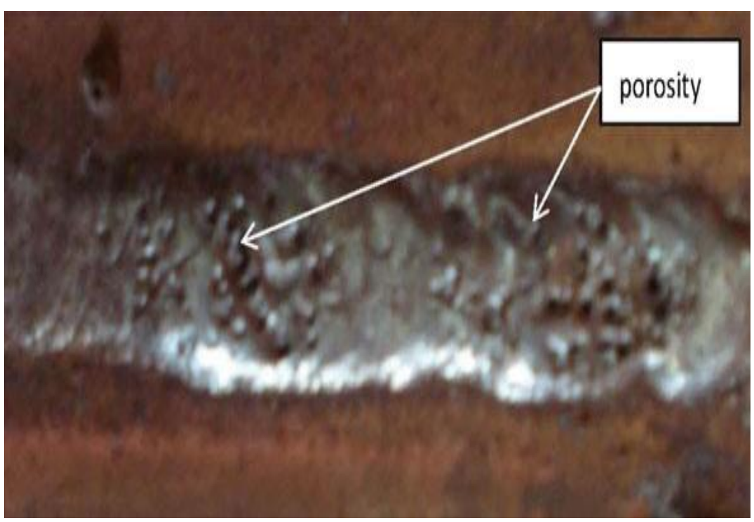
Porosity

Should filler metal and workpiece be sufficiently covered by the protection gas, the atmosphere (O_2 and N in the air) may cause porosities inside the welding. The porosity could have several shapes such as air cavities or clusters. This challenge is relevant for steel welding but is particularly significant in aluminum welds, which is important for unclean surfaces. Cleanliness of surfaces is essential here, particularly when welding aluminum. Most relevant is to control atmospheric conditions and the shield gas during welding at all times.

Figure 49

A Typical Example for Porosities, Air Cavities or Clusters in the Welding Seams.

Source: Mandal (2017)



Welding Cracks

The key element for the forming weld-cracking is the cooling speed since steel, for instance, will face shrinkage during the cooling process. This will cause stresses that will initiate cracking.

A proper WPS, controlling the welding sequences, pre- and post-heating (depends on material), and controlling the interpass temperature provide essential remedies for preventing the cracking. There are hot and cold cracks, which are thoroughly explained in 4.1.6. The hot cracks are typical for stainless steel welds.

Table 15

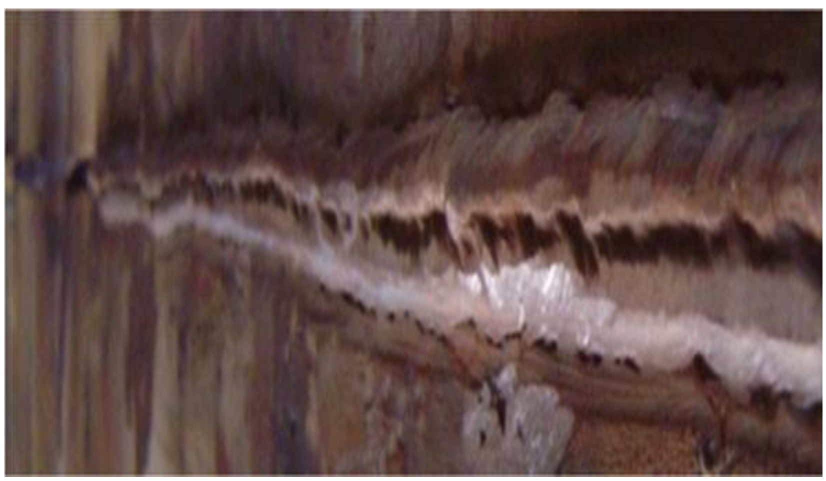
Types of Weld-Induced Cracks and their Characteristic Features. Source: Mandal (2017)

Sl. No.	Description of cracks	Features
1.	Micro crack	Visible under magnification by almost six times
2.	Macro crack	Normally visible or with magnification below six times
3.	Intergranular crack	Crack propagates through grain boundaries
4.	Transgranular crack	Crack penetrates throughout the grain
5.	Hot crack	Cracks forms through a low melting phase
6.	Solidification crack	The crack occurs during solidification of welding metal
7.	Liquation crack	The crack occurs when only the low melting phase is in the molten state as at a grain boundary
8.	Cold crack/delayed crack	A hydrogen-induced crack that develops through increasing residual stresses; hydrogen precipitates as it cannot effuse out of material due to microstructure changes
9.	Shrinkage crack	Cracking form subject to restrained shrinking

Sl. No.	Description of cracks	Features
10.	Toe crack	Develops related to excessive tension among welding toe of fillet joint
11.	Precipitation-induced crack	Happens because of precipitation of brittle phase during welding
12.	Lamellar tearing	Develops due to weld shrinking force behaving in thickness-direction. The cracking is located among parent-metal often below HAZ, in general parallel to the boundaries of the fusions.

Figure 50

A Severe Case of Longitudinal Cracking. Source: Mandal (2017).



Cracks are not acceptable in any welds and all forms, requiring repair and weld to be retested by NDT.

Only after a satisfactory test result, the joint is released.

Table 16

Material Properties

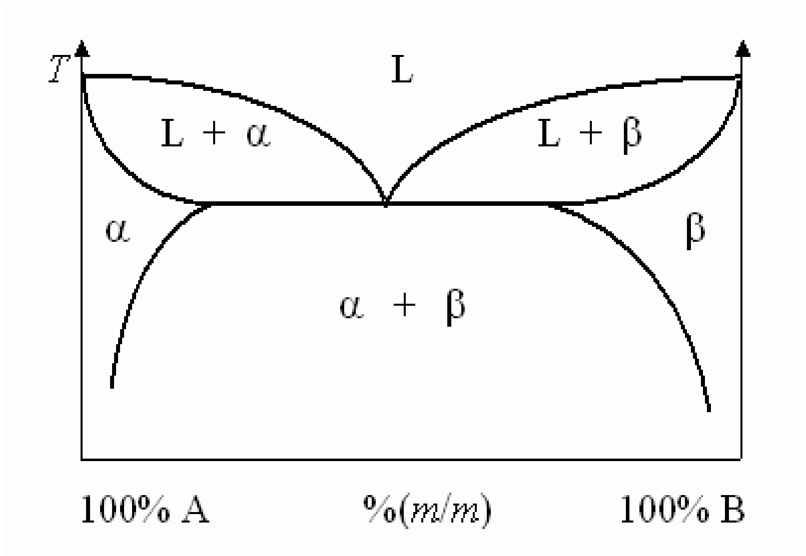
Property	C	CR	Ni	S	Mn	Si	P	Cu	Mo	Se	Ti or Nb
Corrosion Resistance	-	√	√	X	-	-	√	-	√	-	-
Mechanical Properties	√	√	-	-	√	√	√	√	√	-	√
High Temperature Resistance	-	√	√	X	-	-	-	-	√	-	√
Machinability	X	X	-	√	-	-	√	-	-	√	-
Weldability	X	X	-	X	√	-	X	-	√	-	√
Cold Workability	X	X	√	X	-	-	-	√	-	-	-

Table showing the influences of numerous alloy substances on the property of stainless steels (Papantoniou and Engineers, 2010).

The figure showing eutectic points and the condition where various phases may exist.

Figure 51

The Phase-Diagram for a Binary System Displaying a Eutectic Point. Source: Papantoniou and Engineers (2010)

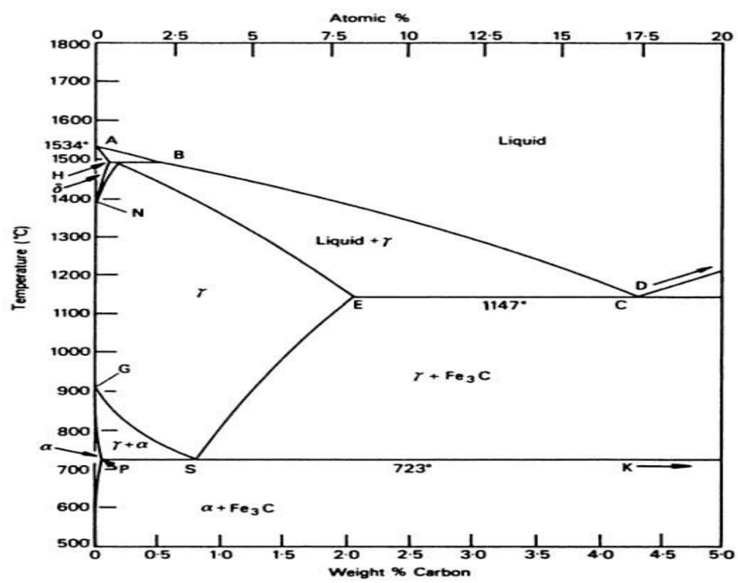


The figure is showing several points of criticality in the ferrite-carbon equilibrium diagrams.

The eutectic reactions happen at temperatures between the meltdown temperature for steels against the temperature of 723 °C.

Figure 52

A Closer Look at the Fe-C Binary System. Source: Papantoniou and Engineers (2010)

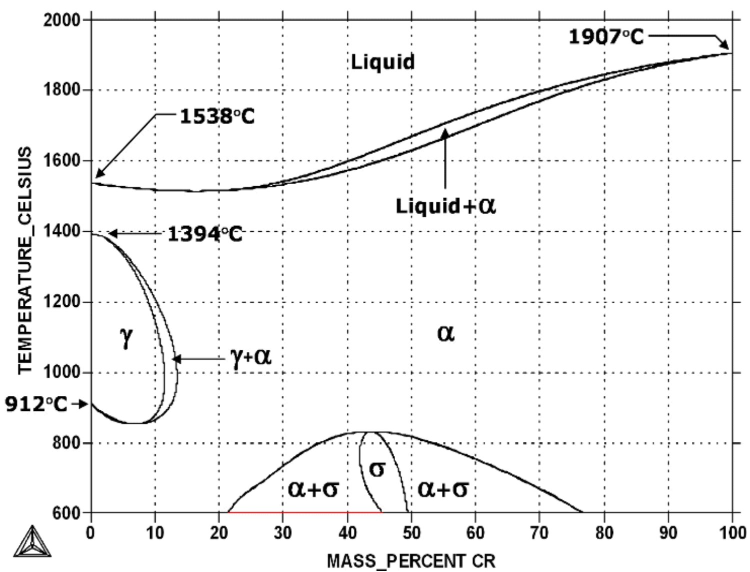


The figure shows the ferrite called delta-ferrite. Adding carbon will extend the γ-loops to the greater content of chromium, responsible for broader α+γ phases.

(by adding max. 0.3% carbon).

Figure 53

A Close-Up of the Fe-Cr System. Source: Papantoniou and Engineers (2010)



The subsequent table 17 lists a general composition range of standard austenite stainless steel.

Table 17

Source: Papantoniou and Engineers (2010)

Chromium:	16 to 25 wt%
Nickel:	8 to 20 wt%
Manganese:	1 to 2 wt%
Silicon:	0.5 to 3 wt%
Carbon:	0.02 to 0.08 wt% (less than 0.03 wt% for "L" grades)
Molybdenum:	0 to 2 wt%
Nitrogen:	0 to 0.15 wt%
Titanium and Niobium:	0 to 0.2 wt%

Table 18

Austenite Stainless Steel Composition Table. Source: Papantoniou and Engineers (2010)

Type	UNS Number	Composition - Percent *							Other
		C	Mn	Si	Cr	Ni	P	S	
201	S20100	0.15	5.5-7.5	1.00	16.0-18.0	3.5-5.5	0.06	0.03	0.25 N
202	S20200	0.15	7.5-10.0	1.00	17.0-19.0	4.0-6.0	0.06	0.03	0.25 N
205	S20500	0.12-0.25	14.0-15.5	1.00	16.5-18.0	1.0-1.75	0.06	0.03	0.32-0.40 N
216	S21600	0.08	7.5-9.0	1.00	17.5-22.0	5.0-7.0	0.045	0.03	2.0-3.0 Mo; 0.25-0.5 N
301	S30100	0.15	2.00	1.00	16.0-18.0	6.0-8.0	0.045	0.03	
302	S30200	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	
302B	S30215	0.15	2.00	2.0-3.0	17.0-19.0	8.0-10.0	0.045	0.03	
303**	S30300	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.15 min.	0.6 Mo
303Se**	S30323	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.06	0.15 min. Se
304	S30400	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	
304H	S30409	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	
304L	S30403	0.03	2.00	1.00	18.0-20.0	8.0-12.0	0.045	0.03	
304LN	S30453	0.03	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.15 N
S30430	S30430	0.08	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	3.0-4.0 Cu
304N	S30451	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
304HN	S30452	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
305	S30500	0.12	2.00	1.00	17.0-19.0	10.5-13.0	0.045	0.03	
308	S30800	0.08	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	
308L		0.03	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	
309	S30900	0.20	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	
309S	S30908	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	
309S Cb	S30940	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	8 x %C - Nb(Cb)
309 Cb + Ta		0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	8 x %C (Nb(Cb) + Ta)
310	S31000	0.25	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	
310S	S31008	0.08	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	
312		0.15	2.00	1.00	30.0 nom.	9.0 nom.	0.045	0.03	
254SMo	S31254	0.020	1.00	0.80	19.5-20.5	17.50-18.5	0.03	0.010	6.00-6.50Mo; 0.18-0.22N; Cu=0.5-1.00
314	S31400	0.25	2.00	1.5-3.0	23.0-26.0	19.0-22.0	0.045	0.03	
316	S31600	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316F**	S31620	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.20	0.10 min.	1.75-2.5 Mo
316H	S31609	0.04-0.10	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316L	S31603	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316LN	S31653	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.30 N
316N	S31651	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.16 N
317	S31700	0.08	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317L	S31703	0.03	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317M	S31725	0.03	2.00	1.00	18.0-20.0	12.0-16.0	0.045	0.03	4.0-5.0 Mo
321	S32100	0.08	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min. Ti
321H	S32109	0.04-0.10	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min. Ti
329	S32900	0.10	2.00	1.00	25.0-30.0	3.0-6.0	0.045	0.03	1.0-2.0 Mo
330	N08330	0.08	2.00	0.75-1.5	17.0-20.0	34.0-37.0	0.04	0.03	
AL6-XN	N80367	0.030	2.00	1.00	20.0-22.0	23.5-25.5	0.04	0.03	6.00-7.00Mo; 0.18-0.25N; Cu=0.75
330HC		0.40	1.50	1.25	19.0 nom.	35.0 nom.			
332		0.04	1.00	0.50	21.5 nom.	32.0 nom.	0.045	0.03	
347	S34700	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min. Nb(Cb) +Ta
347H	S34709	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min. Nb(Cb) + Ta
348	S34800	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Cu; 10x %C min. Nb(Cb) + Ta(c)
348H	S34809	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Cu; 10 x %C min. Nb(Cb) + Ta
384	S38400	0.08	2.00	1.00	15.0-17.0	17.0-19.0	0.045	0.03	
Nitronic 32	S24100	0.10	12.0	0.50	18.0	1.6			0.35 N
Nitronic 33	S24000	0.06	13.0	0.5	18.0	3.0			0.30 N
Nitronic 40	S21900	0.08	8.0-10.0	1.00	18.0-20.0	5.0-7.0	0.06	0.03	0.15-0.40 N
Nitronic 50	S20910	0.06	4.0-6.0	1.00	20.5-23.5	11.5-13.5	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N; 0.1-0.3 Cb; 0.1-0.3 V
Nitronic 60	S21800	0.10	7.0-9.0	3.5-4.5	16.0-18.0	8.0-9.0	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N;

Lamellar Tear (Crack)

A lamellar tear appears owing to cracking in way of the plates' thicknesses due to additional stresses. The issue starts at the rolling of the plating, where the material structure could be weaker in terms of thickness.

Figure 54

A Schematic of Lamellar Tear. Source: Mandal (2017).

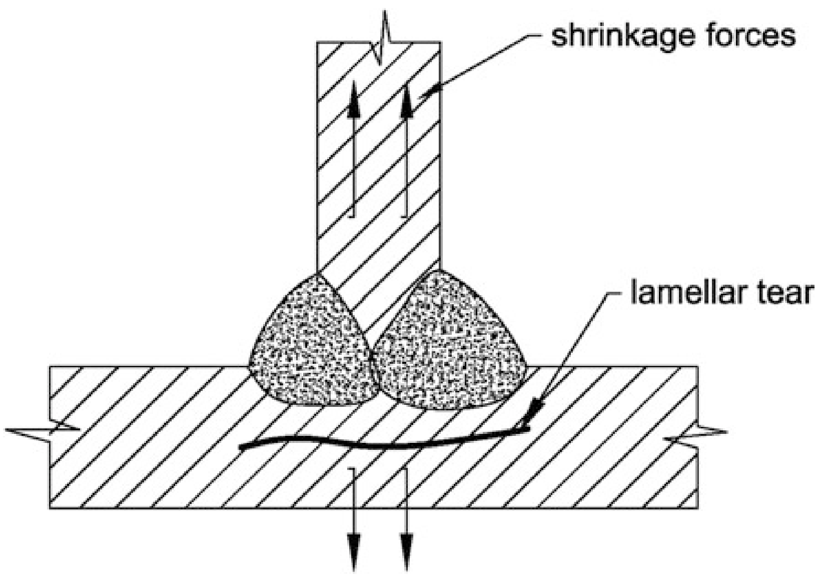


Table 19

Locations of a Different Form of Cracking in the Welding Area. Metallurgical Effect in Connection to the Welding, Leading to Cracks. Source: Mandal (2017).

Cracking phenomenon	Position in welding
Hydrogen attack	Weld deposit
Porosity	Weld deposit
Solidification cracking	Weld deposit
Liquation cracking	Fusion zone
Lamellar tearing	HAZ
Cold cracking or hydrogen embrittlement	HAZ

Crater Crack

This type of crack occurs at the weld ending. It shows lacking finishing and might cause dangerous problems in the seam due to weakness in rates of deposition. The solution is to properly fill the crater and to schedule the time needed for this action. The welding supervisor must control the finishing of the weld as per QC standards and advise the welders accordingly.

Slag Inclusion

The utilized flux is the trigger of such welding defect. The flux is a usual component in different welding processes such as an electrode, MAG, and MIG. The slag developments are identifiable in NDT (for example, RT). High costs are involved in removing and retesting. Slag removal is performed via opening the welding until it reaches the slag to be ground location. The weld must then be rebuilt and retested. Controlling and grinding slag following each welding path is the best feasible solution.

Therefore, the WPS explained in detail in 4.2.1 must be maintained and the parameters of welding kept and traced by welding QC, spot checks, and welding patrols at every welding level, particularly when processing sensitive materials in issues related to crack and porosities such as when welds are executed on aluminum and stainless steel.

Qualification of Welding Procedures

According to the International Association of Class Societies. (2013). No. 47 Shipbuilding and Repair Quality Standard (Rev. 7 June 2013), (1996), 1–63., welding procedure to be assured as per the rules of the class societies or by international standards; for instance, EN 288, ISO9956, American Society for Mechanical Engineers in section 9, American Welding Society section D1.1.

Criteria for evaluating welding defects:

The acceptance criteria are described as per the requirement of classification societies and the international standards.

According to ABS Rules (American Bureau of Shipping [ABS], 2020). Guide for Nondestructive Inspection, inspections and NDT to be conducted to satisfaction of the class surveyors, as indicated in section 10 of guidelines of the American Bureau of Shipping. Subject to material welded and its properties, the requirements will be increased."28

The rules of the classification society engaged in the corresponding newbuilding or ship repair must be obeyed. Nonfulfillment could result in suspending or withdrawing the class certificate. Without a valid class certificate, no insurance is provided to the shipowners, and hence no trade shall be possible.

4.1.6

What are the acceptance criteria for the HAZ in welded shipbuilding high-tensile steels?

Evaluating HAZ in 4.1.6 is critical to connecting the dissertation questions about the welding quality and connects in the same direction, referring to research questions from 4.1.1. through 4.1.5.

HAZ:

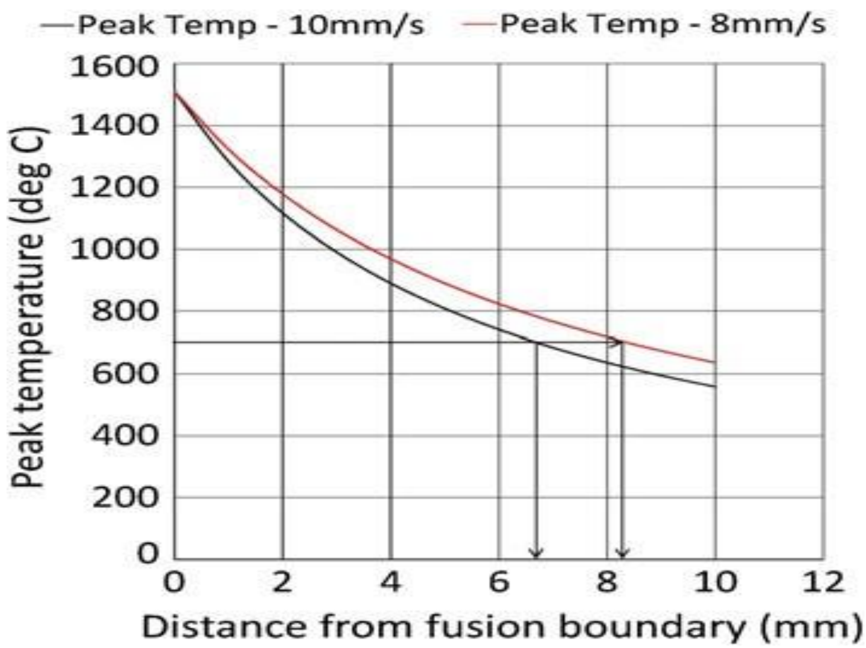
Significance applies to evaluating the magnitude of HAZ. As microstructural transfer might arise among HAZ, this requirement is set to select the relevant welding parameters that keep the HAZ at its lowest rate.

HAZ is expressed as the area where microstructural transit might occur. For steel, 723 °C is the temperature where crystallization happens (variations in microstructure). Structural alterations in the material structure occur only where the temperature becomes higher than the recrystallization temperature of 723 °C. Therefore, the HAZ will exist between the melting material boundary and 723 °C. Due to changing the material structure, grain growth will result. By lowering welding speeds, the cooling rate will decrease. Consequently, the HAZ increases.

HAZ monitoring is a requisite. The acceptance criteria will be compliant with the rules of the class societies or the international standards. A considerable amount of testing is performed, such as the lab mechanical properties, involving notch toughness tests (Charpy tests) and micro and macro tests relevant for actual HAZ toughness.

Figure 55

Peak Temperature Distribution of Fusions Boundaries, at 90 Degrees to the Welding Direction. Source: Mandal (2017)



Based on ABS rules, the figure below for the toughness measurement may be submitted.

Figure 56

The Orientation and Location of Charpy V-Notch Specimens for Weld and HAZ Properties. Source: Rules of the American Bureau of Shipping (ABS), Rules for "Materials and Welding", Part 2, Version 2021, www.eagle.org

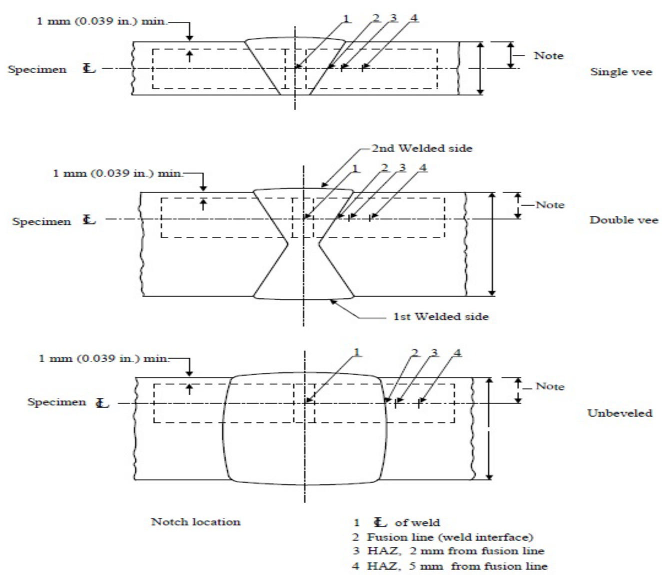


Table 20

Impact Test Requirements for Butt Joints (t ≤ 50 mm). Source: Rules of the American Bureau of Shipping (ABS), Rules for materials and welding, Part 2, Version 2021, www.eagle.org

Grade of steel	Testing temperature (°C)	Value of minimum average absorbed energy (J)		
			For manually or semi-automatically welded joints	For automatically welded joints
		Down hand, horizontal, overhead	Vertical upward, vertical downward	
A(3)	20	47	34	34
B(3), D	0			
E	-20			
AH32, AH36	20			
DH32, DH36	0			
EH32, EH36	-20			
FH32, FH36	-40			
AH40	20		39	39
DH40	0			
EH40	-20			

FH40	-40

Notes:

"For thickness above 50 mm impact test requirements reference must fulfill ABS Rules 2-4-3/11.5. These requirements apply to test pieces with butt weld at 90 degrees to roll-direction of plates. For Grade A and B steels, average absorbed energy onto the line of fusions, at HAZ, minimum 27 J must be fulfilled.” [31]

Excessive heat input causes HAZ. For solving the issue, a technology was developed to increase HAZ toughness.

The method consists of the following steps:

1- Check the sizes of the grains in HAZ

2- Examine the microstructure

3- Check for carbon equivalent

Photo 1

Photo Showing The Detailed Microstructure of HAZ-Simulation (Peak Temperature: 1,400 °C, Cooling Time from 800 °C to 500 °C: 390 S). Source: Suzuki et al. (2005)

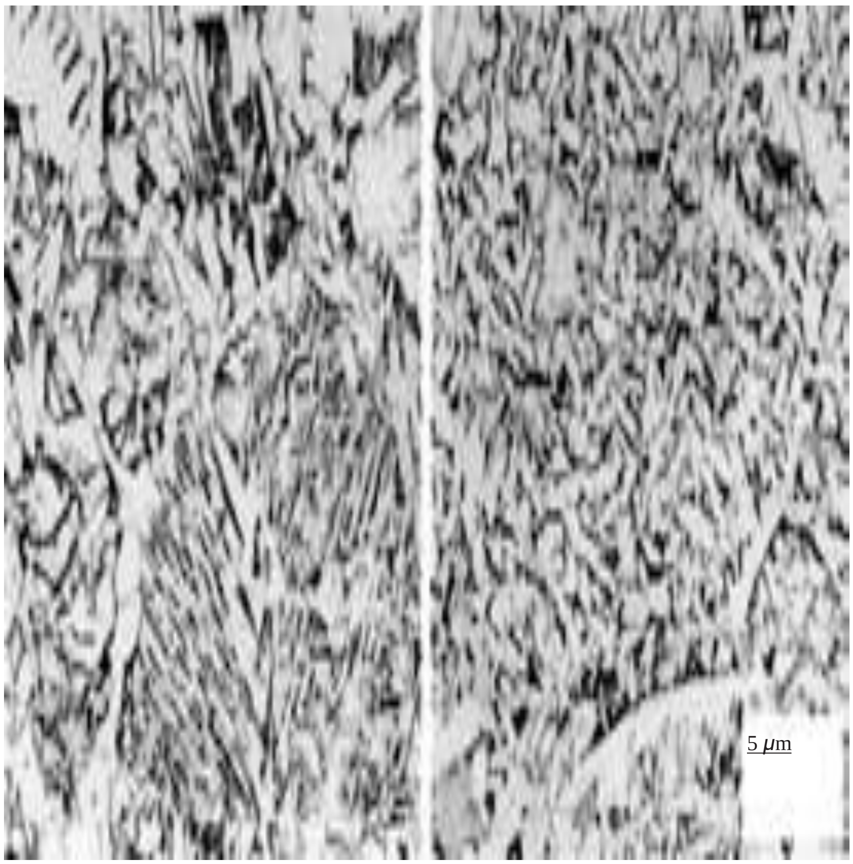


Table 21

Chemical Composition and Mechanical Properties of YS390 N/mm² Class Plate.

