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QUALITY, PRODUCTIVITY AND ECONOMY IN WELDING MANUFACTURING – CASE STUDY: WEST AFRICA

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ABSTRACT

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Quality, Productivity and Economy in Welding Manufacturing – Case Study: West Africa

Master's Thesis

2013

146 Pages, 45 Figures, 16 Tables, 4 Appendices

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Keywords: Welding quality, welding productivity, welding economy, lean manufacturing, total quality management, West African states.

This thesis studies quality, productivity and economy in welding manufacturing in West African states such as Ghana, Nigeria and Cameroon. The study consists of two parts: the first part, which forms the theoretical background, reviews relevant literature concerning the metal and welding industries, and measurement of welding quality, productivity and economy. The second part, which is the empirical part, aims to identify activities in the metal manufacturing industries where welding is extensively used and to determine the extent of welding quality, productivity and economy measurements in companies operating in the metal manufacturing industries. Additionally, the thesis aims to identify challenges that companies face and to assess the feasibility of creating a network to address these issues. The research methods used in the empirical part are the case study (qualitative) method and the survey (quantitative) method. However, the case study method was used to elicit information from companies in Ghana, while the survey method was used to elicit information from companies in Nigeria and Cameroon. The study considers important areas that contribute to creating awareness and understanding of the current situation of the welding industry in West Africa. These areas include the metal manufacturing industrial sector, metal products manufactured, metal production and manufacturing systems deployed, welding quality, productivity and economy measurement systems utilized, equipment and materials on the markets, general challenges facing companies in welding operations, welding technology programs and research in local universities, and SWOT analysis of the various West African states. The notable findings indicate that majority of the companies operate in the construction industrial sector. Also, majority of the companies are project manufacturing oriented, thus provide services to customers operating in the growing industries such as the oil and gas, mining, food and the energy industry. In addition, only few companies are certified under standards such as ISO 9001, ISO 3834, and OHSAS 18001. More so, majority of the companies employ manual welding technique, and shielded metal arc welding (SMAW) as the commonly used welding process. Finally, welder salary is about € 300 / month as of June 2013 and the average operations turnover of medium to large companies is about € 5 million / year as at 2012. Based on analysis of the results of the study, it is noted that while welding activities are growing, the availability of cheap labor, the need for company and welder qualification and certification, and the need to manufacture innovative products through developmental projects (transfer of welding expertise and technology) remain as untapped opportunities in the welding industry in the West African states. The study serves as a solid platform for further research and concludes with several recommendations for development of the West African welding industry.

PREFACE

This thesis work has been carried out in the Welding Technology Laboratory of the Mechanical Engineering department of Lappeenranta University of Technology under the HitNet Project. HitNet is a collaborative research project in welding technology which involves Lappeenranta University of Technology, Savonia University of Applied Sciences, and the Finnish Funding Agency for Technology and Innovation under a long term agreement with the European Union.

The aim of the project is to develop global supply chain in welding network as well as enhancing the efficiency and quality in welding production chain.

Being on this project to research into pertinent issues in welding technology in West African states such as Ghana, Nigeria and Cameroon has been an eye opener and a great privilege to my career development.

During the research period, I had the opportunity to create useful networks with companies, organizations and universities especially in Ghana. Also I had the privilege to found the Ghanaian Institute of Welding (GIW) with the aim to creating awareness and also promoting education and training in welding technology in Ghana.

The six months research period has been tremendously successful with glittering hopes. This research is the first of its kind conducted in the West African states.

Many thanks to the corporate body which instituted this research project to bring welding activities and operations in West African states into the lime light. Also big thanks to all the supporting units for their financial assistance. It was really a good source of motivation towards the completion of this thesis work.

ACKNOWLEDGEMENT

I would like to thank Professor Jukka Martikainen for giving me the privilege to demonstrate my ability by researching in the field of welding technology and also correcting my final script and making useful suggestions.

I am also grateful to my supervisor Dr. (Tech) Markku Pirinen for creating the platform and accepting me on this project. It has been peaceful working with you. Thank you for your constructive comments and directions during the course of the project.

Sincere thanks go to my supervisor at work Dr. (Tech) Paul Kah for his suggestions, advice and constant motivation before and after this project work. You listened to my interests and led me accordingly. Without you I would not have come this far.

Many thanks go to all the companies and institutions which availed themselves to participate in this project. I would also like to thank the staff members in the welding department of Lappeenranta University of Technology for their countless supports and also to my friends Martin Appiah Kesse, Sammy Armstrong Atta-Agyemang and Charles Addai for being sources of motivation during my entire studies.

Big thanks go to my wife Johanna Mustonen-Gyasi for her support, compassion, affection and pieces of advice during this project work, and also to my lovely daughter Jenni Riina Susuana Gyasi for being patient with daddy, even though it seemed that daddy lived in the university.

Finally, I would like to thank my mother Susuana Baidoo, my brother Enoch Afrane Gyasi for their love and encouragement, and also my in-laws Mr. and Mrs. Mustonen for their support throughout my studies and also during this project. May God bless you all.

Lappeenranta, October 2013

Emmanuel Afrane Gyasi.

LIST OF ABBREVIATIONS AND SYMBOLS

ABS	American Bureau of Shipping
AHP	Analytical Hierarchy Process
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BS	British Standard
BV	Bureau Veritas
CBT	Computer Based Training
CNC	Computer Numeric Control
CTI	Cumulative Trauma Injury
ECOWAS	Economic Community of West African States
FCAW	Flux-Core Arc Welding
FINPRO	Finnish National Trade, Internationalization and Investment Development Organization
GDP	Gross Domestic Product
GIW	Ghanaian Institute of Welding
GMFCL	Ghana Metal Fabrication and Construction Limited
GWG	Gulf Western Group
HDPE	High-Density Polyethylene

HERA	New Zealand Heavy Engineering Research Association
HFE	Human Factor Engineering
IIW	International Institute of Welding
ISO	International Organization of Standards
ISO / TC	International Organization of Standards Technical Committee
LPG	Liquefied Petroleum Gas
ME's	Micro Enterprises
MEMOT	Memot Metal Fabrication and Engineering
MIG / MAG	Metal Inert Gas / Metal Active Gas
MIT	Michigan Institute of Technology
MLE's	Medium and Large Enterprises
NIW	Nigerian Institute of Welding
OAW	Oxyacetylene Arc Welding
OHSAS	Occupational Health and Safety Advisory Services
PAW	Plasma Arc Welding
PESTEL	Political, Economic, Social, Technological, Environmental and Legal
PPE	Personal Protective Equipment
RSI	Repetitive Strain Injury
SAW	Submerged Arc Welding
SMAW	Shielded Metal Arc Welding

SME's	Small and Medium Enterprises
SWOT	Strength, Weakness, Opportunities and Threat
TIG	Tungsten Inert Gas
TRIP	Transformation Induced Plasticity
TSC	Takoradi Steel Company
TWI	The Welding Institute
X – Ray	X – Radiation
^{0}C	Degree Celcius
€	Euro
₵	Ghana Cedi
Km	Kilometer
mm	Millimeter
NZ $	New Zealand Dollar
%	Percent
US $	United States of America Dollar

TABLE OF CONTENTS

1. INTRODUCTION

Welding has received a lot of attention worldwide since it is one of the methods used for joining materials in the most efficient and economical way [1, 2]. Recent technologies behind welding have enormously created opportunities to add more value to welded structures and products. Typical examples are the automobiles, air-crafts, ships, trains, space shuttles, offshore platforms, to name but a few. As these structures are predominated by metals, the quest for the use of metals in manufacturing innovative products by utilizing welding as the main joining process is highly indispensable.

In recent times, the interest in welding activities in emerging economies in Africa, Latin America, and some parts of Asia is on the increase. This interest is as a result of the increasing need to outsource welding manufacturing jobs to emerging economies since welding manufacturing jobs in developed economies are becoming more expensive but cheaper in emerging economies, and also the need to boost welding purchasing globally.

More so, huge volumes of metal production activities have been envisaged in emerging economies as a result of metal deposit depletion in Europe and the USA. This phenomenal change has resulted in technological shifts. Immense investments have currently taking place and growth in investments in the next ten years in emerging economies especially in Africa is highly feasible [3].

Metal manufacturing jobs foreseen to emanate in Africa shall be enormous and the use of welding technology shall increase substantially. To elucidate this claim, a survey conducted by the American Welding Society (AWS) shows that the growth of welding is forging into emerging economies / markets [4]. The technological shift in metal production and the need to outsource welding manufacturing jobs to emerging markets including Africa confirms the assumption made.

However, much research has not been conducted in Africa following this interest and the technological shift in metal production. Nevertheless, very few research papers have been published about welding activities and practices in Africa. Moreover, most researched papers tend to focus on general practices [5], and health and safety issues [6, 7, 8, 9, 10] in welding rather than quality, productivity and economy issues. This situation has created a research gap in welding technology in Africa.

The significance of this thesis helps to bridge this research gap in welding technology in West African states namely Ghana, Nigeria and Cameroon. This thesis contributes in revealing the real situation in welding activities and practices in the aforementioned West African states. This thesis therefore investigate into various aspects of welding such as the type of products manufactured by means of welding, the industrial sectors which employ welding in manufacturing, customers industry of operation, welding quality issues (welding quality standards, certification and qualification of companies and welders, welding processes, assessment of weld quality, and welding quality testing), welding productivity issues (productivity measurement, parent materials, and welding techniques) and welding economy issues (welder salary, turnover in welding operations).

This thesis consists of two parts, the theoretical part and the empirical part. The theoretical part consists of chapter one and chapter two in this thesis. Chapter one introduces the significance of the thesis and the structure of the thesis while chapter two reviews relevant literature concerning the metal and welding industries, and quality, productivity and economy in welding. Also, the empirical part occupies chapter three to chapter six in this thesis. Chapter three presents the various research methods adopted for the empirical research and the limitations encountered during the empirical research. In chapter four, data obtained from Ghana is presented and analyzed. In chapter five, data obtained from Nigeria is presented and analyzed. Also in chapter six, data obtained from Cameroon is presented and analyzed. Chapter seven however present the findings obtained from the research with thorough discussion in relation to the research questions constructed for this thesis. Chapter eight draw conclusions on the findings of the research. Chapter nine highlights salient recommendations and proposes models which need to be attended to. A summary of the whole concepts of this thesis is presented in Chapter ten.

1.1 State of Welding in West Africa (Ghana, Nigeria and Cameroon)

Activities in welding in West African states such as Ghana, Nigeria and Cameroon are growing tremendously as a result of industrial sectors utilizing welding in their operations. The major industrial sectors which can be boast of are the construction industrial sector, the heavy manufacturing industrial sector, the light manufacturing industrial sector, the capitalized repair and maintenance industrial sector, and the automotive industrial sector. Figure 1 shows the location of Ghana, Nigeria and Cameroon on the Africa map.

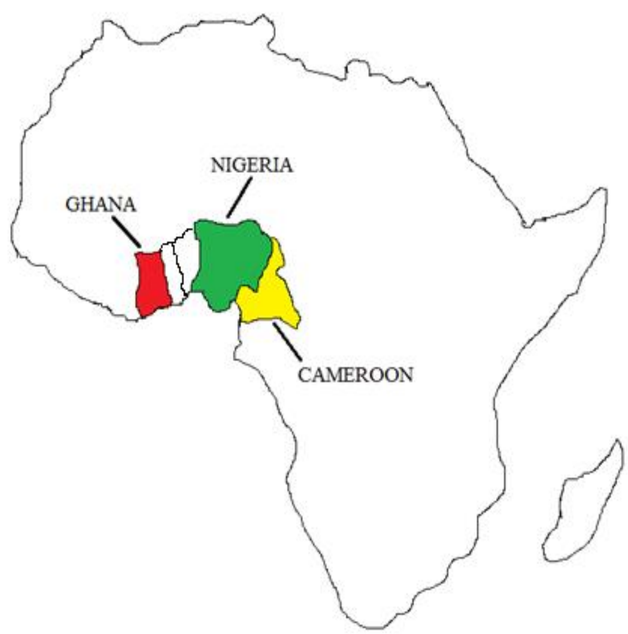

Figure 1. Africa map showing the location of Ghana, Nigeria and Cameroon.

These industrial sectors however provide services to large industries such as the oil and gas industry, the mining industry, and the infrastructure industry. As a result of this, the manufacturing capabilities of these industrial sectors, as termed to be operating in the formal welding sector have not been fully utilized. The interest in manufacturing therefore lies in project (customized) manufacturing than mass production. It is therefore difficult to bring out which typical products these industrial sectors are manufacturing even though tank manufacturing, shipbuilding and repairs, and agro-machinery products are prominent.

On the other hand, enterprises which are not under these industrial sectors but classified to be operating in the informal welding sector use welding in manufacturing products such as car seats, burglar proof doors and windows, wheelbarrows, cement block making machines, gates, chassis and wagons, coal pots, containers, and bill boards for commercial purposes.

The welding process and technique mostly employed in the manufacturing process both in the formal welding sector and the informal welding sector is shielded metal arc welding (SMAW) process and manual welding technique respectively. However, in the formal welding sector, the use of tungsten inert gas (TIG) welding process and metal inert gas / metal active gas (MIG/MAG) welding processes are on the increase.

Activities in welding operations have therefore been focused on the use of the afore-mentioned welding processes and welding technique, thus limiting the use of other welding processes and welding techniques such as submerged arc welding (SAW), plasma arc welding (PAW), laser welding, and automatic welding techniques and robotic welding techniques respectively. Mechanization in welding is therefore very low and for that matter, the benefits of modern-day-welding technology has not been fully harnessed so as to manufacture innovative products in the West African states.

As a result of these practices, issues pertaining to welding quality, welding productivity and welding economy could be assumed to have received less attention. Evidently, welding is unattractive as a profession as a result of the unsolved problems and challenges, even though welding operations seems lucrative in the West African states.

1.2 Research Objectives and Research Questions

- Identify activities in the metal manufacturing industries where welding is extensively used in West African states.

Research Questions

1. Which metal manufacturing industrial sector is welding extensively used?
2. What kind of metal products are being manufactured by means of welding?
3. What kind of metal manufacturing systems are being deployed?

- Determine the extent of welding quality, productivity and economy measurement in companies operating in the metal manufacturing industries in West Africa states.

Research Questions

4. What welding quality measurement system is being practiced in companies?

5. What welding productivity measurement system is being practiced in companies?

6. What welding economy measurement system is being practiced in companies?

- Identify problems, challenges and needs in the West African welding industry (companies and universities) and creating a network in which these issues could be addressed.

Research Questions

7. What problems or challenges do welding companies encounter in welding quality, productivity and economy issues?

8. What kind of linkage do exist between the local universities and the companies?

1.3 Research Delimitations

This research is delimited to welding activities and practices pertaining to the type of products manufactured by means of welding, the industrial sectors which employ welding in manufacturing, customers industry of operation, welding quality issues, welding productivity issues and welding economy issues in West African States such as Ghana, Nigeria and Cameroon. However, welding activities and practices in other African countries were not researched in this thesis.

1.4 Research Methodology

In order to effectuate this research work, a four step approach was adopted.

Step 1 – Review of literature on current trends in metal production and manufacturing as well as issues in welding quality, welding productivity and welding economy measurements. Journal articles, articles, books, and international welding quality standard handbooks were used as sources of data.

Step 2 – Company search: The target group for the company search was metal production and manufacturing companies which main activities include welding operations such as fabrication, repair and maintenance, and metal manufacturing. In the case of Ghana, the Association of Ghana industries and the Ghana Institute of Engineers were contacted but the responses were not fruitful. Also in the case of Nigeria, the Nigerian Institute of Welding (NIW) was contacted but there was no response. Further attempts were made in contacting the Finnish national trade, internationalization and investment development organization (FINPRO) representative in Nigeria and also A&X consulting which is the sole distributer of KEMPPI welding equipment in Nigeria but no information about companies was suggested or provided. In the case of Cameroon, there wasn't any appropriate organization to channel the request to. Direct contact was therefore made to mechanical engineering professionals from Cameroon and three companies were however provided.

Step 3 – Company sampling technique: The final search and selection of companies for the research work was through a purposive and criterion-based sampling technique from the internet. This sampling technique was adopted because the readiness of a database consisting of companies operating in metal production and manufacturing industries was not available from the contacted organizations in the said West African states. However, companies which were selected from the internet were contacted through e-mails and telephone communication and were inform of the research project and its content. The companies where allowed to show their interest whether to participate in the research activity or not. Out of the twenty companies contacted in Ghana, only fifteen expressed interest to participate in the research work both through electronic mail and telephone communication. Also out of the six companies contacted in Nigeria, only four expressed keen interest during telephone communication but not through electronic mail. In the case of Cameroon, six companies were contacted but none of them responded with respect to the electronic mails. Moreover, telephone communication was also not favorable since most respondents in Cameroon spoke French. Electronic mails in French language were thereafter sent to the companies, but did not receive any attention.

Step 4 – Research methods: Upon getting adequate number of companies to participate in the research work, suitable research methods such as the survey and the case study research methods were used for data collection.

2. LITERATURE REVIEW

This chapter presents current literature reviewed to underpin the empirical part of this research work. The main contents include information about the metal industry, the welding industry, quality in welding, productivity in welding, and economy in welding. Much emphasis is laid on welding quality requirements, and welding management systems both productive and economic wise.

2.1 The Metal Industry

The activities practiced in the metal industry contribute significantly to economic growth. These collective activities define the metal industry as an industry which deals with the extraction of mineral ores from the earth crust, refining of mineral ores into pure state metals, and processing of pure metals into useful products through metal working techniques such as production and manufacturing. Basic human amenities such as shelter, energy supply, transportation, food and water supply, construction, education, communication, sewage treatment and vast number of needs are being met due to the building blocks the metal industry provides for human development [3]. Contributions made by the metal industry in some developed countries such as the US, Canada, Australia and some countries in Europe have created sustainable lives to date. A simplified model of workflow in the metal industry is shown in Figure 2.

Mineral ores, mined by mining industries are supplied to the metallurgy industry which in turn smelt and refine these ores into their pure state. Further metal works are carried out on these pure state metals into metal plates, and metal sheets through production means. Products such as automobiles, aircrafts and the alike are thereafter manufactured through fabrication and joining.

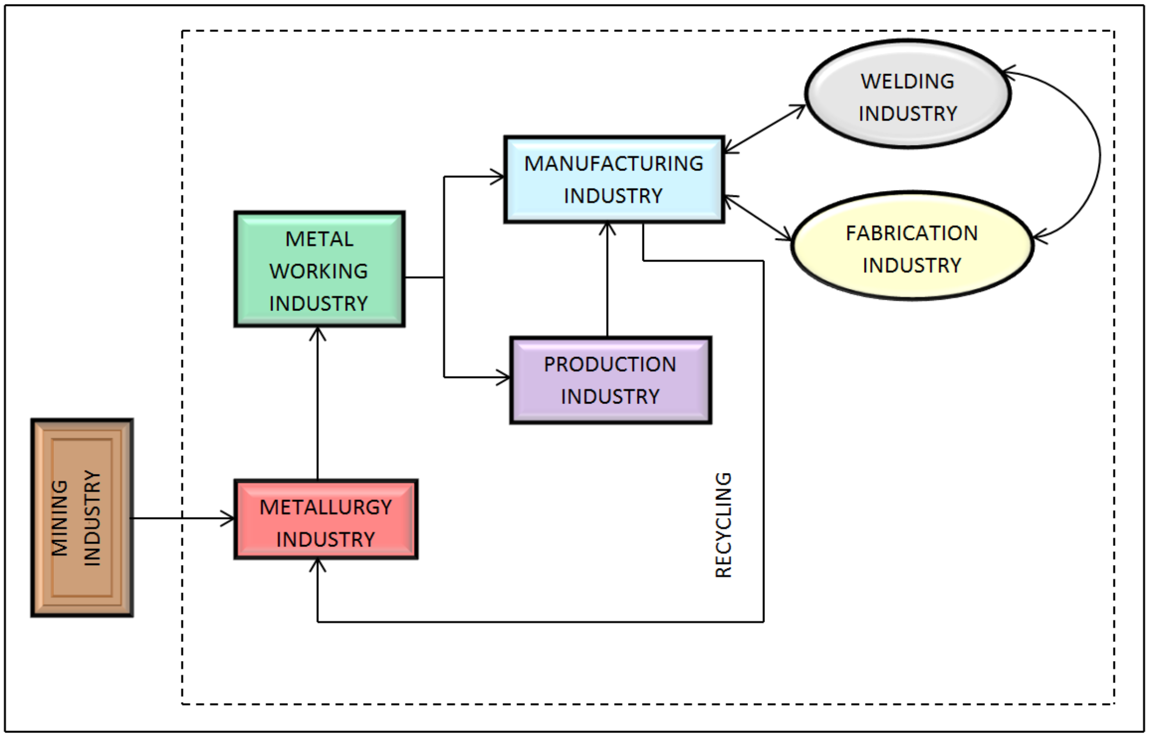

Figure 2. A Simplified Model of work flow in the Metal Industry.

Recent report shows that the US and Europe are experiencing metal deposit depletion [3]. In 2011, it was recorded that the US and Europe (excluding Russia) contributed only 3.5% and 4.2% respectively of world metal mining by value. Other developed countries such as Australia and Canada contributed 13.3% and 2.6% respectively whereas resource-rich developing countries accounted for 22% of world metal mining by value [3]. It can therefore be assumed that, huge volumes of metal production would be paramount in resource-rich developing nations such as in Latin America, Africa and some parts of Asia.

Further investigations have also shown that metal smelter and refinery metal production plants which use to be located in developed countries have found way to resource-rich developing countries due to metal deposit depletion and technological shifts [3]. Huge investments are bound to be made in the next ten years, thus concretizing the assumption made. Nevertheless, the global metal production value is expected to increase through this industrial transitions as well as unprecedented demand from recycled metals [3].

Metal industries, especially in African countries would therefore need to adapt to measures and strategies which would help bridge the transitional gap to meet the paradigm shift in metal production, thus strengthening the manufacturing capabilities in the region. Manufacturing of capital goods such as agriculture machinery, food processing machines, solar machines, power generators, and consumer goods such as automobiles, ships, refrigerators, air-conditioners and the alike would be prevalent in African countries. However, manufacturing these products with metals to meet the quality standards in international market would require compliance with international standards and embracing the transfer of expertise and technology in welding.

As a matter of fact, the need to use advanced joining methods and techniques such as welding in the manufacturing process of metals into economically useful and sustainable products remain highly imperative since welding is one of the most common joining methods used in the metal industry [11]. Moreover, as the welding industry stands to be a promising industry within the metal industry, there is the need to educate and train people to become abreast with modern-day welding processes and techniques to handle the vast amount of manufacturing works which are bound to emanate in the nearest future in the said region. By this far, the welding industry wealth investigating so as to know the key players in the industry, their activities and the contributions they provide towards economic development.

2.1.1 The Welding Industry

The welding industry is an important facet of the metal industry and it consists of a number of welding fraternities such as the welding workforce, welding materials and equipment supply group, welding education and training group, welding organization group as well as the end user group [12]. Over the last decades, the collective operations performed by these groups at local and international levels have contributed enormously towards both national and global development such as in the provision of energy for lighting and cooking, creation of efficient and effective transportation, provision of clean water, safe sanitation, accommodation both for living and working, and the creation of machinery for diverse industrial application especially in the developed countries [12].

As an example, reports laid down by the New Zealand Heavy Engineering Research Association (HERA) shows that the New Zealand's welding industry added a value of NZ $ 813 million to the New Zealand's economy through welding and joining technology in 2007 whiles creating 7,300 welding related jobs [13]. Additionally, an estimated total value of NZ $ 15 million was contributed to the New Zealand's market in 2008 through locally manufactured and imported welding consumables of 4,000 tonnes (HERA) [13]. Figure 3 depicts a schematic diagram of the welding industry and its fraternities.

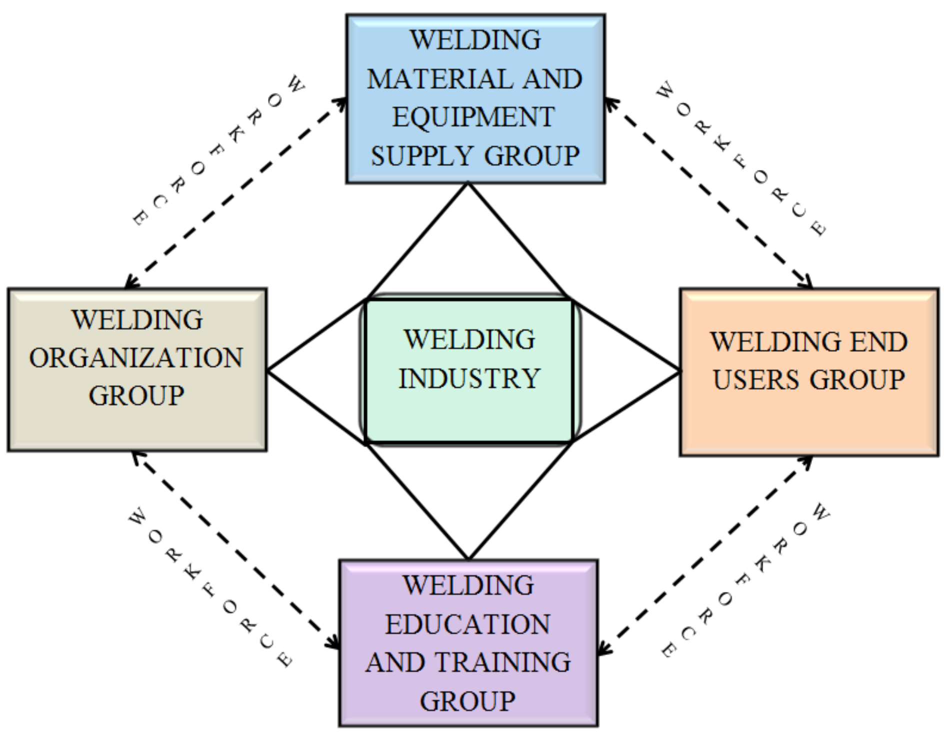

Figure 3. Schematic Diagram of the Welding Industry and its Fraternities.

