University of Nairobi

Institute of Nuclear Science and Technology

INVESTIGATION OF WELDING QUALITY IN THE KENYAN INFORMAL SECTOR (“JUAKALI-SECTOR”)

by

BIRIR K. JOHN

(Bsc Mechanical Engineering, University of Nairobi)

A thesis submitted in partial fulfillment for the Degree of Masters of Science in Nuclear Science of the University of Nairobi.

Declaration /Approval

This thesis is my original work and has not been presented for a degree in any other university.

Signature.. Date...................................
Birir K. John (S56/74424/2012)

This thesis has been submitted for examination with the knowledge of the supervisor(s).

Supervisors

Dr. Michael J. Gatari
Institute of Nuclear Science and Technology
University of Nairobi
Sign………………………
Date……………………..

Prof. S.M Mutuli
Department of Mechanical and Manufacturing Engineering
University of Nairobi
Sign………………………
Date……………………..

Mr David Maina
Institute of Nuclear Science and Technology
University of Nairobi
Sign………………………
Date……………………..

Dedication

This research work is dedicated to my family for their support during my study period.

Acknowledgement

I would like to express my sincere appreciation and gratitude for the help and support I got from all that made this work a success. I thank Dr. Michael Gatari, Mr. David Maina and Prof. Stephen Mutuli who were my project supervisors for their encouragements, guidance, support, advice and criticism. I thank Prof. Johan Boman for his input reading and correcting my thesis. I thank the INST staff for the support they gave me during the project period. I thank KEBS (Kenya) and CNESTEN (Morocco) administration and staff for the NDT training I got and for allowing me to use their equipment. I thank KNEB, NCST and IAEA for their financial support and ISP for infrastructure and Capacity support to INST, which have been of great benefit to me.

I want to express gratitude to my family for their unfailing support while I was studying. I also thank my classmates for their social and moral support. Finally I am grateful to God for the gift of life, good health, wisdom and protection which enabled me to study without disruptions.

Abstract

Welding is a joining method extensively used in fabrications and repairs of most metallic items. In Kenya most of the repairs are done in the unregulated “Juakali” industry by the manual shielded-metal-arc-welding technique. There is however a growing concern over the safety of the “Juakali” works. Failures of many products such vehicle parts is blamed on poor quality of weld joints and such failures may lead to fatal accidents and losses. In general these kinds of failures have created a negative image of “Juakali” products/services and hindered the growth of this vibrant informal industry. In this study, welding work by various “Juakali” enterprises was sampled and analyzed. A total of 92 samples comprising of repaired components and test coupons were collected from eight different locations across Kenya namely Ngong, Dagoretti, Mlolongo, City-stadium, Kitale, Kisumu, Mombasa and Meru. The welded joints were subjected to visual inspection, radiographic tests and tensile tests to identify the kind of flaws present and their mode of failure. It was found that the defects most prevalent in the 92 “Juakali” welds analyzed by visual and radiographic tests were: Incomplete Penetration (41 % of the samples); Lack of Fusion (29 % of the samples); Undercuts (12 % of the samples); Porosity (8 % of the samples) and Cracks (2 % of the samples). From 124 samples subjected to tensile tests, 60 % of them fractured in the welds. Additionally a total of 110 samples comprising of plate and pipe test coupons from the more established SMEs were also subjected to visual and radiographic tests for purpose of comparison. Defects found in SME samples were: Porosity (13 % of the samples); Incomplete Penetration (9 % of the samples), Lack of Fusion (6 % of the samples), and Undercuts (5 % of the samples). From this study it was concluded that the quality of welding is very poor in Kenya especially in the “Juakali” Sector. This was observed to be a result of incompetency and weak skills of artisans and technicians in the sector. Retraining was therefore recommended to improve the knowledge and hands-on skills of the artisans and technicians. Additional studies also need to be taken to determine other variables that may have an impact on the quality of welding such as type of equipment, materials used, experience of artisans and level of education.