Source: Suzuki et al. (2005)

Thickness (mm)	Chemical composition (mass%)							Tensile property (Transverse)			Charpy impact property (Longitudinal)
	C	Si	Mn	P	S	Others	C_{eq}*	YS (N/mm^2)	TS (N/mm^2)	El (%)	vE□40 (J)
80	0.08	0.22	1.54	0.007	0.001	Ti, B, Ca, etc.	0.36	411	532	28	265

Table 22

Condition of Welding for YS390 N/mm² Class Plate. Source: Suzuki et al. (2005)

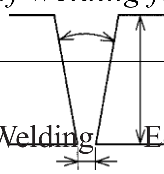
Thickness (mm)	Welding method	Edge preparation	Welding consumable	Pass	Electrode	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)	Heat input (kJ/cm)
80	EGW	 20□ 80 mm 10 mm	DWS-50GTF	1	Face side	400	42	2.9	680
			DWS-50GTR KL-4GT (Kobe Steel, Ltd.)		Root side	400	40		

Photo 2

Photo Showing Macrostructure Of YS390 N/Mm^2 Class Welded Joint (Electro-Gas Arc-Welding, Heat Input 680 Kj/Cm). Source: Suzuki Et Al. (2005)

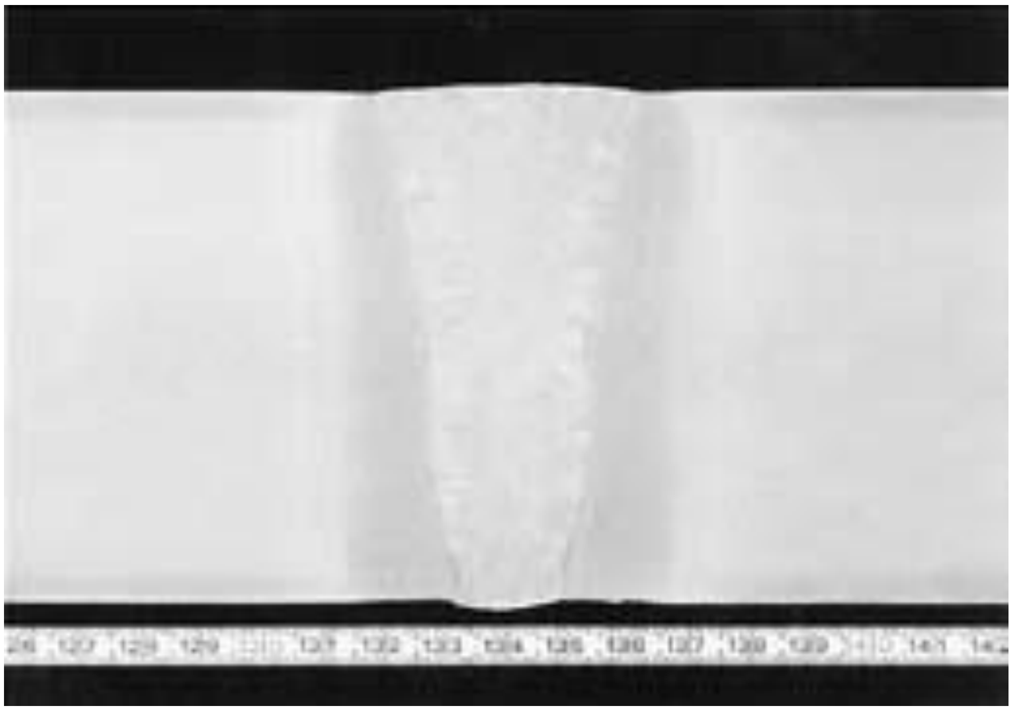


Table 23

Chemical Composition and Mechanical Properties of YS355 N/mm^2 Class Plate at Low Temperatures. Source: Suzuki et al. (2005)

Thickness (mm)	Chemical composition (mass %)							Tensile property (transverse)			Charpy impact energy (transverse)
	C	Si	Mn	P	S	Others	C_{eq}*	YS (N/mm^2)	TS (N/mm^2)	El (%)	$_{V}E_{\square 53}$ (J)
17.5	0.08	0.19	1.56	0.013	0.002	Ti, Ca, etc.	0.34	426	522	22	351

Table 24

Welding Conditions of YS355 N/mm^2 Class Plate for Low-Temperature Service. Source: Suzuki et al. (2005)

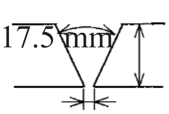
Thickness (mm)	Welding method	Edge preparation	Welding consumable	Pass	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)	Heat input (kJ/cm)
17.5	1 side SAW (FAB)	50□ 17.5 mm  0–3 mm	US255 PFI-50LT RR-3 FAB-1 (Kobe Steel, Ltd.)	1	950	38	20	108

Table 25

Mechanical Properties of Welding of YS355 N/mm² Class Plate for Low-Temperature Service. Source: Suzuki et al. (2005)

Thickness (mm)	Welding method	Heat input (kJ/cm)	Tensile strength* (N/mm²)	Charpy impact energy, $_{v}E_{\square 55}$ (J)** Fusion line	HAZ1 mm	HAZ3 mm	HAZ5 mm
17.5	1 side SAW (FAB)	108	523	84	100	262	301

* Test specimen: Class NK U2A type

** Location of specimen: 1 mm below surface

Table 26

Chemical Composition and Mechanical Properties of YS355 N/mm² Class F Grade Plate. Source: Suzuki et al. (2005)

Thickness (mm)	Chemical composition (mass%) C	Si	Mn	P	S	Others	C_{eq}*	Tensile property (Transverse) YS (N/mm²)	TS (N/mm²)	El (%)	Charpy Test (Transverse) $_{v}E_{\square 60}$ (J)
50	0.07	0.19	1.56	0.008	0.002	Ti, Ca, etc.	0.36	399	546	30	292

Table 27

Weld Condition of YS355 N/mm^2 Class F Grade Plate. Source: Suzuki et al. (2005)

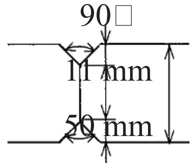
Thickness (mm)	Welding method	Edge preparation	Welding consumable	Pass	Electrode	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)	Heat input (kJ/cm)
50	Double side SAW (KX)	 90□ 11 mm 50 mm 11 mm 90□	KW-101B KB-110 (JFE Steel)	1	L	1 600	35	50	132
					T	1 200	45		
				2	L	1 700	35	55	129
					T	1 300	45		

Table 28

Extended Factors, Measures, and Allowable Criteria of HAZ

No.	Factors influencing HAZ	Measures of improvements
1	Grain size in HAZ	Control optimized dissolution of TiN
2	Microalloying and atomic concentration ratio	Control microstructure
3	Increased rates for cooling	Control of optimum carbon equivalent and alloy design
4	Hardness (lab test)	Control through measurements (Rockwell, Vickers or Brinell.)
5	Hardness (lab test), equivalency	Using hardness conversion tables
6	Allowable hardness criteria	Class society rules and international standards, of ABS: the maximum allowable hardness for Vickers (HV) to be 350 HV 10 according to ABS Rules, Part 2 (Rules for Materials and Welding).

"According to ABS rules, Part 2, rules for materials and welding (2021), Hardness test HV 10 across the welding must be conducted. The impressions will be performed at one mm transverse line under the plate's surface, at the upper and bottom of welding as follows:

● Fusion line

● HAZ: at each 0.7 mm from fusion line into an unaffected base material (6 to 7 minimum measurements for each HAZ)

The allowable hardness value must be equal or less than 350 HV10." [31]

The conclusion of "Suzuki et al. (2005)"[23] lacks the acceptance HAZ criteria regarding hardness. Additional methods have since been added to highlight the assessment and add the evaluating criteria for acceptance.

This study on the HAZ has revealed major technical and economic factors concerning the welds. A rejected lab test for the hardness shall cause rejection of the welds, causing a considerable loss in the financial plan and at delayed ship delivery time (loss for the shipowner and the shipyard). The dissertation demonstrates the value of welding and observing the HAZ, followed by an evaluation of this procedure.

Therefore, it connects all previous research questions from 4.1.1. to 4.1.5 and the coming research questions regarding NDT. This research connects the weld design factors in chapter 4.2 and confirms the DFP principle.

4.1.7

NDT:

Which NDT should be chosen for what material?

Why and when is a combination of NDT methods reasonable

When is a dye penetrant as an NDT method advisable?

What are the limitations of the NDT methods?

4.1.5 of the dissertation considers all relevant welding parameters besides the possible welding defects and deficiencies. 4.1.7 connects 4.1.5 and explains in detail how and by what means those welding defects could be detected. The weld imperfections are major indications meant for welding quality and hence a direct indication to the shipyard's economy and the customer satisfaction alike.

NDT is the method utilized in all shipyards worldwide to detect welding defects.

The preference for an efficient NDT method is essential in finding the defects. NDT is not selected by chance as practiced in several shipyards. Moreover, shipyards used to use one run of NDT. Sometimes, it is essential not just to utilize the right NDT method but to apply a second means of NDT for confirmation. Some defects might be overlooked and could only be identified by a second NDT.

The appropriate NDT method must consider the sort of defect that is mostly expected to exist. This is again subject to the materials in question, relevant thicknesses, welding process, type of edge preparation, shield gas, and welder skill. Furthermore, the NDT part connects all the dissertation questions considered in 4.1 and 4.2. Thus, NDT is considered thoroughly. A good quality welding means that customer is in focus. QC is a vital requirement for competitiveness and keeping the shipyard reputable.

Visual Testing (VT):

The first method for NDT and requires deep human experience. Upon identifying welding defects, those could be rejected, and repair will be mandatory as a condition of acceptance. Suspect areas can be discovered and examined by following NDT methods.

Penetration Testing (PT):

PT is a universally utilized NDT method in shipyards. It has applicability to all materials, particularly for stainless steel besides aluminum.

The welds require cleanliness, then the dye penetrant is utilized according to the weld seam temperatures and considering the instructions of the manufacturer by adding the developer and allowing a development time around 10–15 minutes. Surface cracks, if existing, can be seen.

Note: There are PT systems for high-temperature welds (more expensive).

Limitations of the PT:

The crack must be directly existent at the topmost of the welds.

Cracks below the surface are not identifiable.

Test temperatures of the welds (workpieces) to be between 5 and 50 ºC; otherwise, no reliable results are obtained.

In doubtful situations, another NDT may be utilized or a second NDT engaged (e.g. PT might be utilized additionally to MT, UT, or RT).

Problem during recycling requires approval and charge verification.

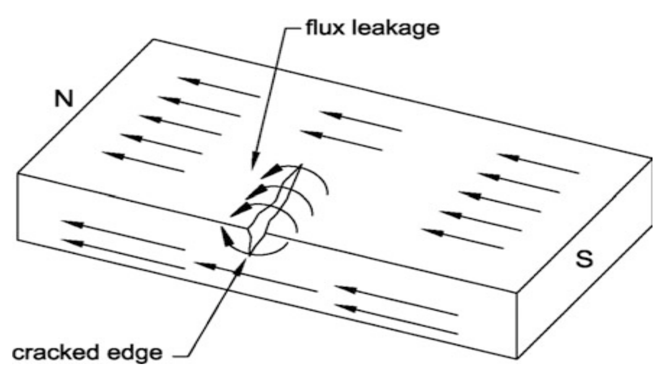
Owing to penetrating and development time, PT is too slow a method for NDT testing.

Magnetic-Particle Testing (MT)

MT is a common NDT method in shipyards. The tested material must be magnetizable. Cracks of up to 3 mm below the surface, if existing, can be detected. Horse shoe magnets are frequently applied. The principle is as follows: the method will induce magnetic flux. Provided the crack is at right angle to flux, the latter will leak inside it, and an indication can be detected where the magnetic-particles accumulate. Attention is given to carrying out the MT by changing the sequence of the magnetism in steps crossing each other at every weld location. Different liquids for showing the cracks visually are used. However, fluorescent oil liquid is best for visual identification.

Figure 57

A Schematic Representation of Magnetic Flux in a Cracked Region. Source: Mandal (2017).



Limitations of the MT method:

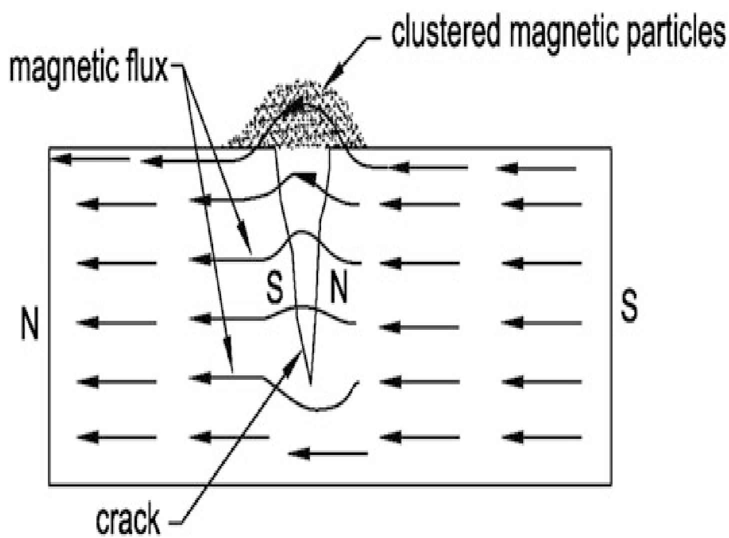
The remaining magnetism could occur (to be demagnetized).

If the remaining magnetism is not considered, difficulties in future welding may apply.

Test liquid might cause corrosion.

Figure 58

A Schematic View of Clustered Magnetic Particles Near the Crack Zone. Source: Mandal (2017).



Radiographic Testing (RT):

For steel, the most used material in shipyards, the following is true:

The assortment of the radiation sources is reliant on utilized material thickness.

IR 192 is applicable for steel thicknesses of up to 100 mm.

Co 60 is applicable for steel thicknesses until 200 mm.

The linear accelerator is sourced for materials up to 400 mm.

The radiation penetrates the welds and passes through the film that is fixed underneath the welded piece. Any defects will be visible onto the developed film (differences in the gray contrast).

The film is a document: filing for reference is necessary.

The source of RT depends on material thickness.

All volume-based welding defects such as porosity and slag can be discovered through contrast alteration.

Limitations of the RT method:

Using RT, only weld defects as such can be allocated; the location (depth) of deficiencies is not identifiable unless second radiation from a different angle is executed (expensive) since a three-dimensional weld is projected as a two-dimensional picture (RT film).

Two-dimensional welding defects such as incomplete fusion in a paralleling plane to the radiation direction might be overlooked.

The judgment of the RT film is a subjective evaluation.

The RT film is high-priced material that will impact the welding economy. Producing excellent welds and implementing RT not exceeding the rule requirements are important measures.

The RT operators must be protected as per international regulations.

Preparing the RT testing takes a longer duration-matched to further NDT methods since precautions regarding work safety are highly considered. Therefore, RT in shipyards is usually executed in the evening or at weekend, where labor is absent from the scene.

The transport of the RT gear is subject to be executed according to actual international standards.

The recycling of the RT equipment to be conducted according to international safety standards and regulations.

Ultrasonic Testing (UT)

UT is common in shipyards as a significant NDT method. The ultrasonic signals are induced and penetrate the welds. Once an imperfection acts as an obstacle to the waves, they reflect on a monitor showing an indication of deficiency and are located in terms of their thickness.

Ultrasonic testing proves the following advantages:

- Identification of defects at all thicknesses
- High penetration possibility

- The locations, shapes, and appearances of the deficiencies are detectable.
- Less time for testing
- Immediate results
- PC to show, store, and print the defect reports and document them
- Utilized for other purposes; for example, thickness gauging
- Utilized to detect cavities exiting inside material structures (for example, air gaps, discontinuities during the manufacturing of rolled materials, such as steel
- Only a single side sufficient for examination of the whole thickness
- A good method for common health
- Portable system, easy to transport
- Operation is feasible in enclosed spaces; for example, tanks
- High accuracy NDT verifications
- Both cracks and incomplete fusions could be well identified by UT

Limitations and problems of UT:

- Difficult finding of weld flaws for material thicknesses below 10 mm.
- HAZ must be tested from both sides.
- Welding spatter and rough surfaces must be ground off before the test.
- The weld seam must be ground off.
- The welded joint must offer access to this test method.
- High skills required.
- Difficult to perform UT on a rough material and irregular in shape.
- Wave sending must be arranged at various angles to identify defects paralleling the waves.
- Annual calibration required.
- Contingent on the materials (metallurgy), the ultrasonic signal may be weakened; for example, stainless steel and fine-grained steel. Results could become inaccurate. It is better to combine PT and RT additionally.

Eddy Current (ET)

Eddy current is applied as NDT when materials are conductive to electricity. Using ET, NDT could be conducted without removing the coating from the structure, which is especially useful in offshore structures, since major costs could be saved, should no repairs be required. A limitation of ET is realized in restricted penetration depth.

Owing to that, eddy current is rarely utilized in shipbuilding and ship repair. Infrared eddy current could be later used for NDT.

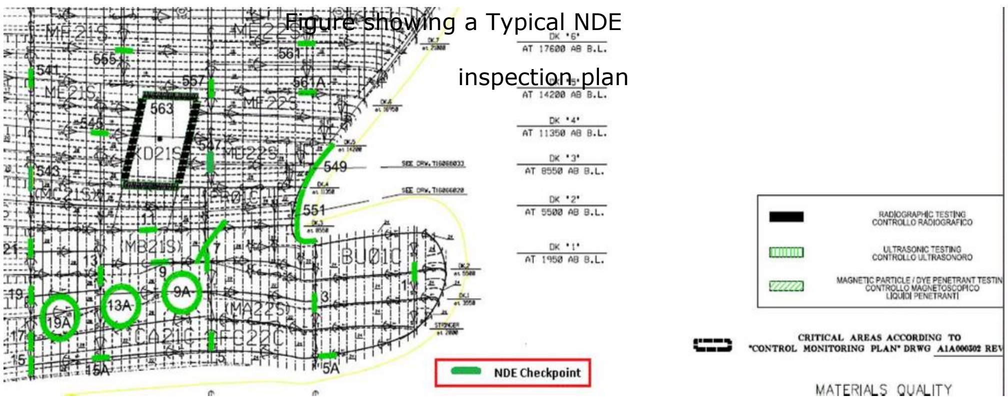
Table 29

Thermal Material Property. Source: Świderski (2015)

Material	Specific heat [J/kg·K]	thermal conductivity [W/m·K]	Density [kg/m^3]
Air (as defect)	1,005	0.07	1.2
Steel	440	25	7,900
Aluminum	880	230	2,700

Figure 59

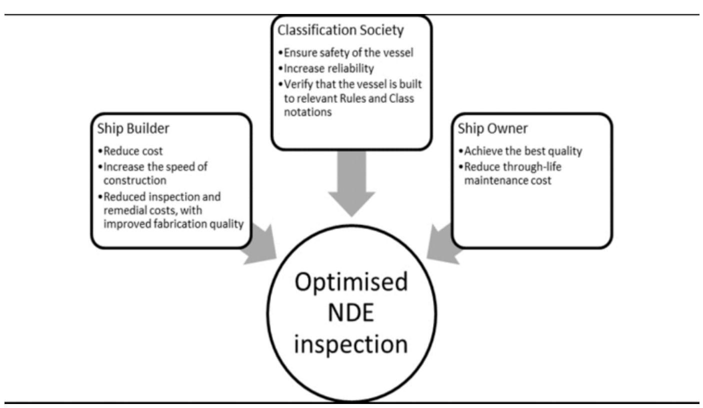
Classic NDE Inspection Plan. Source: Amirafshari et al. (2015)



Stakeholders for Shipbuilding

Figure 60

The Shipbuilding Objectives (Main Stakeholders). Source: Amirafshari et al. (2015)



Key participants in any shipbuilding or ship repair project:

1. Shipowners

2. Shipyard: newbuilding or repair or combined shipyards

3. Classification societies

Table 30

Applicable NDT Methods in Shipyards

Comparison	VT	PT	MT	UT	RT
Thickness	Any	Any	Any	10 mm and upwards	Max. 200 mm
Material	any	any	Only ferritic material	Depends on material	Any
Two-dimensional defects	Depends on size	Defects on surface	Up to 3 mm below the surface	Good	Depends on angle
Three-dimensional defects	Depends on size	Good	Limited	Not accurate	Good
Access requirements	Moderate	Moderate	Moderate	Medium	High

Using this table helps to choose the most proper NDT, making it accessible at the NDT department of any shipyard.

The red color represents a major issue regarding application conditions. The yellow color represents limitations. The green color represents a recommendation.

Value Chain

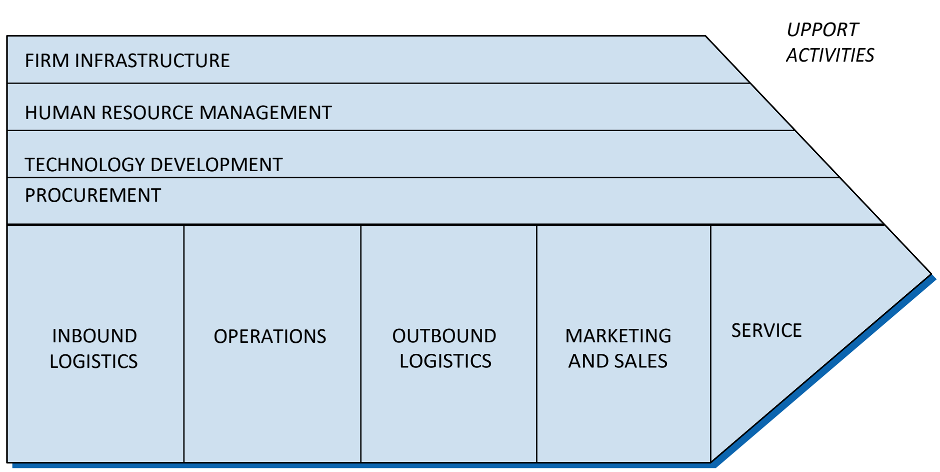
The present dissertation serves to identify major consequences of welding processes, materials, design, and quality for the expense and how cost savings could come to fruition after yards perform major improvements. Explaining the entire cycle including strategy, design, human resources, accounting, labor, marketing, and sales has formed a considerable contribution to this matter.

The facilities of a shipyard are set by carrying out thorough assessments. Considerable effort was expended identifying the real proficiencies in the shipyards considering all relevant departments in the shipyards, technological and managerial alike.

A customer-focused philosophy has motivated the major shipyards to launch a system that adds benefits for customers with no compromise on quality. This system should help to create a scheme that drives the shipyard ahead, despite competitors.

Figure 61

Porter's Value Chain. Source: Grant (2018)

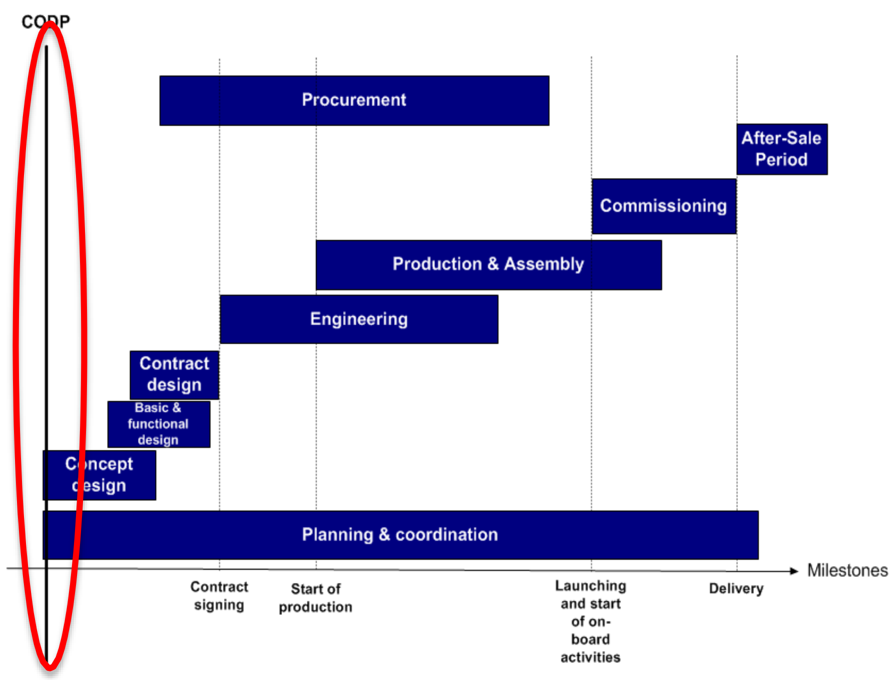


Customized Design

From a strategic point of view, the figure below shows the customized design in shipbuilding, where both plan and coordination start immediately and simultaneously, where the concept-design, basic functional design, then the contract design follow. The design is traced by the engineering, production and assembly, commissioning, after-sales period, and procurement.

Figure 62

Concept, Design, and Procurement in Shipbuilding. Source: Semini and Kolsvik (2014)



Standardized Design

Comparing to the customized design, the standard design does not consider the planning at the launch but rather the later phase, where serious delays could arise due to poor coordination, especially when different subcontractors are involved.

Figure 63

Concept, Design, and Procurement in Shipbuilding. Source: Semini and Kolsvik (2014)

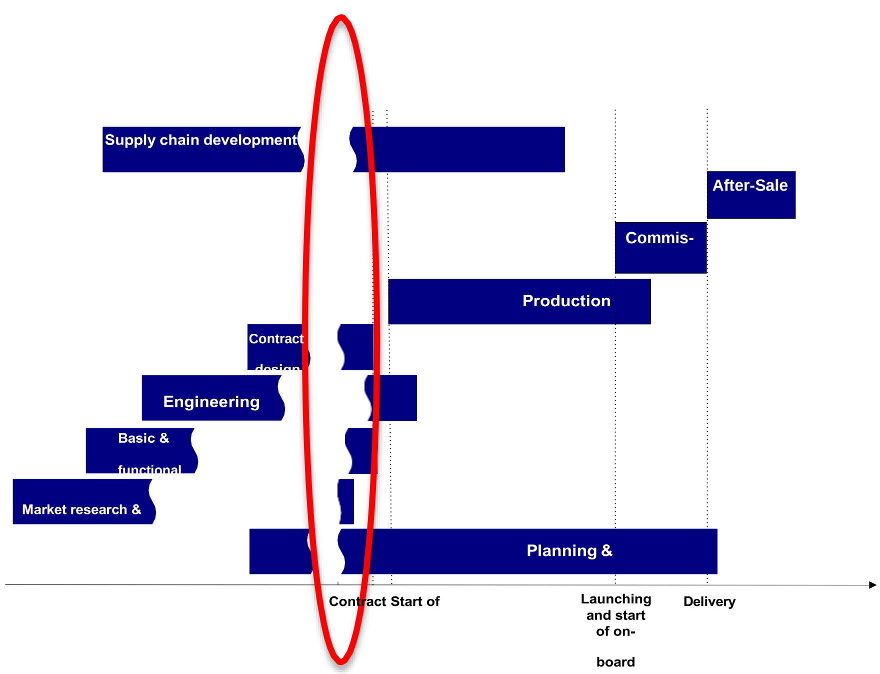


Table 31

Linking Strategies to Product or Market. Comparison Between Customized Design Strategy and Standardized Design Strategy in Shipbuilding. Source: Semini and Kolsvik (2014)

Product/market attributes	Customized design strategy	Standardized design strategy
Cost/price	Higher	The more ships produced, the lower the unit price
Lead time	Longer	Shorter (if production can start quickly)
Delivery precision	More difficult to achieve	Easier to achieve.
Level of customization	Higher	Lower
Variety.	Higher	Lower
Modularity and standardization	Desirable, but difficult to achieve.	Necessary
Accommodation of change orders	The value offered to the customer.	Must be kept low.

Product/market attributes	Customized design strategy	Standardized design strategy
Number of components	Very high	High
Minimum volume requirements	1 or 2	Typically 3 or more
Order qualifiers	Quality, lead time, on-time Delivery, price	Quality, lead time, on-time Delivery
Order winners	Flexibility and customization, product design/features	Price, product design/features

Table 32

Linking Strategies to Product or Market. Comparison between customized design strategy and standardized design strategy in shipbuilding, with reduced cost or price, as shown in 4.1.1 and 4.2.1.

Product/market attributes	Customized design strategy	Standardized design strategy	Customized design strategy with cost saving demonstrated
Cost/price	Higher	The more ships produced, the lower the price	30–50% reduction In welding cost
Lead time	Longer	Shorter (if production can start quickly)	Managed

Product/market attributes	Customized design strategy	Standardized design strategy	Customized design strategy with cost saving demonstrated
Delivery precision	Rather complicated to achieve	Easier to achieve	Precise
Level of customization	Higher	Lower	Average
Variety	Higher	Lower	Higher
Modularity and standardization	Desirable, but difficult to attain	Necessary	Achievable
Accommodation of change orders	The value offered to the shipowner	Must be kept low	Added value
Number of components	Very high	High	Higher than standard
Minimum volume requirements	1 or 2	Typically 3 or more	1 or 2
Order qualifiers	Quality, lead time, on-time	Quality, lead time, on-time	Quality, lead time, on-time
	Delivery, price	Delivery	Delivery, price
Order winners	Flexibility and customization, product design/features	Price, product design/features	Flexibility and customization, product design/features

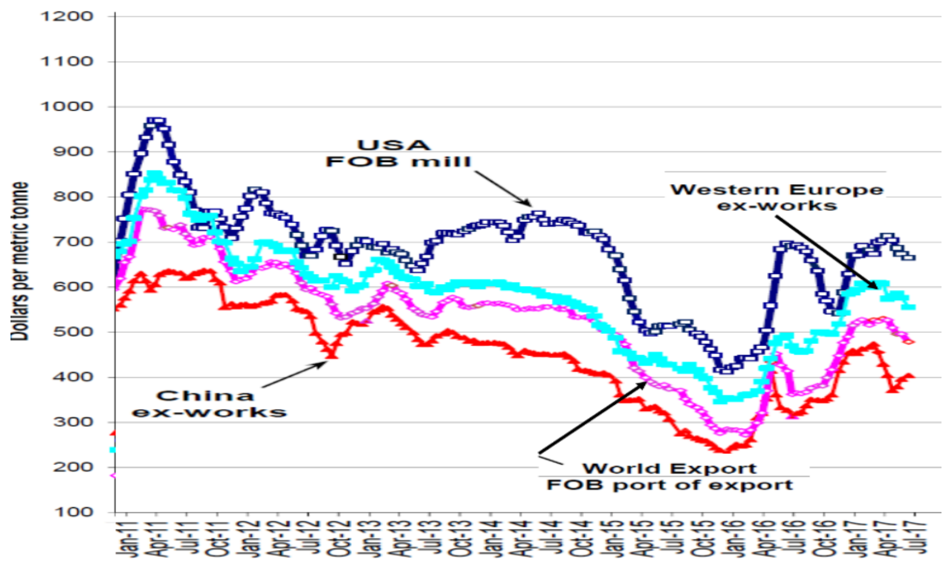
Cost Description

Explaining the cost factors regarding vessel newbuilding led us to consider the ship particulars, such as length, breadth, depth, draught, deadweight, and powering of the propulsion machinery. According to the ship particulars, shipyards could estimate the expenses for new constructions or ship repairs by carrying out mathematical analysis, comparing expenditure of different designs, and adjusting to the approximate expenses of the new build.

The estimated cost will be divided into breakdowns. Thus, expense categories are identified; for example, labor (welders, supervisors, designers, NDT operators) and subcontractors, materials (e.g. profiles and plates, and welding consumables), welding machines, overheads, energy, and QC.

Figure 64

Expense of One Ton of Steel. Source: Garbatov et al. (2018)



The price of steel per ton from the mills could reach up to 1000$, according to the country of purchase.

The consideration here is for a direct cost on the account division of the yard.

In the figure below, hourly labor cost ranges from below 10 euros/hour to 50 euros/hour.

Hence, substantial discrepancy directly influencing the shipbuilding cost, according to country.

The man-hours for the hull structure according to weight group ranges from 200,000–250,000 hours for this hull.