It can be seen from Figure 3 that, the welding industry operates like an ‘ecosystem’ due to the direct linkages the welding workforce provides for the other welding groups. Current reports lay down by the AWS shows that the welding workforce relies on the welding material and equipment supply group for the provision of equipment, products, consumables and services and uses welding technology to perform welding operations [2]. There is a huge degree of dependency between the various welding groups and also the welding workforce. The workforce in this way also coordinates activities across the entire welding industry ‘ecosystem’ to ensure that welding operations are performed in economical, productive and quality manner.

The welding organization group which comprises of associations, societies and institutes also serves as a vital element in the welding industry. An ultimate example is the inception of the AWS in the US welding industry. The services of the AWS have helped the fortification of the US national defense, infrastructure and economic progress [14]. Furthermore, welding institutes such as the International Institute of Welding (IIW) stands as the main international body influencing the welding industry globally. The transfer and exchange of knowledge in joining technologies to improve the quality of life globally are prominently made in countries affiliated to its network [12].

However, in order to leverage developments in production manufacturing through welding, it is recommendable for other nations whose welding industry does not include welding organizations being allied to the IIW to consider taking immediate steps to harness the opportunities disseminated to nations in the international welding arena. On this note, the unforeseen contributions that the welding industry has to provide in resource-rich developing countries cannot be under-estimated. The provision of basic services and infrastructure to up-lift the standard of living is essential to the welfare of the people and cannot be achieved without operations of the welding industry.

Table 1 presents the functions of some of the welding fraternities such as the welding materials and equipment supply group, welding education and training group, and the welding organization group.

Table 1. Functions of some Welding Fraternities [2, 12].

WELDING FRATERNITY	FUNCTION
WELDING MATERIAL AND EQUIPMENT SUPPLY GROUP	• Consistent supply of welding consumables and equipment to both the workforce and the end users. • Providing technical support and assistance on the usage and maintenance of materials and equipment.
WELDING EDUCATION AND TRAINING GROUP	• Providing welding pedagogical solutions to nurture individuals to become welding workforces. • Conducting scientific research towards the creation of innovative product and service development. • Liaising with other welding fraternities to undertake developmental projects.
WELDING ORGANIZATION GROUP	• Implementing edge-cutting technologies in welding. • Implementing welding qualification and certification through education and training. • Implementing occupational health and safety standard.

The current outlook of the welding industry, as depicted in Figure 3 has brought operational balances in the entire welding industry. The welding material and equipment supply group now integrates technical services into its main focus of merchandizing to help customers to choose right welding processes for their needs and also to help solve their technical problems [2].

Also the welding education and training group have introduced several pedagogical solutions such as virtual welding machines to assist smart learning and familiarization with welding processes and techniques, thus replacing the skill of welding into a preferred state-of-the-art manufacturing process [12]. Talented personnel are therefore attracted to the science behind welding and are motivated to conduct researches and pursue further studies to attain qualifications such as master of sciences as well as doctoral studies in welding.

Those individuals who are on the verge to receiving apprenticeship and technician trainings in welding are also mostly nurtured by the welding organization group. Complying with occupational health and safety standards as well as welding quality standards by the welding end user group and the entire workforce are also administered by the welding organization group.

More so, welding end user group are the individual manufacturing sectors where welding is a critical enabling technology in their day-to-day operations. Investigations have shown that, one-third of the total gross domestic product (GDP) of the US comes from the end users in the welding industry [14]. Figure 4 shows manufacturing sectors in the welding industry.

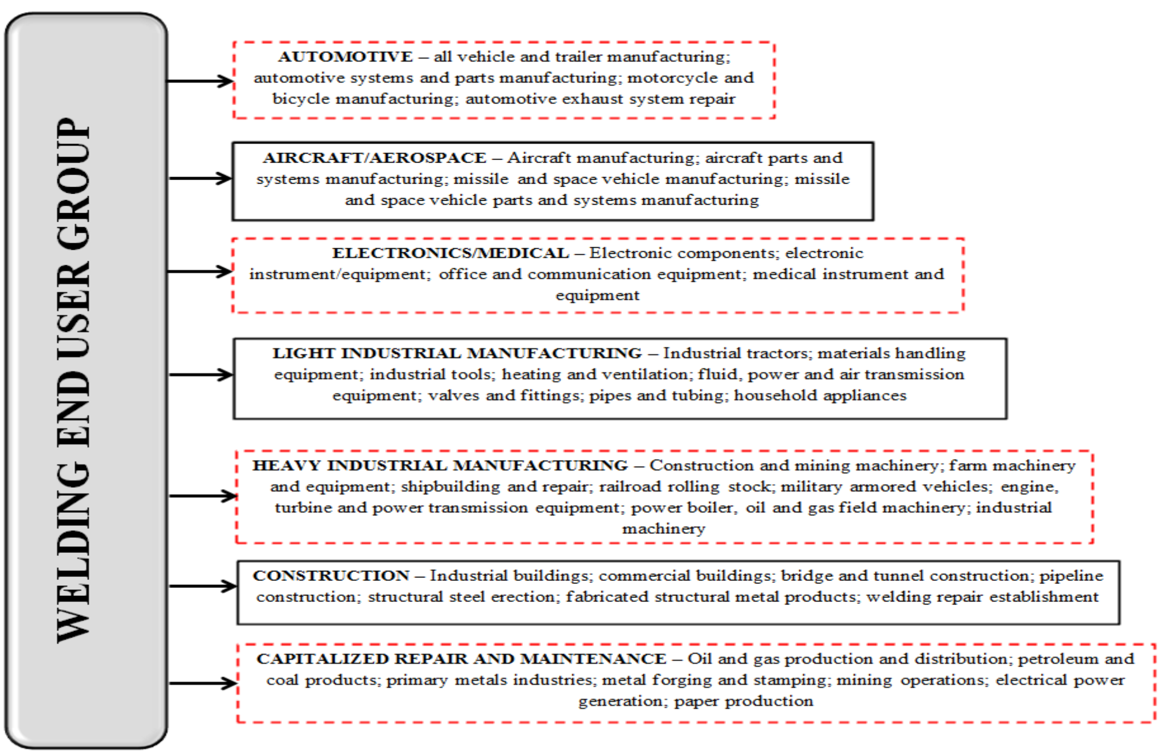

Figure 4. Manufacturing Sectors in the Welding Industry [2, 14].

As the trend to manufacture innovative products from generic products constantly changes and the demand of customers continually increases, the need to utilize modern joining technology by the end user group is highly vital. Also, as welding technology happens to be a precise, reliable and cost-effective means of joining materials [2], the advantage of increasing productivity whiles ensuring guaranteed quality and minimizing cost in the entire welding economy is comparatively vivid than in other joining technology such as riveting, and the alike joining methods.

2.1.2 Challenges in the Welding Industry

Even though it is world proven that welding is one of the best and surest means to join materials together, the challenges in joining metals and new materials such as transformation induced plasticity (TRIP) steels, advanced ferritic steels, super austenitic and super duplex stainless steels, and dissimilar materials for diverse applications is a head-ace to the welding industry [12]. Current challenging issues in welding of materials pertain to productivity, cost and quality. Figure 5 shows the challenges facing the welding industry.

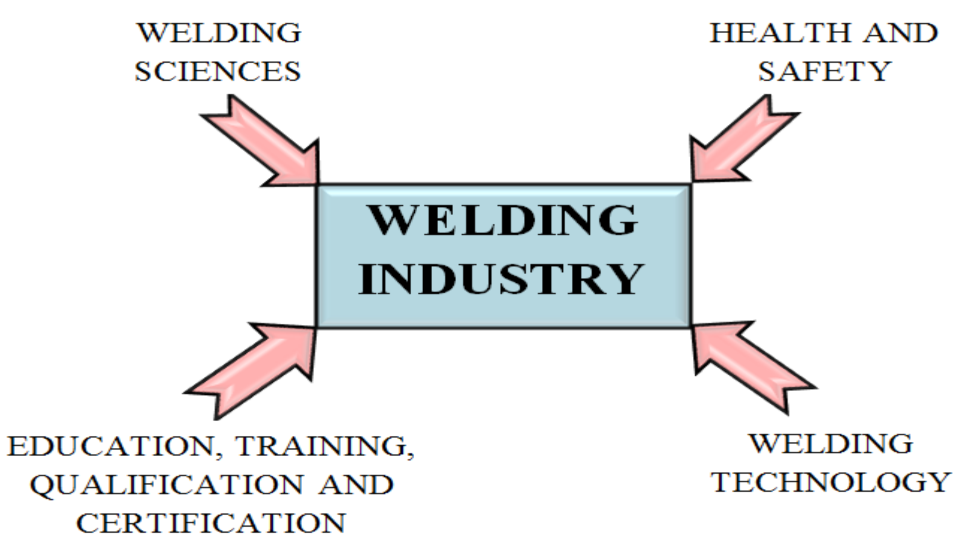

Figure 5. Challenges facing the Welding Industry.

In welding and joining science, the challenges related to quality is about the use of unmatched consumables for high strength or high toughness or high fatigue life weldable steels for structural, maritime and naval applications. A typical example can be seen from steels of 900 MPa yield strength. The filler metals used on such steel lacks adequate ductility and fracture toughness, thus creating weld defects such as hydrogen induced cracking since such steels are mostly applied in high humidity environment where hydrogen concentrates are very high [12].

Also, in repair welding, the ideal welding condition is often not the same as compared to welding during the fabrication process. The weld quality of the repaired area is always questionable since there is a tendency of higher strain constraints than during the fabrication welding. Defects are likely to be prevalent around the repaired area [12].

Although advanced welding technologies such as robotic welding, electron beam welding, laser beam welding, laser hybrid welding, and friction stir welding have increased productivity and improved quality issues in the welding industry, the challenges these technologies bring into the welding industry cannot be disdained. Especially to the small and medium sized enterprises (SME's) where the acquisition and introduction of such welding technologies is of a higher cost. Also the introduction of modeling and simulation tools to decrease testing cost during new product development and also examining different design options is also a challenge [12].

The health and safety of welders as well as environmental issues also remain as a challenge to the welding industry. Even though smart welding equipment such as reverse fume extraction, helmets with sensors and air blowers have been introduced in the welding industry, welders and the environment are exposed to some level of welding fumes, radiations and bad disposable practices respectively. Increasing amount of such exposure leaves welders in Repetitive Strain Injury (RSI) and Cumulative Trauma Injury (CTI), thus lowing productivity, quality and workers satisfaction [12].

In welding education, training, qualification and certification, a lot has been done through pedagogical means utilizing information and communication technology. This has been evident in countries such as Australia, Denmark, and Germany where computer based training (CBT) have been offered to engineers. However, the existing challenge is about the utilization of CBT for practical trainings in welding [12].

Addressing the activities performed by the various groups in the welding industry as well as the over-all challenges facing the welding industry is of high importance both at national and international level. The subsequent sub-chapters give detailed information as to how to develop and improve issues pertaining to welding productivity, quality and economy.

2.2 Welding Quality

The implementation of quality management systems such as ISO 9000, and ISO 9001 in industries have been beneficial at a greater extent despite its draw-backs observed by some companies. Heras and his group presented in their empirical survey paper a summary of the benefits and effects of implementing quality management systems such as ISO 9000. It was observed that certified companies stand higher chances of increasing their productivity, profitability, product quality and competitiveness, increasing market share as well as increasing customer satisfaction. However, the effects include long installation periods, and uncertain time to achieve return on investment [15].

In spite of these, in production and manufacturing networks where welding is a critical enabling technology, the quality of welding is highly essential and cannot rely only on quality management systems as mentioned. Even though ISO 9001 has been considered as a stand-alone quality standard, in welding applications, there is the need for more robust quality requirements. Moreover, due to increasing applications of welded products in relation to customer demands as well as health, safety and environmental issues, welded metallic products are therefore required to demonstrate quality attributes such as reliability, efficiency and safety in a wide range of applications. This is evident in applications such as offshore structures where welded metallic products are made to withstand harsh environmental conditions [16]. Regardless of the product, quality must be efficiently ensured, thus meeting sound quality requirements [17].

However, these attributes of a welded metallic product cannot be built only in the final stages in welding operation since the act and process of welding itself is characterized as a "special process in that the final result may not be able to be verified by testing, thus the quality of the weld is manufactured into the product, not inspected" [18]. For this reason, welded metallic products require being quality assured through quality control and quality management systems before, during and after welding operations.

Most research papers about welding quality tend to focus on ways of achieving welding quality with respect to welding processes and parameters, welding techniques, material types, welding consumables or a combination of either of them, and or monitoring of welding quality . However, very few papers have made mention of the needed requirements to achieving welding quality in metallic products.

Ratnayake presented five "Ps" of welding quality in his paper as suggested by Lincoln Electric Company. It was so that, in order to achieving quality in welding, requirement such as: process selection, preparation, procedure, pretesting and personnel must be considered [19]. Contributes made by other authors suggest that welding quality could be obtained if the design of the joint, electrode, technique, and the skill of the welder are acknowledged [1].

However, achieving the required quality in a welded metallic product cannot be fully obtained by following general hypothesis or emulating only quality management system guidelines or standards such as ISO 9000:2005. As welded metallic products are bound to compete on both local and international markets, quality must be built in them right from the onset. It is therefore required that companies which operations chiefly depend on welding should comply with welding quality standards in order to meet the expected quality in their welded metallic products.

2.2.1 Welding Quality Standards

The provision of welding quality standards is to assure quality in welded product as well as standardizing welding operations globally to streamline international trade barriers. A welded metallic product can therefore be considered as "quality" if the product has been welded according to quality standard requirements laid down by technical experts such as the international organization for standardization technical committee (ISO/TC 44) [18].The approved quality standard which outlines the quality requirements for fusion welding of metallic materials is the ISO 3834 and it consists of six parts such as:

- Part 1: Criteria for the selection of the appropriate level of quality requirements
- Part 2: Comprehensive quality requirements
- Part 3: Standard quality requirements
- Part 4: Elementary quality requirements
- Part 5: Normative references to fulfill the requirement of ISO 3834-2, ISO 3834-3 or ISO 3834-4
- Part 6: Guideline on implementing ISO 3834

As a result of the different levels in variations in design, materials and fabrication processes in any product group, a specific part of ISO 3834 cannot be designated to particular types of products. Therefore, compliance with a higher level of quality requirement from the above parts of ISO 3834 accords a manufacturer the compliance at a lower level (ISO 3834-1). It is advantageous to select a higher level of quality requirement from the list of ISO 3834 parts since it gives the opportunity to apply that quality requirement on a broader range of products. For example, complying with ISO 3834-2 (i.e. comprehensive quality requirement) for fusion welding of metallic materials both in workshops and at field installation sites gives an edge to demonstrate quality requirement for products which require compliance with ISO 3834-3 and ISO 3834-4 respectively [18].

The benefits of implementing ISO 3834 or in addition to ISO 9000 or ISO 9001could be enormous and thus surpass the contributions quality standards such as ISO 9000 or ISO 9001 have brought to welding industries.

2.2.2 Measurements in Welding Quality

In fusion welding of metallic materials, it is a vital approach to set appropriate measurements to ascertain quality in the welded product. As ISO 3834- part 2 signifies a higher level of quality requirements for fusion welding of metallic materials, measurements in welding quality for both complex and simple welded products from the design phase, through material selection, into manufacturing and subsequent inspection could be based on the quality requirements of the said standard [18].

Figure 6 represent the elements of quality requirements for fusion welding of metallic materials (ISO 3834- part 2). These elements of quality requirements serve as a means to measure welding quality if followed appropriately in welding operations. It can be seen that the elements are interconnected, thus forming one complete “house of quality requirements for fusion welding of metallic materials”. This therefore implies that omitting an element from the said requirements could result in weld quality problems. Descriptions of the various elements have been summarized in appendix 1.

More so, as imperfections in fusion-welded joints are bound to occur, the production quality of wide range of welded manufactured products of material thickness above 0.5 mm should fulfill the three quality level requirements designated by symbols B, C and D as stated in ISO 5817. However, the assessment of imperfections by means of radiographic methods in accordance with ISO 5817 is also highly essential.

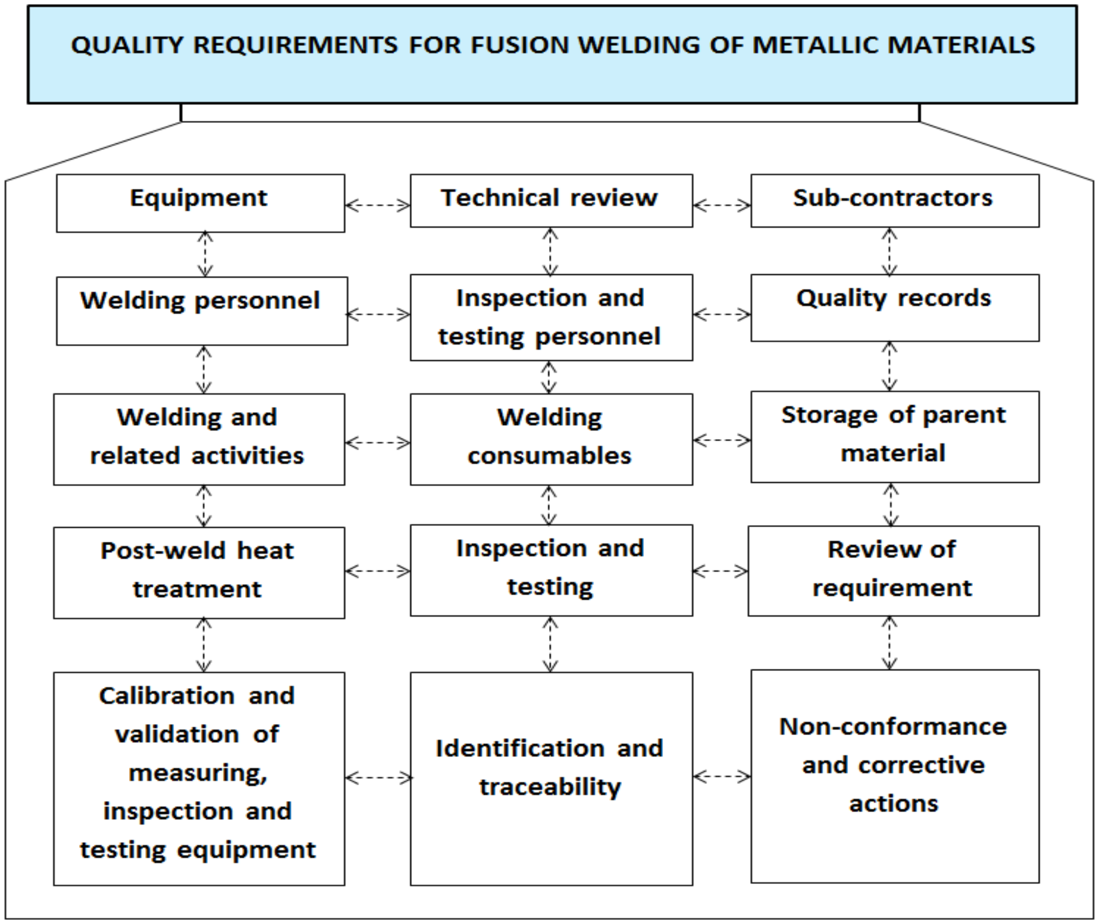

Figure 6. Welding Quality Measurements according to ISO 3834 - part 2.

Incorporation of these quality requirements in welding quality measurement could help welding companies to improve on their product quality, increase productivity, save cost by increasing profitability, and reduce external auditing through customer satisfaction and also competing effectively on international markets.

However, compliance with ISO 3834 does not automatically guarantee 100% productivity in welding operations but gives better possibilities in achieving welding productivity. More so, in order to achieving productivity in welding, there is the need for company certification, thus adhering to stringent requirements and welding management systems.

2.3 Welding Productivity

Achieving productivity in welding is not a unidirectional process. It involves a whole lot of systematic actions and processes to be implemented and adhered to. Ideally, management systems such as total welding management and lean manufacturing are needed to be implemented in welding workshops to boost welding productivity as well as the quality and economy of welding.

A recent research study have shown that productivity in welding depends on variables such as machine efficiency, arcing times, deposition rate, setting time of machine, preparation work of welds and accuracy of parts [20]. Another research also suggests that the welding position, handling of materials, skill of workers, rework, shop layout and the weather could affect welding productivity [21].

Also, the findings from a pilot study conducted by the author in one engineering firm in Finland shows that the receiving and handling time of consumables, parent materials as well as the state of welding machine and equipment, skill of the welder, allocation of task, workshop ergonomics, welding techniques, environment and safety issues are factors which also contribute to welding productivity.

A practical example can be sited as follows: if too much time is used in handling consumables and parent materials, the time actually left for welding becomes shorter, thus impeding welding productivity and vice versa. Moreover, the state of a welding machine is also a contributing factor in a way that new welding machines enhance welding productivity since there is less time involved in setting parameters, and the skill of the welder does not matter to a larger extent as compared to old machines. This phenomenon also applies to the kind of welding technique employed whether manual, semi-automatic, and automatic or robotics welding. However, although the skills and experience of the welder matters in manual welding technique, proper allocation of task through effective coordinating of activities should be of paramount interest to increase welding productivity.

Furthermore, outlining required welding parameters (i.e. joint type, weld type, joint design, parent material thickness, welding process, welding current, welding voltage, and electrode type) in welding-procedure specification (WPS) as well as qualifying the WPS through testing parameters (non-destructive and destructive testing) prior to production with welding-procedure qualification record (WPQR) could contribute immensely to welding productivity. The preparation and controlling of these relevant quality documents therefore increases the tendency to carry out repetitive welding operations for a particular product range, thus reducing time wasting in production and manufacturing. As indicated in ISO 3834-2 standard, there is the need to establish and ensure the correct use of these documents in production planning [18].

Additionally, ergonomics also termed as human factor engineering (HFE) [22, 23] should fit the needs of welding personnel so as to contribute immensely towards productivity and quality in welding. Welding machines and equipment must therefore be placed at appropriate, convenient and vantage points in order to enhance easy accessibility and usage. Obstruction in the flow of materials can delay production, thus decreasing productivity.

The surrounding environment should be safe to prevent unpredictable injuries in the workshop since safety is imperative in productivity and quality activities [17]. However, the common problems associated with bad welding ergonomic include musculoskeletal health problems [24].

Controlling and measuring variables and activities in a welding workshop with deployable management systems would increase both productivity and quality levels. Thus adopting management systems such as the total welding management system, and lean manufacturing system would affect positively on the entire welding economy.

2.3.1 Total Welding Management

Managing the welding workshop with the state-of-the-art total welding management system would go a long way to help improving quality, productivity as well as increasing efficiency and profitability in welding operations.

Quality improvement can be achieved not only by the use of modernized machines and equipment, and the implementation of quality assurance systems but centrally focusing on the welding personnel. Jack R. Barckhoff proposed that activities between departments such as designing, manufacturing, operations and quality assurance department should be coordinated effectively to support the welder [25]. Thus, the provision of blue prints, equipment and machines, tooling, training, process sheets and other measuring equipment should be available for welders.

Although it is important to involve welders in product designing phase, task and responsibilities such as planning, execution, supervision and inspection must be clearly defined and enforced in order to improve quality and productivity in welding. The five welding do's outlined by Jack R. Barckhoff suggests that welding productivity can be improved by:

- Reducing weld metal volume
- Reducing arc time per weldment
- Reducing rejects, rework, and scarps
- Reducing work effort
- Reducing motion and delay time

These welding do's can ultimately be realized and profitability in welding economy achieved if departments such as designing, manufacturing, operations and quality assurance department play their respective roles efficiently to support welders [25].

2.3.2 Lean Manufacturing

Eliminating waste in welding operations and continuously improving on productivity and quality aspects of welding can be achieved by employing lean manufacturing. The lean manufacturing concept has been defined as a set of practices or principles focused on waste reduction and eliminating non-value added activities from manufacturing operations in companies [26, 27, 28, 29, 30, 31]. Without compromising with quality or cost, lean manufacturing aims in minimizing work-in-process, eliminating valueless processes and making processes flexible [32]. Lean manufacturing however, consists of five principles and for these principles to work effective, problems in welding operations must be identified, and welding personnel must work together in a well-documented activity to solve the problems identified whiles managers commit themselves fully in this action by entrusting the entire workforce [32].

A recent research conducted by applying lean to welding operations in a plant producing front-end loaders have reported substantial improvements in welding productivity over a period of one year as a result of the eagerness of the management unit to succeed in the continuous improvement process [32]. Other factors involved in achieving this success include welder training and optimization of welding parameters. Moreover, the key lean principles employed in the study are shown in Figure 7 and also vividly outlined [32].

Figure 7. Lean manufacturing principles [32].

- Perfect first-time quality – The quest for zero defects, revealing and solving problems at their ultimate source, achieving higher quality and productivity simultaneously, teamwork, and worker empowerment
- Waste minimization by removing all nonvalue-added activities – Making the most efficient use of scarce resources (capital, people, space), just-in-time inventory, and eliminating any safety nets.
- Continuous improvement through the dynamic process of change – Reducing cost, improving quality, increasing productivity, rapid cycle time and time-to-market, openness, and information sharing.
- Flexibility in production – Diversity of products without compromising efficiency at lower volumes of production.
- Long-term relationship with suppliers – Through collaborative risk sharing, cost-sharing, and information-sharing arrangements.

The principles of lean manufacturing system have however been practiced by Toyota Motor company after its invention in 1980's by the Massachusetts Institute of Technology (MIT) [32]. Managers striving to improving welding operations are edged to implement both lean manufacturing and environmental management practices in order to benefit fully from their business performance objectives [33].

2.4 Economy in Welding

Welding economy encompasses everything about welding operation being it quality issues, productivity issues, training issues, health and safety issues, environmental issues, and customer satisfaction. Performing welding in economical way therefore requires that all these issues are clarified and properly dealt with. The economy of welding however falls short if any of the above mentioned issues is not attended to in the most appropriate way.