Contents

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

List of Figures

List of Tables

Definition of Terms and Acronyms

INST – Institute of Nuclear Science and Technology

KEBS - Kenya Bureau of Standards

CNESTEN – Centre National de l’Energie des Sciences et des Techniques Nucléaires, Morocco. NDT – Nondestructive Testing

KNEB – Kenya Nuclear Electricity Board

NCST – National Council for Science and Technology

IAEA – International Atomic Energy Agency

ISP - International Science Programme

SME – Small and Medium Enterprises

GoK – Government of Kenya

JKS – “Juakali” Sector (A local term in Kenya referring to Informal Micro and Small Enterprises)

TC – Country Technical Co-operation

CRP – Co-ordinated Research Projects

MDG – Millennium Development Goal

USA – United States of America

GDP – Gross Domestic Product

UNCTAD – United Nations Conference on Trade and Development

OECD – Organisation for Economic Cooperation and Development

ISO – International Organization for Standardization

HAZ – Heat Affected Zone

ASME V – American Society of Mechanical Engineers: Boiler and Pressure Vessel Code Section V

ASME VIII – American Society of Mechanical Engineers: Boiler and Pressure Vessel Code Section VIII

ASME IX – American Society of Mechanical Engineers: Boiler and Pressure Vessel Code Section IX

ASME – American Society of Mechanical Engineers

ASEAN – Association of Southeast Asian Nations

SARB – South African Reserve Bank

CHAPTER 1

Introduction

1.0 Background

The informal sector in Kenya is important in the creation of employment and alleviation of poverty. It employs over 80 % of the working population, 20 % of this group being engaged in manufacturing (GoK, 2012). The "Juakali" sector (JKS) fall under this category of informal industry. The efforts of JKS are extensively employed in the construction industry, fabrication of domestic products and in the repairs of equipment, machinery and in the transport industry (GoK, 1999). Some of the JKS products include; wheelbarrows, hand carts, hoes, chairs, tables, windows, doors, door handles, hinges, water tanks, stands and pressure vessels. These items are fabricated by welding. Figure 1.1 and figure 1.2 shows some of the JKS repair and fabrication work in progress.

Figure 1.1: Repairs ongoing in "Juakali"

Figure 1.2: Some of "Juakali" fabrication products

There are concerns over the quality of welding in JKS that has led to bad reputation and hindered growth of this sector. Workmanship is the most common problem in welded products that eventually cause failures (Devletian and Dyke, 2008; Odero et al., 2003; Matthews, 2001). JKS products and services also compete with cheaper and better quality imports from other countries. In order to win a bigger acceptance in the market and for growth of the sector there is needs to produce reliable quality goods that meet international standards and at a lower cost (Mohd and Mohammed, 2013; Einav, 2005; GoK, 2005; GoK, 1992). Non-destructive testing (NDT) is one of the available quality control tools that can be used to help the industry improve on product quality and safety (Alcala, 2001; Mutuli, 1989).

NDT involves the use of non-invasive techniques to evaluate a product. It enables the determination of the integrity of materials, components, structures and to quantitatively measure some characteristics of an object. The tests can be carried out on a raw material, manufacturing work-in-progress, finished product, and on an item in service without affecting its serviceability and durability (Trimm, 2003; Khan et al., 2002). Common NDTs that can be done on welds include; visual testing, liquid penetrant testing, magnetic particle testing, radiographic testing, eddy current testing and ultrasonic testing (Joon et al., 2012; Alcala, 2001). Mechanical tests can also be done on welds to give additional information on the mechanical properties of the component (Hellier, 2003). In this study two of the NDT methods, namely radiographic testing and visual testing were utilized to analyze the quality of welds in the JKS. Some of the samples were also subjected to tensile mechanical tests to determine their failure modes and strength.

Both NDTs and mechanical tests are important in determining properties of interest in this study. Radiographic testing is one of the peaceful industrial applications of radiation technology (Ahonen, 2008). It is promoted as a necessary quality tool by the IAEA under various programmes such as individual country technical co-operation (TC) projects, regional projects and co-ordinated research projects (CRPs). This technology is needed for the improvement of the quality of industrial products, equipment and plants (Alcala, 2001) especially in the developing world such as Kenya. Tensile tests are destructive tests used to determine the strength and failure mode of the weld joint and it involves subjecting the test specimen to a tensile load until the specimen fails by fracture (Hellier, 2003). Visual tests involve inspection by naked eye with or without some visual or optical aids and are applied at all stages of any manufacturing and inspection process. Some of the discontinuities that can be determined by the NDT tests include; lack of fusion, poor penetration, cavities, inclusions, cracks, undercuts, lamellar tearing, overlap and burn-through (Devletian and Dyke 2008; Alaknanda et al., 2006). In this study discontinuities found in the "Juakali" products and causes of such flaws were investigated and the outcome used as a basis for developing recommendations.