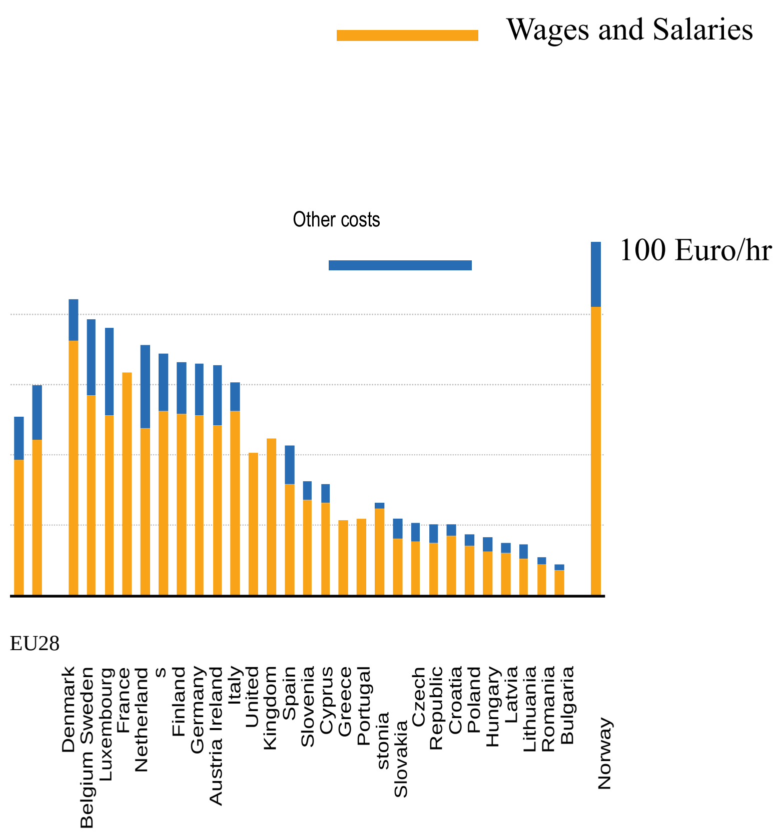


Figure 65

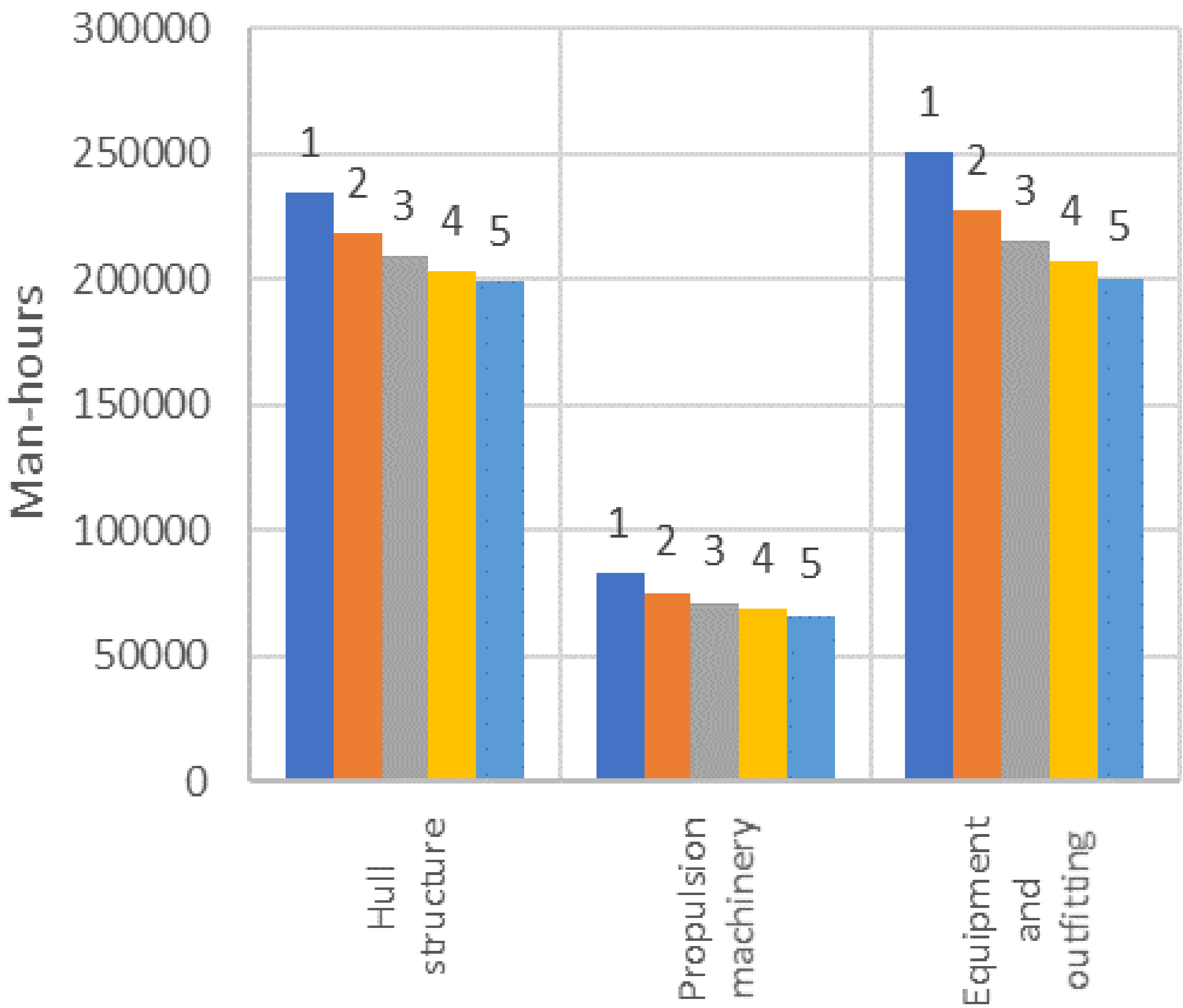
Estimated Hourly Labor Expenses for the Whole Economy in Euros, 2016

Source: Garbatov et al. (2018). Demonstration of direct cost on the shipyard human resources division.

Moreover, the figure shown above demonstrates a direct cost for the yard's human resources division.

Figure 66

Labor Cost of Different Ship Weight Groups. Source: Garbatov et al. (2018)



After the shipyard has decided to build another ship type, risks are introduced regarding estimating the expenses of the ship newbuilding, since the data available to the shipyards are not comparable and hence not transferable to a new situation. Additionally, concerning the maritime and shipbuilding situation, order books, and possible market fluctuations, another risk may prove consequential. Extensive experience and the will to change will shape the spirit of the shipyards' top management to succeed in this challenge.

The data gathering in this dissertation has been utilized to identifying the most suitable function in this matter; that is, best use of materials, welding process, and the shipyard resources and QC on the welds and via NDT.

Considering the study performed in this dissertation demonstrated in parts 4.1 and 4.2, it was proven that both materials and process, WPS, and quality utilized during welding have competed for the main purpose of the expenses, hence delivering cost savings of 30–50% and more.

Both weld-concept alongside the choice of material and welding process are direct factors to manage and synchronize the expense and economy. We note that wasting of material resulting from bad welding quality will lead to rework and retest that will consume additional expensive materials, additional expensive man-hours, and additional expensive testing, besides the delay in delivery of the whole vessel.

4.2

Main research question: How could DFP be achieved in shipyard welding operations leading to competitiveness?

This section of the dissertation examines the responsibility of the designing unit in improving welding cost and economical aspects in shipyards leading to better competitiveness. It consists of considerable subquestions to clarify major welding components influencing costs and qualities. The design in the welding economy manages the implementations of WPS and what factors are necessary. It then continues to shed light on the acceptable limits for important welding features such as throat thickness. Feasibility is to handle the possible welding positions discussing what the best position is from design perspectives. It is significant to clarify how materials are defined for weldability, particularly the high-tensile steel commonly utilized during ship construction.

Welding deficiencies do occur, and consequently, this dissertation considers what deficiencies happen, what their causes are, and measures to avoid them. This dissertation strives for an exciting opportunity to advance our knowledge of how cracks occur while welding process concerning stainless steel, taking reasonable actions to prevent those from arising. The dissertation considers several important issues related to how distortions exist in welding and effective measures to tackle and manage those problems.

This study seeks to verify the acceptable welding criteria concerning the HAZ. All the above research areas are connected, and all must be harmonized to attain the target of welding and its quality and how cost savings are possible.

Subquestions

4.2.1 How should a WPS be conducted and be approved in advance?

What factors are required to design a WPS in a shipyard?

4.2.2 Which measurements are acceptable for the throat thickness and leg length?

4.2.3 What design for the welding position should be considered?

4.2.4 How are materials analyzed for weldability given high-strength steels?

4.2.5 Why do distortions occur in a welded joint and how those could be prevented?

How could distortions be better managed in the welding sequence?

What welding parameters have a major role on the welding quality when welding steel grade,

AH36, DH36, and E36?

4.2.6 What factors affect the edge preparation for the welding of low-carbon steel?

How does a proper edge preparation contribute to high-quality welding low-carbon steel?

Subquestions

4.2.1

How should a WPS be conducted and approved in advance?

What factors are required to design a WPS in a shipyard?

Designing an efficient WPS could be translated into adding value, quality, and profit in the welds among the ship hull in a shipyard. Optimizing the relevant welding parameters indicated in 4.1.5 of the dissertation is the foundation for success.

WPS must contain the following:

Shipyard or subcontractor identification.

WPQR (ref.

Material

Material thickness (if piping, diameter, and thickness)

Weld process

Diameter of welding wires or electrodes.

Edge preparation

Groove angle and butt-welds design

Throat thicknesses for fillet weld

The number of layers

Shield gas

Position of welding

Welding direction

Butt or fillet joint

Backing

Sequences of welds

Welding parameters (current and voltage)

Welding speed

Diameter

Heat input

Preheat temperatures

Interpass temperature

Post-heat treatment

Cleanliness

WPS provides a complete procedure and sequence for welds to be approachable and approved before performing the welding. The approval will be released by a recognized classification society. The WPS for the used welding procedure must be hung at the welding department and inside the welding hall, in reach of yard welders.

The welding supervisor must discuss the WPS with the welders before performing the welding. Any unclear welding sequences to be discussed with yard welders. Welding findings not matching the quality standard must be reported via welders, subject for discussion with involving the supervisor. Welding seams identified as bad must be reworked or otherwise scrapped. However, this will influence the project times negatively, and thus the procedure should be managed using a professional method.

The WPS is required for every welding including defined thicknesses. Carrying out welding for nonapproved materials or for a higher thickness than approved is prohibited.

Should the shipyard intend to be welding thicker plates than approved among the WPS, a new WPS must be established and submitted for approval before implementation.

During the approval process concerning the WPS, the yard prepares the workpiece and adjusts all welding parameters matching the WPS. The surveyor of the class societies must be invited and the demonstration of the WPS must be presented to them. Upon satisfactory process, they will ask for relevant NDT to confirm the welding quality. The shipyard must invite the surveyor on the lab test. Should the lab-test results be unsatisfying, the test will be rejected. Consequently, rework of the welding is here required. Upon satisfactory lab results, the surveyor will assess the lab test report and match it to rule requirements. Once the requirements have been fulfilled, the surveyor will approve the WPS. The shipyard may then start using the WPS.

"According to Öberg and Åstrand (2018), 5 different welding facilities were utilized for evaluating the weld quality of same WPS.

High-tensile steel was used, S460MC, of 6- and 10-mm thickness. A mix of (82% Argon) and (18% CO_2) was applied as shielding gas. The diameter for welding wire was chosen to be 1.2 mm."[9]

Table 33

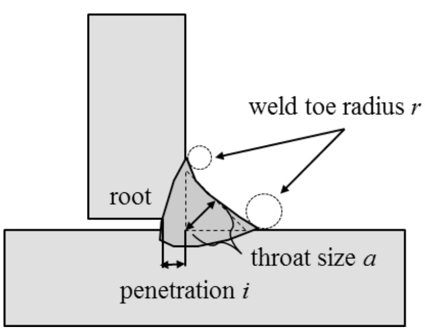
Relevant Weld Parameters for Unified WPS. Source: Öberg and Åstrand (2018)

WPS	Wire feed (m/mn)	Weld speed (mm/min)	Heat input (kJ/mm)	Deposition rate (kg/h)	Welding time/m (min)	Machine cost/m (SEK)	Wire cost/m weld (SEK)	Total cost/m weld (SEK)
A	7.5	330	0.96	3.8	3.1	51.9	2.9	54.8
B	14	550	1.32	7.1	1.9	31.7	3.2	34.9
S	10.2	450	1.16	5.1	2.3	38.4	2.9	41.3
H	10	510	1.22	5.0	2.0	34.1	2.5	36.5
E	8.45	430	1.09	4.3	2.4	40.1	2.5	42.6

Figure 67

Fillet Weld

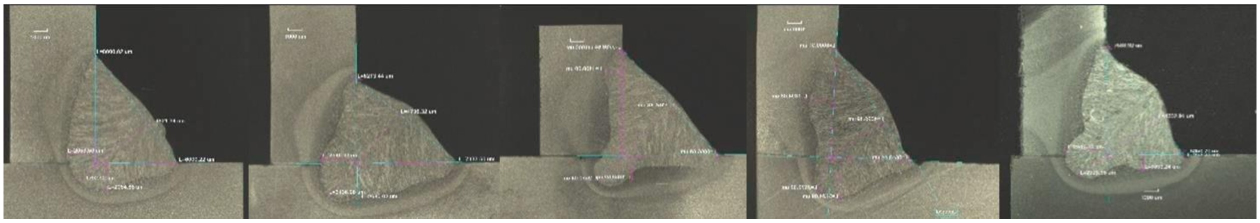
Quality Toward Criteria of Fatigue-Loaded Fillet Weld. Source: Öberg and Åstrand (2018)



Although the same WPS was used, considerable differences in welding quality were identified.

Figure 68

Differences in welding result at unified WPS at various welding shops. Source: Öberg and Åstrand (2018)



A B S H E

A is the ultimate expensive welding with the least penetration.

B is the most economical welding with maximum penetration.

Considering certain properties, such as penetration, interesting results were observed. The discrepancies among the WPSs have been indicated. The WPS initially designed at the "A" welding workshop has proved the lowest penetration. Considerable variations at various welding facilities were observed, although workshop "A" achieved the smallest penetration of about 2.5 mm at the maximum expense.

The “B” welding shop achieved the deepest penetration at minimum cost, about 4 mm.

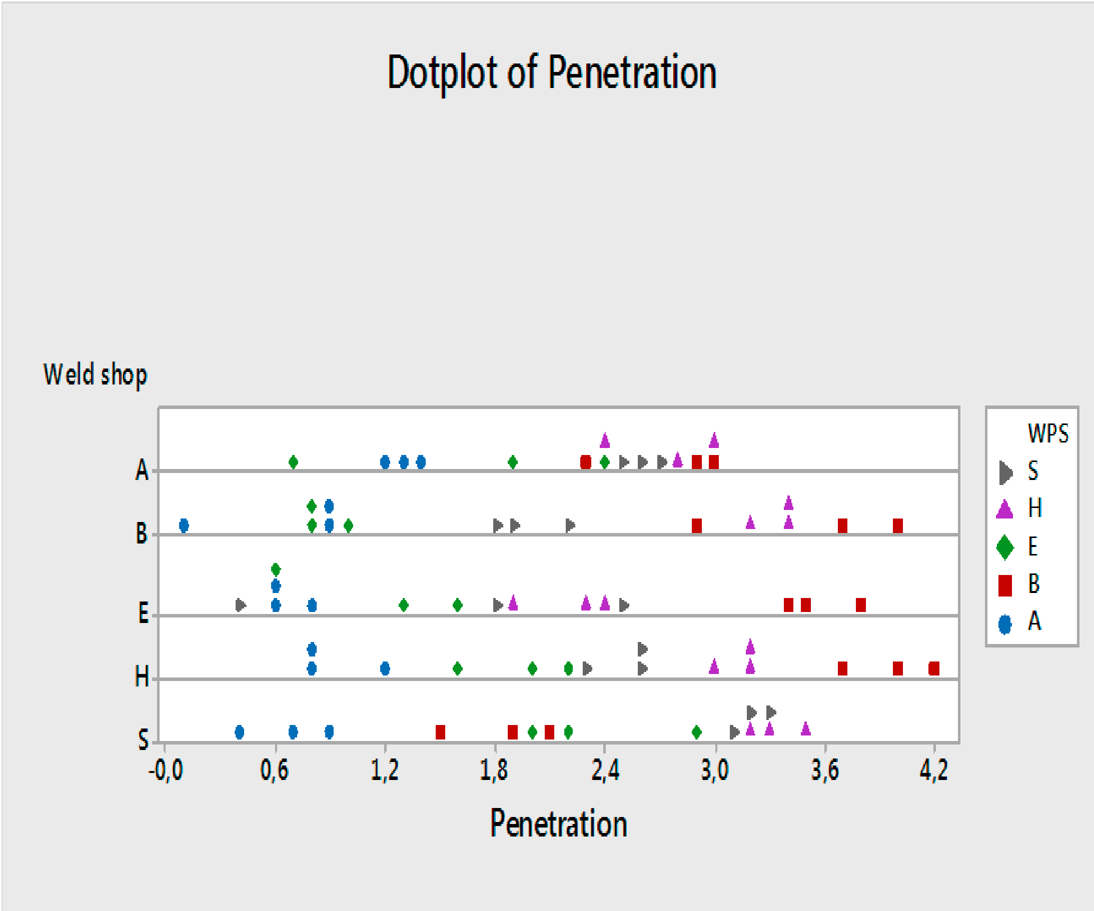


Figure 69

Variation in Cost

Penetrations could be influenced and increased by adding another active welding gas, e.g., (He or H_2) shall raise the penetration by up to 30%, conditional on material structure (usually high-alloyed materials) and concentration of the shield gas. Since hydrogen is an extraordinarily expensive active gas and helium is still an expensive gas, CO_2 is applied—alongside active gases—instead.

H_2: Hydrogen

He: Helium

Hydrogen has maximum heat conduction. Helium is below it.

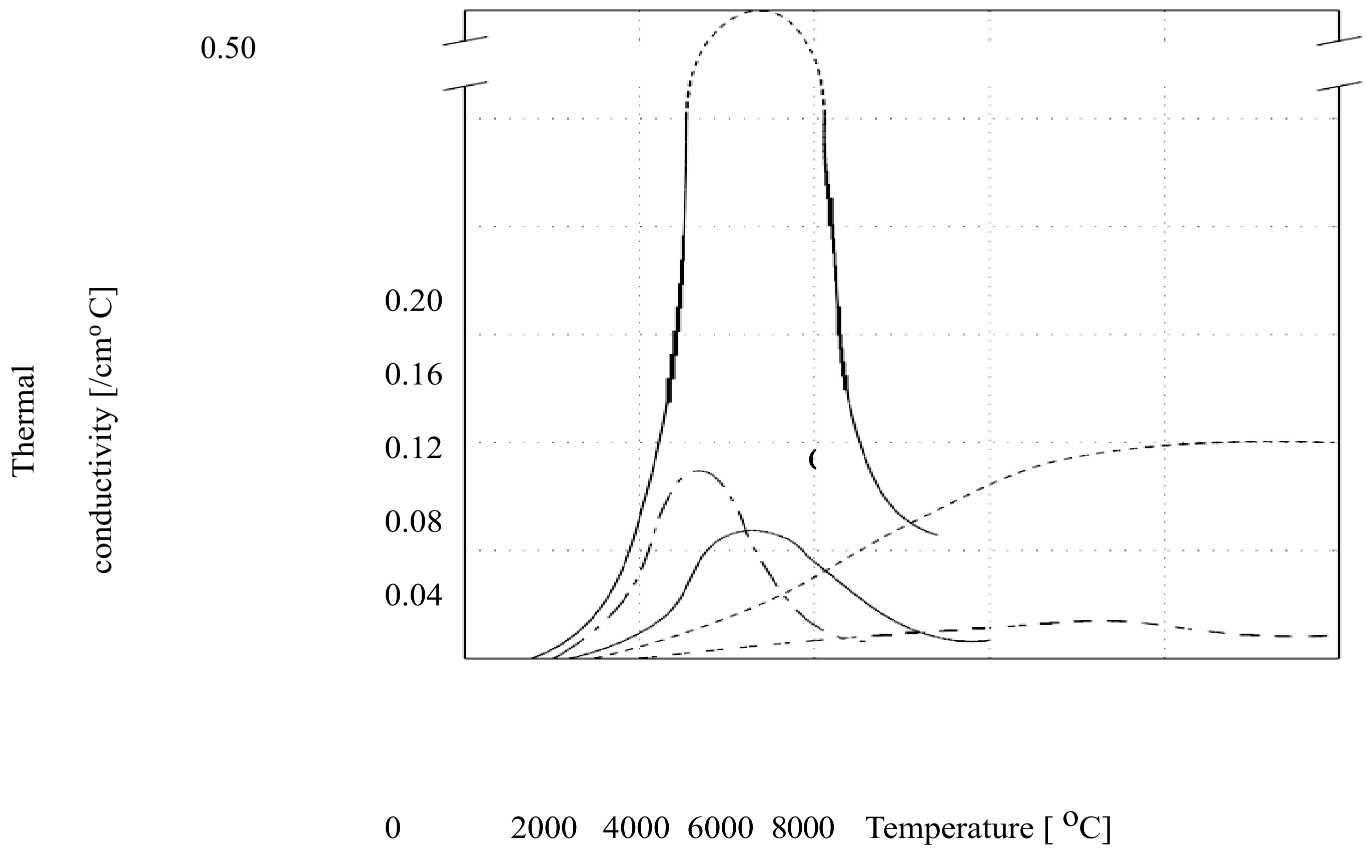


Figure 70

Conduction (Thermal) of Gas Against Temperature.

Source: Suban et al. (2001)

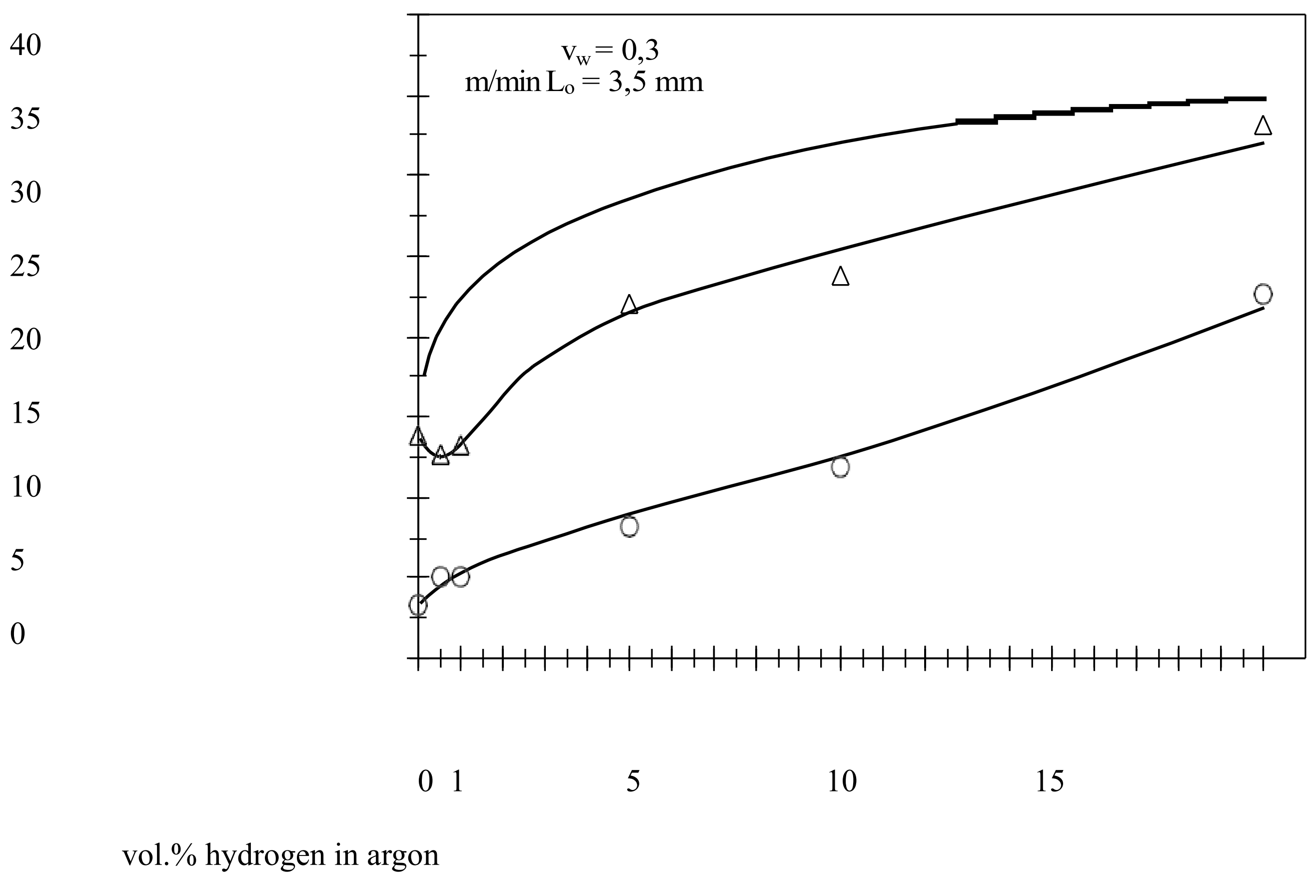
Hydrogen has the greatest thermal conductivity followed by helium. Both gases can be applied to achieve deeper penetrations.

Hydrogen could be integrated with argon and/or helium to weld high-alloy stainless steels. Helium, argon, and hydrogen can all be utilized in TIG and MIG welding processes. Implementation of an argon-hydrogen mixture has increased rates of depositions by 10 to 30%. One factor that influences penetration is increasing the current during the welding process.

Figure 71

Influence of Hydrogen Content in Argon Shield Gas and Welding Current Intensity on Melting Efficiency in TIG Welding (Electrode Negative). Source: Suban et al. (2001)

Upper curve, I=250A,   Middle curve, I=200A   Lower curve, I=150A



Comparing the above physical characteristics, a gain of about 30% has been pursued by adding about 10% H_2 to the protection gas.

Here, a new case is reached in which where the protection gas in the WPS could be set as follows:

Shielding gas: 72% argon, 10% H_2, and 18% CO_2

Instead of shielding gas: 82% argon and 18% CO_2

Explaining the benefit via an advanced trial—we consider workshop no. 6—the welding facility will become the same WPS. However, the amended protection gas must be utilized. All other factors should remain constant. This case 6 must be matched to conditions of B above.

Table 34

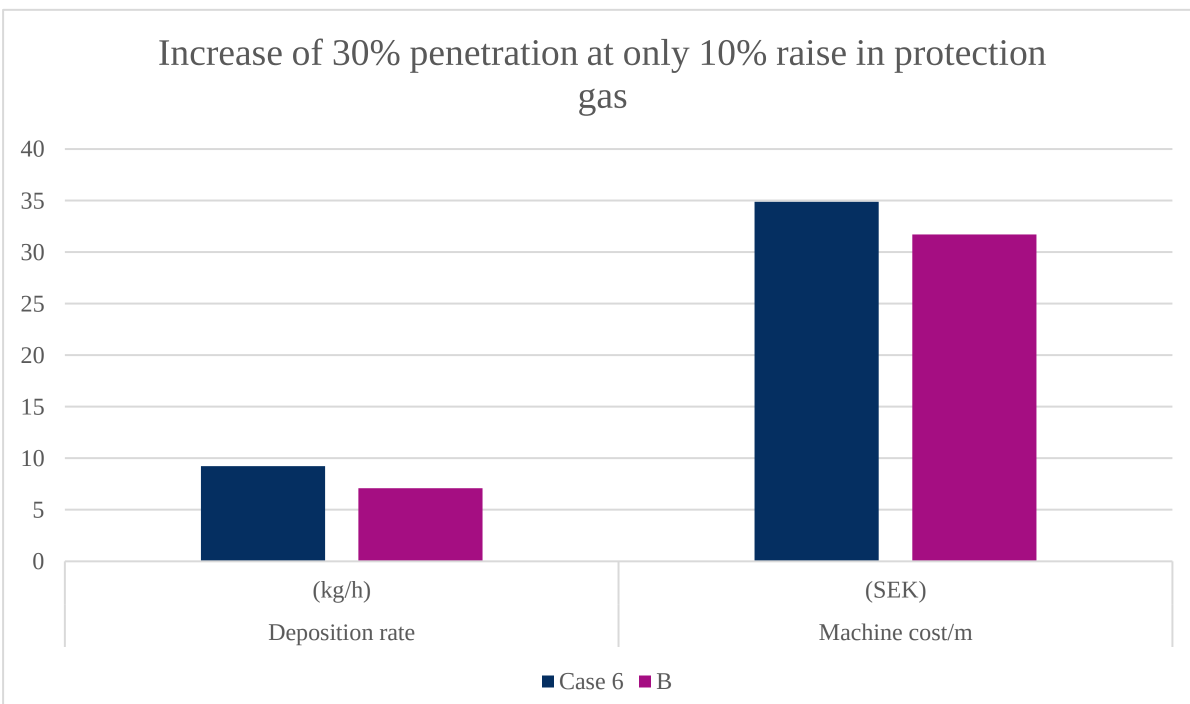
Introducing New Gas Mixture for Extended Penetration

WPS	Wire feed	Weld-speed	Heat-input	Deposition rate	Welding time/m	Machine cost/m	Protection Gas
	(m/mn)	(mm/min)	(kJ/mm)	(kg/h)	(min)	(SEK)	
Case 6	14	550	1.32	9.23	1.9	34.87	72% Ar, 10% H_2, 18% CO_2
B	14	550	1.32	7.1	1.9	31.7	82% Ar, 18% CO_2

Cost/Penetration

Figure 72

Progress of Efficiency via Changing the Protection Gas



Thus, the dissertation makes a major contribution to research about the welding economy by demonstrating how a considerable rise in penetration is reachable by just amending the protection gas.

The most efficient protection gases for deeper penetration are helium or hydrogen. Since the welding business is based on a day-to-day improvement opportunity for the shipyard, the recommendation will be toward adjusting the welding parameter (not only changing the fabrication workshop) and observing the extent to which value is added and the economy and productivity enhanced.

In 4.2.1., it is proved how designing a good WPS could save real production costs by optimizing the welding parameters, welding penetration, and proper implementation of shield gas. About 30% of the welding cost could be saved with the right approach.

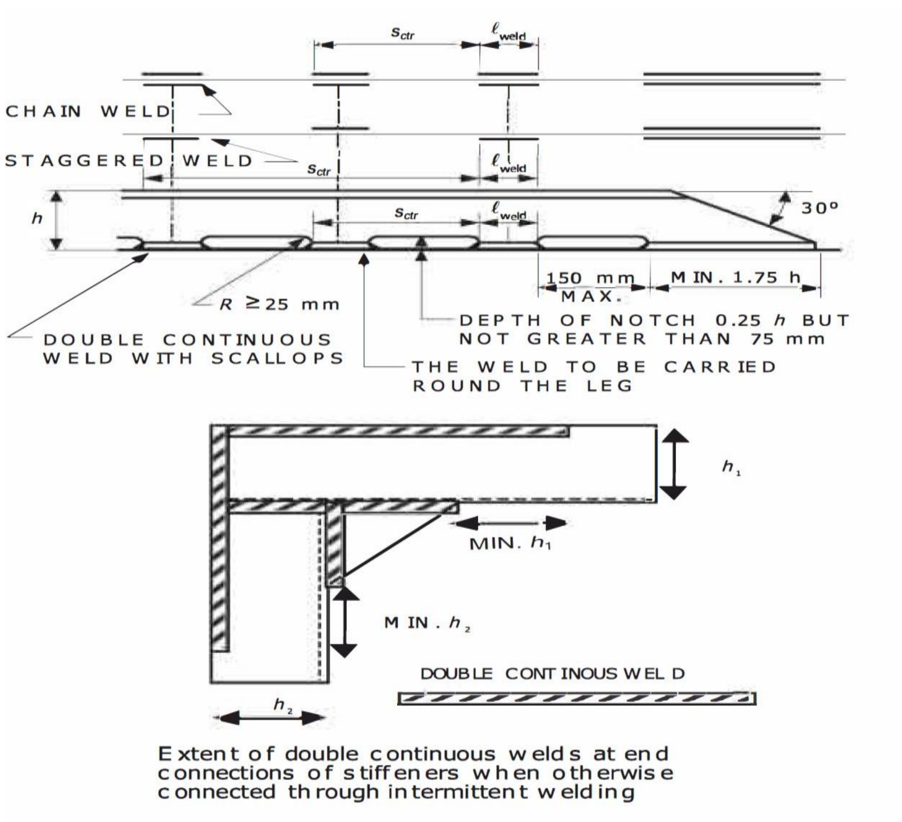
4.2.2

4.2.2 Which measurements are acceptable for the throat thickness and leg length?

Another important issue is the application of fillet welds, which are commonly utilized in shipyards and can save valued budget if performed correctly and/or by reducing the welding consumables optimized by good design. The fillet weld could be continuous or interrupted. The design office will produce a drawing for the welds' details, which shall be presented to the class society for approval in advance.