There have been a lot of discussions about the future growth of welding as a result of some aspects of welding economy such as the shortage of welding skilled labor, cost of welding production, and welding automation. This implies that for the growth of welding in future to be promising, these issues need to be resolved worldwide. However, with the cost of welding as the central focus in welding economy [34], a survey conducted by the AWS has shown that the growth of welding is forging into emerging economies / markets [4]. It could be assumed that, the cheap cost of labor is a contributing factor to this expected growth in emerging markets.

More importantly, immerse welding in emerging markets would be of a great opportunity as a result of the tremendous demand in infrastructural works. More so, the need to equip the workforce in such economies not only to fulfil the infrastructural demands but to manufacture innovative products is also vital and sustainable. The unified welding expenditures however should be carefully evaluated and clarified in welding economy issues.

2.4.1 Welding Expenditures

The expenditures usually regarded in welding economy measurements include labor cost, consumable cost, material cost, joint design and joint position, preparation of the parts, cost of each weld, overhead cost, energy cost, and postweld treatment. However, depending on the welding cost system, whether cost of weldmemt or cost of specific weld [1], other cost associated to research and development, process specification and certification, welding personnel training, and welding consulting (including purchased inspection and testing services) could be also considered.

It has been said that the most compelling cost in welding which necessarily differs with industry, time and country is that of labor [34]**.** However, as labor cost in manual welding working hours is becoming more expensive in developed economies such as in Finland, the need of optimizing the level of welding mechanization and automation is also on the increase. Although the investments made on such systems are extremely expensive, they are expected to pay back to maximize profit in future [20]. The question is that how many companies can afford to invest in such systems and also bear the accompanying cost to train welding personnel to become professional welders and operators? There is therefore high competition between manual welding and automation in welding.

Through investigations, it has been observed that outsourcing welding manufacturing jobs from Finland to Estonia and Russia has been economical as a result of the low labor cost [20]. Similarly, from observations by the author, outsourcing welding manufacturing jobs from Finland to emerging economies such as in Africa could be more economical and profitable since labor cost is very cheap.

Therefore choosing a less labor cost sensitive market for welding operations must be critically examined and evaluated. Moreover, an appropriate decision making tool needs to be adopted in order to minimize uncertainties in future.

2.4.2 Adopting Analytical Hierarchy Process (AHP) in Welding Economy

Recent articles have made mention of the high cost involved in welding production activities in developed countries such as Finland [20]. Methods envisaged to combat issues relating to this matter includes outsourcing some portion of welding production activities to cheap labor countries termed as the emerging markets of today. However, the ultimate avenue to implement this method is through agreements where an outsourced company becomes a subcontractor.

Selecting subcontractors for such jobs could be a tedious process but however can be solved by considering and adopting the analytical hierarchy process (AHP). The AHP is a three layer decision making tool which helps in allocating goals, evaluating different criteria for alternatives and finally comparing the alternatives chosen [35]. Several researches conducted have pinpointed salient criteria to be considered when utilizing the AHP process in selecting suppliers. It was indicated that cost, quality (defects, process capability) and service (on-time delivery, ease of communication, response to change, process flexibility) could be the criteria to consider when selecting a supplier [36].

Other authors also suggests that cost (product price, freight cost, tariff and customs duties), quality (rejection rate of products, increased lead time, quality assessment, remedy for quality problems), service performance (delivery schedule, ease of communication, response to changes), subcontractor profile (financial status, customer base, performance history, production facility and capacity) and risk factor (geographical location, political stability, economy, terrorism) could be the main criteria to consider when selecting a supplier [37].

However, a current research has proposed that the performance assessment (shipment, delivery cost), human resources (number of employees, organizational structure, training), quality system assessment (management commitment, inspection and control, quality planning, quality assurance), manufacturing capability (production capacity, maintenance, lead-time, materials handling and development), business criteria (reputation, location, price, patent, technical capability) and information technology (internet) could be the criteria to consider when selecting a supplier [38].

Generally, the criteria for selecting suppliers / subcontractors by means of the AHP concept could be developed from various findings to suit a particular case since the criteria to be considered is somewhat in relation to the strength, weakness, opportunities and threats (SWOT) analysis of the supplier / subcontractor or the political, economic, social, technological, environmental and legal (PESTEL) analysis of the supplier/ subcontractor.

Adopting this concept would be beneficial to big companies considering of subcontracting welding jobs to emerging markets especially in Africa and also exploiting other business opportunities.

3. RESEARCH METHODS

The research methods adopted for the research work were the survey and the case study methods. The survey method was used for companies from Nigeria and Cameroon while the case study method was used for companies from Ghana since Ghana was chosen as the destination country.

The case study research method was used due to the benefits it brings to the scientific world. It helps in achieving a qualitative data through contextual analysis of current problems and challenges, and thus devising strategies to address and solve the challenges and problems [39, 40]. However, the survey research methods was also used in order to obtain quantitative data to help identify relationships that are common across respondents and thus providing generalizable comments for the research findings [41]. The two research methods were however integrated in this research work so as to strengthen the reliability of the research findings.

3.1 Research Questionnaire

A semi-structured questionnaire, which consists of five parts, was constructed for the research work. Part I elicit information on company product and establishment information. Part II elicits information on company customer information. Part III, IV and V seek information on welding quality measurement, welding productivity measurement and welding economy measurement respectively. The relevance, effectiveness and reliability of the content of the parts of the research questionnaire for the research work were tested through a pilot study.

3.2 Pilot Study

A pilot study was conducted at Jotex Engineering Oy, a medium sized engineering workshop in Finland handling subcontracted jobs from large Finnish companies such as Metso Oy, Andritz, Outotec (Finland) Oy, etc. This study process was undertaken to assist the researcher to know the exact areas to solicit information as to the requirements of Finnish companies when selecting subcontractors. The outcome of this study authenticated the final version of the research questionnaire to be administered.

3.3 Research Work

Before the research work in Ghana, the final version of the research questionnaire as shown in appendix 2 was sent through electronic mail to the various companies in Ghana, Nigeria and Cameroon. A six week itinerary (04.05.2013 – 15.06.2013) was made for the research work in Ghana.

The research work was conducted in the three most industrialized regions in Ghana such as the Greater Accra Region, the Western Region and the Ashanti Region. The research questionnaire was again administered by the researcher (author of this thesis work) to all the companies to be case studied and as well conducted face-to-face interviews and observed activities in the companies. The researcher chose this personal way of conducting the research without employing any workers so as to create a solid network with the companies.

However, during the research work, some universities, welding certification bodies and some micro scale enterprises performing welding were also visited. The universities visited in Ghana are Kwame Nkrumah University of Science and Technology, University of Mines and Technology and the Regional Maritime University.

More so, during the research period, companies in Nigeria were engaged in telephone communication.

At the end of the research period in Ghana, twelfth companies were case studied. However, companies in both Nigeria and Cameroon did not provide information to the research questionnaire sent to them. Nonetheless, from Nigeria, hypothetical data was obtained from A&X consulting, the sole distributer of KEMPPI welding equipment in Nigeria. Similarly, from Cameroon, hypothetical data was obtained from few professionals who are familiar with welding operations in Cameroon through observation and experience from the field of welding. The reason for this approach was because of the unavailable document from the internet or any data base.

3.4 Limitations

Finding the right companies to participate in this research work was challenging but, on the other hand, the six weeks research work in Ghana has been completed successfully. However, other challenges which could somewhat affect the results of the research are summarized as follows:

- Sample size

The sample size used for the case study was not large, thus the findings of the research were not statistically generalized.

- Credibility of survey data

The data obtained from Nigeria and Cameroon cannot be classified as a survey data since hypothetical information was obtained.

- Company secrets

Some of the companies refused to reveal information especially in issues concerning welding economy since they deem it as a company policy. Taking of photographs in some companies was restricted. Also since some companies main activities are off-site; taking photographs of their products was a challenge. It was also challenging for some companies to show documents regarding welding quality operations such as the WPS.

- Meeting the right personnel

The interview section was challenging since some of the interviewees had very little or no knowledge about the subjects in the research questionnaire.

- Postponement of schedules

Some companies postponed on the agreed upon time beforehand but some called for postponement on the very day of interview. This resulted in visiting two companies a day since some schedules were clashing. Too much time was spent in some interview sections due to intermittent breaks on the side of the interviewees. In some companies, the interview section took more than four hours. The researcher was a bit stressed and could not take full observations in some instances.

4. GHANA CASE STUDY DATA

The case study with respect to welding operations in Ghana was carried out in the Greater Accra Region, the Western Region and the Ashanti Region since these regions are the most industrialized regions out of the ten regions in Ghana. Figure 8 shows the ten regions from the map of Ghana. The regions visited are the ones highlighted and indicated in upper case letters.

Greater Accra Region

The Greater Accra region is the capital city of Ghana and has the largest population of about 4 million people. It houses the main international airport, the main shipyard known as the Tema harbor, the main oil refinery and also most of the governmental offices in the country. In view of this, there exist a lot of activities in the region mostly in the engineering and construction industries.

Figure 8. Map of Ghana indicating the regions visited.

With reference to activities in welding operations, some attributes of this region are very influential been it the climatic condition and welding economic factors. The climatic condition in the said region illustrates a tropical savanna climate where the mean monthly temperature ranges from 24.7 ^{0}C to 28 ^{0}C. Humidity levels are higher between the months of August to December. The relative humidity varies between 65% at mid-day to 95% at night. Moreover, the weather is much warmer between the months of January to March followed by rainy season between the months of April to Mid-July. The most industrialized areas in the region are the Tema metropolis and the Accra metropolis.

Welding economic factors such as availability of welding equipment and machines, welding consumables, welding personnel, welding materials such as steel, aluminum, etc. are readily accessible due to direct port delivery and smelting of metals in nearby factories. Cost incurred from materials handling and transportation is significantly low as compared to other regions. Moreover, due to the large number of on-going construction and engineering works in the said region, the availability of welding personnel is high and their attitude towards work is somewhat recommendable.

Ashanti Region

The Ashanti Region is about 250 Km from the capital city of Ghana. It has no direct linkage to the harbors in Ghana, thus increases some of the welding economic factors in the region. Therefore for construction and engineering works to go on in the said region, materials have to be transported from the Greater Accra Region or the Western Region. However, the readiness of materials for such works are available but of higher cost as compared to the same materials in the Greater Accra Region or the Western Region. The most industrialized areas in the Ashanti Region are Suame, located in the Kumasi metropolis (capital city of the Ashanti Region) and Obuasi.

The Suame area has been termed as ‘Suame Magazine’ due to the large amount of engineering and constructional activities. It is a well noted area for the repair of automobiles and the building of agricultural machinery. Obuasi is a mining community where some of Ghana's mineral resources such as Gold are mined. The region houses the main Science and Technology University in the country, which is the Kwame Nkrumah University of Science and Technology where most research activities are carried out but not in welding technology.

The climatic condition in the region is slightly the same as that of the Greater Accra Region. However, the mean temperature is about 26 ^{0}C and is uniformly experienced all year round.

Western Region

The Western Region comprises of twin cities called the Sekondi-Takoradi. Most of the government offices are located in Sekondi while a harbor, known as the Takoradi harbor is located in Takoradi. A distance of 60 km offshore takoradi is located the newly discovered oil and gas fields termed as the Jubilee oil field which is between the Deepwater Tano Basin and the West Cape Three Points Blocks. Furthermore, due to the massive oil and gas exploration off the city, most of the oil and gas companies and service providers have their offices located in the city center of Takoradi.

Moreover, some towns in the region such as Tarkwa and Bogoso houses most of Ghana's mineral resources which aids the production of gold, bauxite, diamond, manganese, etc. on a larger scale. Engineering and construction works such as the erection and construction of steel structures both onshore and offshore is on the increase and there are even gaps to fill in terms of on-going and up-coming projects. For that matter, the demand in welding operations in the said region is critically high. Nevertheless, some attributes of this region which needs to be considered in terms of welding operations are the climatic condition and the welding economic factors.

The climatic condition of this region is different from the other two regions. The region experiences high rainfall, thus contributing to an average temperature of 26 ^{0}C. As a result of mining and oil and gas activities in the region, the average humidity level all year round is about 78% at 26 ^{0}C [42]. The Takoradi harbor provides easy access to imported goods such as equipment, machines, etc., thus reduces transportation cost of goods to the region. The workforce in this region is large due to the huge amount of prominent engineering and construction activities.

Ghana Welding Industry

Welding activities in the Ghanaian welding industry are classified under two sectors; the informal welding sector and the formal welding sector. The formal welding sector comprises of companies operating under the metal production and manufacturing industrial sectors in Ghana. However, the informal welding sector consists of enterprises which are not recognized to be operating under the metal production and manufacturing industrial sectors in Ghana. These classifications are based on a number of considerable factors such as the level of professionalism, size of the enterprise (micro, small, medium and large), type of products been manufactured or produced, type of production and manufacturing systems used, and whether the business is registered or un-registered.

In this thesis, enterprises in the informal welding sector would be denoted as micro enterprises (MEs) while enterprises in the formal welding sector would be denoted as companies i.e., small and medium enterprises (SMEs) and medium and large enterprises (MLEs).

4.1 Informal Sector of Ghana Welding Industry

The informal sector of the Ghanaian welding industry comprises of micro enterprises. The level of professionalism in this sector is low but welders in this sector are experienced as a result of constant practice in the welding trade. Moreover, some of the welders from this sector are actually working in companies even though they do not have academic qualifications in welding or basic qualifications in welding.

However, the main activities performed by this group include fabrication of plate and sheet metals, manufacturing of metallic products, and maintenance and repairs of metallic products.

The range of products manufactured by this group can be classified into three forms such as the agro-processing products, household products and commercial purposed products as shown in Figure 9. Nonetheless, some of the products under these classifications can be multi-purposed products due to their wide range of usage and also their availability.

(a) Cement Block Making Machine

(b) Wagon and Chassis (truck)

(c) Coal pot

(d) Fluid storage tank

Figure 9. Some products manufactured by enterprises in the informal welding sector.

The agro-processing products manufactured include cassava grater, palm oil extractor, tomatoes grinder, corn mill, and nut cracker. The household products include burglary protection shield, iron gates, coal pots while the commercial purposed products include cement block making machine, billboards, car seat frames, wheelbarrow, tanks and chassis and wagon.

The manufacturing system deployed by this sector of the welding industry can be termed as “basic manufacturing system”. This is because common hand tools such as hammer, chisel, grinding tool, and drilling tool are used in the manufacturing process. However, few welding machines used in the manufacturing process are imported ones. Cutting of sheet metals or metallic plates are mostly done by chisel and a hammer. The fabricator uses his energy colloquially termed as “man-power” in cutting these materials. On the other hand, cutting metallic plates of thickness above 5mm are mostly done with an oxyacetylene flame.

With the issue of welding processes, most of the enterprises use shielded metal arc welding (SMAW). The welding machines for this process are locally manufactured and are of two kinds (wet type and dry type). The wet type operates in oil where by heat is easily dissipated, while the dry type is exposed to air for direct air cooling. However, those enterprises that perform maintenance on car bodies use oxyacetylene welding (OAW). The acetylene gas is produced at the workshop premises by mixing calcium carbide with water in pressurized cylinders.

Also, the imported welding machines, colloquially termed as “home use machines” are used in welding operations in this sector. Most of these welding machines are made in China. Due to the price difference between the welding machines, most of the enterprises prefer the locally made welding machines even though the quality output of both machine types varies. The price of a locally made welding machine is about ₵ 200 – 300 while the made in China welding machine is about ₵1,500 – 2,000 Ghana Cedi. As the euro currency is of interest in this thesis, at the time of the research the conversion rate of € 1 was equivalent to ₵ 2.5 Ghana Cedi. However the conversion in currencies is always affected by inflation and deflation rates.

Furthermore, the common materials used in manufacturing are structural steels. These steels are termed as galvanized steels and non-galvanized steels. The galvanized steels are known to be much expensive than the non-galvanized steels. A 4 X 8 feet galvanized steel sheet of thickness 1mm cost ₵ 60 while non-galvanized steel with the same dimension and thickness cost ₵ 35. The galvanized steels are used in areas close to the coast since it has the tendency to withstand the environmental conditions. However, aluminum, and cast iron are also used as materials for manufacturing.

Also, electrodes used are mostly imported from China and occupies about 80% of market share. The price of a box of 2 mm electrode with net weight of 5 Kg from China is about ₵ 20 while the price of the same electrode specification from Europe, say ESAB is about ₵ 25 – 30 Ghana Cedi. However, the electrodes imported from China are noted to be cheaper, but have higher reflectance and evolve a lot of smoke during welding.

Additionally, welding workshop environment and safety issues are less regarded in this welding sector. Welding operations are mostly carried out in structures along the road side and sometimes in miniature workshops and also under trees. Figure 10 depicts a typical example where a welder is welding under a tree and without using welding shield.

Figure 10. Welding operation performed under a tree.

Welding operations are therefore halted when there are rain storms. Welding helmet and eye protective glasses used during welding are outmoded. Some welders don’t use protective shades at all even though they are aware of the dangers associated with this kind of practice. Goggles for grinding purposes are sometime used as welding shades.

Also, most of the welding jobs are carried on the floor and this process normally involves that welders have to squat during the welding process since welding benches are seldom or rarely used. Figure 11 shows a welder in a squatting position during a welding operation carried out on the floor.

Figure 11. Squatting position during a welding operation on the floor.

The market in the informal sector is “price sensitive” so quality aspect of welded products is over-looked since customer demand is solely based on cost. The quality mindset in this sector of the welding industry is however very low and also products are manufactured under no standards or requirements, thus products manufactured from this sector can be termed to less innovative.

With respect to welding training practices, most of the welders learn the trade through apprenticeship. Moreover, most of the welders are school drop-out and majority is junior secondary school leavers. A survey research conducted in Ghana reveals that about 88 % of welders in the Ghanaian welding industry do not receive senior high school education [5].

4.2. Formal Sector of Ghana Welding Industry

The formal sector of the Ghanaian welding industry comprises of companies operating as small and medium enterprises (SMEs) and medium and large enterprises (MLEs) registered in Ghana's trade register with clear-cut business objectives. The welding operations performed by companies in this sector are unveiled by case studies from twelfth companies. The case study encompasses company establishment information, customer information, welding quality, productivity and economy related issues.

The sequence of data presentation commences with companies in the Greater Accra Region (case 1 - case 3) followed by companies in the Western Region (case 4 - case 12). The main research items depicted as Q1, Q2, Q3, Q4, and their corresponding responses pertaining to welding quality measurements are presented in tables in each case. Also, the main research items depicted as P1, P2, P5, P10, and their corresponding responses pertaining to welding productivity measurements are presented in tables in each case. In addition, the main research items depicted as E1, E2, E3, E10, E12, and their corresponding responses pertaining to welding economy measurements are presented in tables in each case.

4.2.1 Case 1: Ghana Metal Fabrication and Construction Limited (GMFCL)

Ghana Metal Fabrication and Construction Limited (GMFCL) is a Ghanaian domestic medium sized engineering company which belongs to the construction industrial sector. GMFCL has been performing welding over thirty years and it products and operations include fabricated tanks, containers, design and construction of gas and oil tank farms, pipeline construction and installation, and reconstruction of mining equipment. Manufactured tanks are either for surface or underground storage of fluids.

GMFCL estimated number of customers ranges from 20 – 50 and a large number of them operate in the oil and gas sector, infrastructure sector and food production industry. Most of GMFCL customers are domestic based while a few are from neighboring countries such as Togo, Benin, and Nigeria. Due to the level of product customization, customers of GMFCL are more concern about quality issues of manufactured products. Quality is therefore highly prioritized followed by the cost of manufactured products. Productivity issues pertaining to delivery time of product or the accomplishment of a project is of less priority to GMFCL customers.

The main facilities of GMFCL are a 2,400 m^2 workshop, machining center, materials handling and storage center, welding machines (SMAW), welding generator, lathe machine, bending machine, drilling machine, fork lifts, cranes, and oxyacetylene equipment for cutting thick metal plates above 5 mm. A typical product manufactured by GMFCL is as shown in Figure 12.

Figure 12. Manufactured tank for underground storage of fuel.

The manufacturing processes for this product include cutting, bending and welding. After manufacturing, some welded portions of the tank are grinded, and the entire product is sand blasted and coated with anti-rust paint. The tank is finally painted with a bituminous paint (black paint) to make it less susceptible to corrosion and rust.

However, due to the layout of the workshop, most welding jobs are done on the bare floor instead of welding on a bench as depicted in Figure 13. The operation as shown in Figure 13 describes manual welding of a 4 mm mild steel (low carbon steel) plate utilizing a SMAW process and a 4 X 400 mm mild steel electrode.

(a) (b)

Figure 13. Welding operation utilizing manual welding technique.

This practice of welding on the floor to some extent can have negative influence on weld quality. Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy is presented in Table 2.

Table 2. Ghana Metal Fabrication Company Limited Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Pressure Test
Q4	Welding processes used	• Shielded Metal Arc Welding
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• 15
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost
E10	Wages of welding personnel	Permanent casual: GH ₵ 50 per day Casual: GH ₵ 25- 20 per day
E12	Funds for welding related research and development per year	• No fund

As observed, welding ergonomic factors such as the layout of the welding center, arrangement of materials and equipment, accessibility to safety devices and the nature of work in the welding workshop were somewhat not appropriate. Welding productivity is affected especially during raining season where rain water drains to the welding center and halts welding operations.

Moreover, the use of personal protective equipment (PPE) such as working overall, and coded welding shields are not strictly enforced in the workshop. The quality of end products with reference to preparations before, during and after welding is not the best. To some extent, even though welders in this company have welding quality mindset the actual welding quality practices are not fully emulated. The standard of work quality in this company as compared to other companies such as Orsam Limited and Group Five is therefore low. Welding personnel in this company needs extensive training and education despite the experiences some welders have acquired through their working lives.

In the aspect of benchmarking, GMFCL claimed that its product and performance level according to domestic competitiveness is high while international competitive is moderate. GMFCL further claimed that its quality and productivity levels according to domestic competitiveness are high and international competitiveness is moderate.

However, from the observations noted, it can rather be said that the quality and productivity levels of GMFCL according to domestic and international competitiveness is moderate and low respectively since quality and productivity has not received much attention.

4.2.2 Case 2: Memot Metal Fabrication and Engineering

Memot is a medium sized engineering company which belongs to the construction industrial sector. Memot has been performing welding operations over thirty years and it products and operations include palm kennel cracker, corn mill, block making machine, vegetable processing machines, fabricated tanks, design and construction of liquefied petroleum gas (LPG) tanks, Oil tank farms and silos, pipeline construction and installation, and general maintenance and repair works of metallic products.

Memot has about 30 customers and most operate in the petrochemical industry and food production industry. Most of Memot customers are domestic based while a few are from neighboring countries such as Liberia, Benin, and Togo. Products manufactured are highly customized but few are manufactured for general market purposes.

The main facilities of Memot are a 1,700 m^2 workshop, machining center, materials handling and storage center, welding machines (SMAW), welding generator, lathe machine, bending machine, drilling machine, fork lifts, cranes, and oxyacetylene equipment. A typical product manufactured by Memot is as shown in Figure 14. This vegetable processing machine is electrically operated. Vegetable such as tomatoes, pepper, and garden eggs are usually processed with the help of this machine in the agro-processing firms. This machine is manufactured from mild steel (low carbon steel) sheet and plates.

Figure 14. Vegetable processing machine.

The welding center as shown in Figure 15 is enclosed but has large openings which aid adequate ventilation. The need of fumes extraction in the welding center is very minimal. However, the absence of a cutting machine in the welding center necessitates the use of oxyacetylene equipment for cutting thick metal plates above 4 mm.

Moreover, the layout of the workshop poses a lot of challenges in welding as observed. These include difficulties in accessing materials, equipment, and safety devices in the welding center. Welding jobs are bound to be done on the floor instead of welding on a bench. The consequences associated to this practice could lead to weld quality problems. These and other practices such as loitering, idling and the mindset of welding personnel in the workshop lower productivity substantially as shown in Figure 15.

Figure 15. Memot Metal Fabrication and Engineering welding workshop.

More so, aspects related to handling and finishing of welded products especially fabricated tanks is abhorring. This is so because such products are left openly to the environment where they probably come into contact with water and other environmental impurities. Supposing it rains for days, these products are left to stand in the rain.

Figure 16 shows a typical scenario of this occurrence. This practice however could affect the quality of the product and productivity of welding operations.

Figure 16. Memot sand-blasting and painting area for fabricated tanks.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Memot is presented in Table 3. Similarly, the working culture and values in Memot is the same as that of GMFCL and far below the working culture and standards of companies such as Orsam and Group Five. This is because welding quality and productivity are less regarded, thus the quality of end products with reference to preparations before, during and after welding is not the best as observed.

It is of much importance that welding personnel in Memot should be trained and educate in welding quality and productivity practices despite the experiences some welders have acquired through their working lives.

Table 3. Memot Metal Fabrication and Engineering Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Pressure Test
Q4	Welding processes used	• Shielded Metal Arc Welding
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• 15
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost
E10	Wages of welding personnel	• Not provided
E12	Funds for welding related research and development per year	• No fund

In the aspect of benchmarking, Memot claimed that its product and performance level according to domestic competitiveness is high whiles international competitiveness is moderate. Memot further claimed that its quality and productivity levels according to domestic competitiveness are high while international competitiveness is moderate.

However, from the observations noted, it can rather be said that the quality and productivity levels of Memot according to domestic and international competitiveness is moderate and low respectively since quality and productivity has not received much attention.

4.2.3 Case 3: PSC Tema Shipyard Limited (PSC)

The Tema shipyard, also known as dry-docks is the main shipyard in Ghana and one of the largest shipyards and dry-docks in Africa. The Tema shipyard is centrally positioned adjacent to the main harbor in Ghana termed as the Tema harbor and about 30 km distance from the main international airport. Tema shipyard belongs to both the heavy industrial manufacturing and the construction industrial sector.