1.1 Statement of the problem

There are serious concerns over the safety, quality and cost of products manufactured in the "Juakali" sector (JKS). For instance, fatalities and injuries related to road accidents in Kenya are caused by defects in motor vehicles which to some extent can be linked to poor workmanship at the fabrication and JKS repair workshops. The growth of this sector also remains inhibited due to inability of JKS products to penetrate and compete in the global market as a result of perceived bad image associated with poor quality. The bad image is portrayed by implications and is not based on any scientific inference that can be used by the entrepreneurs, financiers and regulatory policy makers. To the best of my knowledge, no scientific studies have been done so far to assess the quality of the JKS welding products and services.

1.2 Justification and significance of the study

The informal ("Juakali") Sector (JKS) is important in achieving some of the goals in Kenya's Vision-2030 and Millennium Development Goals (MDGs). Such goals include reducing poverty, promoting sustainable economic development and ensuring environmental mitigation through waste recycling. There is therefore a great need to identify the weaknesses in this vibrant sector and find solutions that will help the industry to grow. The use of NDT will enable the identification of common types of defects and potential causes of these defects. This will help in the design and development of improved welding methods and quality control procedures for the sector. Improved methods and procedures will ensure the production of items at a low cost, high quality, and of high integrity that will be able to easily sell, hence ensuring economic growth and increased employment opportunities.

The findings of this study are expected to be of significance to a wide range of interest groups. For instance, the types of defects identified will be used by the JKS as a basis for developing a continuous improvement program on quality. Similarly training institutions and researchers will be able to identify the skills gap and shortfalls needed to be bridged to meet actual requirements in industry. The policy makers on the other hand will use these findings as a basis of developing policies that will be geared towards a continuous development of the sector. All the improvements will then translate to consumers getting access to affordable good quality and safe products.

1.3 Objectives

1.3.1 Main objective

The main objective of this study was to investigate the quality of welds from Kenya's informal ("Juakali") sector using selected NDT techniques with a view of developing recommendations for the stakeholders.

1.3.2 Specific objectives

The specific objectives were;

i. To determine visible surface flaws by carrying out visual inspection.
ii. To determine volume discontinuities by carrying out radiographic testing.
iii. To determine the failure mode of welded components by carrying out tensile testing.
iv. To determine the causes of identified defects.
v. To compare "Juakali" and SME weld quality.
vi. To disseminate results to stakeholders and policy makers.

1.4 Scope of the study

This study investigated the quality of a random sample of welded products using selected NDTs and mechanical tests. Tests were carried out using radiographic testing, visual inspection and tensile testing. The products targeted were those fabricated and repaired in the JKS in Kenya. This being an exploratory investigation, a sample size of 92 JKS samples was selected due to financial limitations and statistical considerations. Welded components made by other formal sectors were also sampled and tested and a comparison with informal

(“Juakali”) sector products made. The tests were used to identify the type of flaws and the modes of component failure. The cause of the flaws identified was then investigated and ways of improving the quality of services and products was provided to the investigated sector.

CHAPTER 2

Literature Review

2.0 Informal sector

The informal sector entails all small-scale activities that are semi-organized, unregulated and that make use of low and basic technologies (GoK, 2012). The sector continues to play a vital role in complementing the modern formal sector and has potential to form one of the main economic pillars of industrialization and a major source of employment opportunities. It was projected that more jobs would be created in this sector than in any other non-agricultural sector (GoK, 1992). According to the Government of Kenya statistics, 80 % of all people in employment for the period 2008 to 2011 were in the informal sector. 20 % of those employed in the informal sector were engaged in manufacturing (GoK, 2012). The "Juakali" sector (JKS) fall under this category of manufacturers in the informal sector.