The continuous fillet weld is operated in the hull structure, where the interrupted fillet weld—being non-continuous—is activated in vessel areas not under excessive stresses. The interrupted fillet weld could be inline (one-sided) or staggered (changing on two sides of fillet weld). When approved, intermittent fillet welds save almost 50% of filler-metal cost, representing another saving factor for welds and budget. Arrangements of intermittent fillet welds in shipbuilding.

Figure 73 shows fillet welding utilized in shipbuilding



Source DND GL Rules Part 3 Chapter 13

According to DNV-GL rules for determining throat thickness:

$$t_{throat} = \frac{t_{leg}}{\sqrt{2}}$$

The throat thickness, shown in mm, must have or exceed

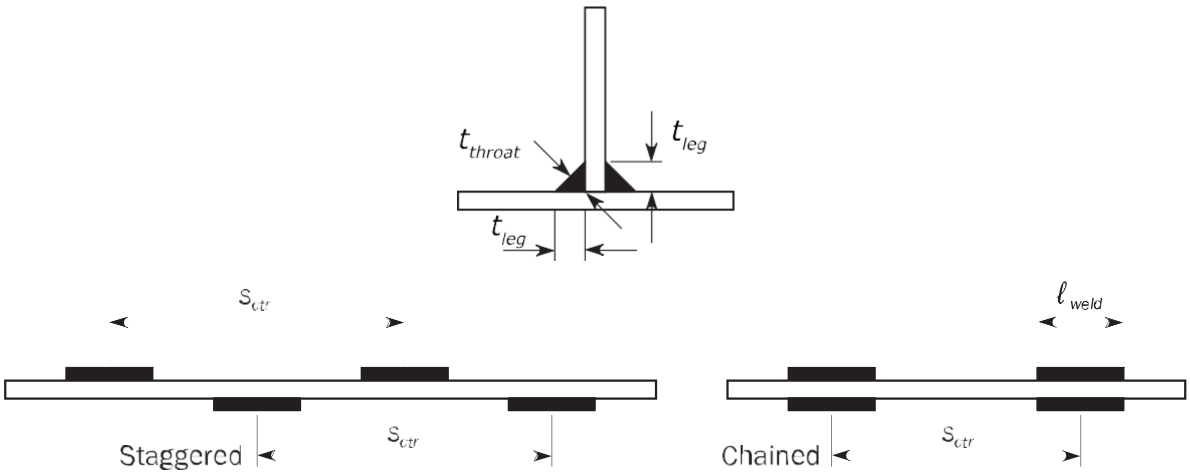


Figure 74

Intermittent Welding

Source: DNV-GL. (2020). Rules for Classification: Ships - Part 3 Chapter 13

Definition of welding scantling:

Table 35

Minimum Leg Length

Effective plate or web thickness, tw, in mm	Minimum leg length, in mm	
	Liquid cargo tank, water ballast tank and hold for dry bulk cargo	Elsewhere
tw ≤ 5.5	4.0	3.5
5.5 < tw ≤ 8.0	4.5	3.5
8.0 < tw ≤ 12.5	5.0	4.0
tw > 12.5	5.5	4.5

Source: DNV-GL. (2020). Rules for Classification: Ships - Part 3 Chapter 13

Depending on the design, staggered or chained filled weld could be utilized.

Calculation of allowed throat thickness:

Fillet weld leg length

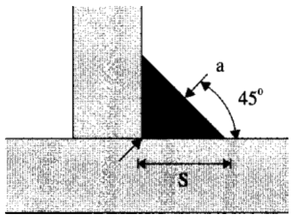


Figure 75

Features of Fillet Weld

Source: International Association of Classification Societies. (2013). No. 47

Features of a fillet weld

s = leg length; a = throat thickness

$s \geq 0.9sd$

$a \geq 0.9\ ad$

over short weld

lengths

sd = design s

ad = design a

The above data from DNV-GL and IACS 47 allow the establishment of the min. throat thickness. However, the max. throat thickness is 0.7, correlating with the thinner plate of the fillet weld. Throat thicknesses and leg lengths that exceed the above allowable limits are not acceptable. Therefore, the weld must be rejected.

Referring to Cairns et al. (2013).

The table below shows the effect of the weld parameters on penetration. The evaluation indicated that current is the guiding parameter on the penetration of the fillet weld.

Table 36

Geometrical Fillet Weld Features and Respective Target Values

Source: Cairns et al. (2013).

Geometrical weld feature	Target value
Penetration	0.1 mm≤x≥1.5 mm
Throat thickness	Min 3 mm
Average leg length	Min 4.24 mm (√2 × throat thickness)
Difference in leg lengths	≤2 mm
Weld geometry ratio	0.5 ≤ × ≥ 0.9

Table 37

Fillet Weld Parameters Used in DOE Analysis

Source: Cairns et al. (2013).

Factor name	Factor letter	Low setting	High setting
Current	A	170	220
Voltage	B	21	26.5
Travel speed	C	250	500

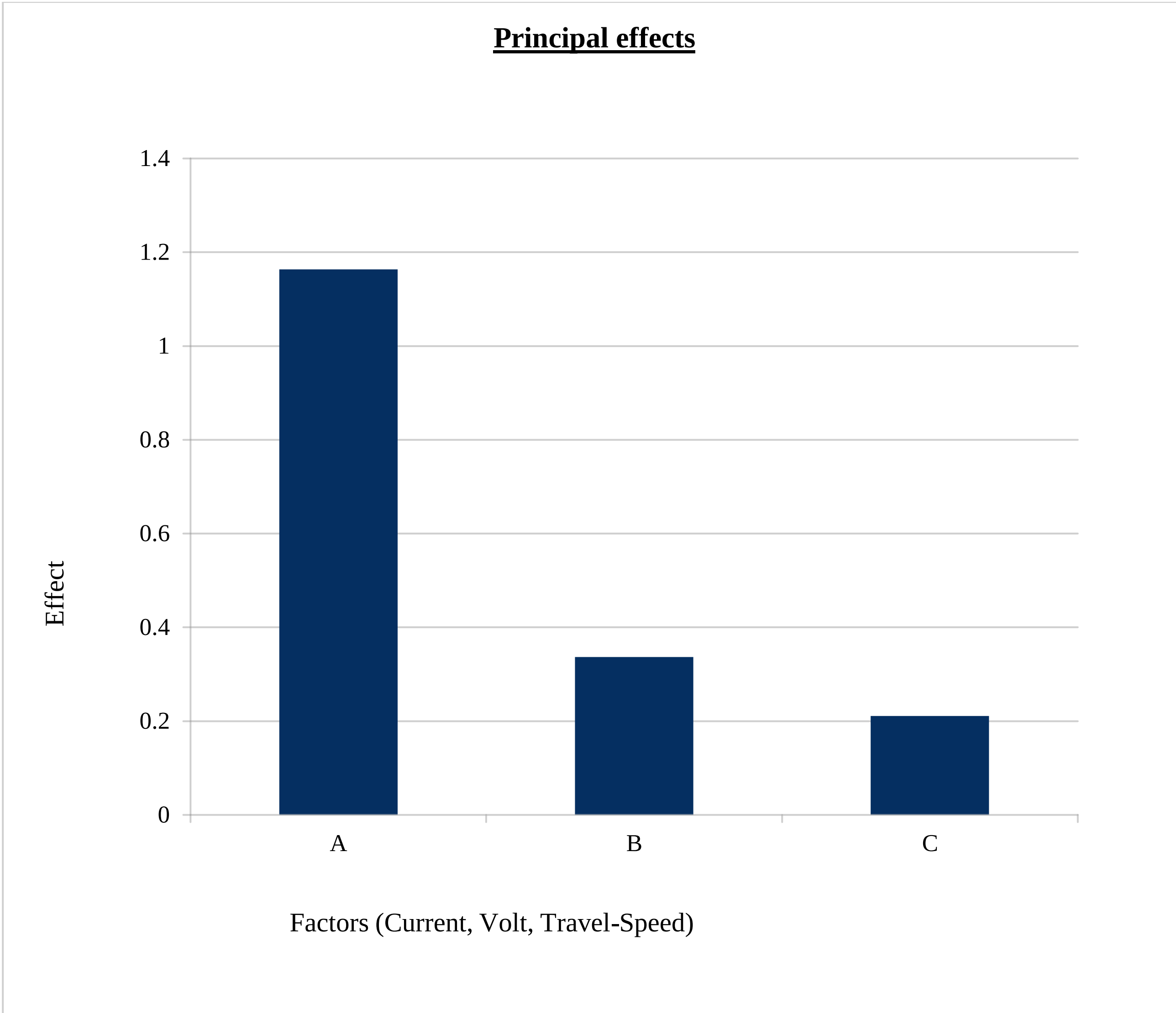


Figure 76

Input Parameter Effects on Penetration (Excluding Travel Angle)

Source: Cairns et al. (2013).

The appropriate factor affecting the penetration is the adjustment of current. Excessive current caused insufficient penetration, which led to rejecting the welds.

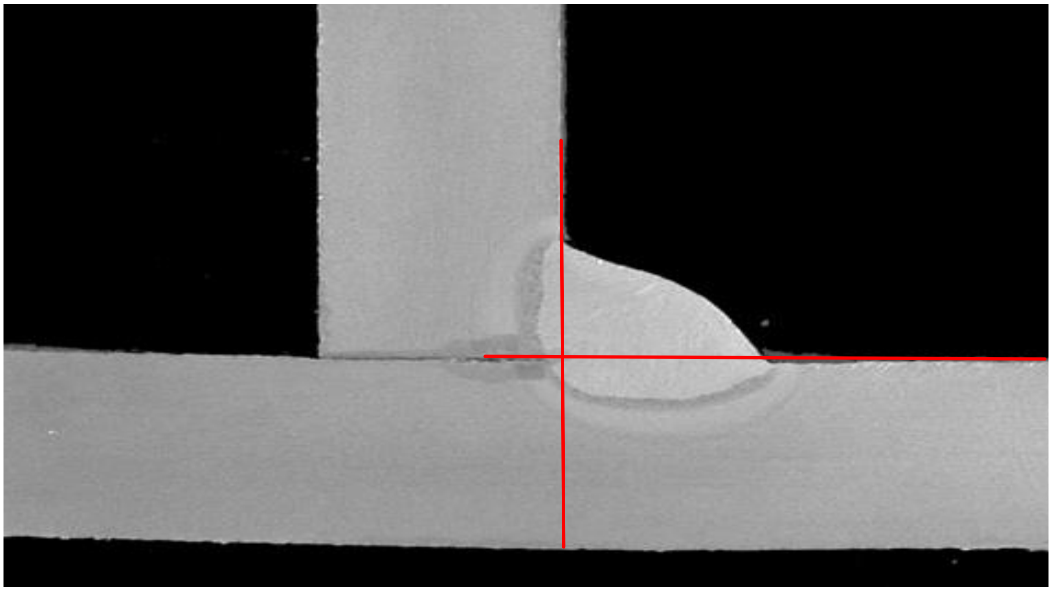


Figure 77

Macro Image of Acceptable Fillet Weld Profile

Source: Cairns et al. (2013).

This fillet weld shows homogeneous welding and indicates a proper condition. However, the throat thickness must be assessed and shall be matched to rule requirements as indicated.

Figure 78

Photograph of Corresponding Acceptable Fillet Weld

Source: Cairns et al. (2013).

The homogeneous fillet weld is in good shape; however, throat thickness must be measured and compared to rules.

Table 38

Input Parameters and Measured Geometry of Acceptable Weld (DF8)

Source: Cairns et al. (2013).

Test No	**Current (Amps)**	**Voltage (Volts)**	**Travel Speed**	**Travel Angle (°)**	**Gun Angle (°)**	**Gas Flow (l/min)**	**Stand off mm)**	**Stick Out (mm)**	**Penetr. (0.1mm - 1.5mm)**	**Avg Leg Length (Min 4.24mm)**	**Leg Length Delta (0mm - 2mm)**
DF8	**170**	**24**	**500**	**-38**	**33**	**20**	**2.0**	**16**	**0.5**	**4.50**	**1.99**

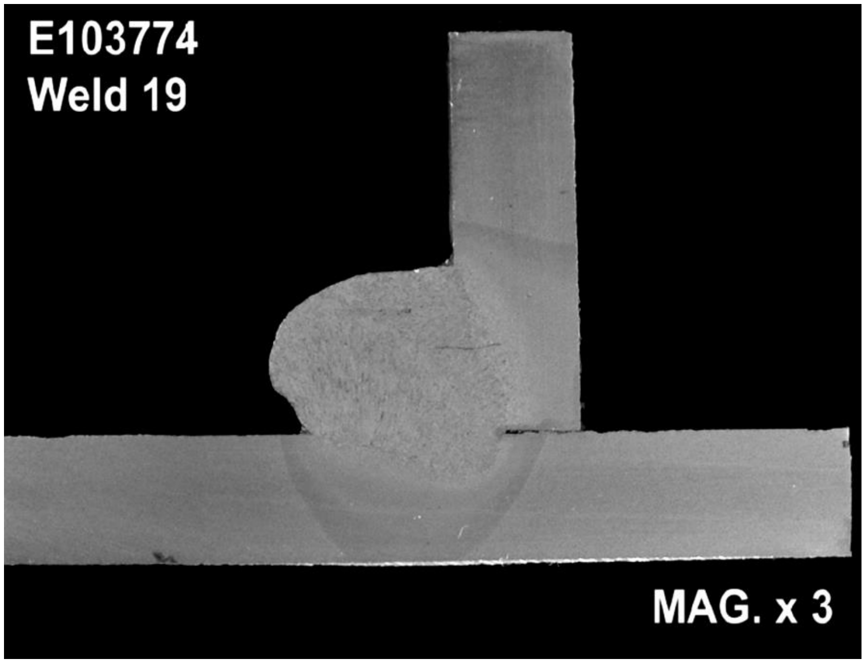


Figure 79

Macro Image of Unacceptable Fillet Weld Profile

Source: Cairns et al. (2013).

This inhomogeneous fillet weld has a bad shape and inadequate penetrations and must be rejected, even if the throat thickness requirement is met.

Figure 80

Photograph of Corresponding Unacceptable Fillet Weld

Source: Cairns et al. (2013).

Indicating an inhomogeneous filled weld that to be rejected, disregarding the throat thickness size.

Table 39

Input Parameters and Measured Geometry of Failing Weld (DF19)

Source: Cairns et al. (2013).

Test No	Current (Amps)	Voltage (Volts)	Travel Speed (mm/min)	Travel Angle(°)	Gun Angle (°)	Gas Flow (l/min)	Stand off (mm)	Stick Out (mm)	Penetr. (0.1 mm-1.5mm)	Avg. Leg Length (Min 4.24mm)	Leg Length Delta (0mm - 2mm)
DF19	270	21	250	-38	33	20	2.0	16	2.30	8.33	2.34

For the economy in shipyards, welding cost became a central issue for optimizing the total expenditure of production. The best result was attained by reducing the welding current along with raising the travel speed. Raising the welding current leads to insufficient penetration, high energy costs, and excessive filler metal consumption.

In 4.2.2, it was found that discontinuous fillet welding is recommended—where permitted—to save time, costs in supplies, and manpower, proving an interesting weight reduction. This saves 50% of the welding expenses. It is therefore strongly advised to specify the size of fillet weld and weld parameters at the early design. leg length, throat thickness, including weld parameters must all be specified. Real cost savings are possible.

It is incorrect to operate a general high thickness for the fillet welds that fulfills the rules but ignores economic considerations. Following the above recommendation will save a considerable budget on paying for excessive welding, which could show deficiencies during NDT and requires an additional budget to be repaired and retested.

4.2.1 and 4.2.2 perfectly combine the progression of WPS, the welds design, parameters and show clearly how those could influence both qualities and expenses of the welds.

Savings up to 30% may be accomplished. In 4.2.3, the dissertation considers the welding positions, their role on welding quality, and cost.

4.2.3

What design for the welding position should be considered?

The weld position should be considered since it is another quality and cost factor.

Production cost and the position of welding:

Choosing the proper welding position and correct process are major factors in excellent quality welding and will show an advantage for the manufacturing of welds that are economical in price.

The welding position must be chosen carefully. The welding position “A” is the recommended position since welding to be conducted within the best reach of welders below their hands is surely cost-effective since it is faster.

However, the welding position “E” is the overhead position, which is difficult and expensive, alike, since poor quality welds with a substantial quantity of rework are required. The designer should give major attention to which method the members will be welded and try to lay out the welding in position “A” as a preference. Position “E” is to be avoided whenever possible.

Welding positions referring to ISO-Standard and ASME/AWS

Table 40

Welding Positions

Nr.	Positions of Welding (ISO)	Welding Positions (ASME/AWS)
1	Position A	1G/1F
2	Position B	2F
3	Position C	2 G
4	Position D	4F
5	Position E	4G
6	Position F	3G-Uphill
7	Position G	3G-Downhill
8	Position H	5G-Uphill
9	Position J	5G-Downhill
10	Position H-L045	6G-Uphill
11	Position J-L045	6G-Downhill

Weld process and production cost:

Efficient applications of DFP are significant factors in any shipyard's economy and competitiveness. The welding expenses in a constructed hull are essential factors that require continuous consideration and innovation.

This dissertation couples cost factors to the welding process to link the key parameter for comparing and improving productivity: man-hours. According to the above results, making (DFP) changes could improve productivity and save up to 55%. of the welding cost, adding significant profit for the shipyard. This research should thereby have an important influence on welding in shipyards.

The design office in the shipyard must consider the best method for welded hull construction. Therefore, the DFP principle makes a major impression on the overall welding price and overall ship's price. The cost-effectiveness begins in the early design and the manufacture of welding could contribute practically to a cost-efficient factor. Saving 55% of weld fabrication expenses reserves a considerable amount that deserves the highest priority when planning the DFP.

Proof in 4.1 was made that above 50% of the fabrication cost of weld could be reduced, particularly the expenses of the labor.

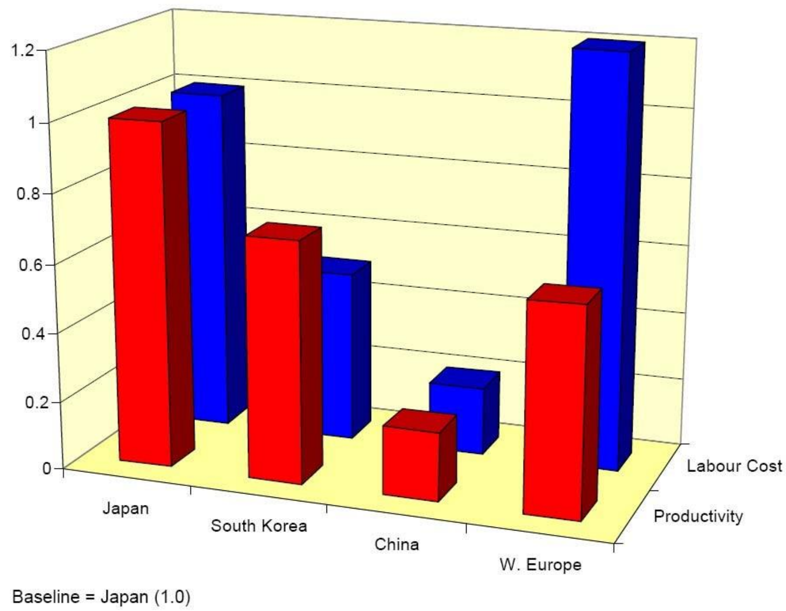


Figure 81

Comparison of Shipbuilding Productivity and Labor Costs

Source: Kolić (2011).

The practical demonstration is detailed in 4.1.1. where material and labor costs are compared for two extremely common welding procedures in shipyards. Above 50% of the weld manufacturing costs could be reduced, particularly the labor expenditures, besides the price of welding procedures and approvals.

Cost in euro

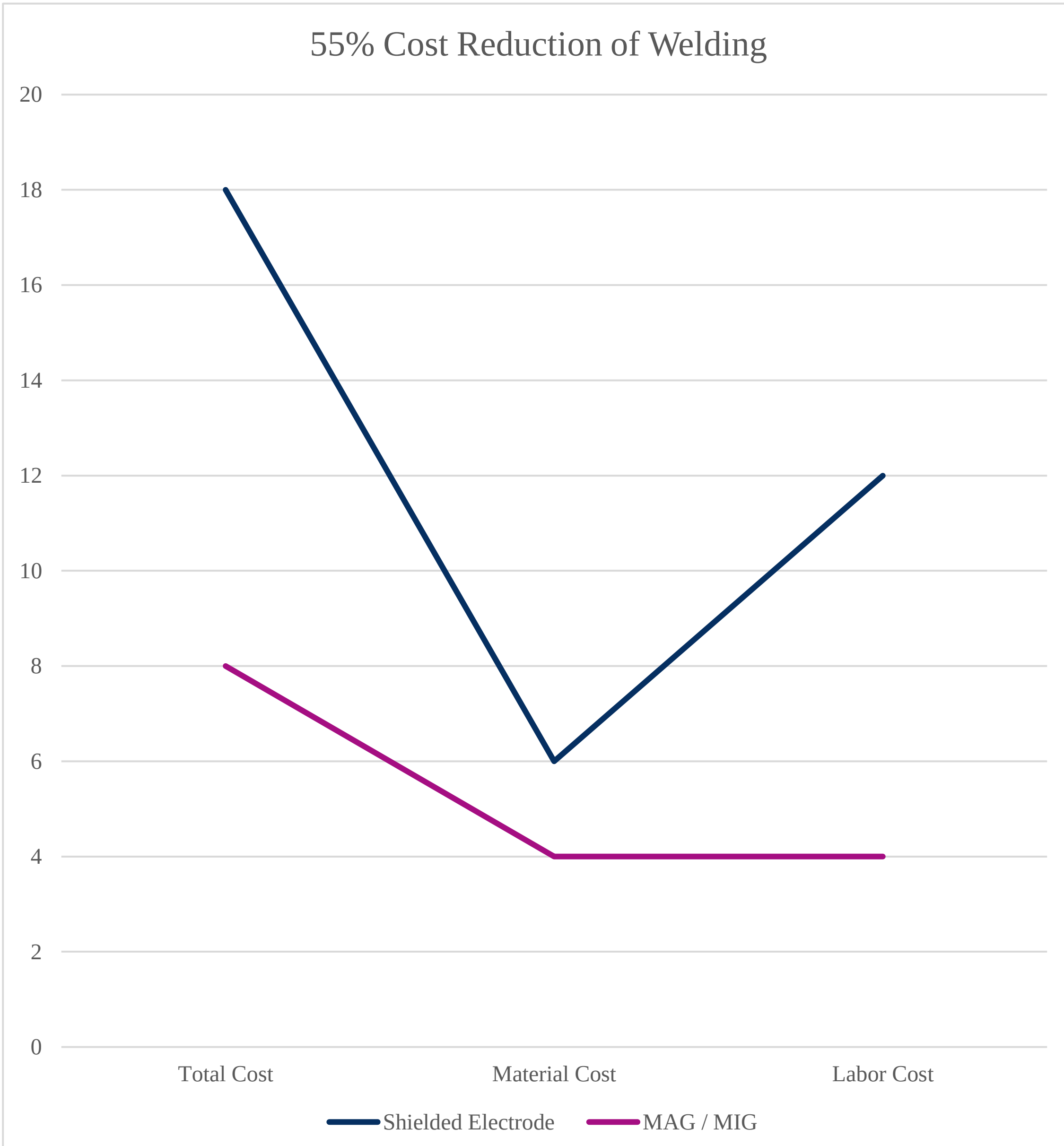


Figure 82 show that that Choosing a Proper DFP Concept Could Save over 50% of Fabrication Expenses of Welding.

The design office can contribute to major cost savings by contemplating the most proper welding procedures and consumables (see 4.1.1).

It has become evident how important the position for executing welds is for optimizing both design and cost. 4.2.3 connects both 4.2.1 and 4.2.2. when considering good design, expenses, and quality alike. Overall, about 50% cost savings are achievable.

4.2.4

How are materials analyzed for weldability given high-strength steels?

This element examines the gains and effects of weldability on the welding process and cost. Weldability is the aptitude to welding materials in an accurate quality subject for acceptance by the class societies of newbuild and the international standards. The carbon "C" is the ultimate relevant component for evaluating weldability. Forms for carbon equivalent were established to facilitate the calculation. The CET equation is defined by the IIW, where under 0.40% C results are considered as good weldability.

Table 41

The Action of Alloy Elements on the Weldability. Source: Keltanen (2015)

Alloying element	C	Si	Mn	P	S	Mo	Cr	Ni	Al	Nb	V
Weldability	Minus	Plus	Plus	Minus	Minus	Minus	Minus	Plus	Plus	Plus	Plus

Where,

Plus indicates a positive effect

-Minus indicates a negative effect

Chemical Composition

Although carbon is basic in steels, when uncontrolled, it destructively influences weldability. Thus, the carbon contents have been facing upper limits in weldable steels. Excessive carbon content leads to hardening of the welds. HAZ thus causes reduced toughness values and will cause a cold crack in the welds. Therefore, additional components are supplied to the carbon to steady the chemical composition to achieve more weldable materials and reduce the growth of grains, hence increasing hardness,. These components include manganese, niobium, titanium, aluminum, and vanadium. For high-alloy steel, chromium, molybdenum, copper, and nickel are contained as alloying elements.

Materials planned to be weldable and tougher to reach the high-strength steels are manufactured by thermomechanical processes. Yield strengths are enhanced by minimizing the grain size. Yield strengths of 1,100 N/mm^2 and higher are possible. Those high-tensile steels are rolled in the manufacturing below the recrystallization temperature besides the cooling effect. The achievement is reached by rolling the steel below its recrystallization temperature via accelerated cooling. For producing steels with even less grain size, rolling is initiated by thermomechanical means. Welding high-tensile steel reduces the deadweight of vessel structure or allows the hull stresses at reduced scantlings, increases the payload (benefit for shipowner), and improves the investment lifecycle.

"According to DNV rules, part 2, the carbon-equivalent value (Ceq) shall be calculated using equation (1):

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \qquad (\%)$$

(1)

The cold cracking susceptibility (Pcm) for evaluation of weldability shall be calculated using equation (2):

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B \quad (\%) \quad (2)$$

If applicable, the carbon-equivalent value (CET) is calculated according to Equation (3):

$$CET = C + \frac{(Mn + Mo)}{10} + \frac{1(Cr + Cu)}{20} + \frac{Ni}{40} \quad (3)$$

Guidance:

The CET is contained in the standard EN 1011-2 and is utilized as the parameter for determination of preheating temperature." [29]

Source of above equations 1 through 3 are the DNV-GL Rules Part 2 Chapter 1, Edition July 2020

Table 42

Maximum Ceq, CET, and Pcm Values. Source DNV-GL Rules Part 2 Chapter 2, Edition July 2020

Carbon equivalent [%] 1)									
		Ceq						CET 2)	Pcm 3)
		Plates			Sections	Bars	Tubulars	all	all
Strength level	Delivery condition	t ≤ 50 [mm]	50 < t ≤ 100 [mm]	100 < t ≤ 250 [mm]	t ≤ 50 [mm]	t ≤ 250 or d ≤ 250 [mm]	t ≤ 65 [mm]	all	all
	TM	0.43	0.45	0.47	0.44	-	-	-	
	QT	0.45	0.47	0.49	-	-	0.46	-	-
	N/NR	0.50	0.52	0.54	0.51	0.55	0.51	0.25	-
	TM	0.45	0.47	0.48	0.46	-	-	0.30	0.23
460	QT	0.47	0.48	0.50	-	-	0.48	0.32	0.24
47	-	0.46	0.49	0.49	-	-	-	0,32	0,22
	TM	0.46	0.48	0.50	-	-	-	0.32	0.24
500	QT	0.48	0.50	0.54	-	-	0.50	0.34	0.25
	TM	0.48	0.50	0.54	-	-	-	0.34	0.25
550	QT	0.56	0.60	0.64	-		0.56	0.36	0.28
	TM	0.50	0.52	-	-	-	-	0.34	0.26
620	QT	0.56	0.60	0.64	-	-	0.58	0.38	0.30
	TM	0.56	-	-	-	-	-	0.36	0.30

690	QT	0.64	0.66	0.70	-	-	0.68	0.40	0.33
	TM	0.60	-	-	-	-	-	0.38	0.28
890	QT	0.68	0.75	-	-	-	-	0.40	-
960	QT	0.75	-	-	-	-	-	0.40	-

Higher carbon equivalents may be accepted subject to prequalification by the manufacturer, see also [1.1.4] and Ch.1 Sec.2 [2]

For steel grades VL 460 and higher, CET may be used instead of Ceq at the discretion of the manufacturer

For extra high-strength steels in TM and QT conditions and with carbon content not more than 0.12%, the specified values for Pcm may be used instead of Ceq or CET at the discretion of the manufacturer.

Table 43

Mechanical Properties for High-Strength Steel. Source DNV-GL Rules Part 2 Chapter 2, Edition July 2020

Grade	Yield strength ReH minimum [MPa]	Tensile strength Rm [MPa]	Elongation A5 minimum [%]	Impact energy, average minimum [J] 1)						
				Test temperature [°C]	t ≤ 50 [mm]		50 < t ≤ 70 [mm]		70 < t ≤ 150 [mm]	
					L	T	L	T	L	T
VL A27S				0						
VL D27S			22 2)	-20						
VL E27S	265	400 to 530		-40	27	20	34	24	41	27
VL F27S				-60						
VL A32				0						
VL D32			22 2)	-20						
VL E32	315	440 to 570		-40	31	22	38	26	46	31
VL F32				-60						

Grade	Yield strength ReH minimum [MPa]	Tensile strength Rm [MPa]	Elongation A5 minimum [%]	Impact energy, average minimum [J] 1)						
				Test temperature [°C]	t ≤ 50 [mm]		50 < t ≤ 70 [mm]		70 < t ≤ 150 [mm]	
					L	T	L	T	L	T
VL A36				0						
VL D36			21 2)	-20						
VL E36	355	490 to 630		-40	34	24	41	27	50	34
VL F36				-60						
VL A40				0						
VL D40			20 2)	-20						
VL E40	390	510 to 660		-40	39	26	46	31	55	37
VL F40				-60						

Table 44

Maximum Carbon-Equivalent Values for High-Strength Steel supplied in TM condition.