Tema shipyard has numerous customers who operate vessels and other offshore facilities such as oil tankers, barges and rigs within Gulf of Guinea and those from-and-to Southern Africa en-routes to Northern African and Europe. Tema shipyard has been performing welding operations over thirty years and its main operation include ship repairs, shipbuilding, dry-dock to heavy steel fabrication, and general metal engineering works.

Its facilities occupy about 44.45 acre of land area and houses two graving docks of deadweight tonnage 100,000 dwt and 10,000 dwt capacity and a 150 tonnage slipway. The welding workshop is furnished with welding machines, bending machines, pressing machines, lathe machine, overhead cranes, and fork lifts, even though most of these machines are out-moded. Figure 17 shows a model of a ship under construction at Tema Shipyard.

Figure 17. A model of a ship under construction at Tema shipyard.

Welding operations on the dry docks are mostly repair works. Ships, vessels or barges are made to shunt through slipways to the dry dock as shown in Figure 18. Repair activities include cutting and insertion, cropping, and gouging. Cutting and insertion refers to the operation where by a defective portion is cut off and replaced with a new material and welded. Cropping and gouging are somewhat alike and the operation is such that a defective portion is scooped and the remaining portion is doubled with a new material and welded.

Figure 18. Tema shipyard dry dock area.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Tema Shipyard is presented in Table 4.

Table 4. PSC Tema Shipyard Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Strength • Toughness • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel • Aluminum • Cast Iron
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• 30 – 50
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost *Cost of each weld *Postweld treatment
E10	Wages of welding personnel	GH ₵ 1,200 per month (Maximum)
E12	Funds towards welding related research and development per year	• No fund

Operations regarding to repair welding are very slow since the entire activity is done by one welder. Carrying of materials and equipment from the main welding workshop to the dry dock area is time wasting as observed. Productivity in welding is low as a result of this practice. However welding quality in Tema shipyard is highly regarded since any quality defects in welding could lead to catastrophic failure of the ships, barges and the other structures.

As Tema Shipyard stands to be the only shipbuilding company in Ghana, its product and performance level domestically and internationally is highly competitive. Moreover, Tema Shipyard claimed that its productivity levels according to domestic competitiveness are high while international competitiveness is moderate. From observations, it can be said that even though Tema Shipyard has the potential to build and repair ship, its welders should be trained so as to improve on efficiency in welding, thus improving welding productivity.

4.2.4 Case 4: Enas Engineering and Construction

Enas is a Ghanaian domestic engineering and construction service company located in Bogoso in the Western Region of Ghana. Enas belongs to both the construction and capitalized repair and maintenance industrial sectors. Over the last six year, Enas has been performing welding operations for companies mostly in the mining industry of Ghana. The main operations performed by Enas include fabrication and welding, construction of silos, tanks, erection of steel structures, high-density polyethylene (HDPE) pipe works, and general engineering works.

Currently, Enas has about eight customers from the mining industry. The needs of its customers are prioritized according to quality, delivery time (productivity) and cost. The main facilities of Enas includes two sizable welding workshops, welding machines, oxyacetylene equipment, welding generators, cranes, forklifts and HDPE welding equipment.

Data obtained from the measurements of variables pertaining to welding quality, welding productivity and welding economy of Enas is presented in Table 5. Welding operations are mostly carried out on site while minor fabrication works are done in the workshop.

Table 5. Enas Engineering and Construction Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Strength • Toughness • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test
Q4	Welding processes used	• Shielded Metal Arc Welding • Oxyacetylene welding
Production	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel • High carbon steel • Cast iron • Galvanized steel • High-density polyethylene (HDPE) pipes
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• Permanent – 8 • Casual - 20
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost
E10	Wages of welding personnel	• GH ₵ 1000 - 2000 per month • Trainees - GH ₵ 600 per month
E12	Funds towards welding related research and development per year	• No fund

Jobs performed by Enas are contract projects which normally last within a year, and most jobs are out-door projects. Figure 19 shows an out-door construction project of water tanks on-site for water supply for gold prospecting at Golden Star Resources Limited, Ghana.

Figure 19. Water tanks construction on- site by Enas Engineering.

In view of the nature of work performed by Enas, workshop ergonomic factors such as the layout of the welding center, arrangement of materials and equipment, accessibility to safety devices and the nature of work have not received much attention as observed. Moreover, there are delays in welding operations on site due to improper organization and time management, thus decreasing welding productivity. In some cases equipment, machines and materials are hired which in a way attracts extra cost.

Nevertheless, the quality of end product is commendable since quality thinking of welders and the welding jobs done are influenced by welding certification bodies. In comparison, the working culture and the quality levels in welding of Enas is better than GMFCL and Memot but below that of Orsam and Group Five.

Interestingly, Enas claimed that its quality and productivity levels according to domestic and international competitiveness are high. Also, in the aspect of benchmarking, Enas claimed that its product and performance level according to domestic and international competitiveness is high and moderate respectively.

However, from the observations noted, it can be said that the productivity levels of Enas according to domestic and international competitiveness is moderate and low respectively since the mindset towards productivity is low and also systems have not been implemented to help maintain productivity levels and to improving productivity levels in future. Relying on the system of employing casual workers to increase productivity levels is unsustainable and ineffective.

4.2.5 Case 5: Group Five

Group Five is a South African company and its international operations span over 20 countries in Africa, Europe and Middle East. In Ghana, Group Five is located in Tarkwa in the Western Region. The company operations belong to three industrial sectors: light industrial manufacturing, heavy industrial manufacturing and the construction industrial sector. The main operations performed in Ghana include fabrication and welding, construction of tanks, erection of steel structures, HDPE pipe works, and general engineering works.

Group Five has been performing welding operations in Ghana between 16-30 years and has won the trust of over 20 international companies operating in the mining industry. The needs of its customers escalate down from quality and safety, cost as well as productivity. The company occupies about 5 acre of land area and has good facilities such as welding machines, oxyacetylene equipment, welding generators, plasma cutting machine, cranes, forklifts and HDPE welding equipment for welding operation. Figure 20 shows the main welding workshop of the company.

Figure 20. Group Five welding workshop.

Machines, equipment and welding benches in the welding workshop are orderly arranged and the environment is suitable for welding jobs. Work flow in this workshop is recommendable, thus delays in production are minimal. Moreover, while some companies dry welding electrodes in the sun before welding, this company has electrode ovens for storing and drying electrodes to eliminate moisture in the electrodes before welding.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Group Five is presented in Table 6. The quality of work done by Group Five has been commendable and attested by its competitors. Welders in this company are enforced to follow welding quality and safety requirements. The end products are of high quality since quality standards such as the ISO 3834 is emulated. That notwithstanding, quality thinking of welders and the welding jobs done are also influenced by welding certification bodies

Table 6. Group Five Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• ISO 9001: 2000 • ISO 3834
Q2	Assessment of weld quality	• Strength • Toughness • Distortion / dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding • Tungsten Inert Gas (TIG) welding • Oxyacetylene welding
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect • Performance verse standard time
P2	Metals used in company's welding operations	• Mild steel • High carbon steel • Galvanized steel • High-density polyethylene (HDPE) pipes
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• Permanent – 12 • Casual - 40
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – $ 10 million • Year 2011 – $ 15 million • Year 2012 – $ 25 million
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost *Postweld treatment *Cost of each weld
E10	Wages of welding personnel	• GH ₵ 7 per hour
E12	Funds towards welding related research and development per year	• Not provided

In comparison, the working culture and the quality levels in welding of Group Five is better than most of the case studied companies but somewhat at the same level with Orsam.

Furthermore, Group Five claimed that its quality and productivity levels according to domestic and international competitiveness are high. Also, in the aspect of benchmarking, the company claimed that its product and performance level according to domestic and international competitiveness is high.

However, from the observations noted, it can be said that the productivity levels of Group Five according to domestic and international competitiveness is high and moderate respectively since the mindset towards productivity falls short and also the systems implemented to maintain productivity levels is weak. This is because the company relies on the system of employing casual workers to increase productivity levels, which in a way does not improve productivity levels in the context of sustainability.

4.2.6 Case 6: Orsam Limited

Orsam Limited is a subsidiary of a French company known as the Ortec group. Its international operations span over 30 countries in Africa and Europe. Orsam has two workshops in Ghana: one in the Greater Accra Region and the other in Western Region. Orsam belongs to the construction industrial sector and its main operation include metallic structures assembly, steel metal works, piping, boiler construction, and storage facility and tank fabrication.

Over six years of providing services in the Ghanaian industrial sector, Orsam have numerous clients in the oil and gas industry, mining industry, energy sector as well as the food industry. The facilities in the welding workshop include welding machines, oxyacetylene equipment, welding generators, plasma cutting machine, overhead cranes, drilling machine, pressing machine and an NDT section for testing. Figure 21 shows the main welding workshop of Orsam (Takoradi branch).

Figure 21. Orsam welding workshop (Takoradi branch).

Workshop organization and practice is strictly adhered to in this welding workshop. Even though some welding operations are done on the floor, most of the welding jobs are performed on welding benches. Figure 22(a) shows a welding operation carried out on an offshore support structure. As it can be seen, three welders are engaged in the welding operation. To some extent, task allocation in this workshop is effective and productivity schedules are well planned. Welded structures are sometimes non-destructive tested before customers send in request for further testing. Figure 22(b) illustrates an MPT performed on the offshore support structure.

(a) (b)

Figure 22. (a) Welding operation utilizing SMAW process on an offshore support structure. (b) Magnetic particle test of the welded joint of the offshore support structure.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Group Five is presented in Table 7. The end products of Orsam are of high quality since the quality thinking of welders and the welding jobs done are influenced by welding certification bodies. Welding personnel are enforced to follow welding quality and safety requirements. The quality of work done and the level of welding operation of Orsam has received attestation by its competitors. In comparison, the working culture and the quality levels in welding of Orsam is better than most of the case studied companies but somewhat at the same level with Group Five.

Table 7. Orsam Limited Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• ISO 9001:2000 • Complies with customer/ client standards provided
Q2	Assessment of weld quality	• Strength • Toughness • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Magnetic Particle Test • Pressure Test
Q4	Welding processes used	• Shielded Metal Arc Welding- scale 5 • Gas Tungsten Arc Welding- scale 4 • Submerged Arc Welding- scale 2 • Gas Metal Arc Welding (MIG/MAG) - scale 2
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect • Performance verse standard time
P2	Metals used in company's welding operations	• Carbon steel – A106, AP15L X60, A234, A233 • Stainless steel – ASTM 316,304,306 • Super Chromium
P5	Welding technique used in company's welding operation	• Manual welding • Mechanize welding
P10	Number of welding personnel	• Permanent – 10 • Casual – 50
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost *Postweld treatment *Cost of each weld
E10	Wages of welding personnel	• Not provided
E12	Funds towards welding related research and development per year	• Not provided

The quality, productivity and product performance levels were rated according to domestic and international competitiveness to be high and moderate respectively by Orsam. However, from the observations noted, it can be said that the level of productivity as claimed by Orsam is a true reflection since the mindset towards productivity falls short and also the systems implemented to maintain productivity levels is weak. This is because the company relies on the system of employing casual workers to increase productivity levels, which in a way does not improve productivity levels in the context of sustainability.

4.2.7 Case 7: REF Engineering and Construction Limited

REF Engineering is a Ghanaian domestic engineering and construction service company located in Tarkwa in the Western Region of Ghana. REF Engineering belongs to the construction industrial sector. The main operations performed by REF Engineering include fabrication and welding, structural steel and plate works, pipe works, construction of tanks, erection of steel structures, HDPE pipe works, and general engineering works.

About five years of effective service rendering, REF Engineering has been performing welding operations for five big companies in the mining sector such as Goldfields Ghana Limited, Anglo Gold Ashanti, Golden Star Resources, Bogoso Gold Mines and Tarkwa Gold Mines. The needs of its customers are prioritized according to quality, delivery time (productivity) and cost.

REF Engineering occupies about 10 acre of land area and houses a 3,000 m^2 welding workshop. Some other facilities include welding machines, welding generators, drilling machine, cutting machine, truck-mounted cranes, and HDPE welding machine. REF Engineering welding workshop is very spacious but not fully furnished as it can be seen from Figure 23(a). This is as a result of the number of welding jobs done outside the workshop premises.

(a) (b)

Figure 23. (a) REF Engineering welding workshop. (b) Articulated dump truck buckets.

More so, REF Engineering happens to be one of the leading companies in Ghana performing relining of buckets of articulated dump trucks. Welding operations for such structures are done in the welding workshop. Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of REF Engineering is presented in Table 8.

The quality of end products is commendable since quality thinking of welders and the welding jobs done are influenced by welding certification bodies. In comparison, the working culture and the quality levels in welding of REF Engineering is better than GMFCL and Memot but similar to that of Enas.

Table 8. REF Engineering Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding- scale 5 • Oxyacetylene Welding- scale 1 • Gas Tungsten Arc Welding- scale 2 • Gas Metal Arc Welding (MIG/MAG)- scale 2
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel – 350W, 355W • Stainless steel • Galvanize Steel • Hardox plates
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• On contract - 16
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – $ 2 million • Year 2011 – $ 4 million • Year 2012 – $3.5 million
E2	Company's welding cost system	• Cost of specific weld • Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost *Postweld treatment
E10	Wages of welding personnel	• Not provided
E12	Funds towards welding related research and development per year	• No funds

Consequently, REF Engineering claimed that its quality and productivity levels according to domestic and international competitiveness is high. Also, in the aspect of benchmarking, the company claimed that its product and performance level according to domestic and international competitiveness is high.

However, from the observations noted, it can be said that the productivity levels of REF Engineering according to domestic and international competitiveness is moderate and low respectively since the mindset towards productivity is low and also systems have not been implemented to help maintain productivity levels and to improving productivity levels in future. Relying on the system of employing casual workers to increase productivity levels is unsustainable and ineffective.

4.2.8 Case 8: Seaweld Engineering Limited

Seaweld Engineering is a Ghanaian domestic engineering and construction service company located in Takoradi in the Western Region of Ghana. Seaweld Engineering belongs to the construction industrial sector. One of the main operations performed by Seaweld Engineering include fabrication and welding and this involves structural steel construction, construction of oil and gas tanks, steel silos, building and maintenance of offshore barges and vessels, and general engineering works. Seaweld Engineering is a dominant oil and gas service provider and has more than twenty customers operating in the oil and gas industry.

Its notable customers are Technip, Tullow oil, Baker Hughes, Maersk Drilling, and Kosmos Energy. In order to strengthen its customer portfolio, Seaweld has strong partnership agreement with Viking SeaTech, CORPRO, Techniques International Corporation, Kepner Plastics, and SIOUX. Seaweld Engineering has two workshops of which one is currently under a renovation process. The main welding facilities include welding machines, welding generators, drilling machine, cutting machine, and truck-mounted cranes. Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Seaweld is presented in Table 9.

Table 9. Seaweld Engineering Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• ISO 9001 • OHSAS 18001
Q2	Assessment of weld quality	• Strength • Toughness • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding- scale 5 • Gas Tungsten Arc Welding- scale 1 • Gas Metal Arc Welding (MIG/MAG)- scale 1
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel • Stainless steel • Galvanize Steel • Aluminum
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• Permanent – 10
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – $ 3 million • Year 2011 – $ 9 million • Year 2012 – $10 million
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Preparation of the parts *Joint position *Overhead cost *Environmental cost *Postweld treatment
E10	Wages of welding personnel	• Offshore - $ 4000 per month • Onshore - $ 1,500- 2000 per month • In-house - GH ₵ 600 – 1,800 per month
E12	Funds towards welding related research and development per year	• No funds

Seaweld Engineering welding operations are mostly carried out offshore and on oil rigs (offshore platform). Figure 24 shows a welding operation carried out on a tubular offshore support structure with SMAW by a Seaweld welder. Quality of end products can be termed to be good since quality thinking of welders and the welding jobs done are influenced by welding certification bodies.

Figure 24. Welding of tubular offshore support structure with SMAW (courtesy of Seaweld Engineering).

In comparison, the working culture and the quality levels in welding of Seaweld is better and similar to that of Orsam. Also, due to external auditing occasionally performed in Seaweld, much focus is on quality manufacturing and safety of the welders.

Additionally, quality, productivity and product performance levels were rated according to domestic and international competitiveness to be high and moderate respectively by Seaweld. However, from the observations noted, it can be said that the level of productivity as claimed by Seaweld conforms with the working culture since the mindset towards productivity falls short and also the systems implemented to maintain productivity levels is weak. This is because the company relies on the system of employing casual workers to increase productivity levels, which in a way does not improve productivity levels in the context of sustainability.

4.2.9 Case 9: Stresster Engineering and Construction Limited

Stresster Engineering is a Ghanaian domestic engineering and construction service company located in Takoradi in the Western Region of Ghana. Stresster Engineering belongs to the construction industrial sector. The main operations performed by Stresster Engineering include fabrication and welding, structural steel and plate works, pipe works, construction of tanks, erection of steel structures, and general engineering works.

About five years of effective service rendering, Stresster Engineering has been performing welding operations for both oil and gas companies and mining companies. The needs of its customers are prioritized according to quality, delivery time (productivity) and cost. The main facilities include a 400 m^2 welding workshop, welding machines, oxyacetylene equipment, welding generators, and cranes. Due to the absence of sizable welding benches, most welding jobs are done on the floor for convenience as shown in Figure 25.

Figure 25. Stresster Engineering welding workshop.

Also, due to the small size of the workshop, material handling and welding ergonomic are not the best in the workshop. Also proximity in welding operations is sometimes delayed as a result of mishandling and improper arrangement and allocation of materials, as can be seen in Figure 26.

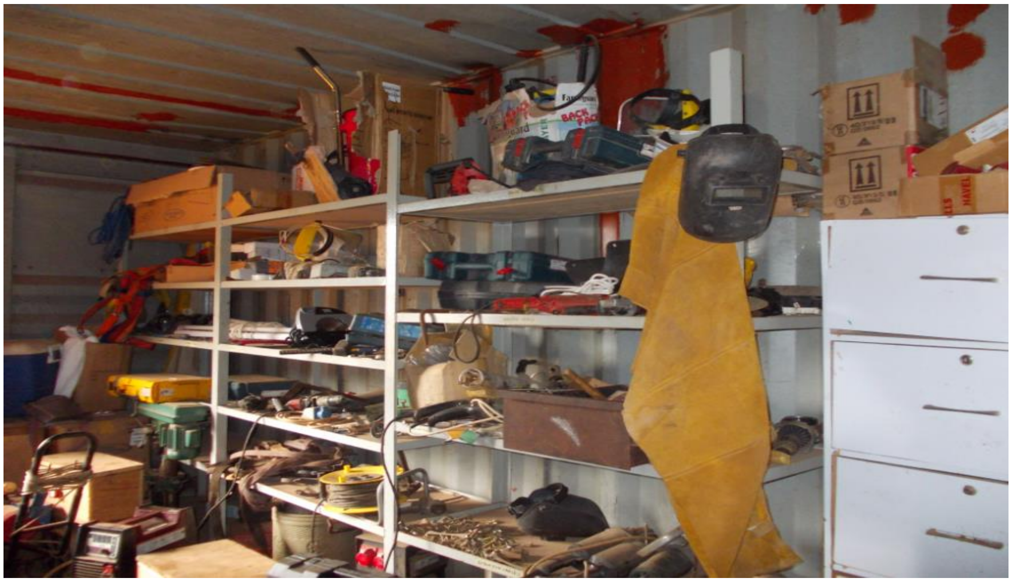

Figure 26. Stresster Engineering materials handling and storage facility.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Stresster Engineering is presented in Table 10. The welding machines used by Stresster Engineering are somewhat out-moded and there is the need for new ones. In view of this, the level of quality of welded products is not competitive as compared to welded products from other companies such as Orsam. The welding workshop cannot be termed as a well-organized workshop since it does not meet the requirement of a standardized workshop.

Table 10. Stresster Engineering Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Strength • Toughness • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding- scale 5
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel • Stainless steel • Aluminum
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• Permanent – 5 • Trainees – 4
Question	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – GH ₵ 247,000 • Year 2011 – GH ₵ 302,000 • Year 2012 – GH ₵ 382,000
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Joint position *Overhead cost *Postweld treatment
E10	Wages of welding personnel	• Permanent - GH ₵ 5 - 10 per hour • Contract - GH ₵ 6 - 12 per hour
E12	Funds towards welding related research and development per year	• No funds

Moreover, quality, productivity and product performance levels were rated according to domestic and international competitiveness to be high and moderate respectively by Stresster Engineering. However, from the observations noted, it can be said that the level of quality and productivity does not conform to the ratings as claimed by Stresster Engineering. This is because even though quality thinking of welders is somewhat high, the actual welding quality practice is not done. More so, the mindset towards productivity is low and also systems have not been implemented to help maintain productivity levels and to improving productivity levels in future. Welders in this company need to be trained and educated on quality and productivity aspects in welding.

4.2.10 Case 10: Swaako Engineering Services Limited

Swaako Engineering is a Ghanaian domestic engineering and construction service company located in Takoradi in the Western Region of Ghana. Swaako Engineering belongs to the construction industrial sector. The main operations performed include fabrication and welding, structural steel and plate works, pipe works, construction of tanks, erection of steel structures, and general engineering works. Products such as metal grates, stanchions, and stairtreads are the main manufactured products of Swaako.

Swaako Engineering has been performing welding operations for the past six years mostly for mining companies. Currently, the company has about twelfth customers whose needs are prioritized according to cost, delivery time and quality. Welding quality issues have been of less concern to its customers since they demand cheaper products and services and thus compromise quality with cost. That notwithstanding, Swaako Engineering is on the verge of providing quality products and services.

The main facilities include a 2000 m^2 welding workshop as shown in Figure 27, welding machines, welding generator, grinding machine, crane, forklift, oxyacetylene equipment, and portable drilling machine.

Figure 27. Swaako Engineering welding workshop.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Swaako is presented in Table 11. The welding machines used by Swaako Engineering are somewhat out-moded and there is the need for new ones as in the case of Stresster Engineering. In view of this, the level of quality of welded products is not competitive as compared to welded products from other companies such as Group Five.

Moreover, quality, productivity and product performance levels were rated according to domestic and international competitiveness to be high and moderate respectively by Swaako Engineering. However, from the observations noted, it can be said that the level of quality and productivity does not conform to the ratings as claimed by Swaako Engineering. This is because even though quality thinking of welders is somewhat high, the actual welding quality practice is not done.

Table 11. Swaako Engineering Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Strength • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding- scale 5 • Gas Tungsten Arc Welding - 1
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect • Performance verse standard time
P2	Metals used in company's welding operations	• Mild steel • Stainless steel • Hardox plate
P5	Welding technique used in company's welding operation	• Manual welding
P10	Number of welding personnel	• Permanent – 5 - 10
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – GH ₵ 2, 900,000 • Year 2011 – GH ₵ 3,600,000 • Year 2012 – GH ₵ 3,800,000
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Joint position *Overhead cost *Environmental cost *Postweld treatment * Cost of each weld
E10	Wages of welding personnel	• Permanent - GH ₵ 450 – 1,500 per month
E12	Funds towards welding related research and development per year	• No funds

More so, the mindset towards productivity is low and also systems have not been implemented to help maintain productivity levels and to improving productivity levels in future. Welders in this company need to be trained and educated on quality and productivity aspects in welding. Thus quality and productivity levels according to domestic and international competitiveness are moderate and low respectively.

4.2.11 Case 11: Takoradi Steel Company (TSC)

Takoradi Steel Company (TSC) is a Gulf Western Group (GWG) company located in Takoradi in the Western Region of Ghana. TSC has offices in South Africa and Houston, Texas in the USA. TSC belongs to the construction industrial sector and its main operation include fabrication and welding, structural steel and plate works, pre-engineering metal building, pipe works, erection of steel structures, and general engineering works.

TSC has been performing welding within fifteen years from now and has about ten to fifteen customers who operate in the food industry, mining industry and the manufacturing industry. The needs of its customers are prioritized according to cost, quality and delivery time. The main facilities of TSC include a 2,000 square feet welding workshop, a 20,000 square feet maintenance and warehouse, welding machines, drilling machine, cutting machine, welding generator, cranes, and forklift.

Figure 28 shows the main welding center of TSC. The workshop has been renovated recently and stuffed with welding benches, welding machines and other useful equipment to ease welding operation on the shop floor.

Figure 28. Takoradi Steel Company welding workshop.

Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of TSC is presented in Table 12.

Table 12. Takoradi Steel Company (TSC) Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided • OHSAS 18001
Q2	Assessment of weld quality	• Strength • Toughness • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test • Penetrant Test • Magnetic Particle Test
Q4	Welding processes used	• Shielded Metal Arc Welding - scale 5 • Flux Cored Arc Welding – scale 4 • Gas Tungsten Arc Welding – scale 1 • Gas Metal Arc Welding (MIG/MAG) – scale 1
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel • Stainless steel • Aluminum
P5	Welding technique used in company's welding operation	• Manual welding • Mechanize welding
P10	Number of welding personnel	• Permanent – 10 • Casual – 5 - 10
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Joint position *Overhead cost *Preparation of the part *Environment cost *Postweld treatment *Cost of each weld
E10	Wages of welding personnel	• Permanent - GH ₵ 650 – 1,200 per month
E12	Funds towards welding related research and development per year	• No funds

The quality of end products is commendable since quality thinking of welders and the welding jobs done are influenced by welding certification bodies. In comparison, the working culture and the quality levels in welding of Takoradi Steel Company is better than GMFCL but similar to that of REF Engineering and Enas.

Consequently, Takoradi Steel Company claimed that its quality and productivity levels according to domestic and international competitiveness are high and moderate respectively. Also, in the aspect of benchmarking, the company claimed that its product and performance level according to domestic competitiveness is high and international competitiveness is moderate.

However, from the observations noted, it can be said that the productivity levels of Takoradi Steel Company according to domestic and international competitiveness is moderate and low respectively since the mindset towards productivity is low and also systems have not been implemented to help maintain productivity levels and to improving productivity levels in future. Relying on the system of employing casual workers to increase productivity levels is unsustainable and ineffective.