The Government of Kenya has long recognized the role and potential of the JKS, as indicated by the many policies formulated to assist this sector (GoK, 1992; GoK, 1996; GoK, 2007). The government set out a comprehensive policy framework, which among other things would enhance the transition of micro and small-scale "Juakali" enterprises into medium size enterprises (GoK, 1992). This approach is in agreement with global experiences which shows that most of the multinationals we see today actually started as small businesses which eventually grew to medium and large businesses and finally to multinational companies (Dana, 1988). The government of Kenya recognized that the informal JKS needed to be fostered to continue to expand and grow so as to bring about a sustainable economic growth and rapid employment generation through industrialization (GoK, 1996). The JKS was also recognized as providing an essential training ground for developing the entrepreneurial skills that are essential to Kenya's industrialization (GoK, 1992). According to its vision 2030, Kenya aims at becoming a newly industrializing, middle income country providing high quality life for all its citizens (GoK, 2007). One of the targeted key sectors in the attainment of the vision 2030 is manufacturing. To this end Kenya aims to become the provider of basic manufactured goods in Eastern and Central Africa through improved competitiveness. These policies developed by the Kenyan government were partly influenced by successes of similar models in the developed countries (Berry, 2002; GoK, 1992).

Advanced countries and all industrialized economies have long recognized the role of small business in creating employment, reducing poverty and increasing the welfare of the society and therefore continue to support the creation and development of SME's (Mukole, 2010; Pang, 2008; Tulus, 2008; Horn, 1995; Thornburg, 1993). For instance in USA, there were 24.0 million businesses in 2004, of which 5.7 million were small businesses employing about 5.7 million people (Longley, 2006). Similarly, in China, SME's are a major contributor in the rapid economic development experienced and accounts for about 40% of GDP (Mukole, 2010). In Pakistan also, the development of its economy is partly attributed to SME's which constitute nearly 90% of all the enterprises, employs 80% of the work force and accounts for approximately 40% of GDP (Harvie and Lee, 2003; Neumark et al., 2008). And in New Zealand as well, SME's accounted for 39% of total value-added output in 2004 and formed 96% of all enterprises in the country (Dalziel, 2006). The case is the same in South Africa, in which SME's account for about 91% of the formal business entities, contributing between 51 to 57% of GDP, providing about 60% of employment (Ntsika, 1999; Berry et al., 2002). The SMEs in these industrialized countries have managed to grow partly due to focus on export market in which SMEs account for a significant volume of exports from these countries (Mukole, 2010).

JKS has potential to make a significant contribution to exports market for Kenya. These exports will lead to increases in foreign exchange earnings, creation of employment opportunities, improved income per capita and trade surplus (GoK, 1996). Experiences from countries such as China, India, Taiwan and South Korea indicate that SME's contribute up to 60% of exports volume (Tulus, 2008; UNCTAD, 2003; Mephokee, 2004; OECD, 1997). This shows the important role played by SME's in the development of any country (Feeney and Riding, 1997). In Kenya, an increase in exports can be a big solution to address the imbalance of trade experienced. For instance, in the year 2011 Kenya's total exports was worth 0.5 billion, against imports of 1.3 billion (GoK, 2012). Industrial supplies accounted for 30 % of the exports and 31 % of imports. Welded metal containers were part of the domestic exports (GoK, 2012), indicating an already existing export market that only needs to be expanded. Quality JKS products should therefore be made readily acceptable and be able to compete in the global market by ensuring the absence of defects in welded joints (Khan, 2001).

2.1 Welding

Welding is a joining process of two or more metal parts that involves melting of the metal adjacent to the joint, then establishing an atom-to-atom bond (Hellier, 2003). The atom-to-atom bond is achieved by application of heat and pressure. Some of the common welding heat sources include; arcs, electron beams, light beams, exothermic reactions, and electrical resistance (Grieve, 2009).

Arc welding (based on arc source) and Oxy-fuel gas welding (based on exothermic reactions source) are two techniques extensively used in the “Juakali” Industry. The Oxy-fuel gas welding uses a fuel gas (normally acetylene) combined with oxygen to produce a flame having sufficient energy to melt the base metal. The welder controls the welding flame to melt the base metal and the filler metal in the joint (Were et al., 2011). In arc welding, the common methods of welding include; manual metal arc welding, gas metal arc welding, flux cored arc welding, submerged arc welding, and gas tungsten arc welding (Khan, 2001). The parameters of interest to be controlled in arc welding include; welding current, welding voltage, welding speed, torch position, gas protection, filler material addition and wire feed speed. When welding manually, it is difficult to maintain most of these parameters constant (Sun et al., 2005). The fluctuations and inappropriate selection and combination of these welding parameters result in weld flaws (Dar et al., 2009; Alaknanda et al., 2006).