Source DNV-GL Rules Part 2 Chapter 2, Edition July 2020

Grade	t ≤ 50 [mm]	50 < t ≤ 100 [mm]	100 < t ≤ 150 [mm]
VL A27S, VL D27S, VL E27S, VL F27S	0.34	0.36	0.38
VL A32, VL D32, VL E32, VL F32	0.36	0.38	0.40
VL A36, VL D36, VL E36, VL F36	0.38	0.40	0.42
VL A40, VL D40, VL E40, VL F40	0.40	0.42	0.45

The weldability has shown how design should govern the choice of weldable materials since all welding processes and filler metals—and hence welders—are based on weldable materials. Using materials that cannot be welded or partly weldable is a waste of time, resources, and budget.

4.2.4 ideally connects 4.2.1, 4.2.2, and 4.2.3 and thoroughly proves the accountability of the ship design department, which should define the most suitable and economical welding procedure specifications, joint types and forms, and welding positions alongside weldability. Cost savings of 50% and more are the benefit.

4.2.5

Why do distortions occur in a welded joint, and how those could be prevented?

How could distortions be better managed in the welding sequence?

What welding parameters have a major role on the welding quality when welding steel grade, AH36, DH36 & E36?

Demonstrating the distortion problem in welds, its causes, methodology to manage it, to take the case 4.1.4 and explore the distortions resulting from welding when using (SAW, FSW) and T-GMAW, SAW) as welding processes and AH36, DH36, and E36 as material. Distortions will change the shape permanently.

The distorted welding shows the inspirations of the remaining stresses in welded members.

Reducing the distortions, the requirement aims to lower the remaining stresses or perform stress relief; for example, by way of post-heat treatment.

There are six sorts of distortion:

Transversely distorted at a right-angles to the welds.

Longitudinally distorted at even direction of welds.

Rotationally distorted in angle direction

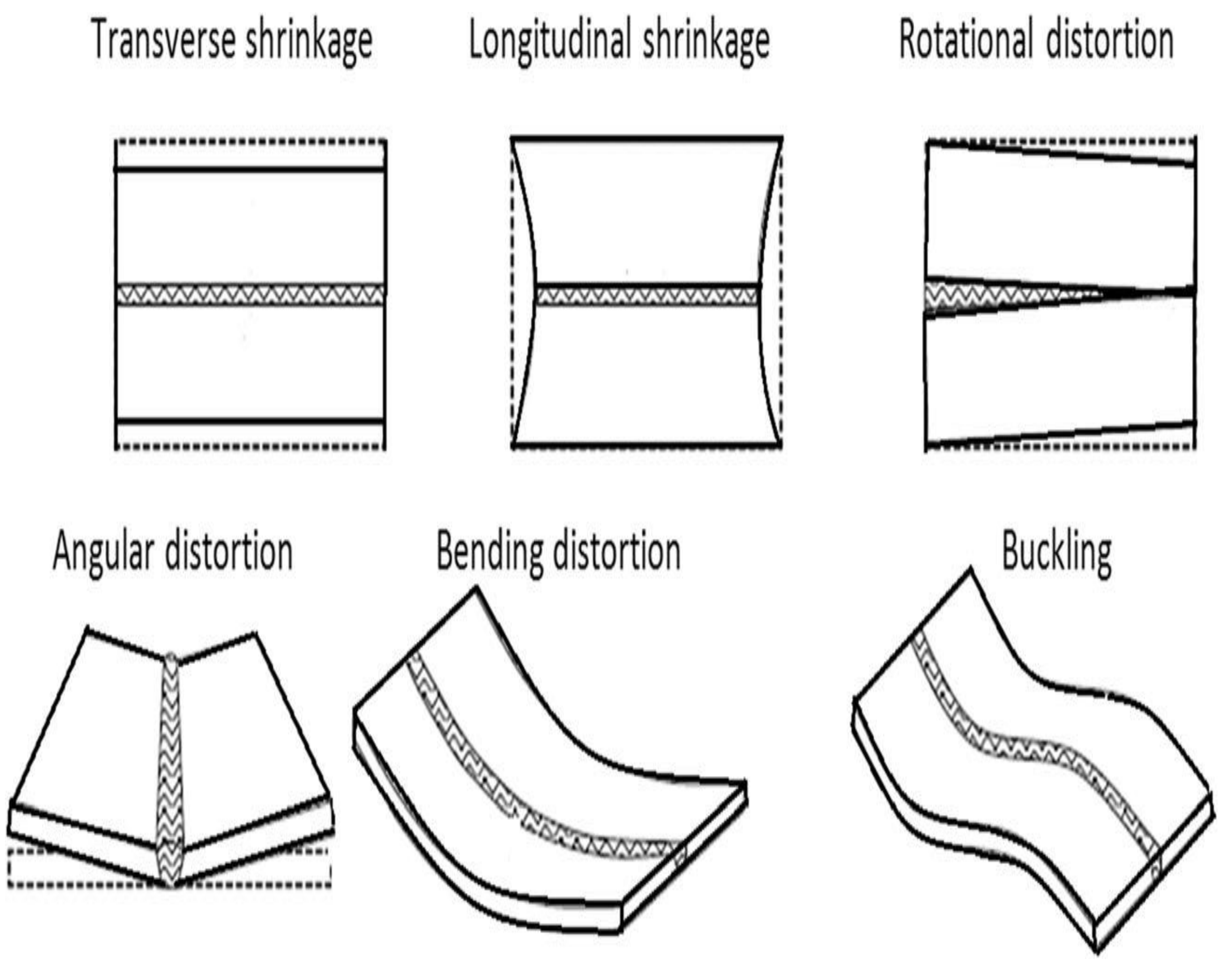
Distortion in an angular direction because of various temperatures acting in thickness.

Bend distorted welding middle and at right-angle to the welds.

Buckle induced by compression forces and stress factors.

Figure 83

Diverse Welding Distortion Possibilities. Source: Pazooki et al.. (2017)

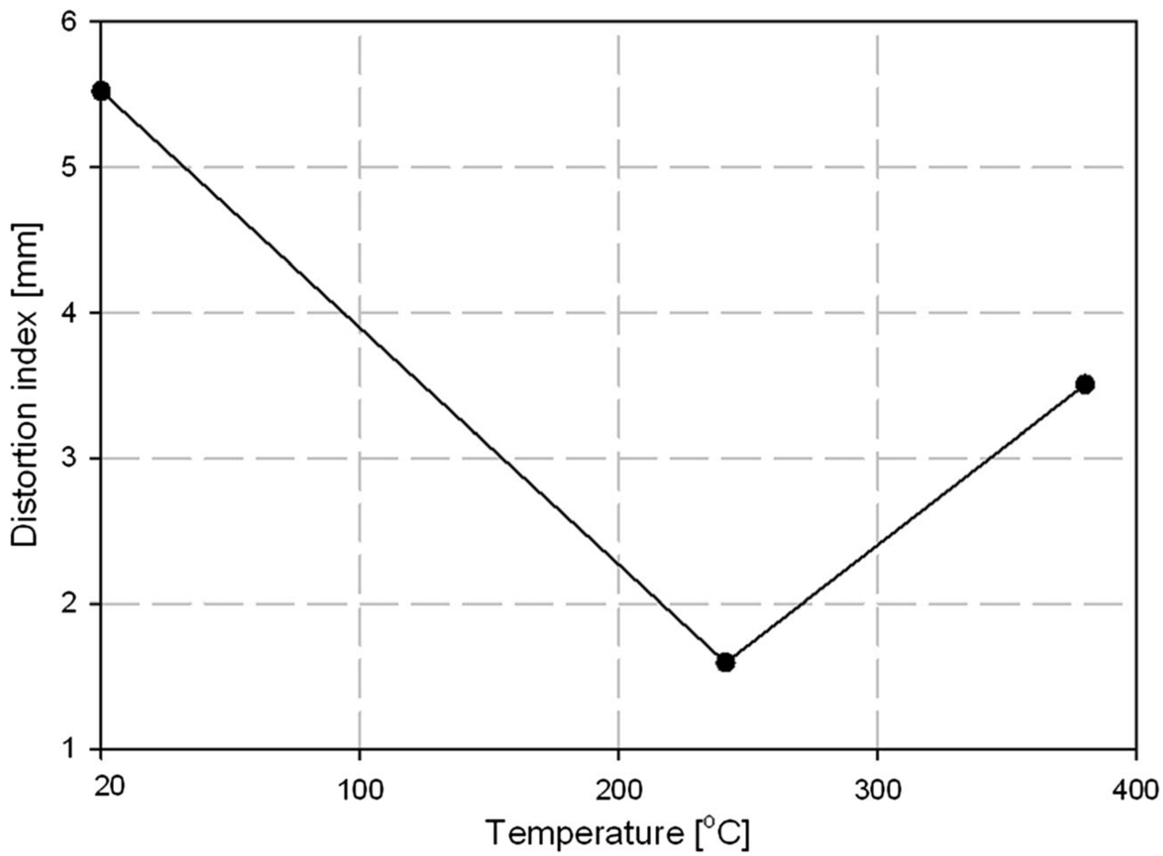


This methodology of decreasing the distortion is generated by adding heat.

Thereby, the distortion will first be reduced continuously till a temperature equal to about 240 °C before increasing again.

Figure 84

The Conclusions of Welding with Additional Heating on the Distortions for AH36 Plate Source: Pazooki et al. (2017).



By comparing the distortions resulting after welding by SAW and FSW for high-strength shipbuilding steels DH36 and E36 with a yield strength of minimum 360 N/mm^2, where toughness test requirement is 36 joules at -20 °C, it was discovered that fewer distortions were achieved via FSW.

Comparing SAW and FSW, SAW proved more distortion with a plate thickness of 4 mm.

Figure 85 shows a distortion comparison between 4 mm thickness DH36 steel plates of 2,000 × 400mm, where the butt weld is alongside the outer side of the 2,000 mm edge:

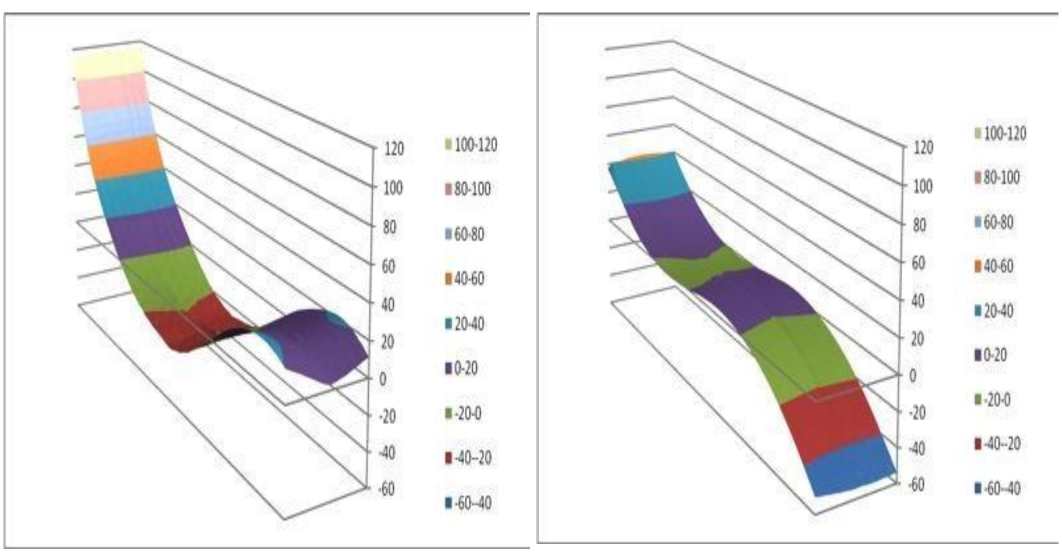
SAW.

FSW.

Figure 85

Comparing SAW and FSW, SAW Showed More Distortion (plate thickness 4 mm)

Source: Cater et al. (2013)



a- more distortion b- less distortion

Comparing SAW and FSW, SAW proved more distortion (plate thickness 6 mm)

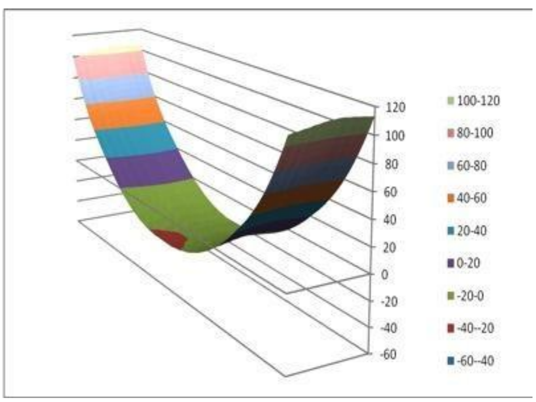
Figure 86

a) & b) distortion Comparison Between 6 mm Thickness DH36 Steel Plates (2,000 × 400mm, Butt Weld Along the 2,000 mm Edge).

a- SAW.

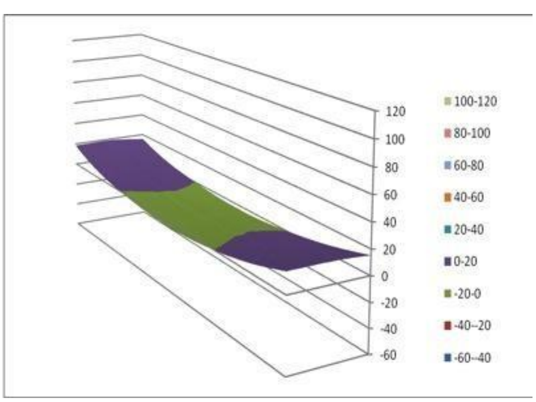
b- FSW.

Source: Cater et al. (2013)



a- more distortion

b- less distortion



Comparing SAW and FSW, SAW proved more distortion (plate thickness 8 mm)

a- more distortion b- less distortion

Figure 87

Distortion Comparison Between 8 mm Thickness DH36 Steel Plates (2,000 × 400 mm, Butt Welded Along the 2,000 mm Edge)

a- *SAW.*

b- *FSW.*

Source: Cater et al. (2013)

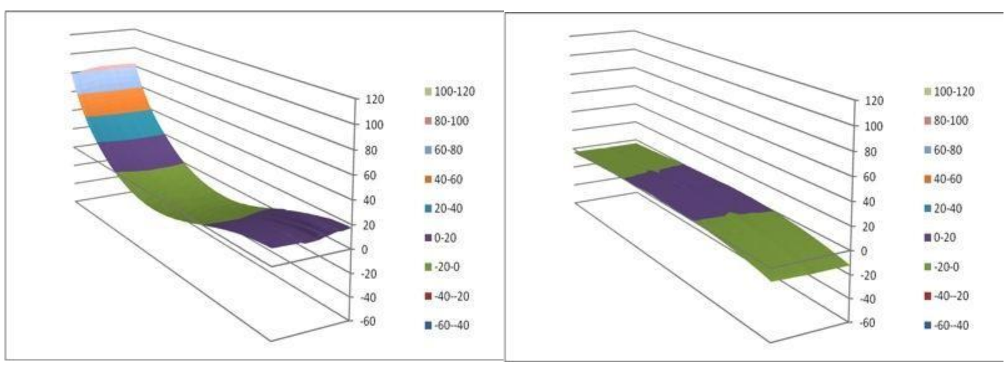


Table 45

The Outline of Distortions in DH36 Steel Plates with Butt Joint Along the 2,000 mm Edge.

Source: Cater et al. (2013)

Plate thicknesses, mm	Distortions, above 2,000 mm SAW plates	Distortions, above 2,000 mm FSW plates
4	120	60
6	110	20
8	80	15

Cater et al. (2013)[6] concluded the following:

Single/double-sided FSW of both E36 and DH36 shipbuilding steel produces lower angular-distortion and longitudinal-distortion than the light arc welding of DH36."[6]

Analysis of the produced data supports the evidence that FSW seems to enhance a superior process to the conventional SAW process, regarding the distortion approach. However, as indicated in 4.1.1, SAW is a more economical process.

A methodology for reducing or eliminating the distortion (preshaping of plating before welding):

Additionally, plating may be preformed, and hence the resulting distortion after welding completion may equalize the preforming, eliminating the distortion. The preforming to be confirmed in a sample until satisfactory results are achieved. When an acceptable shape is reached, the process may be utilized for plate welds. The final shape after welding will become a straight edge without distortion. Hence, adding a further, underestimated point—that can easily be applied—is highly recommended.

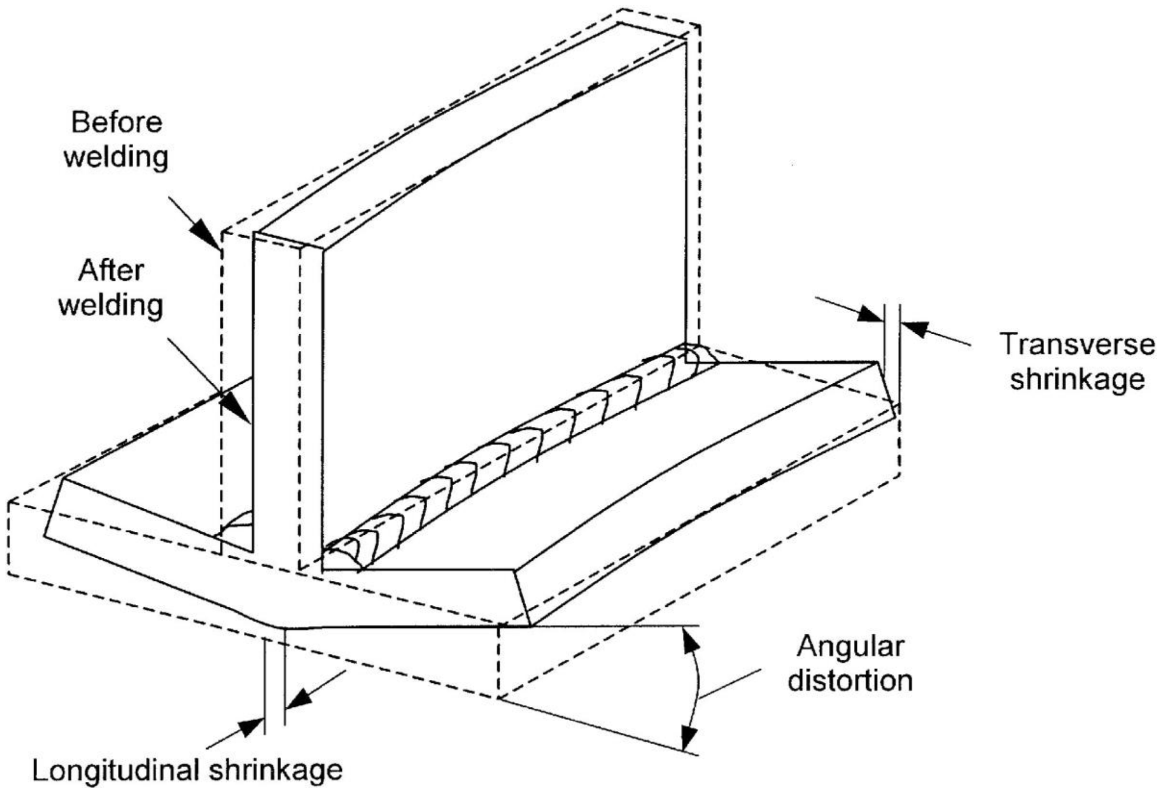
Attributing the distortion issue to improper design or bad workmanship in the shipyard is an improper and misleading approach. In practice, higher management is involved, where both skilled designing unit and skilled labor must be referred to. The target of the optimization of skills and resources in the shipyards requires long experience with this specific branch in the industry. Proper procedures, processes, and policies are the main duties of the executives. Continuous team training and motivation add considerably to efficient operations. Focusing on the elimination or reduction of distortion will offer significant benefits to the shipyards.

The figure below shows the distortion resulting after completing the fillet weld.

Figure 88

Dimensional Changes Occurring in Fillet Welds

Source: Sukovoy and Kuo (2003)



However, prevention of distortion is feasible by proper preparation for the plates before welding (preforming).

Using this approach, much lower —even zero—distortions are feasible. The table below shows distortion in DH36 steel plates butt joint along the 2,000 mm edge, considering preshaping the material (plate) before welding.

Table 46

Reduction of Distortion

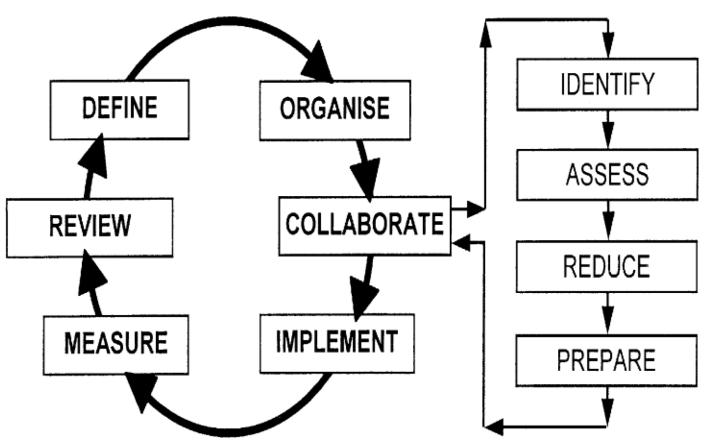
Plate thickness, mm	Distortion over 2,000 mm SAW-welded plates, Provided preshaping	Distortion over 2,000 mm FSW-welded plates, provided preshaping
4	0–60	0–30
6	0–55	0–10
8	0–40	0–7.5

Preshaping the plates before welding could reduce the distortion to half, if correctly done, even to zero.

Adding the management factor results in the following model:

Figure 89

Key Characteristics of the Responsibility Sharing Management model. Source: Sukovoy and Kuo (2003)



The distortion may be minimized as follows:

Table 47

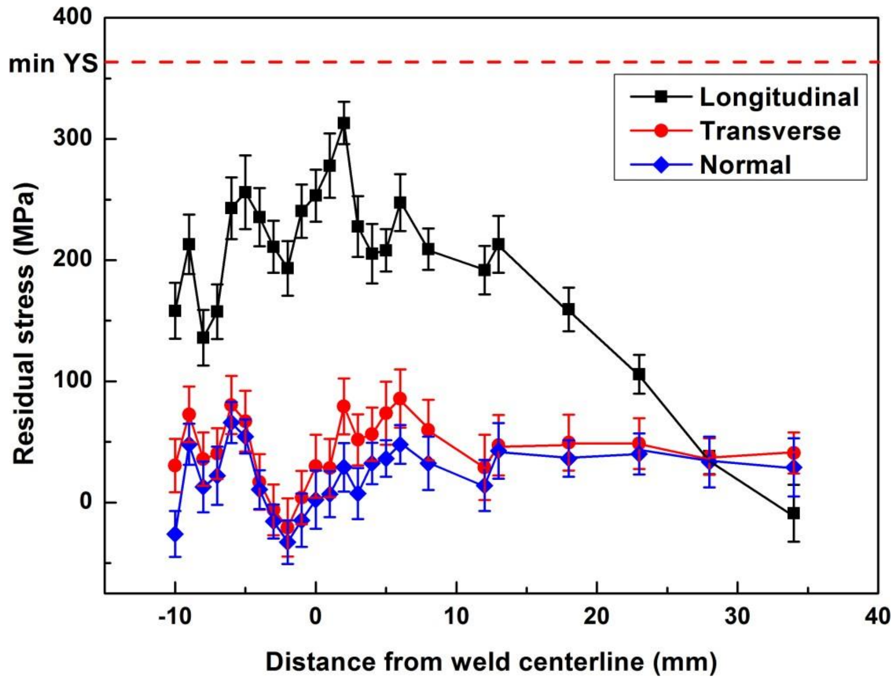
Enhanced Procedure by Adding the Testing Requirement

Define	Organize	Collaborate	Implement	Measure	Review	Testing
Objectives and targets	Human, physical, financial, and purchasing resources	Stakeholders and subcontractors	Policies, rules, and procedures	Definition and quality manual	Progress and experience exchange seminars	In addition to RSM, e.g. NDT

Remark: Testing is a major element of the QC/management (quality manual)

Figure 90

The Residual Stress Measurement Results for the T-GMAW Sample. Source: Shen (2013)

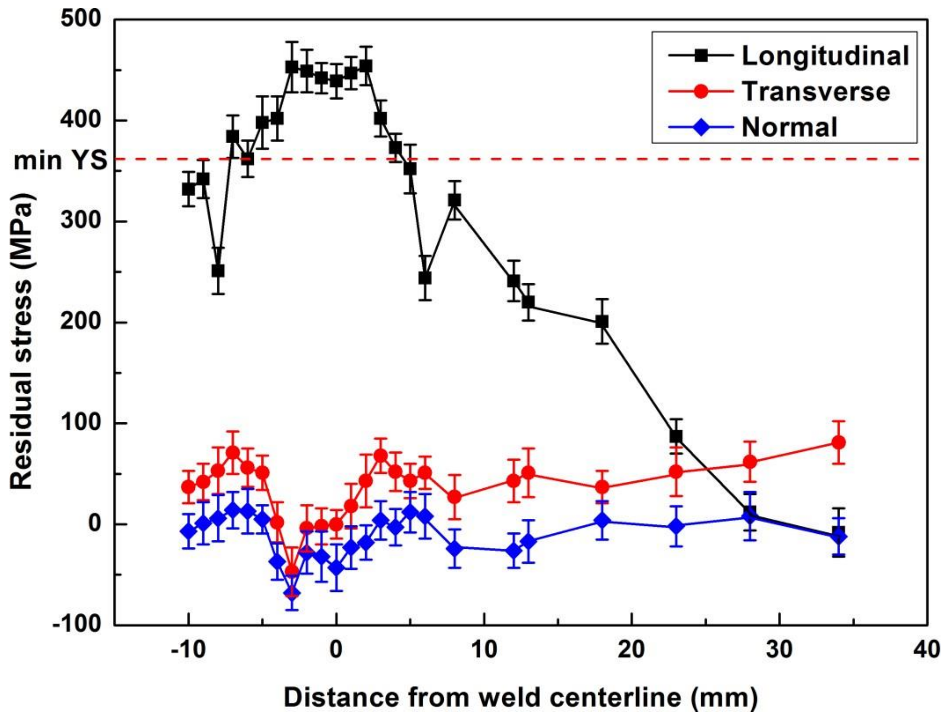


Compared to SAW, which is a widely-utilized welding method in vessel manufacturing, the remaining stress reduction in T-GMAW welding is shown.

Figure 91

The Residual Stress Measurement Result of SAW Sample

Source: Shen (2013)



The remaining stress in SAW welding—displayed in the figure above—where it has exceeded the minimum yield stress of 430 N/mm^2, results in distortion. This explains why T-GMAW has less distortion than SAW. The distortion will eventually be ascertained by the material utilized, welding parameters (preheating), plate preshaping, welding process utilized, and shipyard management system.

Finally, 4.2.5 connects the welding processes described in 4.1.4 with methods for reducing or avoiding distortion.

4.2.6

What factors affect the edge preparation for the welding of low-carbon steel?

How does a proper edge preparation contribute to high-quality welding of low-carbon steel?

This dissertation here investigates the magnitude of welding edge preparation in the advancement of welding quality and economy. This research question connects 4.2.5 to distortion reduction methods and provides recommendations about improvements. Two welding processes were utilized for demonstration purposes, according to Bodude and Momohjimoh (2015) [22], where low-carbon steels having a thickness of 10 mm were welded. Welding techniques such as oxyacetylene welding (OAW) and SMAW were used (SMAW). Welding parameters varied between 100 to 150 amps for the current. The voltage was between 100 and 220 volts. The weld was subject to tensile strength, hardness, and Charpy tests, the results of which demonstrated.

An OAW weld has a better heat input than a SMAW weld. Raising the heat input, HAZ expanded, and the distortion increased, consequently causing a large HAZ (see section 4.2.5).

Weld current, voltage, and speed are major influential factors in reducing weld heat input.

However, edge preparation in advance of welding may give a constructive influence on the weld quality. Hence, defining that excellent edge preparation is critical in any WPS.

Performing an excellent edge preparation will allow proper filler-metal diffusion into the groove, and the heat input will be improved to avoid distortions.

Demonstration of the mechanical properties at welding straight edge at a steady voltage and changing the currents.

According to Bodude and Momohjimoh (2015).

The heat input may be obtained from the following equation:

$$H = \frac{(I \times V)60}{S}$$.

Where

H = heat input (joule/mm)

I = current (ampere)

V = voltage (volt)

S = weld speed (mm/min)

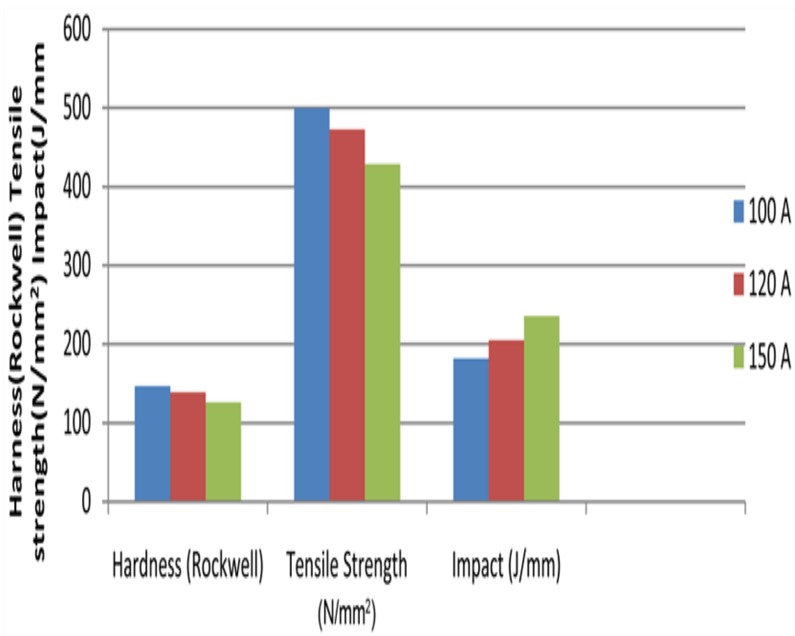
Increasing I and V has a direct impact on heat input and thus reduces mechanical properties at high distortion and stress levels. Hence, above 6 mm material thickness, a straight edge is not allowed.

Considering constant voltage at 220 volts with increased current, it was realized the mechanical properties are changed at welds with a single V-groove sample. As the current increased, the tensile strength and the hardness were reduced, while the toughness increased. The based metal was influenced via heat input among the welding, resulting in increased grain size.