4.2.12 Case 12: Wayoe Engineering Services Limited

Wayoe Engineering is a Ghanaian domestic engineering and construction service company located in Takoradi in the Western Region of Ghana. Wayoe Engineering belongs to the construction industrial sector. The main operations performed include fabrication and welding, structural steel works, piping, construction of tanks, erection of steel structures, and general engineering works.

About thirteen years of effective service rendering, Wayoe Engineering has been performing welding operations mostly for the mining industry, oil and gas industry, and companies in the chemical industry. Currently, Wayoe has about fifty customers and their needs are prioritized according to delivery time, quality and cost. The main facilities include a 1,000 m^2 welding workshop, welding machines, drilling machine, cutting machine, welding generator, truck-mounted cranes, and forklift. Figure 29 shows the main welding workshop of Wayoe.

Figure 29. Wayoe Engineering welding workshop.

Due to limitations in materials handling and storage facilities, materials for welding operations such as metal are often stored outside the welding workshop and eventually exposed to environmental climatic conditions such as rainfall. Figure 30 illustrates a typical scenario of how materials are handled in Wayoe Engineering.

Figure 30. Wayoe Engineering material handling and storage facility.

Welding jobs are bound to be done on the floor instead of welding on a bench. The consequences associated to this practice could lead to weld quality problems. Moreover, material preparation before welding with regards to this practice requires some time and effort. Time is absolutely wasted in the process of doing things in the welding workshop. Data obtained from the measurement of variables pertaining to welding quality, welding productivity and welding economy of Wayoe Engineering is presented in Table 13.

Table 13. Wayoe Engineering Company Data.

Quality	Research Item	Response
Q1	Company welding quality policy or welding quality and assurance standards	• No welding quality policy but complies with customer/ client standards provided
Q2	Assessment of weld quality	• Strength • Toughness • Distortion/ dimensional • Surface finish
Q3	Welding quality measures or testing	Non-Destructive Testing • Visual Test – scale 5 • Penetrant Test – scale 4 • Magnetic Particle Test – scale 1
Q4	Welding processes used	• Shielded Metal Arc Welding- scale 5 • Gas Tungsten Arc Welding – scale 1 • Gas Metal Arc Welding (MIG/MAG) – scale 1
Productivity	**Research Item**	**Response**
P1	Welding productivity measure used	• Rate of defect
P2	Metals used in company's welding operations	• Mild steel • Stainless steel • Aluminum • Carbon steel • Cast iron
P5	Welding technique used in company's welding operation	• Manual welding • Mechanize welding
P10	Number of welding personnel	• Permanent – 20
Economy	**Research Item**	**Response**
E1	Company's welding operations turnover	• Year 2010 – Not provided • Year 2011 – Not provided • Year 2012 – Not provided
E2	Company's welding cost system	• Cost of weldment
E3	Factors considered when estimating cost of welding	*Labor cost *Consumable cost *Material cost *Joint design *Joint position *Overhead cost * Environmental cost *Postweld treatment
E10	Wages of welding personnel	• Not provided
E12	Funds towards welding related research and development per year	• No funds

To some extent, even though welders in this company have welding quality mindset the actual welding quality practices are not fully emulated. The standard of work quality in this company as compared to other companies such as Orsam Limited and Group Five is therefore low. Welding personnel in this company need extensive training and education despite the experiences some welders have acquired through their working lives.

In the aspect of benchmarking, Wayoe claimed that its product and performance level according to domestic competitiveness is high while international competitiveness is moderate. Wayoe further claimed that its quality and productivity levels according to domestic competitiveness are high and international competitiveness is moderate.

However, from the observations noted, it can rather be said that the quality and productivity levels of Wayoe according to domestic and international competitiveness is moderate and low respectively since systems have not been implemented to help maintain productivity levels and to improving productivity levels in future. Relying on the system of employing casual workers to increase productivity levels is unsustainable and ineffective.

4.3 Data Analysis

In this sub-chapter, data obtained from the case study is analyzed. Various elements that were considered include: company industrial sector of operation; customer industry of operation; welding quality measurements; welding productivity measurements; and welding economic measurements.

However, the statistical values shown in the analysis might not show true reflections for the overall population since the sample size chosen was relatively small. Nevertheless, the goal of the case study is not towards statistical generalization of the sample size but rather analytical generalization.

Moreover, supporting research items which were used to sought opinions from the companies according to their knowledge about welding quality, productivity and economy issues in welding operations are represented as Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12; P3, P4, P6, P7, P8, P9, P11, P12, P13, P14, P15; and E4, E5, E6, E7, E8, E9. The responses to these research items are shown in appendix 3.

4.3.1 Company Industrial Sector of Operation

Figure 31 illustrates the industrial sectors of companies operating in the Ghanaian metal production and manufacturing industry. Analytical values in relation to responses obtained shows that all the 12 (100%) companies operate in the construction industrial sector, 2 (17%) companies operate in the capitalized repair and maintenance industrial sector and also the heavy industrial manufacturing sector and 1 (8%) company operates in the light industrial manufacturing sector. However, some companies indicated more than one industrial sector of operation. Nonetheless, it is evident that the level and extent of welding operations in the various industrial sectors afore-mentioned corresponds to the amount of companies operating in that industrial sector. The high level of welding operations in the construction industrial sector can be attributed to increasing infrastructural works prevailing in the country currently. However, the low level of welding operations in both the heavy and light industrial manufacturing sectors is as a result of lack of effective production and manufacturing systems.

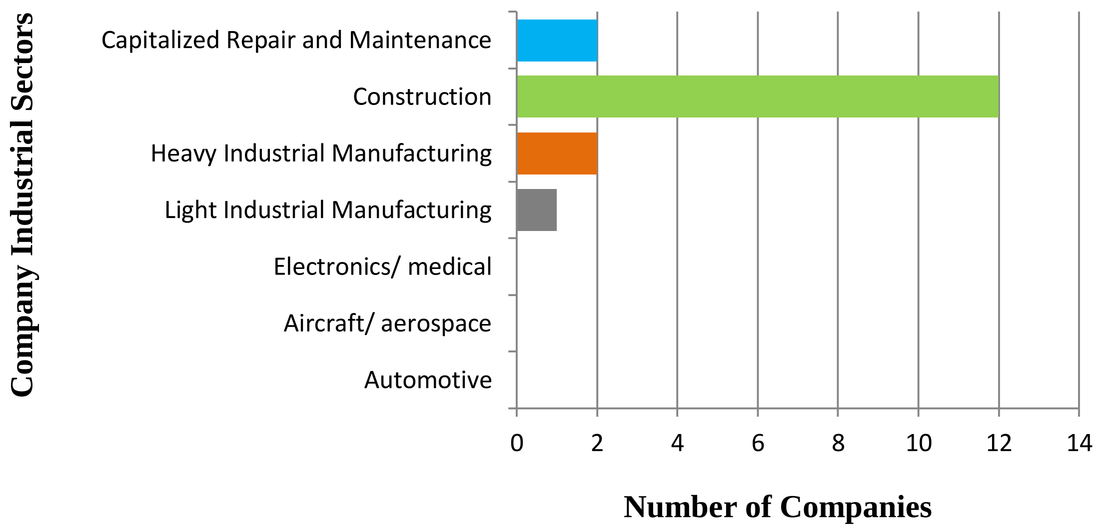

Figure 31. Company industrial sector of operation.

On the other hand, companies operating in industrial sectors such as the electronic / medical, the aircraft / aerospace, and the automotive were not captured since there is no major production and manufacturing works in these industrial sectors. However, welding operations to somewhat are carried out in these industrial sectors.

4.3.2 Customer Industry of Operation

Customer industry of operation as indicated by companies operating in the Ghanaian metal production and manufacturing industry is shown in Figure 32. Analytical values in relation to responses obtained shows that 10 (83%) of the customers operate in the oil and gas industry, 7 (58%) of the customers operate in the mining industry, 3 (25%) of the customers operate in the food industry and 4 (33%) of the customers operate in the energy industry.

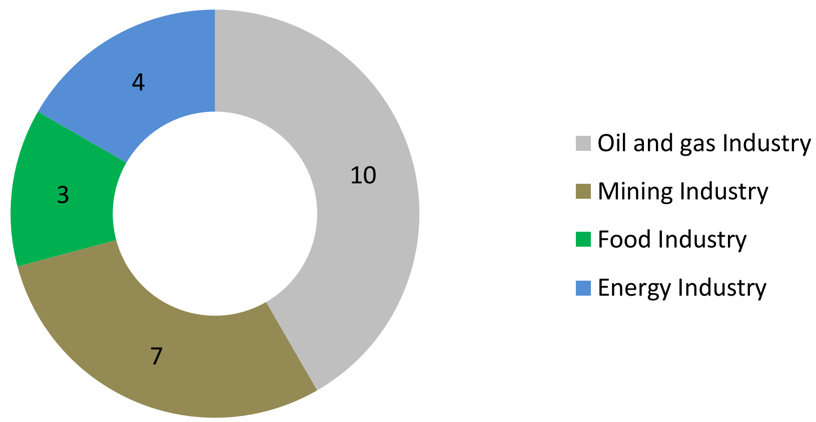

Figure 32. Customer Industry of Operation.

The large amount of customers in the oil and gas industry as well as the mining industry is as a result of recent oil and gas reserve discoveries and the large scale gold mining activities respectively. It is therefore no wonder that companies operating in the construction industrial sector outnumber those in other industrial sectors. Consequently, customers operating in the energy industry as well as the food industry are relative small as compared to customers operating in the oil and gas and mining industries. This phenomenon clarifies why there are few companies operating in both the heavy and light industrial manufacturing industries. Thus the ability to build or manufacture products in such industrial sectors is very low. For example, the current energy crisis in Ghana can be linked to the inability of companies providing services to the energy industry to produce or manufacture equipment or machines to generate electricity. Also, products manufactured to be used in the food industry are very limited resulting in the inability to process most of Ghana’s agricultural products. Nevertheless, the production and manufacturing of such equipment and machines needed in these industries depends somewhat on welding operations extensively.

4.3.3 Company Welding Quality Policy or Welding Quality Assurance Standards

The level of welding quality policy or welding quality assurance standards implementation or practiced in companies performing welding operations is shown in Figure 33. Analytical values in relation to responses obtained shows that 9 (75%) companies do not have welding quality policy nor are certified under any welding quality assurance standards, 2 (17%) companies operate under the occupational health and safety (OHSAS 18001) standard, 2 (17%) companies operates under the ISO 9001 standard and 1 (8%) company operates under the ISO 3834 welding quality standard.

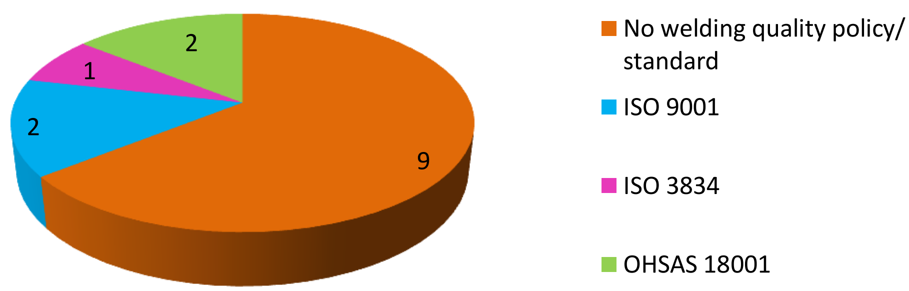

Figure 33. Company Welding Quality Policy or Welding Quality Assurance Standards.

On the other hand, companies which do not have any welding quality policy nor certified under any welding quality assurance standard do perform welding operation under standards provided to them by their customers. The system is such that most often customers provide welding standards to companies before welding operations commence. This implies that if no welding standard is provided, welding operations are carried out under no quality standard or welding quality policy. Moreover, welding quality standard if provided, are obtained from third parties known as welding certification bodies. The notable international welding certification bodies are the American Bureau of Shipping (ABS), Bureau Veritas (BV), British Standard (BS), American Society of Mechanical Engineers (ASME), and some domestic certification bodies such as Sonic Control Engineering, and Probe Engineering. This process of acquiring welding standards also involves certification of welders purposely to assess weld quality.

Also, even though companies operate under standards such as ISO 9001 and OHSAS 18001, the welding quality requirements of welded products cannot compromise with such standards. However, those companies operating under the afore-mentioned standards also operate under standards provided by their customers.

4.3.4 Assessment of Weld Quality

Weld quality assessment as indicated by the companies is shown in Figure 34. Analytical values in relation to responses obtained shows that 12 (100%) companies assess weld quality by surface finish of the weld joint, 9 (75%) companies assess weld quality by the strength of the weld joint and 7 (58%) of the companies assess weld quality by the toughness of the weld joint as well as the distortion of the weld joint or the weld bead.

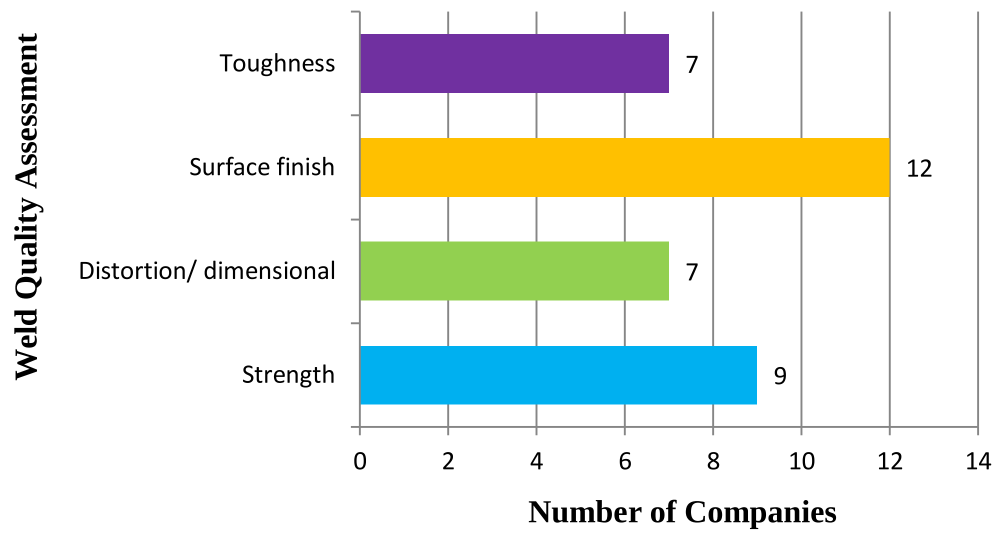

Figure 34. Assessment of Weld Quality.

It is therefore obvious that surface finishing is the commonly used method in assessing weld quality by the companies. On the contrary, assessment of weld quality by its strength, toughness and distortion is not a usual practice by the companies but upon request from their customer. In that sense, destructive tests are performed on the welded joints to assess weld quality. The process associated with destructive testing of welded joints is such that the company providing welding service brings a number of welding personnel to be tested by a certification body proposed by the customer. Welders are made to perform specific welds and after, the weld joint are tested either through bend test, tensile test, hardness test or charpy impact test. Welders who pass the test are therefore certified to work under a specific project. The certification body therefore takes full responsibility of WPS and WPQR documentation. However, in projects were destructive test is not needed some non-destructive tests are performed to assess weld joint quality.

4.3.5 Welding Quality Measures or Testing

Welding quality measurements or testing performed by the companies is depicted in Figure 35. Analytical values in relation to responses obtained shows that 12 (100%) companies perform visual test, 8 (67%) companies perform penetrant test (also done by certification body), 2 (17%) companies perform pressure test, 10 (83%) companies perform X-ray test (mostly done by certification body), 9 (75%) of the companies perform magnetic particle test (mostly done by certification body), 8 (67%) companies perform ultrasonic test (mostly done by certification body), and 8 (67%) companies perform radiography test (mostly done by certification body) .

Test such as pressure test, X- Ray test, ultrasonic test, radiography test and magnetic particle test are done upon customer request. However, X-Ray test is mostly preferred by the customers.

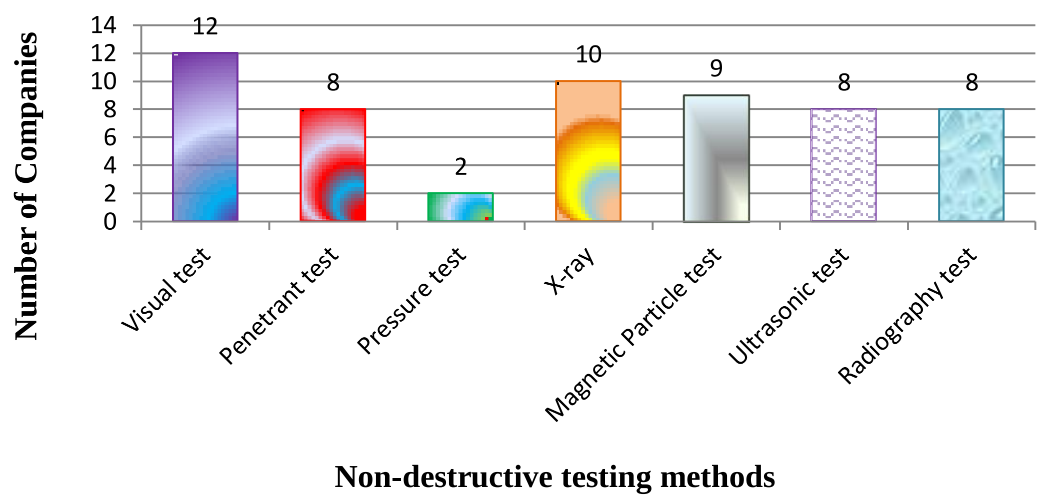

Figure 35. Non-destructive testing methods.

Also, due to the large number of customer operating in the oil and gas industry, the used of X-ray test is comparatively high to that of visual test. This is because of the increased amount of pipe welding work. The use of magnetic particle test and penetrant test are comparatively high to that of X-ray because of the increasing steel structural and erection works in both the oil and gas industry and the mining industry. Although some companies build tank and tank farms, the use of pressure test is relatively low as compared to some other test methods. Visual test however can be termed to be the most commonly used method in measuring weld quality.

4.3.6 Welding Processes Used

The welding process used as indicated by the companies is depicted in Figure 36. Analytical values in relation to responses obtained shows that 12 (100%) companies use SMAW, 6 (50%) companies use TIG, 5 (42%) companies use MIG/MAG, 3 (25%) companies use oxyacetylene welding, 1 (8%) company uses SAW as well as FCAW.

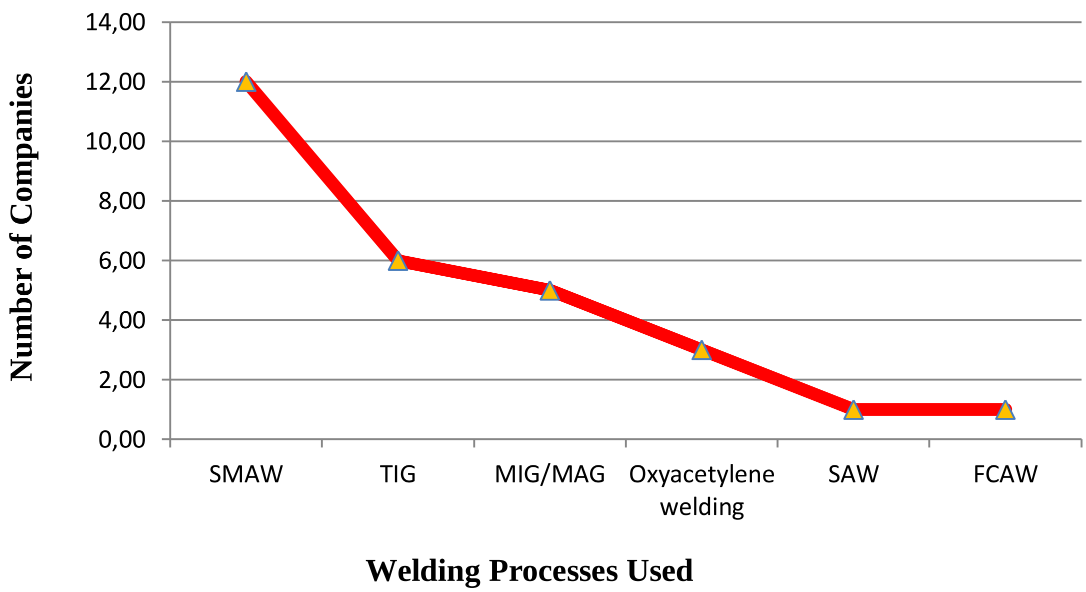

Figure 36. Welding Processes used in companies.

The high level of usage of SMAW is associated to its low investment cost and the area of application. Also it is as a result of it flexibility and familiarity, the type of dominant materials applicable for its use, and availability of workforce. As already noticed, most of the welding operations are carried out in the construction industrial sector, thus favoring the usage of SMAW. However the usage of TIG and MIG/MAG welding processes is comparatively higher than the usage of oxyacetylene welding, SAW and FCAW even though investment cost and usage cost (equipment cost, shielding gas and other consumable cost) in the former processes is a bit high than the investment cost in the latter processes. The main reason to this is due to the area of application of the processes and the suitable material availability. The trend in the usage of welding processes can be attributed to investment cost, area of application, types of dominant materials and the availability of workforce.

4.3.7 Welding Productivity Measurement

The welding productivity measure used by the companies is illustrated in Figure 37. Analytical values in relation to responses obtained shows that 12 (100%) companies measure welding productivity by rate of defects and 3 (25%) companies measure welding productivity by performance versus standard time. The standard time refers to company’s own working time set for completing specific welding tasks. In that sense, performance versus standard time used by some companies is a means to compare the rate of production or manufacturing to a pre-defined standard time set by the company. Moreover, because of the mindset that welders will rush on jobs and produce defective weld joints and less quality works, welding productivity measurement such as performance versus standard time is less practiced in the companies.

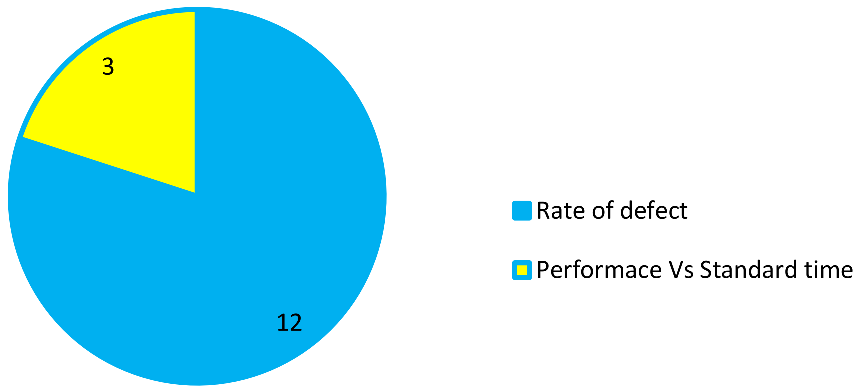

Figure 37. Welding productivity measurement.

On the other hand, the rate of defect used in welding productivity measurement by most companies is a means to ensure defect free welding joints, thus eliminating rejects, reworks and scraps in the production or manufacturing chain. This practice however results in, there are a lot of delays in the production or manufacturing process due to unnecessary movements as a result of poor workshop layout and the condition of material storage places, and long arc time per weldment, thus resulting in wide weld beads.

4.3.8 Materials Used in Welding Operations

The materials used in welding operations as indicated by the companies are shown in Figure 38. Analytical values in relation to responses obtained shows that 11 (92%) companies use mild steel, 7 (58%) companies use stainless steel, 5 (42%) companies use aluminum, 3 (25%) companies use cast iron, 4 (33%) companies use high carbon steel and galvanized steel, 2 (17%) companies use HDPE pipes, 1 (8%) company uses super chromium and 3 (25%) companies use Hardox plate in welding operations.

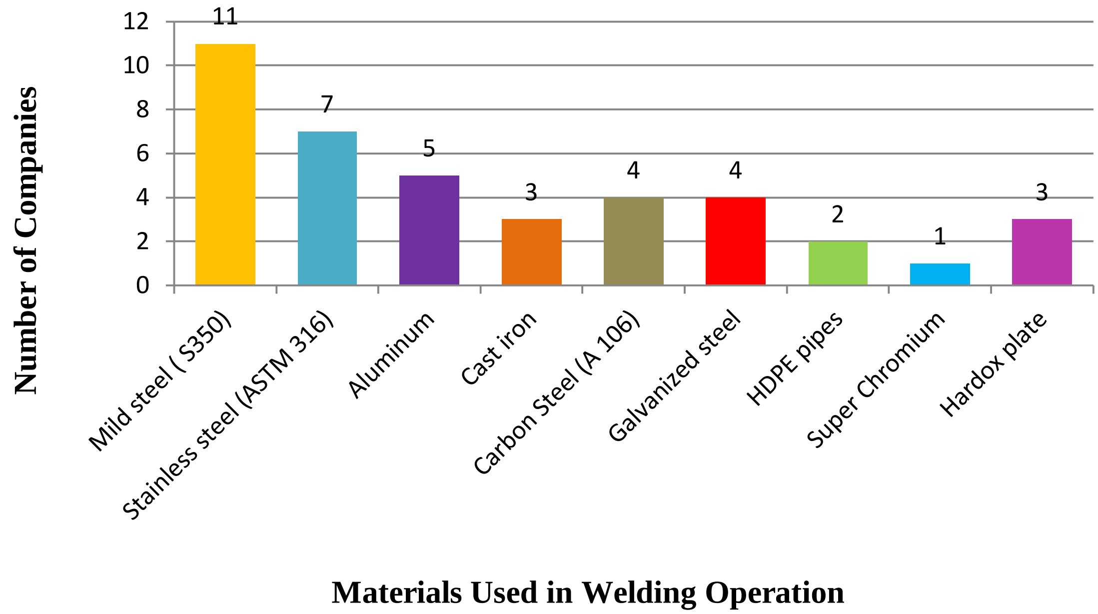

Figure 38. Materials used in welding operations.

The high usage of mild steel as compared to other metals is because of its suitability for most fabrication and welding work, relative cost, availability, and the dominant welding process suitable for its weldability. Although low carbon steel (mild steel grade S355) is the commonly used metals, in some environment such as in the coastal areas stainless steel (ASTM 316, 304) and galvanized steels are mostly used since they can without to some extent the corrosive environment.

However, the trend in metal selection and usage in welding operations is highly characterized by the type of product to be produced or manufactured, relative cost of the metal, availability of the metal, suitable welding processes, and the environment where the product would be used.

4.3.9 Welding Techniques in Welding Operation

Welding techniques used in welding operations as indicated by the companies are illustrated in Figure 39. Analytical values in relation to responses obtained shows that 12 (100%) companies employ manual welding technique, 3 (25%) companies employ semi-automatic welding technique and none employs automatic welding and robotic welding techniques.

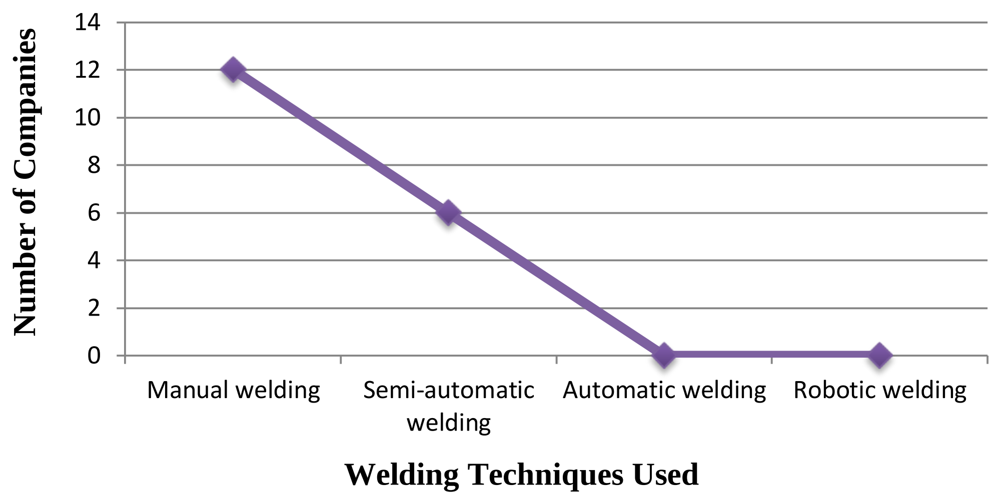

Figure 39. Welding Techniques in Welding Operation.

It is therefore evident that manual welding technique is the commonly used welding technique by the companies. The obvious reason is low initial investment cost in equipment, machines and infrastructure as compared to the other welding techniques. Although the initial investment costs and other considerable factors pertaining to the use of automatic welding and robotic welding techniques are high, integrating them with manual welding technique would increase productivity substantially.

However, there is a general mindset that, introducing such sophisticated welding techniques will affect welder employment rate as well as lowering the skill of welders.

Nevertheless, manual welding technique is a cheap means to utilize the full potentials of welders.

4.3.10 Welding Operations Turnover

The turnover in welding operations in the companies is expected to grow steadily in the next five to ten years. A projection of welding operation turnover in the companies is depicted in Figure 40. Analytically, the currently average turnover of medium to large companies operating in the Ghanaian metal production and manufacturing industry is about € 5 Million as of 2012.

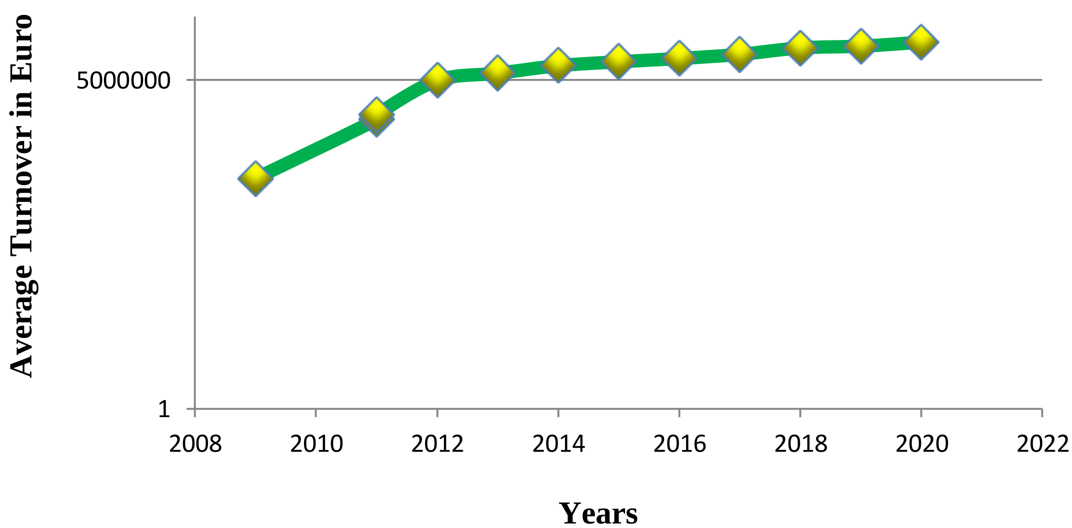

Figure 40. Welding Operations Turnover.

Even though the average turnover of small to medium sized companies is not up to the level as shown in Figure 40, the booming infrastructural works in the oil and gas industry, mining industry, food industry, energy industry and other industries predicts a positive growth in welding operations turnover. It is however analytically projected that by 2018 the average turnover of companies into massive welding operations shall be approximately € 23 Million.

4.3.11 Welder Average Salary

The average salary of a welder as illustrated in Figure 41 is about € 300 per month as at 2013. This base salary rate is however dependent on the experience, qualification and skill of the welder. Analytically it is predicted that by the year 2018, the average salary of a welder shall be € 500.

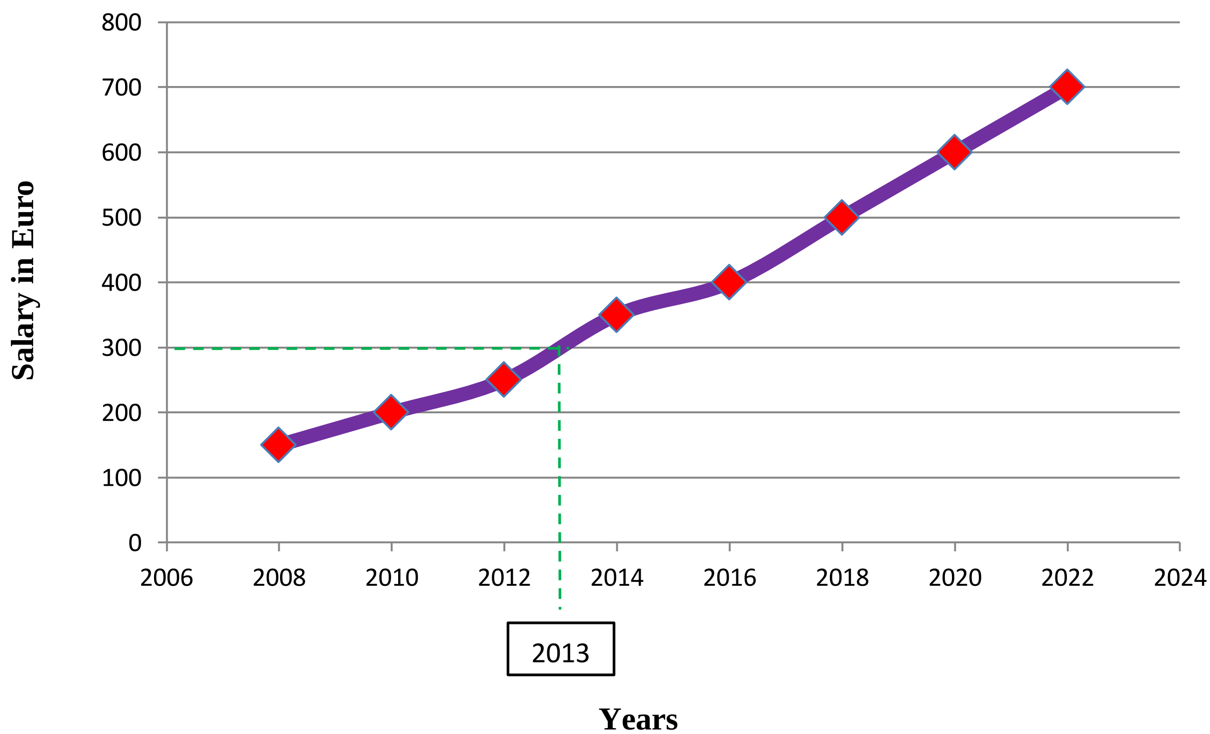

Figure 41. Welder Average Salary.

Interestingly, some welders earn slightly more than others due to the considerably factors afore-mentioned and also the industrial sector where the welder works. An obvious example is welders working offshore. There is high disparity in the salary range for welders working in such environment due to the nature of the welding jobs.

4.3.12 Supporting Research Questions

All the twelfth companies interviewed gave a “yes” response to most of the supporting questions pertaining to welding quality as shown in appendix 3. The only question which received “yes” and a “no” answer was about welding quality manual. It was such that three companies responded “yes” while nine companies responded “no” to the question. Also all the twelfth companies responded that their quality levels are high in terms of domestic competitiveness. However, in terms of international competitiveness, six companies responded to be high while five responded to be moderate. None of the companies responded to be competitively low.

In addition, all the twelfth companies interviewed gave a “yes” response to most of the supporting questions pertaining to welding productivity as shown in appendix 3. The only question which received “yes” and a “no” answer was about welding productivity chart. It was such that four companies responded “yes” while eight companies responded “no” to the question. Also all the twelfth companies responded that their productivity levels are high in terms of domestic competitiveness. However, in terms of international competitiveness, four companies responded to be high while seven responded to be moderate. None of the companies responded to be competitively low.

Surprisingly, all the twelfth companies interviewed gave a “yes” response to supporting questions pertaining to welding economy as shown in appendix table 3. Also all the twelfth companies responded that their product performance / benchmarking levels are high in terms of domestic competitiveness. However, in terms of international competitiveness, five companies responded to high while six responded to be moderate. None of the companies responded to be competitively low.

5. NIGERIA SURVEY DATA PRESENTATION AND ANALYSIS

The survey conducted in welding operations in Nigeria did not capture direct information from companies as mentioned earlier in chapter 3. The information presented herein is therefore classified as a hypothetical data but not a survey data. The hypothetical data obtained from welding operations in Nigeria however cover areas such as industrialized regions, welding industrial sectors, production and manufacturing industrial sectors where welding is extensively used, type of metal products manufactured, the kind of manufacturing systems deployed, measurements in welding quality, productivity and economy.

5.1 Nigeria Welding Industry

The Federal Republic of Nigeria, popularly known as Nigeria comprises of 36 states and a common territorial federal city, Abuja. Welding operations in Nigeria is comparatively huge as a result of the large number of states involved in the operation and the frequent campaigns made by the Nigerian Institute of Welding (NIW) which is a member country of IIW. Currently, welding operations in the Nigerian Welding Industry is extensive in notable states such as the River State, Delta State, Bayelsa State, Akwa Ibon State and the Cross River State due to the high level of industrialization.

Welding industrial sectors in the Nigerian Welding Industry consists of the formal and the informal welding sectors. Although quantifiable amount of enterprises in the informal welding sector operate in less industrious areas, some of them however operate in industrious areas. On the other hand, it is vague to say that all companies in the formal welding sector operate in industrious areas.

Welding operations in enterprises in the informal welding sector are carried out by personnel with little or no educational background and qualification. They are called non-professional welders but somewhat experience in the welding trade. The major products manufacture by this group includes chairs, bill boards, wheel barrows, coal port, iron gates, storage tanks, containers, burglar proof doors and windows, block machines. Majority of repair work is also done by this group due to the versatility they possess in diverse ways. Common manufacturing tools such as chisel, hammer, hand drilling machines, etc. are used in the manufacturing process.

With regards to welding operations in the formal welding sector, most of the companies operate mainly in the construction industrial sector, heavy industrial manufacturing sector and the capitalized repair and maintenance industrial sector owing to the large number of customer operations in the oil and gas industry. However, the erection of steel structures, construction of pipelines, and the repair of offshore structures are paramount in the said industrial sectors. Nonetheless, customer current operations in the railway and local automotive assembly units have attracted some level of welding activities but have not fully received credence as industrial sectors where welding is highly utilized. Manufacturing processes are carried out with the help of lathe machines, bending machines, cutting machines, drilling machines. On the other hand, very few companies employ computer numeric control (CNC) machines in their manufacturing process.

5.2 Welding Quality Measurement

The aspect of welding quality has received some level of attention in the Nigerian Welding Industry. Even though most of the companies don’t have welding quality policies and also not certified under welding quality and assurance standards, some emulate requirements according to ISO 3834 welding quality standard. The quality of a weld joint is tested to ensure its compliance with the said standard. However, weld joints are tested prior to customer request. A certification body is always introduced in such case. Weld joints are therefore assessed by its strength, toughness, and or distortion through destructive test such as tensile test, hardness test, fracture test, charpy impact test or bend test. In cases where there is no request from the customer, weld joint is somewhat assessed by its surface finish.

Moreover, apart from destructive tests, some non-destructive tests requested by the customer are also performed. These include ultrasonic test, magnetic particle test, penetrant test, radiography test and visual test. Third party, known as a certification body, as already mentioned is sub-contracted by the customer in the testing process. The certification body, the customer and the company to perform the welding operation agrees on a welding procedure specification (WPS) for a particular welding task and also documents the welding procedure qualification records (WPQR) accordingly. However, the companies mostly practice visual testing due to the cost involve in performing the other non-destructive tests.

The welding processes used by the companies include SMAW, TIG, MIG/MAG, FCAW, SAW and oxyacetylene welding. Moreover, SMAW process is commonly used due to its suability for most jobs and less expensive when compared with other processes. The overall quality level of companies according to domestic competitiveness is high but moderate according to international competitiveness.

5.3 Welding Productivity Measurement

Welding productivity measurement in the companies is based on rate of defect of a welded component and also welds completed per time period. The aim of using rate of defect as welding productivity measurement is to reduce reworks, rejects and scraps. Welders are therefore enforced to weld accurately to actually eliminate weld defects. In addition, the method of using welds completed per time period in measuring welding productivity by the companies is to know the productivity of the welders. Welder however, estimates the time of start and completion of a welding operation. There is therefore no welding productivity chart governing welding operation in the companies.

Due to the nature of jobs and the kind of projects handled by most companies, the predominant metals often used for such works are steels and aluminum. Welding operations are normally carried out by manual welding techniques since welding techniques such as semi-automatic, automatic and robotic are expensive to deploy. Although manual welding technique is mostly practiced, training of welders in companies is apparently very low. In this sense welders find their own means to train themselves mostly undergoing apprenticeship training from a "senior" or experienced welder. The actual fact is that, companies do not want to retain welders but somewhat prefer to employ them on short contract so that welder training would not be their responsibility.

5.4 Welding Economy Measurement

The aspect of welding economy measurement is very critical in every company which performs welding operations. This is because of factors which need considerations in estimating cost of welding. These include: labor cost; consumable cost; material cost; cost in joint design; cost in preparation of materials; overhead cost; environmental cost; postweld treatment cost; and ultimately the welding cost system been deployed by the company.

With all these factors under consideration, the companies prefer to use cost of specific weld as their welding cost system. This simple implies that the cost of any welding operation performed is priced according to the specific or each weld made either by size or length. The wages and salaries of welding personnel are greatly influence by this welding cost system in place. Welding personnel are mostly paid per job but not on monthly bases. However, those few welders (at most five) employed as permanent staff receive salaries ranging from €250-300 per month. The unwillingness of companies to retain large number of welders is due to uncertainty of the contractual projects they get, thus avoiding the tendency of paying monthly salaries to welders.

6. CAMEROON SURVEY DATA PRESENTATION AND ANALYSIS

The survey conducted in welding operations in Cameroon did not capture direct information from companies as mentioned earlier in chapter 3. The information presented herein is therefore classified as a hypothetical data as in the data obtained in the case of Nigeria. The hypothetical data obtained from welding operations in Cameroon however cover areas such as industrialized regions, welding industrial sectors, production and manufacturing industrial sectors where welding is extensively used, type of metal products manufactured, the kind of manufacturing systems deployed, measurements in welding quality, productivity and economy.

6.1 Cameroon Welding Industry

The Federal Republic of Cameroon, commonly known as Cameroon has 10 provinces and one national capital, Yaoundé located in the centre province. The most industrialized provinces are the South-West (Buea as provincial capital), Littoral (Douala as provincial capital) and Centre (Yaoundé as provincial capital). The state of welding operations in these regions is huge as a result of onshore and offshore metal work activities especially in the Rio del Rey oil and gas basin, Douala / kribi-camp basin and also the Logone-Birni basin in the northern part of Cameroon.

However, these metal work activities are carried out both in the informal welding sector and the formal welding sector of the welding industry of Cameroon. Welders who operate in the informal welding sector are classified as non-professional welders while those operating in the formal welding sector are classified as professional welder. The products manufactured by the non-professional welders include iron gates, windows, high tension poles, buckets, chairs, coal pots, burglar proof doors, bill boards, storage tanks, wagon and chassis, etc. as well as performing major repair works. Manufacturing tools such as chisel, hammer, hand drilling machines, etc. are usually used in the manufacturing process.

In the formal welding sector, products manufactured depend on the metal production and manufacturing industrial sector and customer industry of operation. As most customers operate in the oil and gas industry, the notable industrial sectors happens to be the construction industrial sector, capitalized repair and maintenance industrial sector, and the heavy and light industrial manufacturing sectors. Moreover, shipbuilding and repairs, piping, construction of oil and gas storage tanks, cylinders, steel beams, boilers, maintenance of oil rig and barges stands out to be the major works in these industrial sectors as illustrated in Figure 42.

Figure 42. Welding manufacturing in Socafer A.S, Cameroon:Tanks, cylinders and beam structures (courtesy of Paul Kah, Lappeenranta University of Technology).

Manufacturing processes are carried out with the help of lathe machines, bending machines, cutting machines, drilling machines. On the other hand, very few companies employ CNC machines in their manufacturing process.

6.2 Welding Quality Measurement

Although most of the companies performing welding don’t have welding quality policies and also not certified under welding quality and assurance standards, the quality of a weld joint is measured so as to ensure its compliance with standard such as the ASW codes for structural works and American Petroleum Institute (API) or ASME for piping work. However, these standards are used prior to customer request. A certification body is always sub-contracted in such case. Weld joints are therefore assessed by its strength, toughness, and or distortion through destructive test such as hardness test, tensile test, charpy impact test or bend test. In cases where there is no request from the customer, weld joint is somewhat assessed by its surface finish.

Apart from destructive tests, some non-destructive tests placed as a request by customers are also performed. These include radiography test, ultrasonic test, magnetic particle test, penetrant test, and visual test. A third party, known as a certification body, as already indicated is sub-contracted by the customer in the testing process for certification and issuance of WPS and also performing documentations of WPQR. However, the companies performing welding task mostly practice visual testing due to the cost involve in performing the other non-destructive tests.

Welding processes used by the companies include SMAW, TIG, MIG/MAG and oxyacetylene welding. Moreover, SMAW process is normally used due to its suitability for most jobs and its low investment cost. The overall quality level of companies according to domestic competitiveness is high but moderate with regards to international competitiveness.

6.3 Welding Productivity Measurement

Welding productivity measurements in the companies are based on rate of defect of a welded component. The sole aim of employing rate of defect as welding productivity measurement is to reduce reworks, rejects and scraps. Welders are therefore entrusted to weld meticulously to eliminate weld defects. Welders however, estimate the time of start and completion of a welding operation. There is therefore no welding productivity chart controlling welding operation in the companies. However, in the process of manufacturing defect free products, welders tend to spend too much time on welding. This is as a result of long arcing time, incorrect positioning of welding equipment and consumables in the workshop, and poor layout of the workshops.

Due to the nature of jobs and the kind of projects handled by most companies, the predominant metals grades often used for structural works are S235 or S355. Also for piping works ASTM106, ASTM105, SS316L, SS304L or API 5L Grade B are mostly used. Additionally, aluminum are somewhat used as base material too. Furthermore, welding operations are mostly carried out by manual welding techniques as shown in Figure 43. This is because welding techniques such as semi-automatic, automatic and robotic are expensive to deploy. Even though manual welding technique is used in most companies, training of welders to familiarize with this technique is apparently very low.

Figure 43. Manual welding of a steel grid structure in Socafer A.S, Cameroon (courtesy of Paul Kah, Lappeenranta University of Technology).

6.4 Welding Economy Measurement

Welding economy issues are very critical in every company which performs welding operations. Welding cost system deployed by the companies is cost of weldment where welding jobs are priced before the actual welding operation starts. The considerable factors involved in this welding costing system includes labor cost; consumable cost; material cost; cost in joint design; cost in preparation of materials; overhead cost; environmental cost; and postweld treatment cost.

The wages and salaries of welding personnel are influenced by the welding cost system deployed. It is such that in-experienced welders are paid monthly salaries between €150-200 per month while experienced welders receive between €250-390 per month. The welding economy issues in companies fluctuate due to uncertainties in the cost of materials and other consumables. Companies are therefore unwilling to retain large number of welders, thus avoiding the tendency of paying monthly salaries to welders.

7. FINDINGS AND DISCUSSIONS

This chapter presents discussion of findings of the entire research work (theoretical findings and the empirical findings). In order to provide relevant information to the objectives of this thesis work, the findings are however discussed with respect to the research questions constructed for the empirical research work. Moreover, findings from the theoretical part of the research are synthesized with the findings obtained in the empirical research.

7.1 Metal Production and Manufacturing Industrial Sectors

Welding activities in West African States such as Ghana, Nigeria and Cameroon have been revealed through this research work. Analytically, it was found that metal production and manufacturing industrial sectors where welding is extensively used in Ghana are the construction industrial sector, capitalized repair and maintenance industrial sector and the heavy industrial manufacturing sector. Hypothetically, it was found that metal production and manufacturing industrial sectors where welding is extensively used in Nigeria and Cameroon was the same as in Ghana. These similarities found could be assumed or associated to the kind of products manufactured as well as the industries customers operate in. In Ghana, most customers were found to operate in the oil and gas industry. Interestingly, the assumption made corroborates with the findings obtained from Nigeria and Cameroon, thus indicating that majority of customers operates in the oil and gas industry.

7.2 Metal Products Manufactured

Manufacturing of metallic products by means of welding usually depends on the welding sector. The classifications of welding sectors as noticed from the three West African States are the formal welding sector and the informal welding sector. The formal welding sector automatically comprises of small, medium and large companies operating in the metal production and manufacturing industrial sectors while the informal welding sector consists of micro enterprises utilizing welding as a manufacturing process. In Ghana it was found that most companies operating in the formal welding sector do not manufacture or produce specific products for commercial purposes but engage extensively in project (customized) manufacturing.

However, few companies manufacture or produce specific products such as tanks for liquid storage, and agro-processing equipment. Surprisingly, this finding somewhat substantiates the findings obtained from both Nigeria and Cameroon. Even though manufacturing of specific products is not the main aim of companies in these manufacturing industrial sectors, general activities in the various sectors are performed such as shipbuilding and repairs, bridge and tunnel construction, pipeline construction, structural steel erection, etc. This finding corroborating with the findings in the literature that welding is used in industrial sectors such as the light industrial manufacturing, heavy industrial manufacturing, construction and the capitalized repair and maintenance industrial sectors.

On the other hand, it was found that enterprises operating in the informal welding sector across Ghana, Nigeria and Cameroon manufacture the same kind of products. Examples of such products are wheel barrow, bill board, metallic gate, metallic chair, burglar proof door and window, block machine, coal pot, car seat, bucket, wagon and chassis, etc. This indicates that, the potential of welding technology has not been exploited to the fullest due to the kind of products manufactured and the disproportional usage of welding in both welding sectors in the West African States.

7.3 Metal Production and Manufacturing Systems Deployed

Manufacturing systems deployed in the informal welding sector in Ghana was found to be very basic in the sense that common hand tools such as chisel, hammer, hand drilling machine, grinding machine and locally manufactured welding machines were used in the production and manufacturing process. Although findings pertaining to this subject captured from Nigeria and Cameroon seems ambiguous, it can however be assumed that enterprises in the informal welding sector of these countries deploy the same basic manufacturing system as a result of the similar products manufactured and the kind of welding practices deployed in the informal welding sector.

Conversely, the level of manufacturing systems deployed in the formal welding sector in Ghana was found to be higher than in the informal welding sector. Equipment such as bending machines, lathe machines, cutting machines, drilling machines, and welding machines were predominant. However, very few companies utilize CNC machines in their manufacturing process. These findings are somewhat consistent with the hypothetical information obtained from both Nigeria and Cameroon.

These findings therefore indicate that, advanced manufacturing systems such as flexible manufacturing systems, Just In Time, and Lean manufacturing systems are not used in companies or enterprises operating under these two welding sectors. It can therefore be presumed that, work flow could be slow, thus lowering productivity in welding operations. However, one of the issues that emerge from these findings is the power supply problem in the West African states. Companies are forced to purchase generator sets to power their equipment and machines during manufacturing. It is obvious that there would be high cost involved if advanced manufacturing systems as mentioned earlier are deployed. So in other to minimize such cost, companies prefer to use the normal system even though they would prefer to use advanced manufacturing systems in their manufacturing and production operations.

7.4 Welding Quality Measurement System in Companies

The system used in measuring welding quality involves weld quality assessment methods, types of test performed on weld joint, types of welding processes used in welding operations, and whether the entire system is certified under a welding quality standard or quality assurance standard. In Ghana, it was found that majority of the companies do not operate under any welding quality standard or quality assurance standard nor have a welding quality policy. Only few companies are certified under the ISO 3834 standard, the ISO 9001 standard as well as the OHSAS 18001 standard. These findings as to whether some companies in Nigeria and Cameroon are certified under the ISO 3834 standard, the ISO 9001 standard as well as the OHSAS 18001 standard were not consistent with the findings as in the case of Ghana. However, the findings about companies not operating under any welding quality standard or quality assurance standard nor having a welding quality policy corroborates with the findings of Nigeria and Cameroon. These findings clearly indicate why certification bodies are involved in issues concerning welding quality testing and assessment.