Figure 92

Constant Voltage (220 V) and Changing Current with a Straight Edge.

Sources: Bodude and Momohjimoh (2015).



Considering constant voltage at 220 volts with increasing current, the mechanical properties changed in the welds with a single V-groove sample. Increasing current, the hardness, and the tensile strength were minimized, while the toughness increased.

Figure 93

Constant Voltage (220 V) and Changing Current with V-Groove Edge.

Sources: Bodude and Momohjimoh (2015).

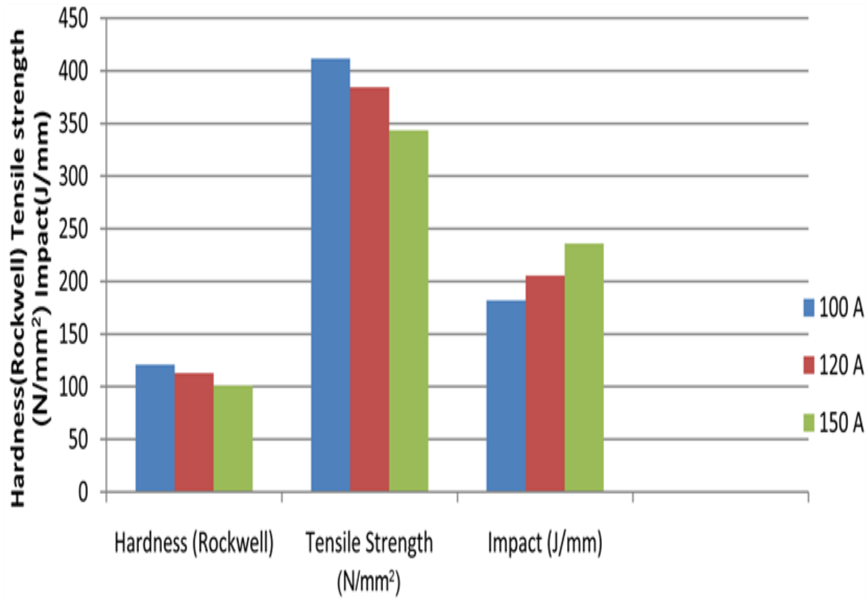


Figure 94

Constant Current (100 A) Changing Voltage with a Straight Edge.

Sources: Bodude and Momohjimoh (2015).

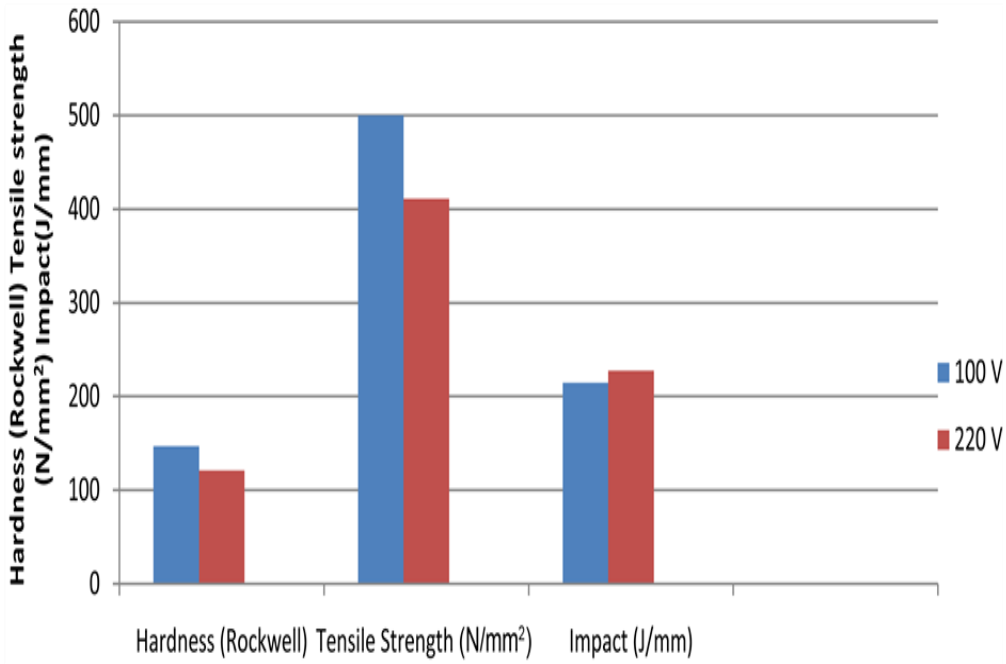

Hardness (Rockwell) Tensile strength (N/mm²) Impact(J/mm)
600
500
400
300
200
100
0
100 V
220 V
Hardness (Rockwell)
Tensile Strength (N/mm²)
Impact (J/mm)

Figure 95

Constant Current (100 A) Changing Voltage with V-Groove Edge. Sources: Bodude and Momohjimoh (2015)

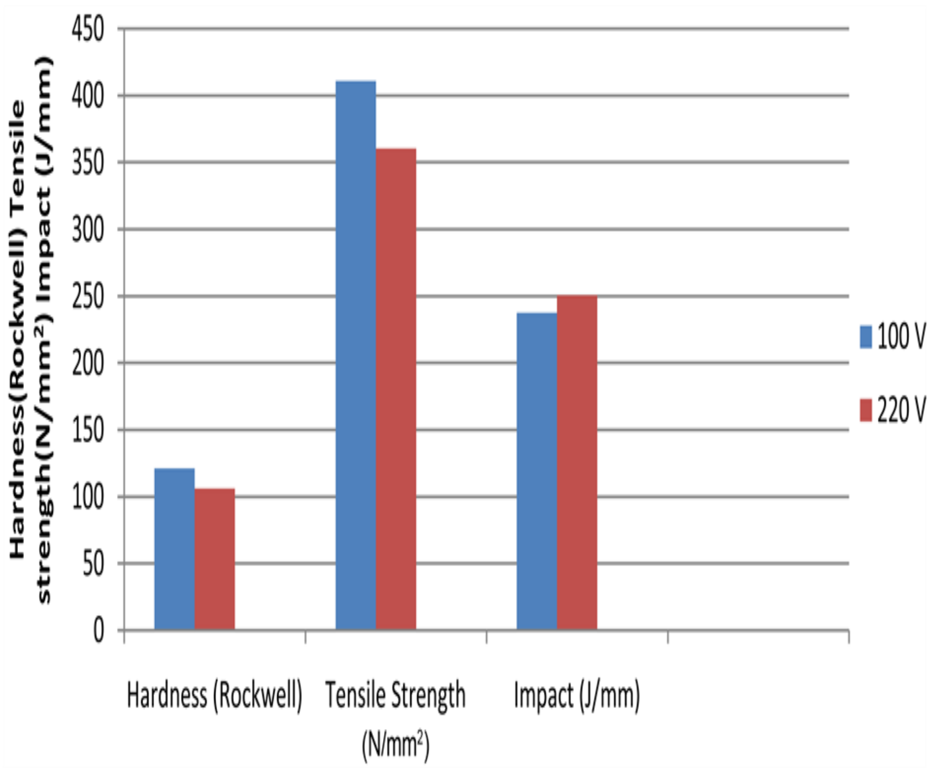


Figure 96

Constant I and V with Straight-Edge Preparation. Sources: Bodude and Momohjimoh (2015).

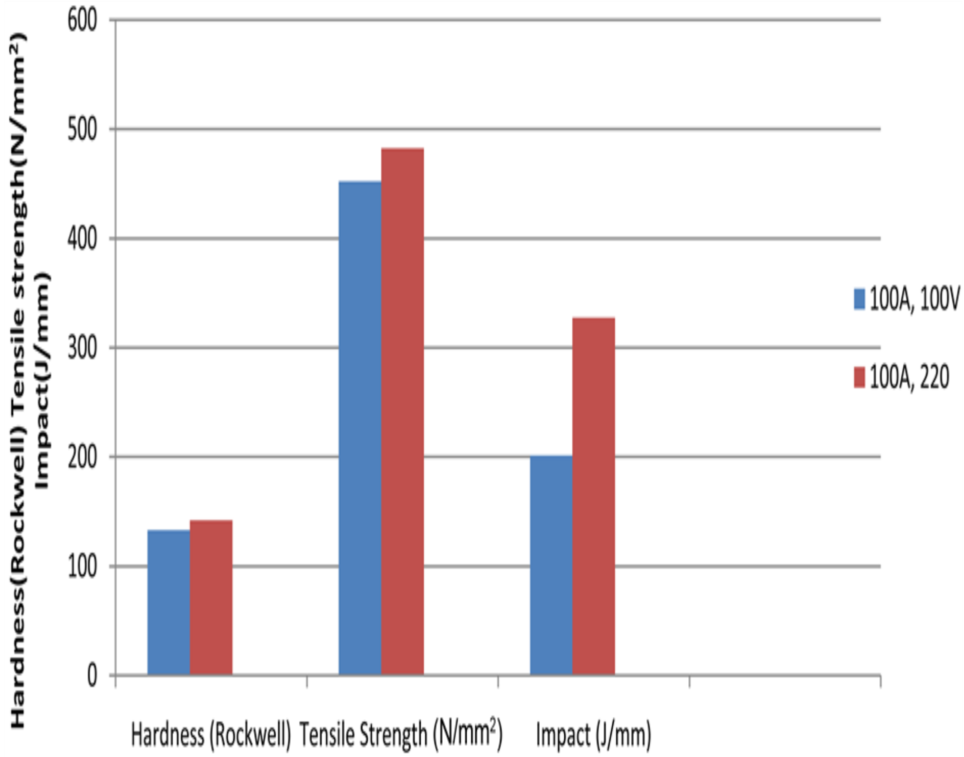


Figure 97

Constant I and V with V-Groove Edge Preparation.

Sources: Bodude and Momohjimoh (2015).

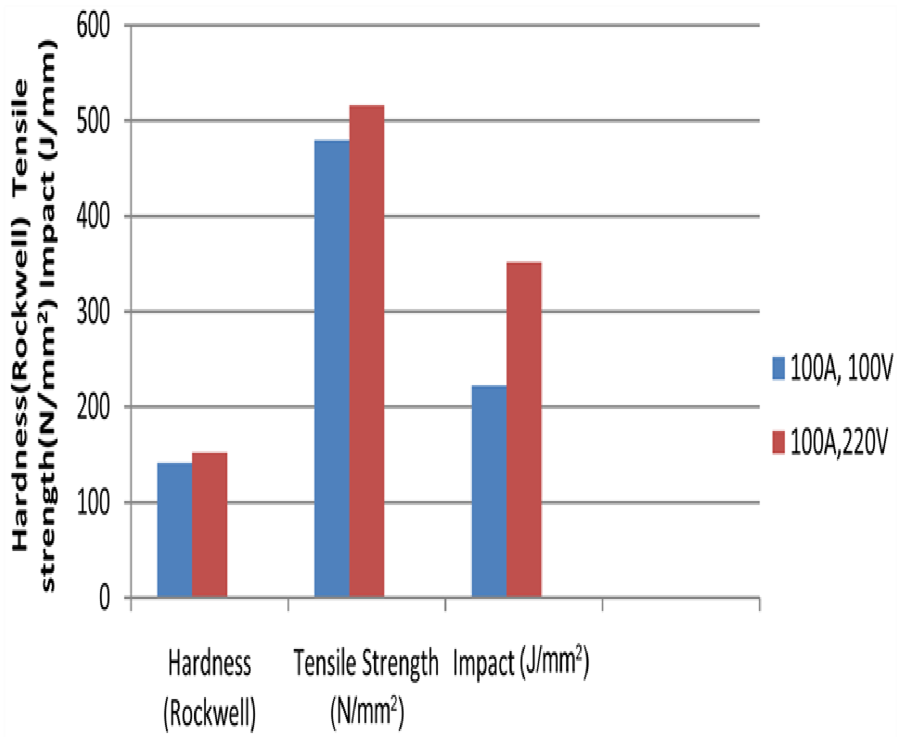


Figure 98

Constant I and V for Numerous Sorts of Electrodes with Straight Edge.

Sources: Bodude and Momohjimoh (2015).

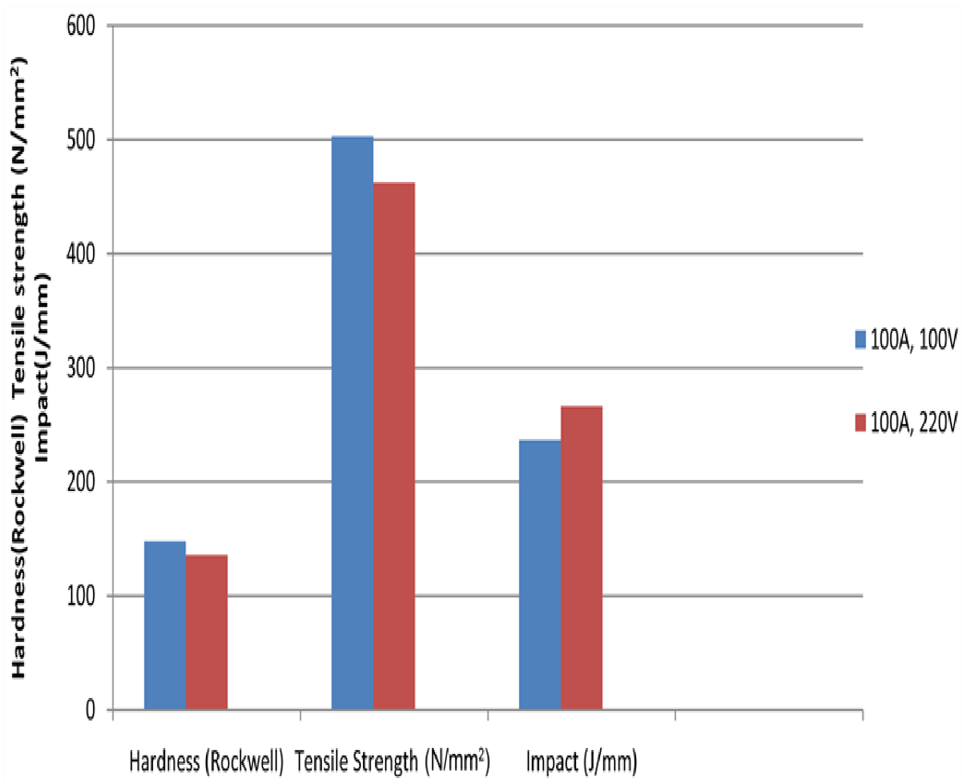
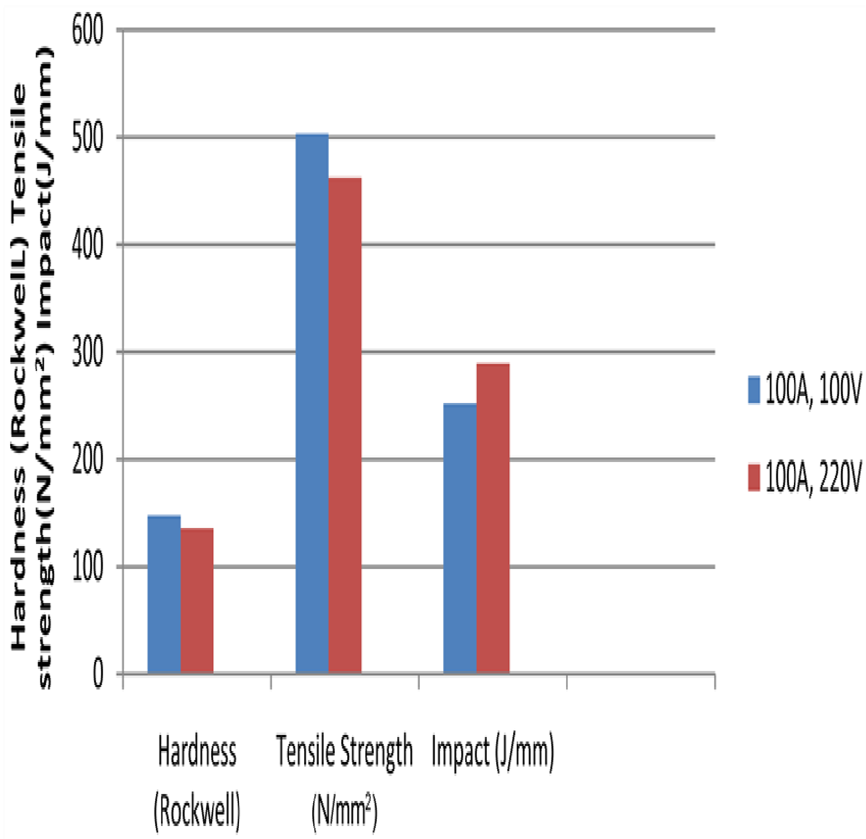


Figure 99

Constant I and V for Numerous Sorts of Electrodes with V-Groove Edge.

Sources: Bodude and Momohjimoh (2015).



The straight edge has less impact energy than the V-groove edge.

Figure 100

Constant I and V for Various Cooling Media with a Straight Edge.

Sources: Bodude and Momohjimoh (2015).

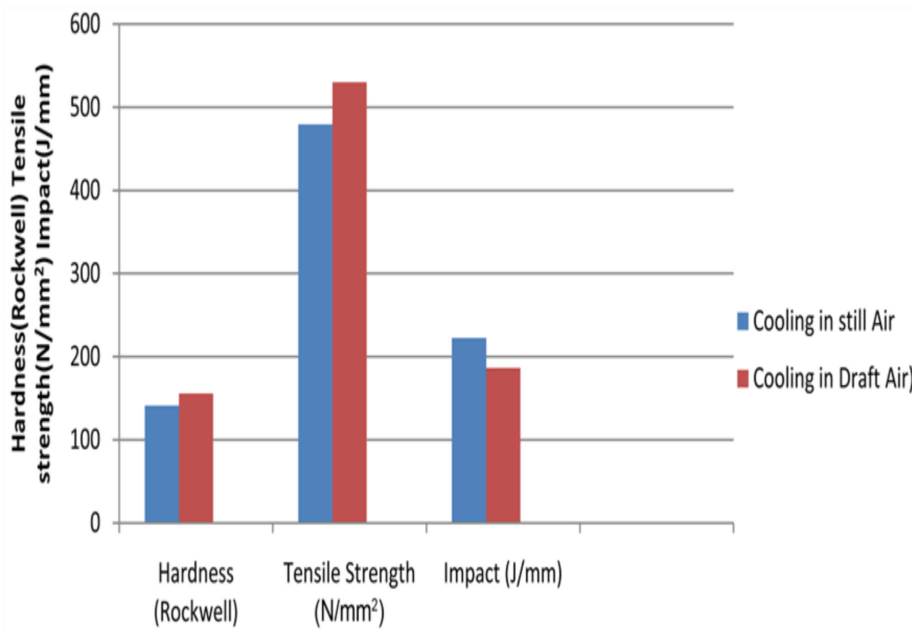


Figure 101

Constant I and V for Various Cooling media with V-Groove Edge.

Sources: Bodude and Momohjimoh (2015).

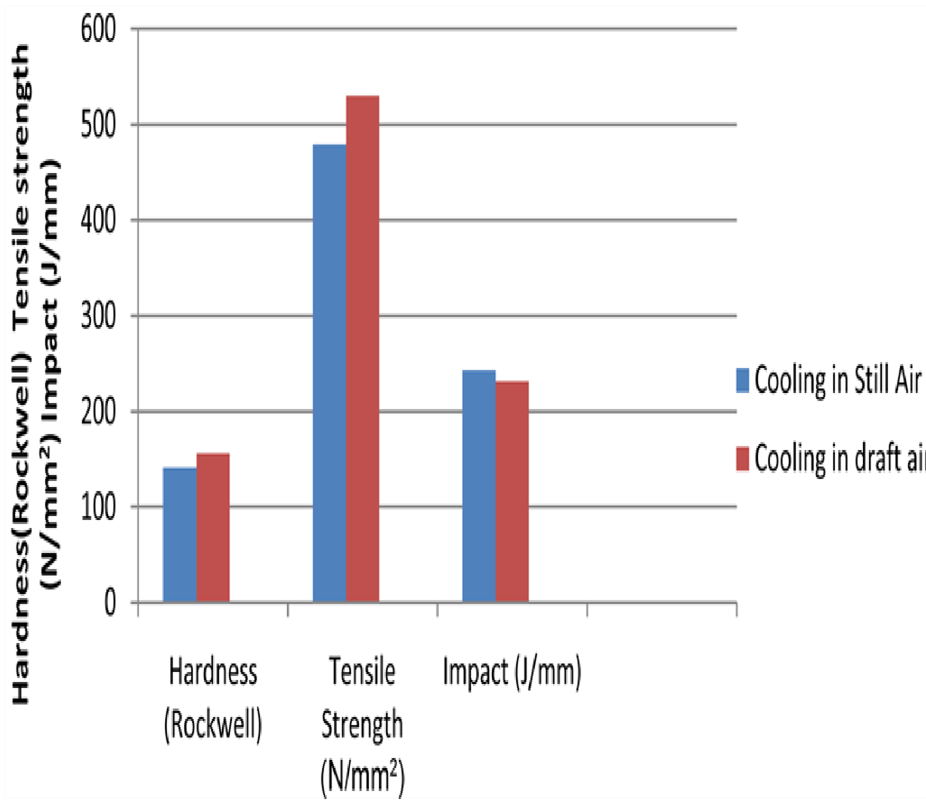
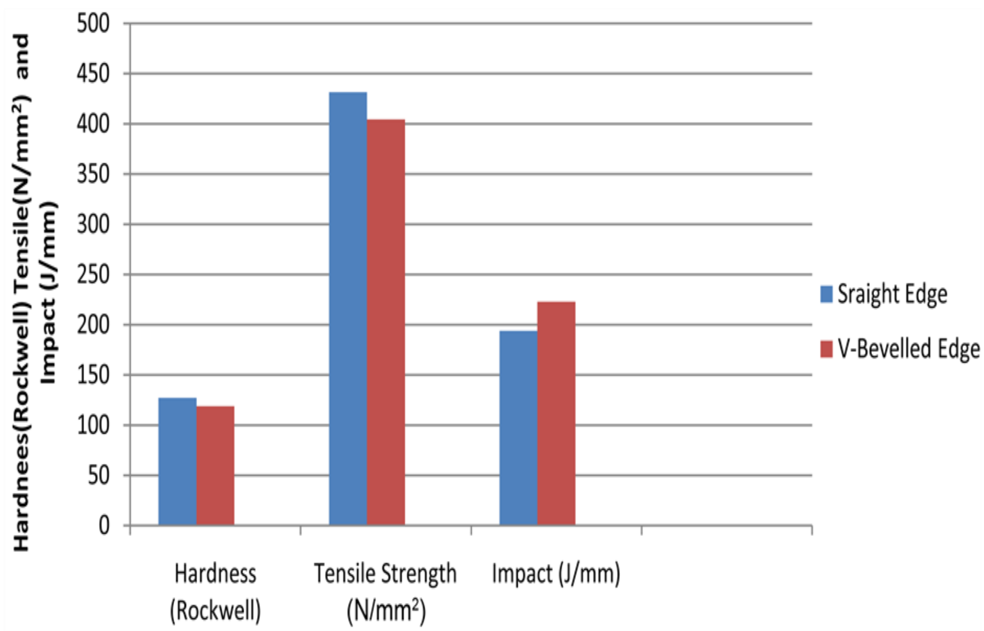


Figure 102

Showing Welding with Oxyacetylene Flame with A straight Edge and V-Beveled Edge.

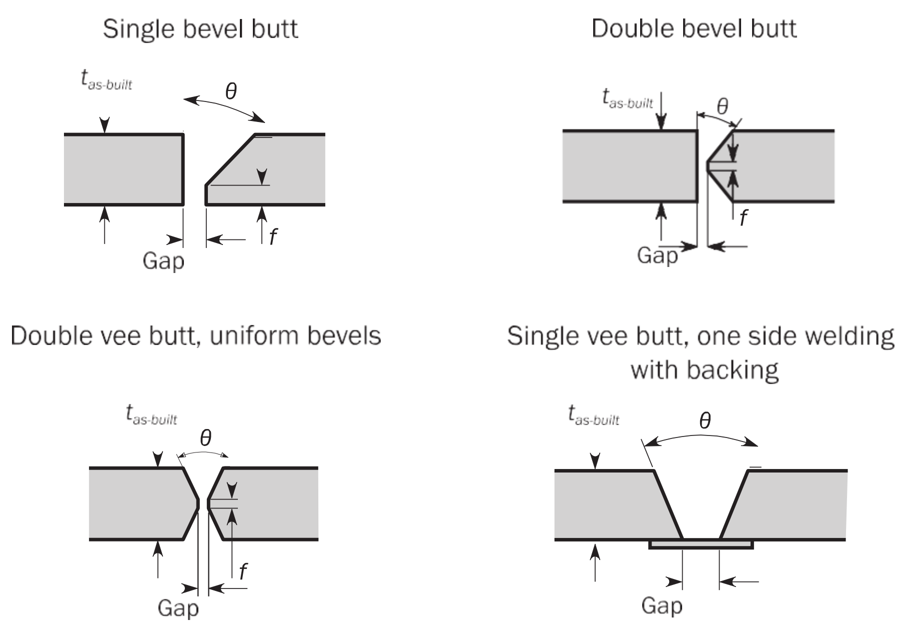
Sources: Bodude and Momohjimoh (2015).



The beveled edge has more impact energy and less tensile strength and less hardness than the straight edge.

Figure 103

Typical Butt Welds. Source: DNV-GL Rules, Part 3, Chapter 13



The shaping of edge preparation differs with material thickness. Thicknesses below 6 mm do not require edge preparation (straight edge).

The following edge preparation forms are possible:

Single V (frequently used)

Double V (X-form), frequently used)

Half V (frequently used)

K (occasionally used)

Y (occasionally used)

U (less used)

Double U (less used)

The following recommendations for the edge preparation can be summarized:

Proper edge preparation increases the accuracy of the welds, thus forming a characteristic and an element of the WPS (see 4.2.1).

The material's microstructure indicates the hardness and tensile and impact strengths of the welds.

Upon decreasing the heat input, the hardness of the seam increases, at less toughness. Therefore, heat input is a component of the WPS. The Charpy test is a requirement to confirm the required toughness. If the toughness is less than indicated in the rules, the welding must face rejection (losing fabrication efficiency).

Preheating the shielded electrodes has become enormously important when used—typically for the basic electrode—to eliminate the humidity and decrease the cracks following from the fusion of H_2 over and above to minimize the distortion.

Excellent advice proves to use electrode dryers and controlling the electrode temperature, WPS, interpass temperatures when proceeding with the welds.

Using straight, V, or double V as edge preparation must be compliant with the class societies' rules (e.g. DNV-GL, Part 2)

The conclusion of 4.2.6 accompanies question 4.2.5, presenting methods of

The Balanced Scorecard: "BSC"

The dissertation has introduced typical problem areas in shipyards including smart technical and financial solutions that are vital for all shipyards to consider for both quality retainment and coat efficiency. These findings enhance our awareness of the day-to-day processes in the shipyards' domain and the possibilities of improving those continuously.

Part 4.1 and 4.2 in the dissertation have shed light on major areas of welding and NDT as well as on direct solutions to problems facing and challenging the management and the employees daily. The management and processes of welding and NDT require efficient tools to control and monitor the performance and to improve it and continuously provide innovations to the system.

The BSC is a management tool applied in corporations and businesses worldwide to optimize the strategies of the business. However, it is not correct to think that only the financial aspects will alone drive the business ahead. The financial status of any business is essential in its existence. but it is not the only factor that determines long-term success.

Considering a shipyard nature and atmosphere, the CEO and the board of directors must have a vision and mission that should develop the corporate in the foreseen direction, make reasonable profits, take a market segment in the maritime business, and boost the reputation of the yard among local, regional, and international yards.

Shipbuilding is a complex project, often involving billions of dollars of investment. Understanding the vision and mission of the shipyard management among the employees will not guarantee excellent and cost-effective production unless those are connected to a thorough strategy that considers the significance of the employees and their roles. In modern strategies, every employee in the company is implicated in the strategy and hence is also responsible for implementing it. During the production, the CEO is not looking after each employee to verify the perfect implication of the production. Every employee must work within a system that has been established by the management and within set rules and quality standards. Thus, the yard management is interested in receiving an anonymous opinion from all employees about their job, career prospective, and payment on an annual basis. Simply put, the management is looking for good work conditions for the employees, aiming for their satisfaction. Satisfaction is an excellent indication of retention that yards are focusing on.

However, retention is not achievable if the management system is missing. The philosophy of the BSC is founded on having a score; specifically, measurable targets that have scores and thus can be assessed and evaluated. If something cannot be measured, it is not possible to evaluate it.

Investigating the BSC is a continuing concern within the management. Having created a scoring system is not sufficient to run the business because the strived scores must be balanced too. The task becomes much more complicated and takes a wider dimension than just filling out evaluating scores.

The function of BSC:

BSC aligns the vision and mission of the organization (shipyard) to the business.

BSC monitors the business performance.

BSC is a business-performance measurement scorecard.

BSC's focus is on KPIs.

BSC consists of four perspectives, explained below.

BSC aligns the business performance to the business strategy.

BSC considers both the financial and the nonfinancial performance of a business (shipyard). Financial and nonfinancial performances alike are important.

BSC is a score (a record) of all shipyard data.

BSC utilizes measurable data.

BSC is intended to measure and assess the shipyard performance on long-term condition.

BSC proves the successes of the yard via actual scores and figures, hence "scorecard."

BSC is not only a score-based management tool but also seeks a balance between the scores.

Establishment of the BSC

BSC is established by the top management of the business (shipyard); specifically, CEO and the board of directors.

The Advantages of the BSC

Supports long-term strategies.

Useful for various management domains including financials.

True figures.

The complete and updated condition of the shipyard.

The disadvantages of the BSC

KPIs require a large amount of data.

Difficult to attain a balance of all perspectives.

A thorough update is required.

Continuous feedback is obliged to keep it running properly.

The BSC consists of four main perspectives:

1- Customer
2- Financial
3- Growth
4- Internal processes

The present dissertation provides additional evidence concerning the business and economic welding processes that have not been published before and hence adds unique and valuable inputs from practical experience applicable to shipyards, shipbuilding, ship repair, and maritime businesses.

The emphasis will concentrate on analyzing the above perspectives in detail, showing by what means those are playing a significant function in shipyards.

Customer

Leading a shipyard successfully requires that the customer will always be in the spotlight of the management, including all employees.

For the shipyard management, the following KPIs are significant:

- Customer satisfaction.

- Customer retention.
- Winning new customers.

All KPIs must cascade down from top management to the department managers and from those to their employees. Everybody must work on those KPIs; specifically, on the strategy of the yard. Every KPI has a weight, dependent on the vision of the management. The total weight sums up to 100%. The actual KPI of each yard department should not be less than the set KPI; however, it may exceed it. The annual evaluation of the employees is directly connected to fulfilling the KPI. All KPIs must be measurable.