In Ghana, it was further found that the quality of a weld joint performed by welders is often assessed by a certification body prior to customer request. The weld joint performed is assessed by its strength, toughness, distortion or surface finish conforming to standards such as the ASME, ABS, BS, API, ASW, and ISO 3834 provided by the certification body. This assessment process is mostly accompanied by destructive tests on the welded joint. The common destructive tests performed are bend test, tensile test, charpy impact test, and hardness test. In addition, some non-destructive tests such as visual test, magnetic particle test, penetrant test, X-ray test, ultrasonic test, radiography test, and pressure test are also performed. Welders involved in this process are in turn certified if they pass the test. Interestingly, these findings are consistent with the findings of Nigeria and Cameroon.

In addition, it was found that SMAW, TIG and MIG/MAG are the main welding processes used in Ghana, Nigeria and Cameroon. The usage of SMAW process is of high preference as a result of its low investment cost, availability of machines due to local production and its suitability to weld most metals.

It can therefore be assumed that companies perform tests on welded joint only when requested by a customer. This assumption is somewhat evident because in the case of Ghana, it was further observed that surface finishing was the usual method used when assessing weld quality of a joint. More so, it was conspicuous that visual test was the conventional non-destructive method used. Companies therefore see it to be an extra cost if they perform other tests and assessment methods other than visual and surface finish assessment if not requested by a customer. However, as the literature confirms, welded metallic products can only be regarded as quality welded products if the ISO 3834 – 2 standards is emulated. Although welding quality measurements in the West African States is driven by cost sensitivity, it can thus be suggested that the need to adhere to ISO 3834 – 2 is essential. Also the certification and qualification of both companies and welders are needed since welders are certified prior to projects.

7.5 Welding Productivity Measurement System in Companies

Welding productivity measurement as observed in Ghana reveals that majority of the companies use rate of defect. However, few companies practice performance versus standard time as welding productivity measurement. These findings affirm the findings obtained from Cameroon. On the other hand, in the case of Nigeria it is such that welding productivity is measured by welds completed per time period as well as rate of defect.

In addition, it was found that in Ghana, the common metals used in welding operations are mild steel, stainless steel, aluminum, carbon steel, cast iron, and galvanized steel. Surprisingly, similar findings were obtained in the case of Nigeria and Cameroon. It can be presumed that the predominance of these metals in welding operations in the West African States is as a result of the metals weldability, availability, and cost. It can further be suggested that the type of welding processes and techniques used influence the choice of metals used.

Another important finding which was obvious across the three West African States was the use of manual welding technique in the companies. Aside this finding, in Ghana, it was further observed that very few companies utilizing the semi-automatic welding technique. More so, none of the companies were found employing automatic or robotic welding technique. These findings corroborate with that obtained from Nigeria and Cameroon, but the authenticity of this information is somewhat vague.

It can thus be assumed that, productivity levels could be low as a result of the current productivity measurement system in use. Moreover, the connection between welding ergonomics and welding productivity measurement system used in companies is not evidently established. Literally, it was evident that the use of total management systems and lean manufacturing systems could improve productivity and quality issues in companies. This finding is directly opposite to the empirical findings as mentioned herein. Thus, the findings have important implications for developing issues in welding productivity in the West African states under study.

7.6 Welding Economy Measurement System in Companies

As observed, economy of welding involves cost associated to labor, consumables and materials, preparation of parts, joint design, joint position, overheads, environmental conditions, and postweld treatments. However, the more sensitive part of welding economy is about how welds are performed economically. Some of the issues emerging are welder wages or salaries and the turnover of welding operations.

In Ghana, it was found that the average salary of a welder in a company is about € 300 per month while in Nigeria the average salary ranges between € 250 – 300. These average salaries are based on experience, qualification and skill of the welder. However, it is important to bear in mind that these average salaries can be more in some instances (location of the work whether offshore or onshore). On the other hand, in Cameroon, it was such that in-experienced welders in a company receive €150 -200 per month while experienced welders receive between €250 -390 per month.

These findings indicate that, cost of labor in the West African States is fairly cheap. However, it is also possible that welders in the informal welding sector could receive very less wages or salaries even though they could be experienced welders. Nonetheless, such welders require formal training in welding.

An equally significant aspect of welding economy aside welder's salary is the turnover of welding operation. In Ghana, I was found that companies have had increase in their welding operations turnover, thus indicating profit increase. Contrary to expectations, this study did not find information relating to this aspect in Nigeria and Cameroon. Notwithstanding, it can be assumed that companies are seeing profits in turnover due to the huge amount of construction activities in the West African states.

7.7 Equipment and Materials on the Market

It was observed that welding machines and equipment used on the Ghanaian market are mostly imported from China. Minority of the welding machines and equipment are imported from countries such as the USA. The major USA brands are Miller and Lincoln Electric. Finnish Kemppi welding equipment and machines were scarce on the Ghanaian and the Cameroonian markets but somewhat prominent in the Nigerian market. Also welding electrodes from China were found to have large market share. On the other hand, electrode brands such as Esab and Hilco were also found but not as dominant as that of the Chinese brands in the Ghanaian market.

However, even though the Chinese made welding machines, equipment and electrodes are cheaper than the other brands; most companies are on the verge of turning away from them due to the inefficiencies and poor performances. It can be presumed that any company or distributor which can provide machines, equipment and electrodes with high efficiency and performance and also with moderate price margins would compete effectively on the Ghanaian market and gain higher market share.

7.8 General Challenges/ Problems Companies face in Welding Operations

The general challenges or problems companies encounter in welding operations in the various West African states are presented in Table 14.

Table 14. General challenges or problems in welding operations.

Challenges/ Problems	Comments
Welding health, safety and environmental issues	• Lack of access to personal protective equipment, especially right welding shields or helmet. There is high risk of ocular eye problems among welders • Welders are over-stressed as a result of the welding technique employed and long hours of working • No insurance policies for welding personnel • The disposal of waste from welding workshops have received less attention, thus causing environmental problems
Poor welding management practices	• Welders are regarded as low level professionals and are always at the bottom of the organizational chart • The welding department has been fused together with other departments, thus leading to improper management as well as records and documentation handling • Departments are not following any organizational systems and don’t have organizational strategies to manage and develop welding operations

Lack of government support	• Very low motivation from the government to create awareness in welding technology development • No governmental supports such as a government funding agency to promote research, development and innovation in welding technology
Poor welding quality practices	• Reluctance in the use of welding quality standards since companies rely on customer request • Quality is less attended to since it is compromised with cost • Types of machines, equipment, materials and electrodes on the market account for the quality level of manufactured products
Poor welding productivity practices	• Welding workshop ergonomics have received less attention, thus resulting in delays in manufacturing and production • Productivity management principles are not deployed • The mindset of welding personnel and the primitive ways of welding • The level of welding mechanization is very low • The fear that automatic and robotized welding machines and equipment would contribute to high unemployment rate
Welding economy issues	• Unavailability of quality machines, and equipment and materials, thus leading to higher cost when such items are imported • Financial constraints as a result of low assess to loans and government development funds • Tendering and bidding power of domestic companies is low due to doubt to execute excellent jobs from contractors
Lack of Welding education, training, qualification and certification	• Low level of qualified and certified welders • The progression of welding personnel in academics is very limited due to the lack of educational structures and appropriate programs • Competence level of most welding personnel is low due to inadequate education and practical training in welding

7.9 Welding Technology Programs and Research in Universities

It was found that none of the universities visited in Ghana (Kwame Nkrumah University of Science and Technology, University of Mines and Technology and the Regional Maritime University) conduct research in any area in welding technology. However basic courses in welding are being taught alongside mechanical engineering programs at both bachelor and master degree levels. Nevertheless, these universities have the potential to conduct research related activities in welding technology if the needed infrastructures are implemented.

Information pertaining to this subject was not captured from Nigeria and Cameroon. Although it could be presumed that the same system of welding education and research level exists in universities in Nigeria and Cameroon, with Nigeria this situation might be different due to the influence and inception of the Nigerian Institute of Welding (NIW) in the Nigeria Welding Industry. As evidence, the first ECOWAS welding conference and technical exhibition organized by NIW in 2010 received quite a number of research paper abstracts from students in Nigerian universities than Ghana and Cameroon [43]. However, the notable universities in Nigeria which could conduct research activities in welding technology are University of Ilorin, and University of Benin since they have strong mechanical engineering curriculum both at the bachelor and master degree levels.

Similarly, universities in Cameroon such as the University of Douala, University of Yaoundé I, University of Buea and Bamenda University of Science and Technology could also conduct research in welding technology since they have comparable facilities such as in Ghana and Nigeria. Interestingly, an Institute of Welding is being established under the College of Technology of University of Buea due to the current cooperation the University had with Lappeenranta University of Technology to commence welding research activities in the near future.

Despite these facts, the link between universities, companies, welding organizations and government agencies is not well established in these West African states, thus hindering the progress of welding education and research in the West African Welding Industry.

7.10 SWOT Analysis of the West African States

A simplified SWOT analysis for the West African states is presented in Table 15.

Table 15. SWOT Analysis of Ghana, Nigeria and Cameroon.

SWOT	GHANA	NIGERIA	CAMEROON
STRENGTH	• Workforce (ability to manufacture) • Industrial sectors in welding manufacturing (construction, heavy manufacturing, and capitalized repair and maintenance) • Environment • Language (English) • Friendly business atmosphere • Medium population density • Strong democratic governance • Sound economic viability (High GDP per capital)	• Workforce (ability to manufacture) • Industrial sectors in welding manufacturing (construction, heavy manufacturing, and capitalized repair and maintenance) • Environment • Language (English) • IIW member state • Very large population density • Sound economic viability (Moderate GDP per capital)	• Workforce (ability to manufacture) • Industrial sectors in welding manufacturing (construction, heavy manufacturing, and capitalized repair and maintenance) • Environment • Language (English and French) • Low population density • Sound economic viability (Moderate GDP per capital) • Political stability
WEAKNESS	• Mindset towards quality and productivity • Attitude towards work • Quality and productivity systems not implemented in companies • Communication problems (e-mails not treated with urgency)	• Mindset towards quality and productivity • Attitude towards work • Quality and productivity systems not implemented in companies • Communication problems (e-mails not treated with urgency)	• Mindset towards quality and productivity • Attitude towards work • Quality and productivity systems not implemented in companies • Communication problems (e-mails are not treated with urgency)
OPPORTUNITY	• Growing Industries (oil and gas, mining,, food and energy) • Cheap cost of labor • Availability of welding materials with moderate prices • Emerging market for new products and services	• Oil and gas Industry • Cheap cost of labor • Emerging market for new product and services • Availability of welding materials with moderate prices	• Oil and gas Industry • Cheap cost of labor • Emerging market for new product and services • Availability of welding materials with very moderate prices
THREATS	• Power supply problems • Corruption • Inflation	• Power supply problems • Corruption • Inflation • Political instability	• Power supply problems • Corruption • Inflation

8. CONCLUSIONS

This thesis has investigated welding quality, productivity and economy in production and manufacturing networks in West African States such as Ghana, Nigeria and Cameroon. Three main objectives were defined for this research work. Moreover, eight research questions were set to provide relevant information to the research objectives.

The first objective was to identify activities in the metal production and manufacturing industries where welding is extensively used in West African States. It was found that welding is extensively used in construction industrial sector, capitalized repair and maintenance industrial sector and the heavy industrial manufacturing sector. This information provides an answer to the first research question.

A second major finding was that the welding industry consists of two welding sectors; the formal welding sector and the informal welding sector. The formal welding sector comprises of medium and large companies operating in industrial sectors while the informal sector encompass micro enterprises which do not operate in any industrial sector. It can be said that the difference between these welding sectors is the level of professionalism in welding operations. Another important finding which was surprising was that companies operating in industrial sectors were not manufacturing specific products but are rather project (customized) manufacturing oriented. The micro enterprises are however noted for manufacturing commercial products which are however less innovative. These findings answer the second research question.

Additionally, it was found that the manufacturing ability of companies in industrial sectors surpasses those micro enterprises because manufacturing tools used by micro enterprises are very basic as compared to manufacturing tools or machines used in the companies. Nevertheless, the level of manufacturing in both the companies and the enterprises fall short since advanced manufacturing systems such as flexible manufacturing systems are not in use. This information provides answers to the third research question.

The second objective was to determine the extent of welding quality, productivity and economy measurements in companies operating in metal production and manufacturing industries. With welding quality measurements, it was found that the use of welding quality standards in companies is rare since quality test and certifications are done by third parties known as certification bodies. Weld quality is therefore assessed through destructive test and also non-destructive test according to standards such as the ASME, ABS, BS, API, ASW and also ISO 3834. However, the companies themselves assess weld quality through surface finish and visual tests. With reference to welding processes, the SMAW, TIG and MIG/MAG are used in welding operations. As a result of low investment cost, the SMAW is the commonly used welding process. Moreover, the use of MIG/MAG has been considered as better competitive option to SMAW despites the cost involved in its usage. On the other hand, these findings imply that welding processes such as plasma arc welding (PAW) and beam welding processes are not in effective use. It can however be assumed that the investment cost in these welding processes scare companies from using them. This information somewhat provide answers to the fourth research question.

With welding productivity measurements, it was found that companies rely on the rate at which defects occur in their welding operations. However, it was also evident that companies rely on performance verses standard time, which means that some manufacturing tasks should be completed in a stipulated time. These productivity measurement systems used does not reflect true productivity levels in the companies. It can thus be said that without implementing or emulating standard systems such as lean manufacturing systems, and total welding management systems, the correct monitoring of productivities levels in welding operations cannot be achieved. Furthermore, the use of manual welding technique was found to be dominant over semi-automatic, automatic and robotic welding techniques. This finding however was not surprising because it is the cheapest technique to employ in welding operations in the companies. Another significant finding was welding ergonomics which falls below standard. To some extent, this aspect in welding productivity measurement has received less attention since managers have shown less commitment to properly organize the welding workshop in a more suitable and productive way. Nevertheless, these findings provide answers to the fifth research question.

With welding economy measurements, the most significant finding was the salaries of welders. Averagely, the monthly salary of a less experienced welder ranges from €150-200 while experienced welders receive between €250-390 per month. These findings indicate that the cost of labor is cheap. This finding provides an answer to the sixth research question.

The third objective was to identify problems, challenges and needs in the West African welding industry and thus create a network in which these issues could be addressed. It was found that welding health, safety and environmental issues were the main challenges companies encounter in their day-to-day operations. Also, poor welding management practices, lack of government support, poor welding productivity practices, and lack of welding education, training, qualification and certification are the problems hindering the progress and competitiveness of companies. This reveals that welding has not received the utmost attention because these challenges and problems as stated are enormous, thus limiting the credibility of the welding industry in the West African States. However, it can be suggested that, these challenges and problems should rather be seen as new avenues for wealth creation in welding technology but not a detriment to the progress of welding in the said economies. This finding provides useful information to the seventh research question.

More so, it is not surprising these challenges and problems are prevailing because the nexus between companies, government funding agencies and the universities is not available. Thus addressing issues as mentioned results to no avail. It is therefore up to the companies to endeavor to establish networks with universities, government funding agencies and welding organizations to help resolve issue of this kind. Also, the universities must strengthen welding technology courses in mechanical engineering curriculums so that high research activities could be carried out to help the entire welding industry in the various West African states.

This research work makes several noteworthy contributions to the general understanding of welding activities in West African states such as Ghana, Nigeria and Cameroon. The most important implication is that, welding activities are growing and there are a lot of un-tapped opportunities in welding in the said West African states. Although the companies in West African states have the ability to manufacture, however the intriguing challenges are issues relating to welding quality and productivity. Therefore the need to strengthen welding quality, productivity and well as welding environmental issues is highly imperative.

9. RECOMMENDATIONS

Based on the findings and conclusions of this research work, the author have proposed a number of recommendations which could be useful and wealth exploiting for companies in the West African states and also for Finnish companies and higher education institutions as well as the entire international community if treated with urgency.

9.1 Recommendations to Companies Performing Welding in the three West African States

Table 16. Recommendations to companies performing welding in West African states.

Challenges / Problems	Recommendations
Welding health, safety and environmental issues	• Welding personnel should be educated on the use of protective equipment and should be entrusted to use them • Waste from welding workshops must be disposed appropriately through waste management agencies • Welders must be covered with insurance schemes to safeguard their profession
Poor Welding management practices	• Management should focus on welders and also device strong management methods to develop welders quality and productivity levels • The welding workshop must be managed separately from other departments so that proper records and documentation could be tracked. • Total welding management principle or lean management principles should be practiced to improve issues in quality and productivity in welding

Lack of government support	• Government should allocate funds for developing welding technology through research activities • Government should institutionalize welding technology education and training right from the teacher training institutions through to the university level • Government should support organizations which are into welding to create the awareness of how welding can help towards nation building
Poor Welding quality practices	• Companies must be encouraged to use welding standards and follow the requirement so as to be competitive on the domestic and international markets • Companies must be enforced to carry out routine maintenance on their equipment and machines
Poor Welding productivity practices	• Welding workshop layout should be properly constructed so as to ease ergonomics in welding • Companies should engage their welding operations with mechanized systems and consider the extensive use of other welding processes in addition to SMAW to harness the full potentials of welding technology while assigning welding personnel to other duties to increase welding productivity. • The use of MIG/MAG should be embraced fully since it is highly competitive with SMAW, thus has higher productivity rate than SMAW.
Welding economy issues	• Companies should strive to have partnership with foreign companies to create strong welding manufacturing network and also accept on “win-win” agreements were applicable.
Lack of Welding education, training, qualification and certification	• Universities and higher educational institutions should endeavor to establish cooperation with foreign institutions in welding technology and also accept on “win-win” agreements were applicable.

9.2 Recommendations to Finnish Companies and Higher Education Institutions

Establish as a welding company or through partnership

Finnish companies can establish companies in the three West African states and thus rely on the strengths and opportunities of the markets but also work on the weaknesses in the countries. This is very vital because the markets as discussed are the newly emerging markets in welding in Africa especially the Ghanaian market and the Cameroonian market. This draws the attention to the latest success stories of Finnish companies such as Metso, Outotec and Wärtsilä in the Ghanaian market and also YIT in Cameroonian market. However, even though the Nigerian market has had long history in welding operations and the market seems to be saturated, there is still room for exploration.

Moreover, those Finnish companies which may consider entering the markets through partnership should pay critical attention in the selection process. Actually, this research work has created solid networks to companies in Ghana, thus easing preliminary search for partnership in the case of Ghana. Moreover a model has been created to serve as a platform to guide in selecting welding partner companies or subcontractors. One essential suggestion is to enforce stringent welding management systems between the partnering companies since issues with regards to this aspect if often overlooked or ignored. In addition, whichever way is considered, it is also very essential for the Finnish companies to introduce and promote Finnish working culture so as to effectively nature the mindset of the workforce while utilizing the cheap cost of labor in the said regions. The implementation of quality and productivity systems in the companies should also be considered. Figure 8 illustrates a model for selecting subcontractors in the West African countries.

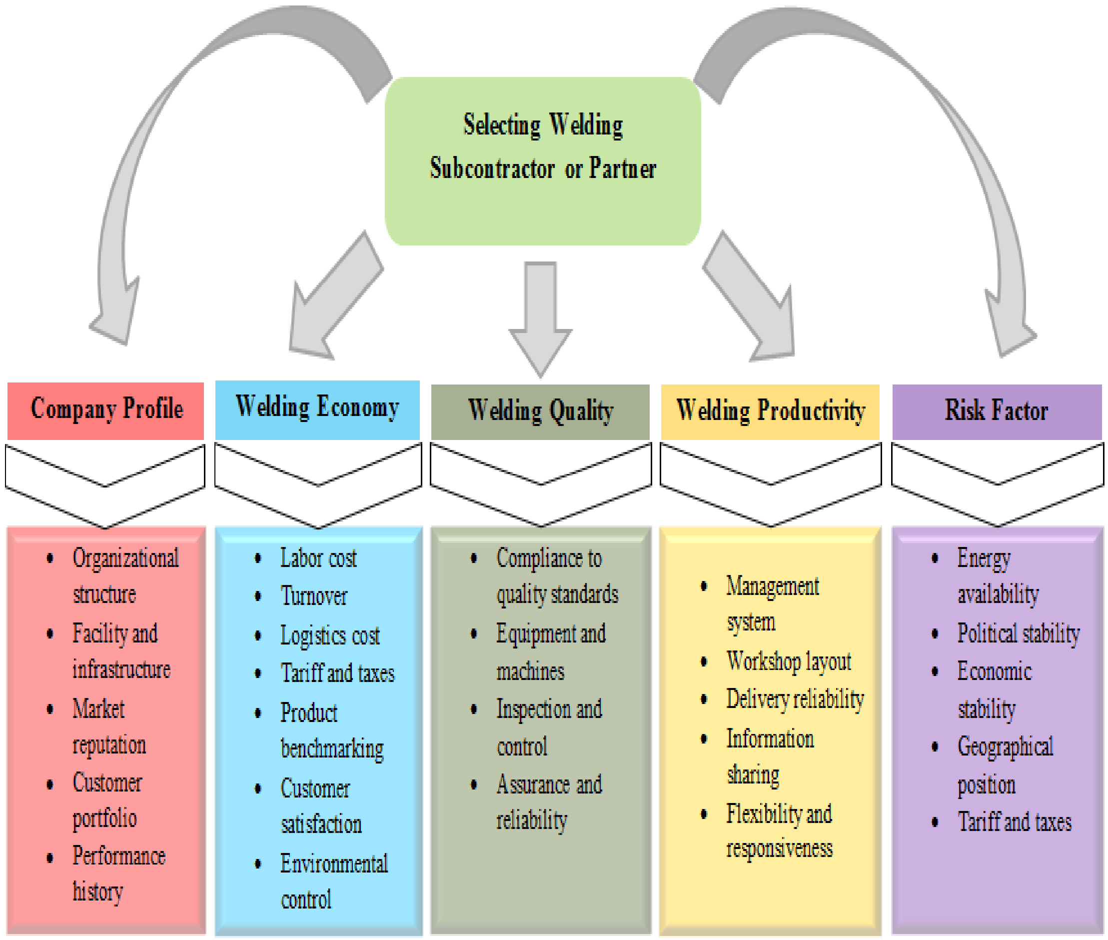

Figure 44. Model for selecting subcontractors in West Africa.

Establish as a welding qualification / certification body

There is a huge potential success to establish as a welding certification body especially in the Ghanaian market and the Cameroonian market since international companies currently operating in this welding business are very few. In this sense, those Finnish companies which will be offering subcontracting jobs to some companies or partner companies in Ghana, Nigeria or Cameroon would somewhat rely on a Finnish certification body to perform qualification or certification of welding personnel, equipment and machines, welding workshop and environment, and the entire welding system in use as well as providing welding quality test services.

Moreover, currently there is lack of certification bodies certifying individual welding personnel on the Ghanaian market especially. Usually, the norm has been that some certified welders are those engaged in welding projects or working in companies. Ceasing this opportunity would help create a “bank of welders”. However, since companies are not interested in certifying welders, such companies would turn to employ welders from this created “bank of welders”. In some circumstances, contractual agreement for employment could be made between the companies and the certification body, and in turn between the certification body and the welding personnel.

Establish equipment and consumables distribution channels

There is high demand of welding equipment and machines in Ghana and Cameroon. For those Finnish companies which have distributors in Nigeria, it is also necessary to establish distribution channels in Ghana and Cameroon as well if only those markets are of interest. More so, the welding electrode market should also be considered imperatively. Actually, building an electrode producing plant in Ghana would be a great investment because currently there is no such factory in Ghana as well as the entire West African region.

In addition, Finnish companies should device new ways of distributing their products to the growing industries such as the oil and gas, mining, food and energy industry in the West African states. By so doing, a strong customer portfolio could be established and in turn, the Finnish companies could sell their expertise and technology in welding to other welding manufacturing companies in the markets.

Establish as a welding education and training partner

Higher education institutions in Finland, the Finnish Welding Institute, Finnish companies and the Finnish government should encourage and establish partnership agreement to educate, train, quality and certify welding personnel and interested individuals under the International Institute of Welding standards in West African states where welding organizations have not got to the level to affiliate with the international institute of welding to provide such services.

The Ghanaian Institute of Welding which was recently created but not affiliated to the International Institute of Welding would somewhat rely on this partnership to promote welding education, qualification and certification in Ghana. Even though, in Nigeria there is the Nigerian Institute of Welding providing qualification and certification for both welding personnel and companies, there is still the need for partnership. On the other hand, there is no Welding Institute in Cameroon and this could be an opportunity to explore in Cameroon.

Also this partnership would help in capacity building so that higher institutions in Ghana, Cameroon and Nigeria who don't have direct links to build cooperation with higher institutions in Finland would have that privilege to create cooperation with Finnish higher institutions. Figure 46 illustrates a model for establishing cooperation / partnership between institutions in welding technology.

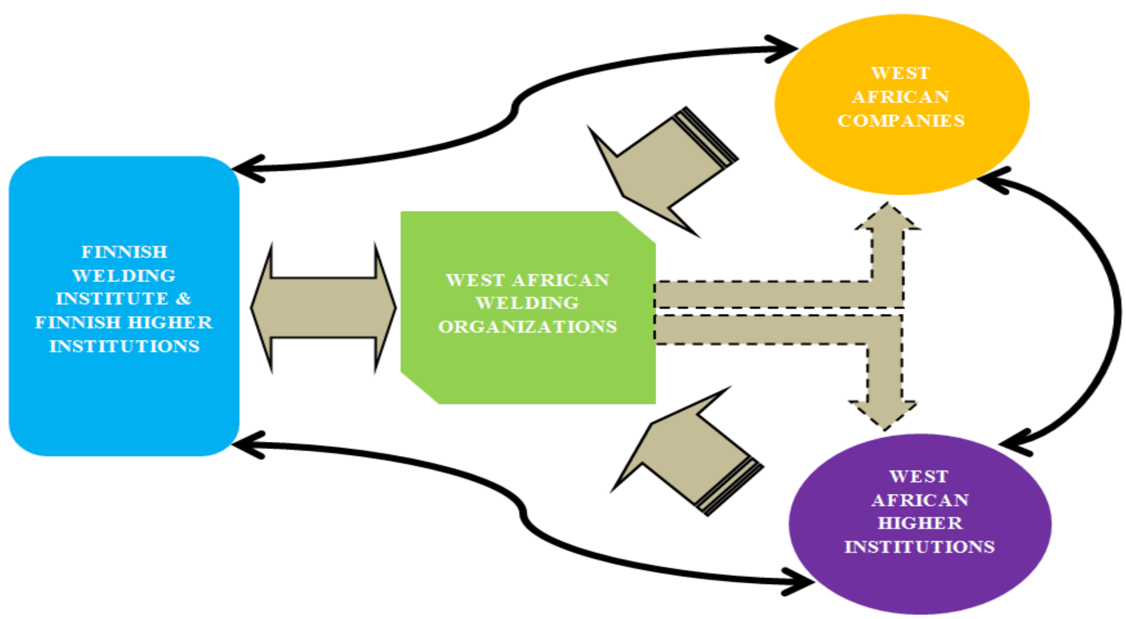

Figure 45. Model for establishing cooperation/ partnership.

9.3 Further Studies

- The need to create and test the feasibilities of a two-way business model;

  A business model should be created and tested on how to penetrate into the markets of the three West African states. On the other hand, further contacts should be made to some of the case studied companies. In this way, those case studied companies would be involved in the business model. This will however ease some penetration factors into the markets.

- Research into welding environmental and waste management issues;

  Environmental issues about activities in welding and how waste generated from the welding workshop should be managed is of high concern. As this research work did not focus much on welding environmental and waste management issues, the need to carry out a research in this subject would be of a great benefit to companies and the community at large.

- Create a network with Finnish companies already in the market of West African states;

  The need to create networks with Finnish companies in the existing markets is important because this will help to know their future projects and plans so that strategies could be made to meet these future needs. Also these Finnish companies can create the opportunity for the in-coming Finnish companies by referring them to other business partners who might need their services. A typical example is by creating networks with Metso, Outotec and Wärtsilä in the Ghanaian market.

10. SUMMARY

This thesis presents a research study carried out to investigate quality, productivity and economy in welding manufacturing in West African states such as Ghana, Nigeria and Cameroon. The research study however consists of two parts; the theoretical part and the empirical part. The research commenced with the theoretical part by reviewing literature concerning the metal industry, the welding industry, and quality, productivity and economy in welding to underpin the empirical part which is the main focus in this thesis. After obtaining relevant information, the empirical part of the research also commenced.

Research methods adopted for data collection during the empirical part of the research study were the case study method and normative survey technique. A research questionnaire was constructed to serve as the main data collection tool for both research methods. The case study was used for companies in Ghana while the survey was used for companies in Nigeria and Cameroon. A total number of twelfth companies were case studies in Ghana. However, in Nigeria and Cameroon, the survey approach failed but hypothetical information was somewhat obtained from professionals in both countries.

Based on the interviews, observations and data analysis the empirical research generated eight solid findings which answer the research questions constructed for the research work. Moreover, upon the finding obtained, a SWOT analysis was made for each participating West African state. In addition, the objectives of the research were used as reference points in the conclusion part of the thesis.

Finally, based on the conclusions of the research work, two models were developed. The first model is to assist Finnish companies to accurately select welding subcontractors or partners from the West African states. The second model is also to ease cooperation in research, education and training in welding technology between universities, welding organizations in the West African states and Finnish institutions. These models however

reflect on some of the recommendations which need attention from foreign investors, the government body, welding organizations and higher education institutions.

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APPENDICES

Appendix 1: Welding Quality Requirements (ISO 3834- Part2)

ELEMENT	DESCRIPTION
A. Review of Requirements	• The manufacturer must review product standards to be used in conjunction with statutory and regulatory requirements as well as any additional requirement, etc.
B. Technical review	• The manufacturer must review technical requirements right from the start of the welding operation to the end. These technical requirements to be reviewed include elements number from ‘‘**C** to **O**’’ in the column of the welding quality requirements element in this table.
C. Sub-contracting	• Manufacturer supplies applicable requirements and ensure its compliance if it intends to used sub-contracted services such as welding, inspection, non-destructive testing, heat treatment, etc. However, the sub-contractor in turn provides records and documentation for the manufacturer’s perusal.
D. Welding Personnel	• Welders and welding operators – The qualification of such personnel shall be approved by an appropriate test as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes. • Welding coordination personnel – The quality activities performed by such personnel shall be vividly defined as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes.
E. Inspection and testing personnel	• Non-destructive testing personnel – A qualified personnel shall be responsible for the planning, performing, and supervision of the inspection and testing of welding operations as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes.
F. Equipment	• Production and testing equipment – The availability of equipment is required when necessary. These include: power sources, joint and surface preparation equipment, thermal cutting equipment, jigs and fixtures, cranes and handling equipment, personal protective and safety equipment, ovens, quivers for treatment of welding consumables, surface cleaning facilities, destructive and non-destructive facilities, etc. • Description of equipment – A list of important equipment for production must be maintained in order to evaluate the capability and capacity of a workshop. These include:

	maximum capacity of cranes, handling capacity of the workshop, capacity of mechanized or automatic welding equipment and forming equipment, post-weld heat treatment dimension and maximum temperature. • Suitability of equipment – The equipment must be suitable for the intended job. • New equipment - Testing and documentation conforming to appropriate standards shall be performed for newly installed equipment. • Equipment maintenance – The manufacturer must have a plan to maintain its equipment and document the outcomes. Items such as cables, hoses, connectors, flow meters, measuring instruments must be checked and defective once should not be used.
G. Welding and related activities	• Production planning – The manufacturer is to ensure adequate production planning including sequence and identification of individual processes for construction; specification for inspection and testing; environmental conditions; and allocating qualified personnel, etc. • Welding-procedure specifications – The manufacturer must prepare and ensure the use of the welding-procedure specification correctly in production as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes. • Qualification of the welding procedures – Relevant product standards must be used to qualify welding procedures before production as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes. • Work instructions – The manufacturer must decide to use instructions in the welding-procedure specification or a work instruction prepared from a qualified welding-procedure specification. • Procedures for preparation and control of documents – The manufacturer establishes and maintains procedures for the preparation and control of important quality documents including welding-procedure specification, welding-procedure qualification record, welders and welding-operations qualification certificates.
H. Welding consumables	• Batch testing – Welding consumables shall be batch tested if specified. • Storage and handling – With reference to the supplier's recommendation, the storage, handling, identification and use of welding consumables which eschew moisture pick-up, oxidation, and damage shall be produced and implemented by the manufacturer.
I. Storage of parent materials	• Identification shall be maintained during storage in order not to destroy materials.

J. Post-weld heat treatment	• Any post-weld heat treatment must be compatible with the parent material, welded joint, and construction in accordance with product standards. The process must be specified and documented by the manufacturer.
K. Inspection and testing	• Inspection and testing before welding – The suitability; validity of welding personnel qualification certificates; welding-procedure specification; identity of parent material and welding consumables; joint preparation; fit-up, jigging and tacking; and working conditions for welding such as environment should be checked. • Inspection and testing during welding – Welding parameters such as welding current, arc voltage and travel speed; and preheating/interpass temperature; cleaning and of runs and layers of weld metal; back gouging; welding sequence; correct use and handling of welding consumables; control of distortion; intermediate examination should be checked at suitable intervals or by continuous monitoring as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes. • Inspection and testing after welding – Visual inspection; non-destructive inspection; destructive inspection; form, shape and dimension of the construction; and results and records of post-weld operations should be checked after welding as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes. • Inspection and test status – Measurements shall be taking to indicate test of the welded construction.
L. Non-conformance and corrective actions	• Measurements should be implemented to control items and activities in order to prevent re-occurrences of non-conformances. Repair works should be re-inspected, tested and examined in accordance with the original requirements.
M. Calibration and validation of measuring, inspection and testing equipment	• The manufacturer should perform these actions at specified intervals as specified in ISO 3834-5:2005 quality requirement for arc welding, electron beam welding, laser beam welding, gas welding and other welding processes.
N. Identification and traceability	• Manufacturer must maintain documented system to identify production plans; routing cards; weld locations in construction; non-destructive testing procedures and personnel; welding consumables; parent material, location of repairs; and location of temporary attachments. • Manufacturer must maintain documented system to trace fully mechanized and automatic welding units to specific welds, welder and welding operators to specific welds, and welding-procedure specification to specific welds.

O. Quality records	• The quality records shall be functional for a minimum of five years in the absence of any specified requirement. This include: record of requirement/technical review; material inspection document; welding consumable inspection document; welding-procedure specifications; equipment maintenance records; welding-procedure qualification records (WPQR); welder or welding-operator qualification certificates; production plan; non-destructive testing personnel certification; heat-treatment procedure specification and records; non-destructive testing and destructive testing procedure and reports; dimensional reports; and records of repairs and non-conformance reports.

Appendix 2: Research Questionnaire

QUESTIONNAIRE

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY, FINLAND

DEPARTMENT OF MECHANICAL ENGINEERING

(*LABORATORY OF WELDING TECHNOLOGY*)

PROJECT TOPIC:

QUALITY, PRODUCTIVITY AND ECONOMY IN WELDING MANUFACTURING – CASE STUDY: WEST AFRICA

I am a postgraduate student of Lappeenranta University of Technology in Finland and pursuing my major studies in Mechanical Engineering (design and manufacturing). The laboratory of welding technology of Lappeenranta University of Technology is embarking on an international project in welding technology and I have been assigned as a researcher to that project to focus on West Africa. This project aims to determine the extent of welding quality, productivity and economy measurements in companies whose operations chiefly depend on welding and also to identify the activities, needs and challenges in the metal production and manufacturing industries where welding is a critical enabling technology in West Africa. Information gathered from this research would be analyzed, so as to help contribute in the improvement and development of activities in the welding industry in West Africa. It will as well facilitate the development of a model which will aid in the accurate selection of welding subcontractors from West Africa for international partnership with Finnish companies, and also the development of a model which will serve as a platform for effective co-operation between Lappeenranta University of Technology, Finland and some Universities in West Africa.

It would be highly appreciated if honest information and answers are provided to the questions in this research questionnaire. However, be assured that any information provided will be treated accordingly.

PART I – ESTABLISHMENT INFORMATION

1. COMPANY NAME AND ADDRESS:

Company Name: ☐

Street Address: ☐

Location: ☐ e-mail: ☐

2. INDICATE WHERE YOUR COMPANY BELONGS TO, FROM THE SECTORS OF METAL PRODUCTION AND MANUFACTURING INDUSTRIES:

INDUSTRIAL SECTOR	MARK
Automotive	☐
Aircraft / aerospace	☐
Electronics / Medical	☐
Light Industrial Manufacturing, eg. Industrial tools, heating and ventilation, household appliances	☐
Heavy Industrial Manufacturing, eg. Construction and mining machinery, shipbuilding, oil and gas field machinery	☐
Construction, eg. Bridge and tunnel construction, pipeline construction, structural steel erection, fabrication, structural metal products	☐
Capitalized repair and maintenance, eg. Primary metal industries, metal forging and stamping, paper production	☐

3. DESCRIBE BRIEFLY YOUR COMPANY'S OPERATIONS AND PRODUCTS:

4. INDICATE THE NUMBER OF YEARS YOUR COMPANY HAS BEEN PERFORMING WELDING OPERATIONS:

☐ 1 – 15 years

☐ 16 – 30 years

☐ Above 30 years

PART II - CUSTOMER INFORMATION

5. ESTIMATE THE NUMBER OF CUSTOMERS YOUR COMPANY HAS:

6. WHICH INDUSTRIAL SECTORS DOES YOUR CUSTOMERS OPERATION IN? PLEASE INDICATE THEIR LOCATION:

CUSTOMER OPERATING SECTORS	LOCATION	
	DOMESTIC	FOREIGN
	☐	☐
	☐	☐
	☐	☐
	☐	☐
	☐	☐
	☐	☐
	☐	☐

7. WHAT ARE THE NEEDS OF YOUR CUSTOMERS IN WELDING OPERATIONS (QUALITY, PRODUCTIVITY AND COST):

8. WHICH PROBLEMS OFTEN DO ARISE BETWEEN YOUR COMPANY AND YOUR CUSTOMERS?

PART III – WELDING QUALITY MEASUREMENT

Q1. WHAT IS YOUR COMPANY'S WELDING QUALITY POLICY OR WHICH WELDING QUALITY AND ASSURANCE STANDARDS DOES YOUR COMPANY COMPLY WITH?

Q2. IN WHICH WAYS DOES YOUR COMPANY ASSESSES WELD QUALITY?

A. STRENGH ☐

B. TOUGHNESS ☐

C. DISTORTION/ DIMENTIONAL ☐

D. SURFACE FINISH ☐

E. FATIGUE ☐

F. OTHERS ☐ , please specify………………………………………………………

Q3. WHICH OF THESE WELDING QUALITY MEASURES DOES YOUR COMPANY USES: PLEASE INDICATE THE MOST FREQUENTLY USED FROM SCALE 5 to 1, where 5 is the highest.

NON DESTRUCTIVE TESTING		**DESTRUCTIVE TESTING**	
VISUAL TEST	☐	TENSILE TEST	☐
PENETRANT TEST	☐	BEND TEST	☐
MAGNETIC PARTICLE TEST	☐	NOTCH TOUGHNESS TEST	☐
ULTRASONIC TEST	☐	PRESSURE TEST	☐
RADIOGRAPHIC TEST	☐	HARDNESS TEST	☐
OTHERS, please specify	☐	OTHERS, please specify	☐

Q4. UNDERLINE WHICH OF THESE WELDING PROCESSES YOUR COMPANY USES: PLEASE INDICATE THE MOST FREQUENTLY USED FROM SCALE 5 to 1, where 5 is the highest.

ARC WELDING	**OXYFUEL GAS WELDING**	**RESISTANCE WELDING**	**OTHER WELDING**
ELECTROGAS WELDING FLUX CORED ARC WELDING GAS METAL ARC WELDING (MIG/ MAG) GAS TUNGSTEN ARC WELDING (TIG) PLASMA ARC WELDING SHIELDED METAL ARC WELDING SUBMERGED ARC WELDING OTHER:……………………… ……………………. ………………………… ………………………...	AIR ACETYLENE WELDING OXYACETYLENE WELDING OXYHYDROGEN WELDING PRESSURE GAS WELDING OTHERS:…………… ……………………… ……………………… ………	FLASH WELDING PROJECTION WELDING RESISTANCE SEAM WELDING RESISTANCE SPOT WELDING UPSET WELDING OTHERS:……………… ………………………… ………………………… …………………………	COLD WELDING EXPLOSION WELDING FRICTION WELDING HOT PRESSURE WELDING ROLL WELDING ULTRASONIC WELDING LASER WELDING ELECTRON BEAM WELDING ELECTROSLAG WELDING OTHERS:…………… ……………………… ……………………… ………………

Q5. DO YOU AGREE THAT THE SELECTION OF A WELDING PROCESS IN WELDING A PARTICULAR METAL INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q6. DO YOU AGREE THAT WELDING EQUIPMENT INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q7. DO YOU AGREE THAT WELDING TECHNIQUE INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q8. DO YOU AGREE THAT METAL PREPARATION BEFORE AND AFTER WELDING INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q9. DO YOU AGREE THAT SHIELDING GASES INFLUENCE WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q10. DO YOU AGREE THAT THE SELECTION OF AN ELECTRODE IN WELDING OPEARATION OF A PARTICULAR METAL INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q11. DO YOU AGREE THAT THE WELDING CENTER ENVIRONMENT, STORAGE OF MATERIALS, CONSUMABLES AND SAFETY INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q12. DO YOU AGREE THAT THE SKILL OF THE WELDER AND TRAININGS RECEIVED INFLUENCES WELDING QUALITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

Q13. DOES YOU COMPANY HAVE A WELDING QUALITY MANUAL?

YES ☐

NO ☐

Q14. HOW WOULD YOU RATE YOUR COMPANY'S OVERALL QUALITY LEVEL ACCORDING TO:

	HIGH	MODERATE	LOW
DOMESTIC COMPETITIVENESS	☐	☐	☐
INTERNATIONAL COMPETITIVENESS	☐	☐	☐

Q15. PLEASE PROVIDE ANY ADDITIONAL COMMENTS OR INFORMATION REDARDING YOUR COMPANY'S WELDING QUALITY MEASUREMENTS, PROBLEMS AND AREAS YOU WOULD NEED IMPROVEMENT:

PART IV – WELDING PRODUCTIVITY MEASUREMENT

P1. WHICH OF THESE WELDING PRODUCTIVITY MEASURES DOES YOUR COMPANY USES:

WELDING PRODUCTIVITY MEASUREMENT	**MARK**
Components completed per time period	☐
Rate of defect	☐
Performance verse standard time	☐
Joints completed per time period	☐
Welds completed per time period	☐
Metal deposition per time period	☐
Welding cell arc time	☐

P2. WHICH METALS DOES YOUR COMPANY USES IN WELDING OPERATIONS? PLEASE INDICATE THE MOST FREQUENTLY USED FROM SCALE 5 to 1, where 5 is the highest.

P3. DO YOU AGREE THAT THE SELECTION OF A WELDING PROCESS IN WELDING A PARTICULAR METAL INFLUENCES WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P4. DO YOU AGREE THAT WELDING EQUIPMENT INFLUENCES WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P5. WHICH WELDING TECHNIQUES DOES YOUR COMPANY USES IN WELDING OPERATIONS/ AND WHY?

P6. WHICH SHIELDING GASES DOES YOUR COMPANY USES IN WELDING OPERATIONS? INDICATE THE MOST FREQUENTLY USED FROM SCALE 5 to 1, where 5 is the highest.

P7. DO YOU AGREE THAT THE TYPE OF SHIELDING GAS AND ELECTRODE INFLUENCES WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P8. HOW OFTEN DO YOU TRAIN YOUR WELDERS?

NOT AT ALL	☐	EVERY 2 YEARS	☐
EVERY YEAR	☐	EVERY 3 YEARS	☐

P9. DO YOU AGREE THAT METAL PREPARATION BEFORE AND AFTER WELDING INFLUENCES WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P10. HOW MANY WELDING PERSONNEL DO YOU HAVE IN YOUR COMPANY?

P11. WHICH QUALIFICATIONS AND CERTIFICATES DO YOU LOOK FOR IN WELDERS BEFORE EMPLOYMENT?

P12. DO YOU AGREE THAT THE SKILLS OF A WELDER AND TRAININGS RECEIVED INFLUENCES WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P13. DO YOU AGREE THAT THE EASY ACCESS TO MATERIALS, CONSUMABLES AND EQUIPMENT IN THE WELDING CENTER AFFECTS WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P14. DO YOU AGREE THAT WELDING CENTER ENVIRONMENT AND SAFETY INFLUENCES WELDING PRODUCTIVITY?

NO ☐

YES ☐ PLEASE GIVE REASON:

P15. DOES YOU COMPANY HAVE A WELDING PRODUCTIVITY CHART?

NO ☐ YES ☐

P16. HOW WOULD YOU RATE YOUR COMPANY'S OVERALL PRODUCTIVITY LEVEL ACCORDING TO:

	HIGH	MODERATE	LOW
DOMESTIC COMPETITIVENESS	☐	☐	☐
INTERNATIONAL COMPETITIVENESS	☐	☐	☐

P17. PLEASE PROVIDE ANY ADDITIONAL COMMENTS OR INFORMATION REDARDING YOUR COMPANY'S WELDING PRODUCTIVITY MEASUREMENTS, PROBLEMS AND AREAS YOU WOULD NEED IMPROVEMENT:

PART V – WELDING ECONOMY MEASUREMENT

E1. WHAT IS YOUR COMPANY'S WELDING OPERATIONS TURNOVER?

A. YEAR 2010………………………………………………
B. YEAR 2011…………………… ………………………..
C. YEAR 2012………………………………………………

E2. WHICH WELDING COST SYSTEM DOES YOUR COMPANY EMPLOYS?

COST OF WELDMENT ☐

COST OF SPECIFIC WELD ☐

E3. WHICH FACTORS DOES YOUR COMPANY CONSIDER WHEN ESTIMATING THE COST OF WELDING WITH REFERENCE TO YOUR WELDING COST SYSTEM?

LABOR COST ☐ CONSUMABLE COST ☐ OTHER ☐

MATERIAL COST ☐ JOINT DESIGN ☐

PREPARATION OF THE PARTS ☐ JOINT POSITION ☐

OVERHEAD COST ☐ ENVIRONMENTAL CONDITION ☐

POSTWELD TREATMENT ☐ COST OF EACH WELD ☐

E4. DO YOU AGREE THAT THE USE OF A SPECIFIC WELDING PROCESS INFLUENCES THE COST OF WELDING?

NO ☐

YES ☐ PLEASE GIVE REASON:

E5. DO YOU AGREE THAT THE USE OF A SPECIFIC WELDING TECHNIQUE INFLUENCES THE COST OF WELDING?

NO ☐

YES ☐ PLEASE GIVE REASON:

E6. DO YOU AGREE THAT THE USE OF WELDING QUALITY SYSTEMS INFLUENCE THE COST OF WELDING?

NO ☐

YES ☐ PLEASE GIVE REASON:

E7. DO YOU AGREE THAT TRANSPORTATION COST INFLUENCES THE COST OF WELDING?

NO ☐

YES ☐ PLEASE GIVE REASON:

E8. DO YOU AGREE THAT THE WELDING ENVIRONMENT AND SAFETY ISSUES INFLUENCE THE COST OF WELDING?

NO ☐

YES ☐ PLEASE GIVE REASON:

E9. DO YOU AGREE THAT THE USE OF WELDING EQUIPMENT INFLUENCES THE COST OF WELDING?

NO ☐

YES ☐ PLEASE GIVE REASON:

E10. WHAT ARE THE WAGES OF YOUR WELDING PERSONNEL PER MONTH?

E11. HOW WOULD YOU BENCHMARK YOUR COMPANY'S PRODUCTS AND PERFORMANCE LEVEL ACCORDING TO:

	HIGH	MODERATE	LOW
DOMESTIC COMPETITIVENESS	☐	☐	☐
INTERNATIONAL COMPETITIVENESS	☐	☐	☐

E12. HOW MUCH FUNDS DOES YOUR COMPANY PUT INTO WELDING RELATED RESEARCH AND DEVELOPMENT?

E13. PLEASE PROVIDE ANY ADDITIONAL COMMENTS OR INFORMATION REDARDING YOUR COMPANY'S WELDING ECONOMY MEASUREMENTS, PROBLEMS AND AREAS YOU WOULD NEED IMPROVEMENT:

R

Appendix 3: Supporting Research Questions Results

QUESTION	RESEARCH ITEM	RESPONSE											
		WELDING QUALITY				WELDING PRODUCTIVITY				WELDING ECONOMY			
		Yes	No	Companies No.		Yes	No	Companies No.		Yes	No	Companies No.	
				Yes	No			Yes	No			Yes	No
Q5/P3/E4	The selection of a welding process in welding a particular metal influences:	✓	-	12	-	✓	-	12	-	✓	-	12	-
Q6/P4/E9	Welding equipment influences:	✓	-	12	-	✓	-	12	-	✓	-	12	-
Q7/P5/E5	Welding technique influences:	✓	-	12	-	✓	-	12	-	✓	-	12	-
Q8/P9/E3	Metal preparation before and after welding influences:	✓	-	12	-	✓	-	12	-	✓	-	12	-
Q9/P6/P7	Shielding gases influences:	✓	-	12	-	✓	-	12	-				
Q10/P7	The selection of an electrode in welding a particular metal influences:	✓	-	12	-	✓	-	12	-				
Q11/P13/14/E8	The welding center environment, storage of material, welding consumables and safety issues influence:	✓	-	12	-	✓	-	12	-	✓	-	12	-
Q12/P12	The skill of the welder and training received influences:	✓	-	12	-	✓	-	12	-				
Q13	Does your company have a welding quality manual?	✓	X	3	9								
P15	Does your company have a welding productivity chart?					✓	X	4	8				
E6	The use of welding quality systems influences the cost of welding?									✓	-	12	-
E7	Transportation cost influences the cost of welding?									✓	-	12	-

QUESTION	RESEARCH ITEM	QUALITY LEVEL			PRODUCTIVITY LEVEL			PRODUCT/PERFORMANCE BENCHMAKING		
		High	Moderate	Low	High	Moderate	Low	High	Moderate	Low
Q14/P16/E11	Domestic competitiveness	12	-	-	12	-	-	12	-	-
	International competitiveness	6	5	-	4	7	-	5	6	-

Appendix 4: Welding Procedure Specification (WPS) : SFS-EN ISO 15609-1

Welding Procedure Specification:

WPQR No.:

Manufacturer:

Mode of metal transfer:

Joint Type and Weld Type:

Weld Preparation Details (Sketch)*)

Method of Preparation and Cleaning:

Parent Material Designation:

Material thickness (mm):

Outside Diameter (mm):

Welding Position:

Joint Design	Welding Sequences

Welding Details

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

Filler material designation and make:

Any Special Baking or Drying :

DesignationGas/Flux: – Shielding:

– Backing:

Gas Flow Rate – Shielding:

– Backing:

Tungsten Electrode Type/Size:

Details of Back Gouging/Backing:

Preheat Temperature:

Interpass Temperature:

Post-heating:

Pre-heat maintenance temperature:

Post-Weld Heat treatment and/or Ageing:

(Time, Temperature, Method:

Heating and Cooling Rates*):

Other information*, e.g.:

Weaving (maximum width of run):

Oscillation : amplitude, frequency, dwell time:

Pulse welding details:

Distance contact tube/work piece:

Plasma welding details:

Torch angle:

....

Manufacturer

(name, signature, date)