The shipowner is a key in this business since they will decide on building their ship in a specific yard, depending on the facilities and abilities of the yard and its skilled personnel. Billions of dollars could be invested in building a new fleet of ships. The shipowner has the power to make sure that it will be an investment for a least 25 years. Therefore, no space exists for wrong investments. On one hand, this is a terrific business opportunity for the shipyard. However, major challenges arise in building up the proper management system to accommodate the order of the ship owners. On the other hand,

experienced shipyards do not only see the order placement as a one-time change but as customer retention for future new buildings, ship repairs, or supply chain to the ship owners, wherever the vessels might be, worldwide.

Customer retention is a direct result of customer satisfaction. The shipyard management will certainly make no efforts to gain customer satisfaction. The board of the shipyard will envision customers at the center of the vision and mission, alike, and integrate all possible customer services to be in the center of all activities the yard is offering.

Strategy for improving the customer (shipowner) satisfaction:

- Excellent quality
- Competitive prices
- Short delivery time in comparison to the competition
- The spare parts (supply chain) worldwide within a defined time
- Warranty on hull, machinery, and equipment
- Offering life cycle cost plan
- Offering a classification society suitable to the shipowner
- Possible training facilities for personnel of the shipping company (customer)
- Offering consultancy services to the shipowner
- Offering high shipyard standards

Strategy for improving the customer (shipowner) retention:

- Offering innovation to the design of the hulls.
- Offering innovation to the propulsion machinery.
- Offering innovation on operations cost.
- Offering innovation on environmental aspects.
- Offering references for the innovations, possibly from other customers.
- Excellence in handling nonconformities in a professional, constructive way
- Learning abilities from lessons and past experience

- Applying the principle "Customer is King"
- Keeping an eye on customer satisfaction, since only a satisfied customer can be retained

The customer satisfaction and retention that have been recognized therefore assist in our knowledge of the customer role in focus. However, customer satisfaction and customer retention may also ideally contribute to the winning of new customers. Winning of new customers (shipowners) has shown to be much harder to achieve than customer retention. This explains why customer retention is unavoidable for expanding the business.

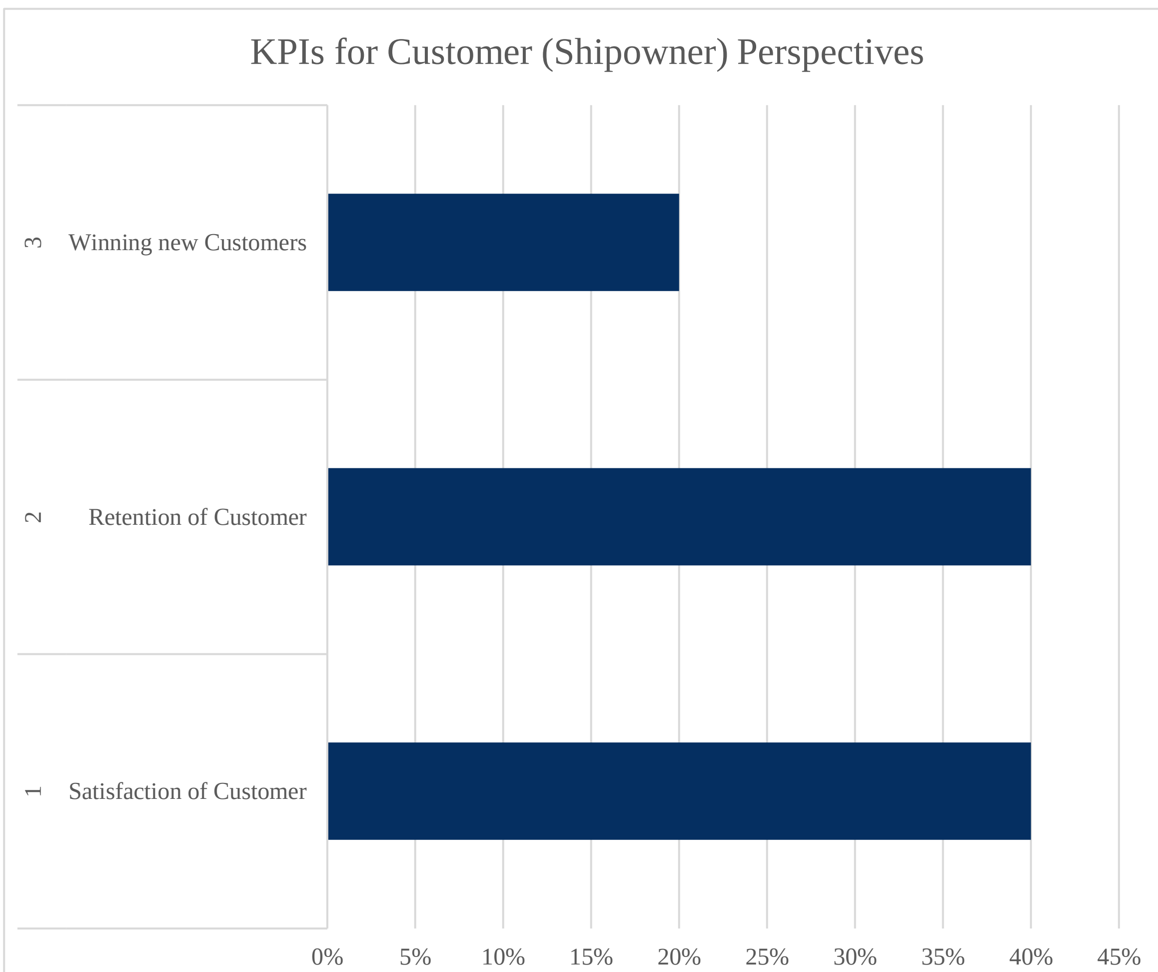
Strategy for improving the winning of a new customer (shipowner):

- Customer in focus (customer satisfaction) as a motivator for new customers
- Customer retention as a motivation for new customers
- Customer development tools; typically, setting a dedicated key account manager for each customer (shipowner)
- Arranging seminars for customers (shipowners) to boost the business
- Participation in local, regional, and international maritime exhibitions
- Promoting advanced, cost-efficient welding techniques and NDT to the shipowners, as explained in detail in 4.1 and 4.2
- Arranging a reputable, strong quality department, where the quality manager reports directly to the executive board, independent from the production department

Therefore, top management pays special attention to the quality, services, and prices of the ship deliveries, targeting the pleasure and hence the retention of their customers (shipowners). The latter could induce the promotion of the shipyard by mouth-to-mouth propaganda and as an actual reference as well. Additionally, customer satisfaction and retention affect the reputation of the shipyard. This is where reputation comes from.

Figure 104

Customer (Shipowner) Perspectives



The figure demonstrates the principle of customer focus, in line with the vision and mission of an efficient shipyard. Customer satisfaction and retention are the keys to winning new customers. A balance between all three must be attained. Therefore, there are weights for the KPIs established by the management and cascaded down to managers and employees, introducing the yard's strategy toward customers.

Table 48

KPIs and Weights in % for the Welding Department of the Yard.

KPIs toward customers

Perspective	KPI	Weight	Measures for welding department
1	Customer satisfaction	40%	- 90% or more of welds must pass at 1st inspection (10%). - 90% or more of NDT must pass at 1st test. (10%). - QC must verify the welds before customer invitation for inspection. (2.5%). - Visible defects to be fixed before customer inspection (2.5%).

Perspective	KPI	Weight	Measures for welding department
			- WPS to be strictly followed (2.5%). - The best appropriate process to be utilized (2.5%). - Electrodes to be completely consumed (2.5%) - Electrodes to be dried, as required (2.5%). - Pre- and post-heat treatment to be operated as appropriate (2.5%). - Shielded gas to be carefully chosen (2.5%).
2	Customer retention	40%	- Remaining items by customers to be obeyed (10%). - NDTs to be announced to the customer (10%)

Perspective	KPI	Weight	Measures for welding department
3	Winning new customers	20%	- NDT results to be provided to the customer (5%). - Defects, if any, to be properly repaired (5%). - Repeated NDT result to be provided to the customer (5%). - Regular welding and NDT quality meetings to be involving the customer (5%). - Focusing on customer satisfaction (5%). - Focusing on customer retention (5%). - No compromise on quality (5%). - Leading by example from management (5%).

2. Financial

It has been explained that BSC concentrates on four perspectives, among them the financials (financial stakeholders). The successes of an organization (shipyard) is an essential task of its financial stability. The financial situation of a shipyard will reflect whether the financial objectives and the implementations are matching the strategy of the yard or not. Achieving more sales via smart production models in welding, explained in detail in 4.1 and 4.2, may also boost the financial situation considerably.

The financial objects must start by identifying long-term financial objects. Those may be linked to the customer, internal processes, and the return on investment. The shipyard may have the same financial objects for all departments or may assign different financial objects dependent on the department. For example, the financial objects for the welding department, expressed in KPIs, could have a weighting of 30% on reduction of welding time, 20% on reduction of preparation time, 30% on implementing the most proper process, and 20% on achievement of all welds without failure or rework or retest. Those financial objects are set by the board of directors, from where they cascade down to the department head of the welding department and in turn to the supervisors, welders, and testing operators' level.

For the shipyard management, the following KPIs are significant:

Expenses

Revenues

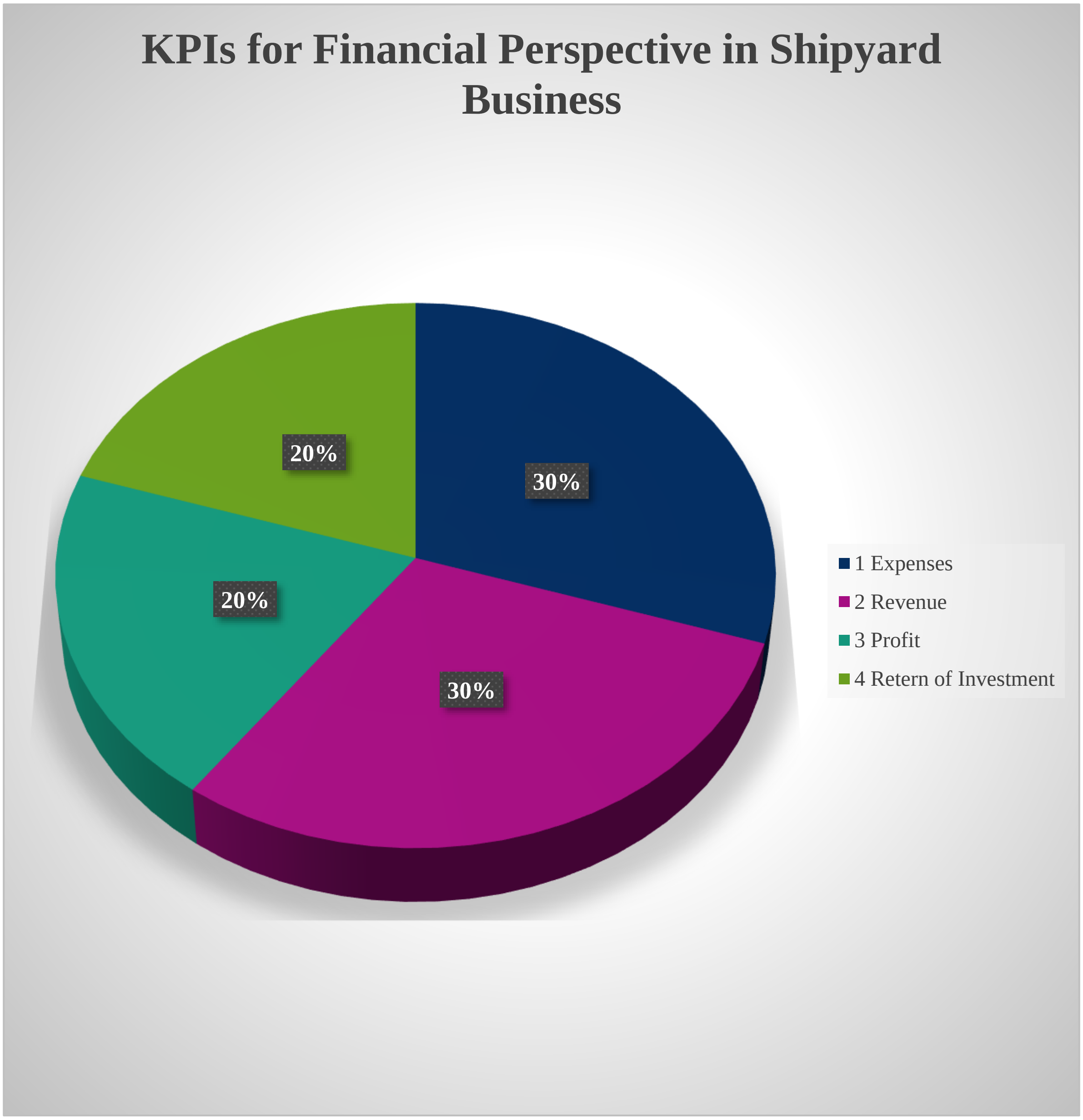
Profit

Return on investment

The above set figures play a considerable role on the expenses, revenues, profit and hence on the return on investment. The dissertation has proved major implementations in 4.1 and 4.2 that will lead to the expected success.

Figure 105

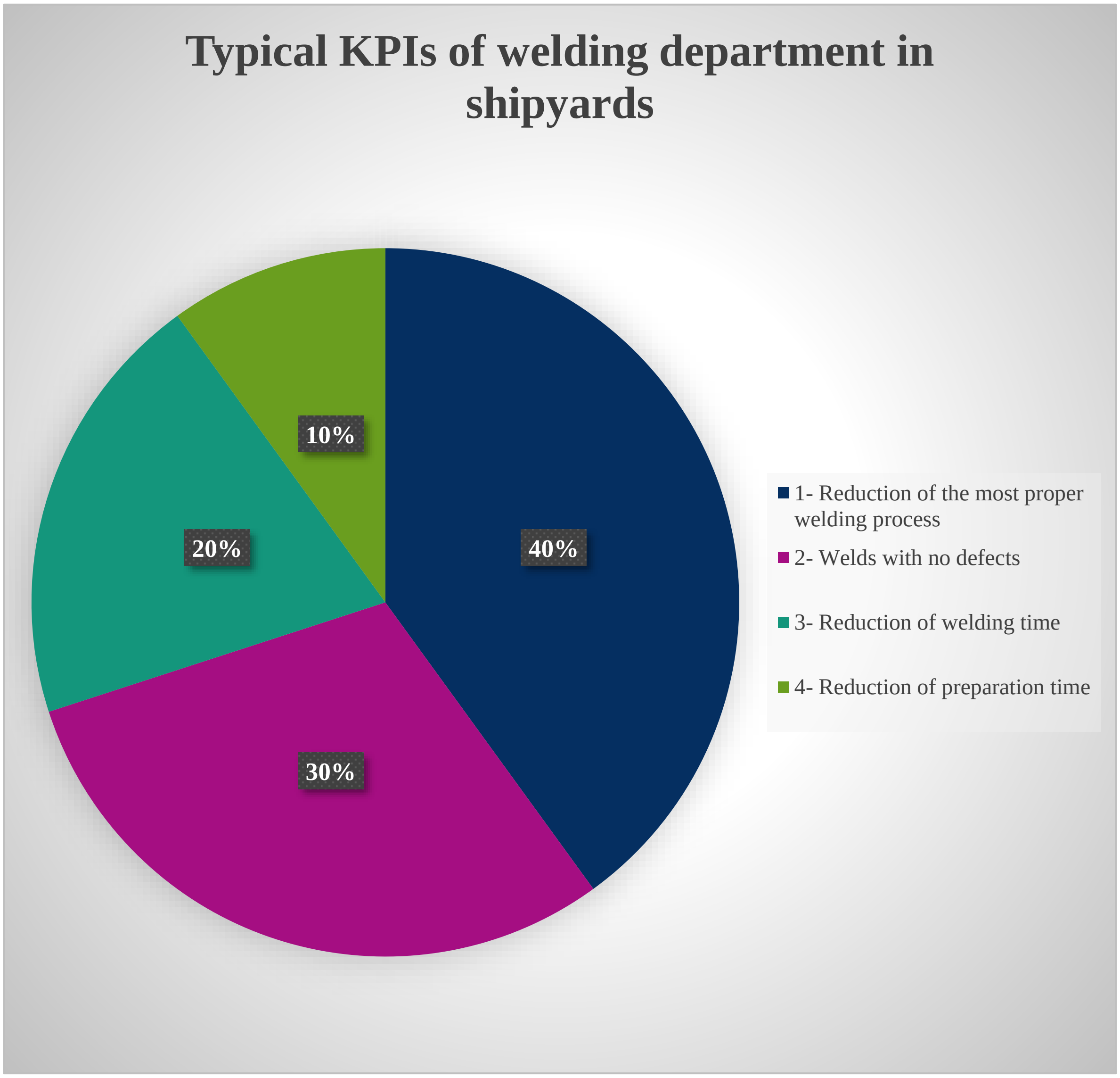
The Elements of the Financial Perspectives that May Apply in Shipyards



The dissertation analyzes the processes and cost reduction of the welding processes in shipyards in 4.1 and 4.2.

Figure 106

The KPIs for Welding Financial Perspectives Among Shipyards



The dissertation proves that the above perspectives are of major impact on the welding economy. Achieving those smart KPIs will enable the shipyards to achieve their financial goals via reducing the expenses, increasing revenue, and increasing profit, thereby reaching a rewarding return of the investment via optimal utilization of the assets. The best practice of the BSC could score the above perspectives since all are measurable. Introducing the balanced scores stated in the KPIs will allow the updating and recording of all figures. Due to the magnitude of the processes, 40% weight for the KPI is reasonable.

3 Growth:

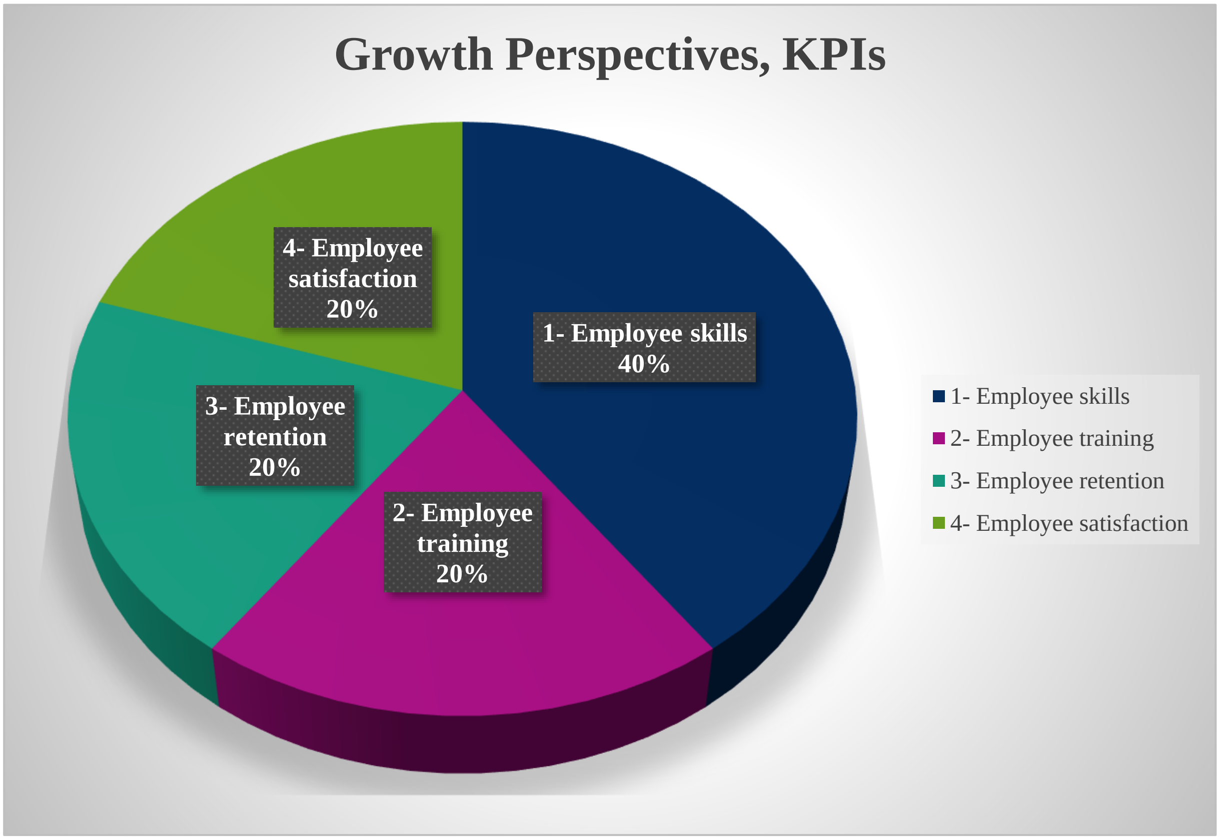
There are several important areas where this study makes an original impact on the value of the workforce in shipyards.

The growths of shipyards can be attained by improving the following:

- Employee skills
- Employee training
- Employee retention
- Employee satisfaction

Figure 107

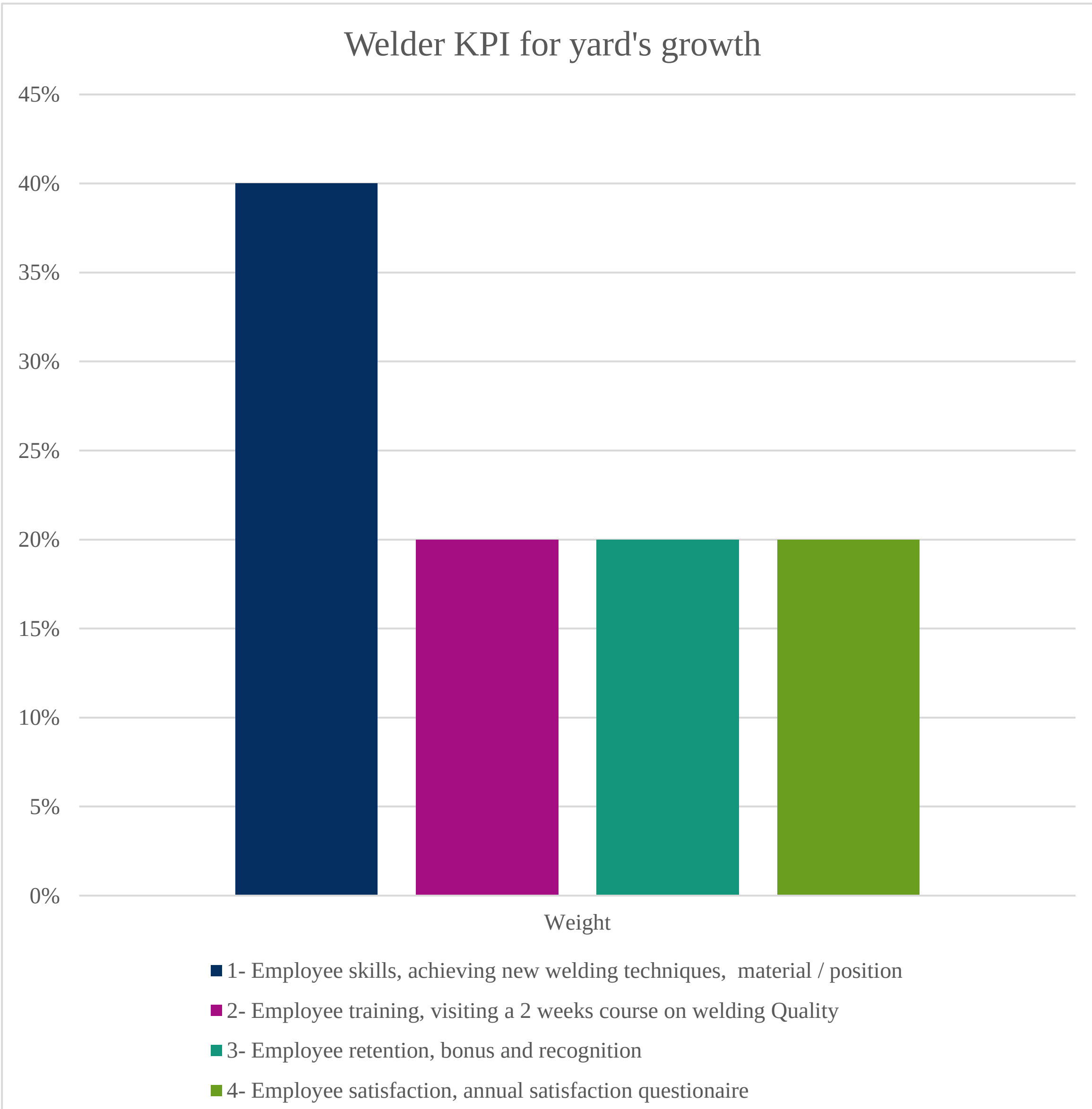
The KPIs of the Growth Perspective in Shipyards



The talents of the employees in shipyards are among the major factors for the shipyards' growth. Therefore, a KPI equal to 40% is reasonable to achieve the perspectives of the balanced scorecard.

Figure 108

A Typical KPI Demonstrating the Growth of the Shipyard via Personnel Improvement



The excellence of the welders and their retention are continuous goals for growth.

4 Internal processes

The internal processes are essential procedures that contribute to economical welding production—with high quality—and that will add value to the customer. The dissertation considers the welding process, QC, and the welding economy in detail and produces with valuable recommendations, advice, and checklists causally associated to the profit of the shipyards and the customers alike.

The internal processes consist of three parts:

- Innovation
- Operations
- Aftersales services

Innovation:

The innovation contains the evaluation conducted by the shipyard toward customer needs. The welding processes shown to be uneconomical and expensive and after all not fulfilling the customer expectations must be further developed and new, smarter processes must be introduced. The dissertation proves that certain welding processes are much more expensive related to other processes. Realizing this fact, the shipyards are expected to change the management of such processes and to learn continuously. It is demonstrated that using the MAG welding process saves more than 50% of the fabrication cost. Knowing this, the shipyard management must add a KPI for improving the welding processes yearly. The shipyards will be under competition for implementing such improvements, introducing them through sales and marketing strategies, and toward winning new customers.

Operations

The operation process starts by receiving the demand for the shipbuilding or ship repair and concludes by delivering the vessel to the shipowner. Quality, efficiency, and timely delivery are key factors for success. Earlier, shipyards only strengthened on the financials. Modern methods consider the cost of machinery, running cost, maintenance, training, or replacing inefficient machinery with more efficient and most economical machinery.

Shipyards have also realized that it is essential to make the labor busy all the time. Hence, the machinery will be best used. Downtimes for the labor and machinery are extraordinarily expensive for the operations and profits. The key strength of the businesses is the welding quality. Previously, quality was supposed to be a complementary segment of the production line. Soon, the shipyards realized that quality is the key to success and development. Quality is the most significant factor for customer satisfaction and retention. Therefore, quality is always integrated into the business strategies of the shipyards, in the short and long run. KPIs are developed to gauge quality fulfillment and total quality management.

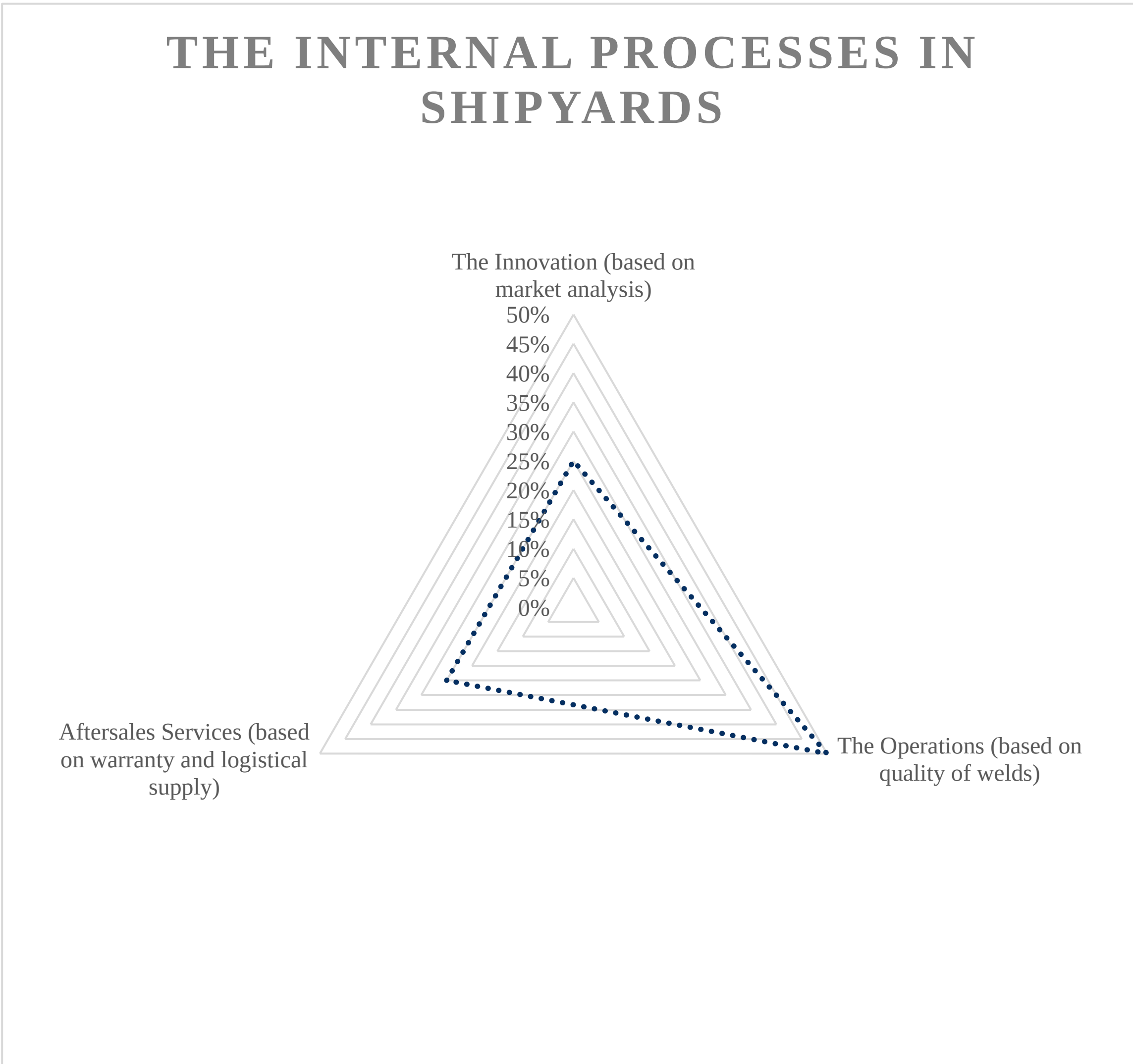
Aftersales Services

The aftersales services include the warranty for the welded products (for example, ship hull) including the repairs of any deficiencies that raised after delivery of the ship. Well-reputed shipyards make efforts such that those deficiencies do not arise at all, or remove those once announced by the shipowner, even outside the shipyard or abroad.

The aftersales services must also contain the logistical supply of essential spare parts and the delivery worldwide within a given time. The aftersales services could also offer technical and management training for using the ship equipment. The aftersales services, if properly performed by shipyards, could be the start of new order placement by the shipowner that will boost the internal processes. This creates a cycle and a chain of responsibilities and service toward customer satisfaction, retention, and gaining new customers.

Figure 109

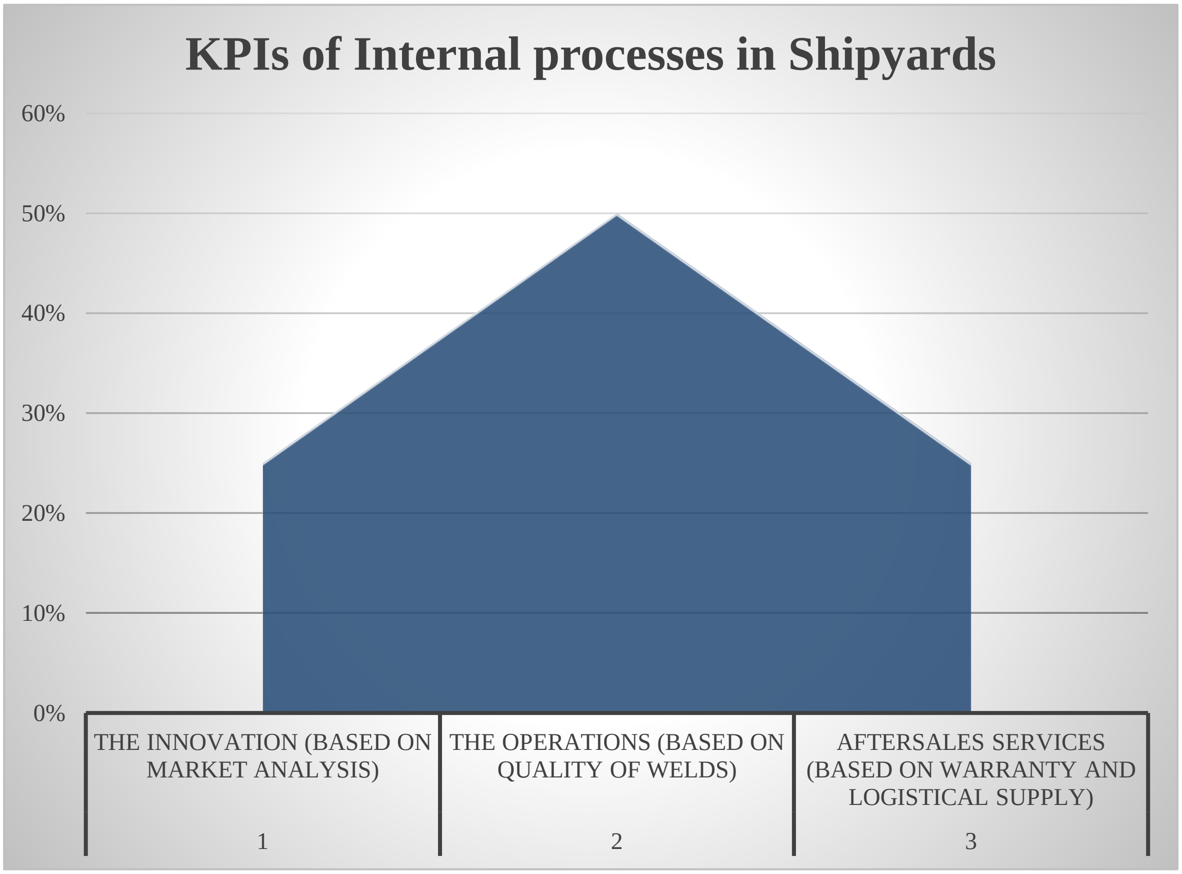
The Internal Processes in Shipyards



The internal processes are essential procedures that ensure that the welding production is economical, is of high quality, and will add value to the customer. The dissertation considers the welding process, QC, and the welding economy in detail and identifies valuable recommendations, advice, and checklists causally linked to the profit of the shipyards and the customers alike.

Figure 110

How Shipyards Apply the Strategy for their Visions and Missions



Chapter V:

DISCUSSION

5.1 Discussion of Results

The following profits have been derived via the present study:

Through a proper DFP, WPS, and correct choice of welding processes, 30–50% cost savings are achievable as displayed in 4.1.1, 4.2.1, and 4.2.2.

It has been identified that 70% of the price is accounted for by welder, supervisor, and their experience.

Forty percent of the cost of the welds is reliant on the weldability and welding piece thickness.

The welding time and the provision of welds (edge preparation) represent about 40% of the processing welding cost.

The maintenance cost, energy cost, and frequency of machine utilization form 60% of the welding expenses regarding the deployment of the welding machine.

6Sixty percent of planning cost hangs on the assortment of the welding process, QC, and NDT.

The detailed WPS among the dissertation demonstrates cost savings of about 30%. For these savings, both a high-quality attitude and efficient management are required.

In this dissertation, WPS as a quality checklist and system for welds provides a considerable method of a high quality and minimal expense. Cost savings of up to 30% may be reached at improved quality.

Both cost leadership (cost savings of 30–50%) and difference barriers through better quality were disclosed within the dissertation. The competitiveness through cost management alongside QC was established among the dissertation in parts 4.1 and 4.2.

In consideration of optimizing the turnover, efficient welding processes should be applied as revealed in this dissertation. Production optimizations for welded parts could attain savings of 50% and more (see 4.1.1).

Fifty-two percent of expenses are for drop welding. Labor expenses are major and hence are subject to monitoring.

Implementation of an argon-hydrogen mixture has rates of deposition that are increased by 10 to 30%.

The parts 4.2.1 and 4.2.2 in the dissertation perfectly combine the progression of WPS, the weld design, and parameters and show clearly how those could influence both qualities and expenses of the welds. Savings up to 30% could be reached.

The cost for building just the 15 blocks mentioned under Main Costs in the dissertation differs depending on the process utilized. The table below and figure show considerable savings of 46,950 euro. For a ship hull consisting of 1,000 diverse blocks, the savings would be 3,130,000 euro for the hull alone. Those savings may be planned to fulfill the balanced scorecard concerning the customers, financials, growth, and internal processes.

Table 49

Welding Cost for 15 Blocks of Ship Hull

Welding process	Weld length (m)	Cost/m (euro)	Total Cost of welding (euro)	Savings (euro)	% of savings	Welding process
1- MAG	4,695 m	8	37,560	46,950	55.55%	1- MAG
2- Electrode	4695 m	18	84510	0	0%	2- Electrode

Figure 111

Shipyard Savings by Utilizing the Most Economical Process

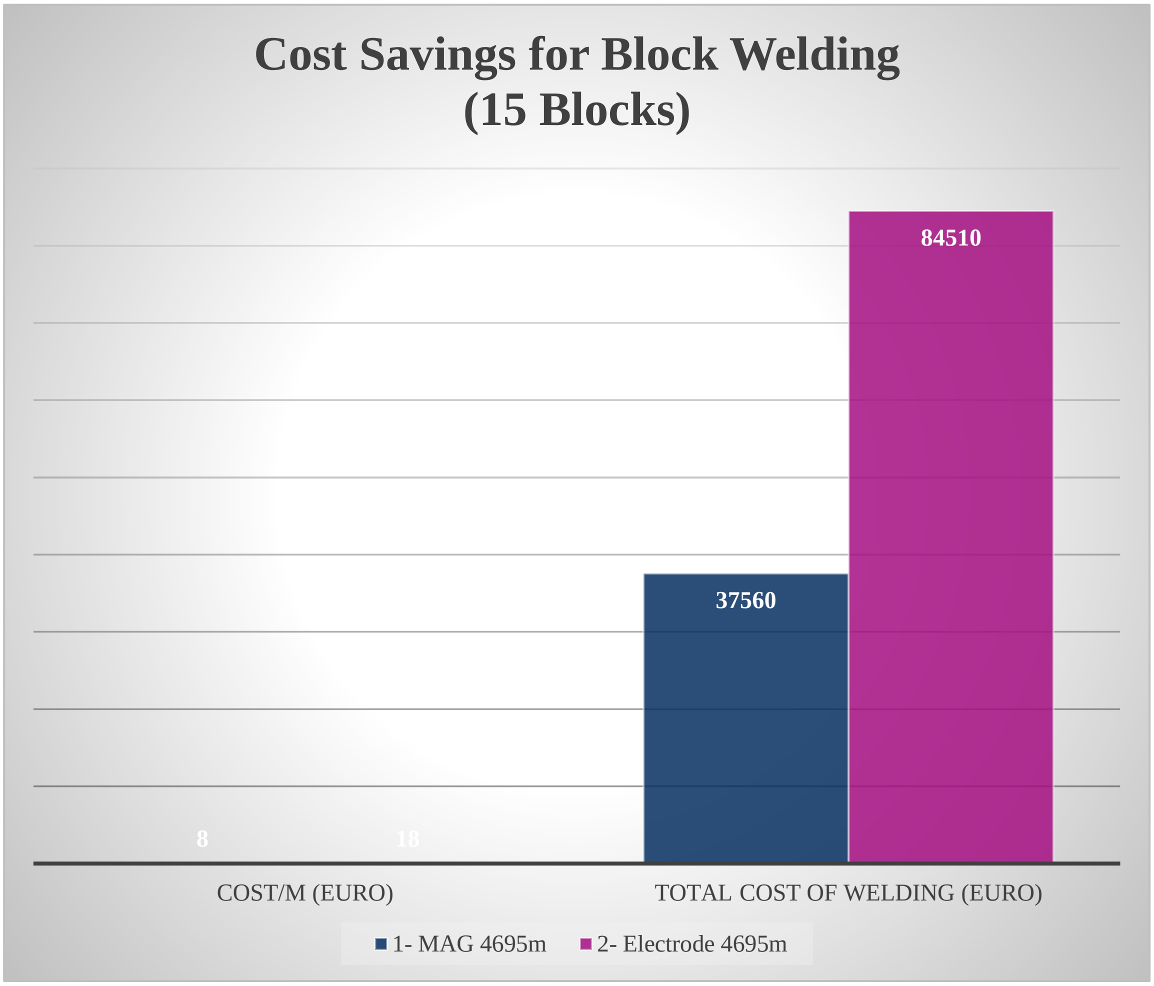


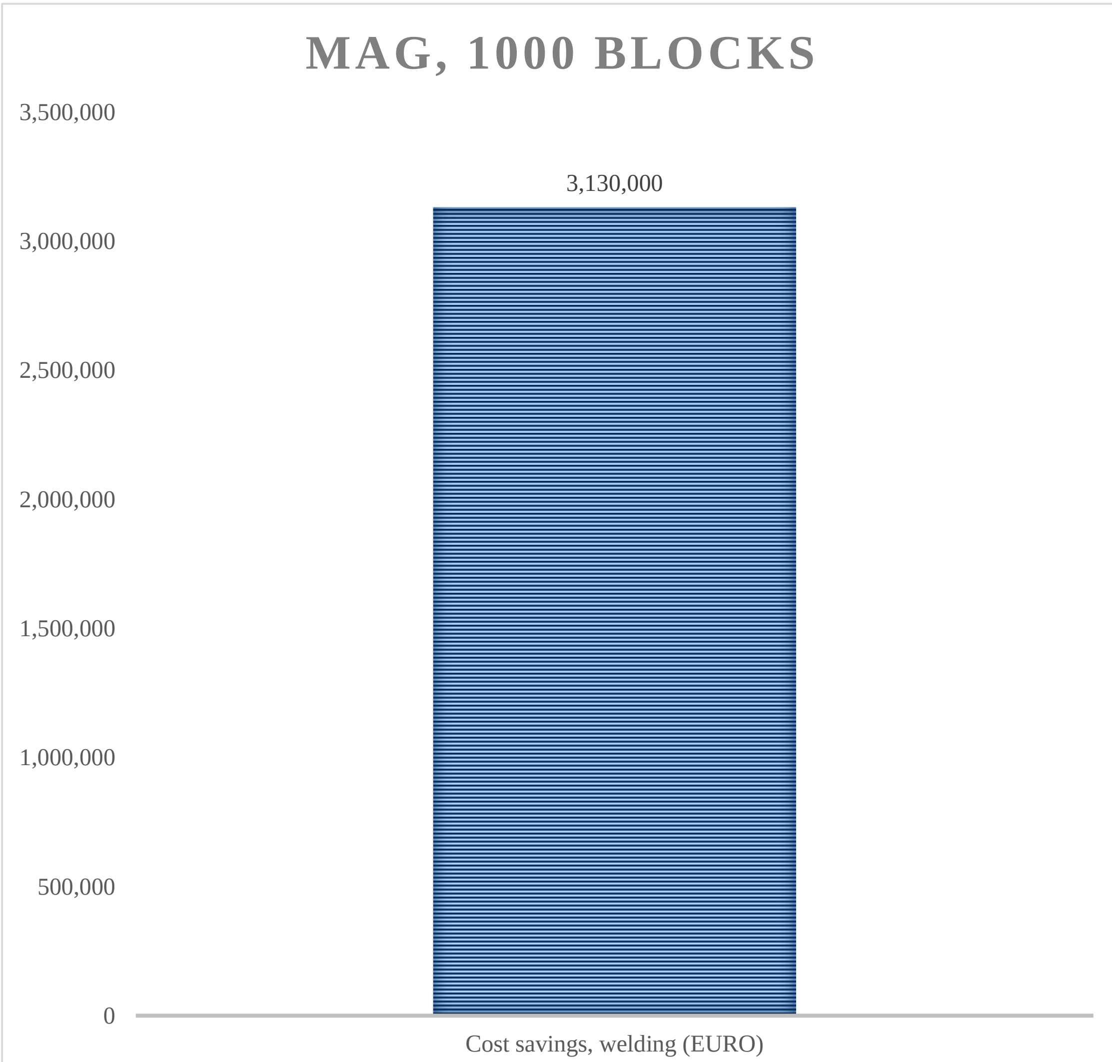
Table 50

Cost Savings when Welding 1,000 Blocks of Ship Hull

Welding process	No. of welded blocks	Cost savings, welding (euro)
MAG	1,000 blocks	3,130,000

Figure 112

Cost Savings of Proper Welding Method



Cost savings of 3,130.000 euro can be achieved when welding 1,000 ship blocks by utilizing MAG as the welding process

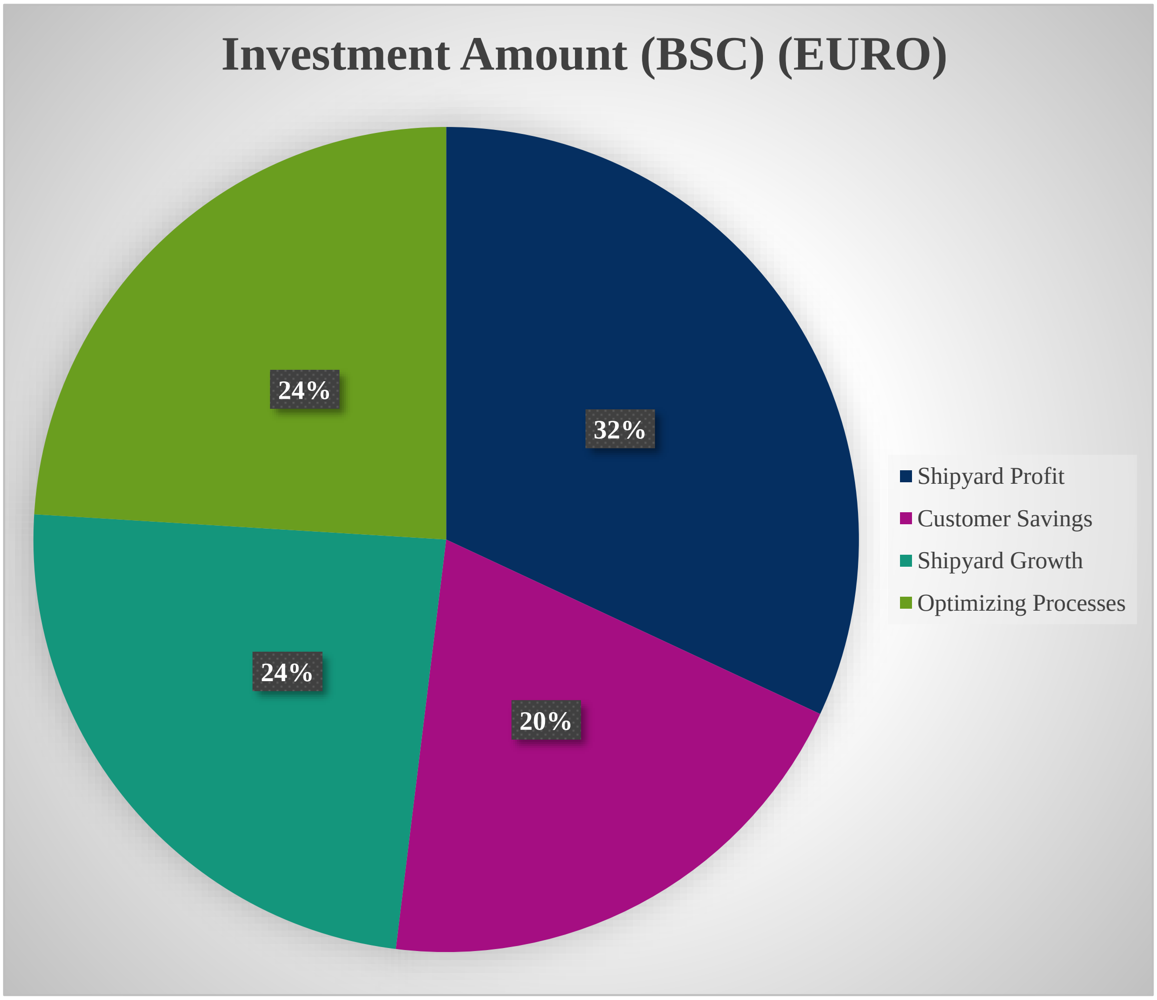
Table 51

Actual Implementation of the BSC

Cost savings	Investment amount (euro)	Percentage BSC
Shipyard profit	1.000,000	31.94%
Customer savings	626,000	20%
Shipyard growth	752,000	24.03%
Optimizing processes	752,000	24.03%
Total	3,130,000 euro	100%

Figure 113

The Realization of the Balanced Scorecard in Shipyards



Chapter VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

The value of this dissertation indicates that significant cost savings of more than 50% could be realized by applying smart welding processes, applying best welding practices for diverse materials and their properties, suitable welding gases, proper QC on the welding, the best practice when choosing the welding method, best choice of the welding parameters, best practice for avoiding the welding imperfections, and the most suitable choice for the applied NDT methods.

6.2 Implications

The implication of this dissertation will allow shipyards to plan strategies for their financials, growth, and internal processes in cost-effective and smart methods which will ensure the profitability and the reputation of the yards in the short and the long run. The dissertation demonstrates the importance of the ship design and implementation of proper WPS. Major adjustment and measurement requirements for excellent welds—considering the characteristics for weldability, the measures for avoiding distortions of different materials, and the specifications for the proper edge preparation for welding—are thoroughly investigated.

Proper DFP, WPS, and the correct choice of welding process are keys for the success for the welding strategy. The major task of strategic management is meeting the essential decision about the road map of an organization, developing the training and team motivation, and developing intelligent procedures to boost the production in the best quality, monitoring and controlling costs, and if required, returning them to the desired course.

6.3 Recommendations for Future Research

The developments of the welding science, technology, applications, and cost management will always be continual. This dissertation is currently state-of-the art. Further methodologies for welding economy must be observed, traced and improved as might be appropriate.

Making further developments will require hands-on experience in shipyards, shipbuilding, ship repair, and in the maritime field. Expertise must be encouraged and improved to accommodate advanced research and studies that will enable the increase and development of the knowledge in the welding and its economical implementations, management, and financials.

The dissertation demonstrates methods and procedures that could save large sums of money that was previously wasted. The shipyards should apply the recommendations, advice, and checklists demonstrated in the dissertation to enhance and improve the production lines in the welding business.

The top management of the shipyards should improve the procedures accordingly, particularly developing a balanced scorecard for the welding and NDT departments that will ensure full utilization of the labor, machines and assets. The focus on the shipowners (customers), high-quality of the welding, and the reputation of the yards shall continue to be at the heart of the strategies.

6.4 Conclusion

Starting the innovation of products and processes in shipyards requires several implementations, including human resources.

The ground of expertise in human resources, their motivation, and the management behind them are critical factors in propelling shipyards forward. The design office of a shipyard is crucial for improving DFP, cost, and quality. These are strategic considerations. Working on designs that cannot be practically fabricated or are extremely difficult and expensive is a waste of resources. There should be no design which cannot be economically manufactured. Accordingly, yards are constantly challenged to find new solutions. Thereby, an optimum profit for the shipyard can be realized.

As a principle, welding processing could change the cost factors to be profit factors, if the welding processes are well planned and professionally managed. The cost for low quality is especially essential for any shipyard project. The shipyard profits result from the expenses and the income. The more the revenue and the less the cost, the greater the profit.

The cost reduction for the shipyard could mean more profit in connection to less cost for the owner of the vessel.

The cost reduction may be attained via the following:

- Excellent weld quality, leading to no or limited rework requirements
- Boosting welding speeds

- Reduction of no. of welders
- Reducing the diameter of the welding consumables; that is, cost reduction
- Reducing welding preparation periods
- Reducing inspection time for optimum planning
- Optimizing the assortment of the proper NDT method, saving a foremost part of the financial plan

Any successful shipyard has established visions, missions, and business goals that are the consequence of strict procedures and a wealth of experience. Welders and materials are required resources.

The fabrication is symbolized by the welding processes and testing. Referring to the analysis, demonstrated in this dissertation, major strategic methods to produce welding have been discovered. In this context, the thesis concerns comparing and selecting the best methodology.

The difference here contrasted to the former method is that experiments are required. In line with the conclusion of the experiments, a strategic approach must be determined. The resources are the welders and materials. This is environmentally done by employing the welding processes. A proof hereof is displayed in this dissertation under 4.1.1, 4.2.1, and 4.2.2.

Strategies of assets and capability are set to fit the company's resources along with being capable of all available possibilities. An attractive and innovative product with superior quality and a competitive price is a strategic target for any shipyard. In consideration of optimizing the turnover, efficient welding processes to be executed as revealed in this dissertation. Production optimizations for welded parts could be attained, up to savings of 50% and more, see 4.1.1 in this dissertation.

Because shipyard profits are conditionally founded on the prices paid by shipowners, it puts shipyards in a tough position, as the shipowner will negotiate newbuilding or ship repair prices with several shipyards until an acceptable radio between prices and quality is reached. Shipowners will make every effort to reduce costs. The cost reduction trials by the shipowners are governed by the following:

Resemblance to the expenses of other shipyard facilities for identical quality

Negotiation skills of the shipowners

A reasonable investment is mandatory to increase profits. The graph below shows that if no money is invested, no profit is attainable. Within the dissertation, it is shown that investment in welding process (equipment) could save costs of more than 50%. The adjustments that arise externally could influence an important shipyard's improvement decision. If those changes are significant and should the yards be prepared to face changes by a solid strategy, competitive advantages could be generated.

The shipyard reaction to those changes contains either market expectation or market reaction.

Market expectation:

Shipowners are awaiting effective vessels where continuous new ideas at lower cost are offered. innovations in layout and production at competitive prices.

Therefore, those are rough confrontations and continuous challenges among the yards for a superior creation at progressively more cost competitiveness, introducing the best method and forming a distinction among shipyards.

Since the shipbuilding business has turned to be challenging to make stable or to forecast the market, it became a significant matter to remain in continuous competition with other shipyards. The shipyard's directions must develop advanced methods measuring shipbuilding business and the current needs and to acquire quick reaction to the economic situation, being in close contact with the shipowners.

After shipyards have developed competitive advantages, they are surrounded by strong competitions among relevant yards. The more the competitive advantages are successful, the less the competitors are ready to face the concern of the innovations. Therefore. the innovation strategies and the innovation practices are patented.

This dissertation creates a major contribution to study main expenses and fee structures by demonstrating relevant cost and economical figures in shipbuilding. The study will lead us to evaluate the cost of the weld by determining the welding length. Applying 4.1.1. and 4.1.2 in the dissertation, we can calculate the welding cost

The dissertation presents a method for reducing welding cost by using estimating factors for establishing the weld lengths and estimating the welding cost (see also 4.1.1, 4.1.2, and 4.2.1). It connects the DFP and the welding processes alongside clearly indicating how to design to be efficiently produced via lean production that avoids wastage in all categories. Depending on plan approval being considered by the classification society, all efforts are vital to augment the ship design; specifically, not only designing a drawing that fulfils the rules but also important saving factors.

The competitive intelligence consists of obtaining and assessing data concerning other shipyards. It contains four principles:

Realizing the competitor

Forecasting strategies of other shipyards

Predicting how other shipyards behave

Developing quick action to react to the competitor's approach

The innovations of the welding practices and welding processes require confidential treatment by the shipyards for reasons that were indicated earlier in this dissertation.

For most shipyards, lean production, talents of yard employees, plan and schedule, total quality management (TQM), process management, and continual improvement as per ISO 9001 principles are major components of economic performance and profit of the shipyards. All reputable shipyards conduct annual strategy planning. The strategy is signed by the management and cascades to the department heads, who in turn transmit the strategy to their employees, explaining and evaluating the strategy with them. Key performance indicators (KPIs) are then created by the unit heads with a weighing system and each employee will have a tailor-made KPI. Matching the corresponding KPIs, the employees will be under assessment on an annual basis.

The controlling of welding expense trusts on a considerable number of factors, including materials, welding process, welding consumables, QC, and NDT. The focus is on thoroughly considering how to select all the above factors and determining what will fit in the welding process and how costs can be reduced while maintaining consistently good quality. The task is to manage the cost without compromise on the quality.

The present dissertation serves to identify major consequences of welding processes, materials, design, and quality for the expense and how cost savings could come to fruition after yards perform major improvements. Explaining the entire cycle including strategy, design, human resources, accounting, labor, marketing, and sales has formed a considerable contribution to this matter. The facilities of a shipyard are set by carrying out thorough examinations accordingly.

Considerable effort was expended identifying the real proficiencies in the shipyards considering all relevant departments in the shipyards, technological and managerial alike.

A customer-focused philosophy has motivated the major shipyards to launch a system that adds benefits for customers with no compromise on quality. This system should help to create a scheme that drives the shipyard ahead, despite competitors.

From a strategic point of view, the customized design in shipbuilding applies, where both plan and coordination start immediately and simultaneously and where the concept-design, basic functional design, then the contract design follow. This is monitored by the engineering, production and assembly, commissioning, after-sales period, and procurement.

Comparing to the customized design, the standard design does not consider the planning at the launch but rather the later phase, where serious delays could arise due to poor coordination, especially when different subcontractors are involved.

Explaining the cost factors regarding vessel newbuilding led us to consider the ship particulars, such as length, breadth, depth, draught, deadweight, and powering of the propulsion machinery. According to the ship particulars, shipyards could estimate the expenses for new constructions or ship repairs by carrying out mathematical analysis, comparing expenditure of different designs, and adjusting to the approximate expenses of the new build.

The estimated cost will be divided into breakdowns. Thus, expense categories are identified; for example, labor (welders, supervisors, designers, NDT operators) and subcontractors, materials (e.g. profiles and plates, and welding consumables), welding machines, overheads, energy, and QC.

Though, after the shipyard has decided to build another ship type, introducing risks about estimating the expenses of the ship newbuilding, since available date so far to the shipyards are not comparable and hence not transferable to a new situation.

Besides, according to the maritime/shipbuilding situation, order books, and possible market fluctuations, another risk may add up.

Extensive experience and the will to change to shape the spirit of the shipyards' top management for succeeding in this challenge.

The data gathering in this dissertation has been utilized to identifying the most suitable function in this matter, i.e., best use of materials, welding process, and the shipyard resources and QC on the welds and via NDT.

Considering the study performed in this dissertation demonstrated in parts 4.1 and 4.2, it was proven that both materials and process, WPS, and quality utilized during welding have competed the main purpose of the expenses, hence delivering cost savings of 30–50% and more.

Both weld-concept alongside the choice of material and welding process are direct factors to manage and synchronize the expense and economy.

We note that waste of material resulting from bad welding quality will lead to rework and retest that will consume additional expensive materials, additional expensive man-hours, and additional expensive testing, besides the delay in delivery of the whole vessel.

The dissertation has introduced typical problem areas in shipyards including smart technical and financial solutions that are vital for all shipyards to consider for both quality retainment and coat efficiency. These findings enhance our awareness of the day-to-day processes in the shipyards' domain and the possibilities of improving those continuously. Part 4.1 and 4.2 in the dissertation have shed light on major areas of welding and NDT as well as on direct solutions to problems facing and challenging the management and the employees daily.

The management and processes require efficient tools to control and monitor the performance and to improve it and provide innovations to the system continuously.

The balanced scorecard “BSC” is a management tool applied in enterprises and businesses worldwide to optimize the strategies.

However, it is not correct to think that only the financial aspects will alone drive the business ahead. The financial status of any business is essential in its existence. but it is not the only factor that determines long-term success. Considering a shipyard nature and atmosphere, the CEO and the board of directors must have a vision and mission that should develop the corporate in the foreseen direction, make reasonable profits, take a market segment in the maritime business, and boost the reputation of the yard among local, regional, and international yards.

Shipbuilding is a complex project, often involving billions of dollars of investment. Understanding the vision and mission of the shipyard management among the employees will not guarantee excellent and cost-effective production unless those are connected to a thorough strategy that considers the significance of the employees and their roles. In modern strategies, every employee in the company is implicated in the strategy and hence is also responsible for implementing it. During the production, the CEO is not looking after each employee to verify the perfect implication of the production. Every employee must work within a system that has been established by the management and within set rules and quality standards. Thus, the yard management is interested in receiving an anonymous opinion from all employees about their job, career prospective, and payment on an annual basis. Simply put, the management is looking for good work conditions for the employees, aiming for their satisfaction. Satisfaction is an excellent indication of retention that yards are focusing on.

The BSC must be designed to exceed the financials of shipyards by setting, balancing, establishing, and updating scorecards including updating the scores with customer data, financial data, data for shipyard growth, and methods for improving the internal processes, continuously. KPIs set by the top management must comply with the vision and mission of the yards as well as the set strategies. By cascading down the KPI, the same must be obeyed within the department heads of the yards as well as by their employees.

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