2.1.1 Welding defects

Welding defects are flaws that affect safe functioning of a component. Some flaws in materials are inherent while others are introduced during manufacture and operation. Inherent flaws are due to crystal lattice imperfections and dislocations. Manufacturing processes such as welding, casting and forging may create additional flaws on these materials (Campbell, 2011). In operation the materials are subjected to stresses, fatigue and corrosive environments (Kang and Kupca, 2009; Einav, 2005; Alcala, 2001). These operating environments may induce additional flaws or may aggravate the already existing ones (Exworthy et al., 2002; Khan, 2001). The purpose of carrying out the inspection of welds therefore is to determine whether they are defective or not. This is done by first establishing the size, type and number of flaws and then making a decision based on some standard requirements (Valavanis and Kosmopoulos, 2010; Alcala 2001) on whether to accept, reject, reduce the life, or reduce the loading on the weld product.

Defects reduce the load carrying capacity of a component by causing high stress intensities. Beyond a certain limit the stresses induced in the component will exceed design limit due to defects. This leads to sudden unexpected failure below the design load and after fewer load cycles than predicted in design (Devletian and Dyke 2008; Khan, 2001). There are several causes of welding defects. According to Mathews (2001), the causes of welding defect can be broken down into the following; 45 % poor process conditions, 32 % operator error, 12 % wrong technique, 10 % incorrect consumables, and 5 % bad weld grooves. Most of these defect causes are as a result of poor workmanship skills. Some of the welding defects include lack of fusion, poor penetration, cavities, inclusions, cracks, undercuts, lamellar tearing, overlap and burn-through (Ramesh, 2012; Otegui et al., 2009; Alaknanda et al., 2006). These defects are discussed in detail below.

2.1.1.1 Lack of fusion and poor penetration

Lack of fusion is a linear defect that results when there is poor adhesion between weld bead and parent metal. It can be as a result of presence of slag, oxides, scale, or other non-metallic substances, little heat input, incorrect edge preparation, or rapid welding speed (Aalami and Rashidi, 2012). Lack of complete fusion reduces considerably the strength of a joint (Khan, 2001).

Poor penetration is a linear defect that results from either incomplete or excessive penetration. Incomplete penetration is when the weld metal does not extend to the required depth into the root of a weld joint (Figure 2.1). It results from improper joint preparation such as when the gap between plates being welded is narrow. It can also be caused by an electrode being held at an incorrect angle, large diameter electrode, fast welding speed, or insufficient welding current (Shen et al., 2012; Baughurst and Vosnaks, 2009). Cracks tend to initiate at points of incomplete penetration during the service life of components (Sungho et al., 1994). Excess penetration on the other hand (Figure 2.1) is when the weld metal does extend past required level beyond the root of a weld joint. The excessive penetration arises from application of too high heat input or too slow welding speed (Grieve, 2003; Martikainen and Moisio, 1993). Poor penetration and lack of fusion defects are likely to be experienced in JKS due to the manual nature of operations in this sector.

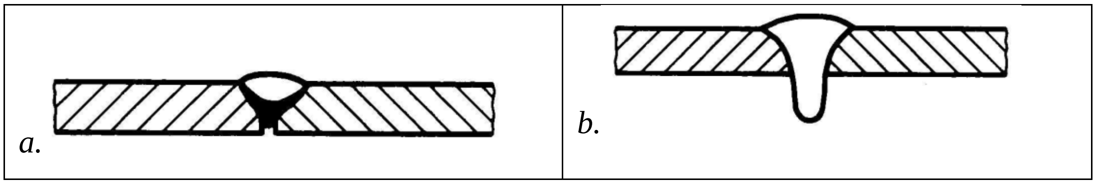


Figure 2.1: (a.) Incomplete root penetration and, (b.) Excessive penetration (Were et al., 2011)

2.1.1.2 Cavities and Inclusions

A Cavity is a rounded defect that results when there is presence of gas pockets in a weld either due to entrapment of gases or due to shrinkage of weld metal during solidification. Cavities may be caused by removal of the arc shield during welding, by creating a long arc or interrupting the shield gas. Presence of wet areas on the welding electrode may also create fine cavities. The types of cavities include gas porosity, pipe/wormholes and shrinkage cavities. Gas porosity is as a result of entrapment of gases such as oxygen, hydrogen, nitrogen, or carbon monoxide, as the molten weld metal solidifies (Grieve, 2003; Daugherty and Cannell, 2003) and is most likely to occur in JKS welding due to the open environments the work is done. Pipe or wormholes are gas inclusions that have an elongated form usually almost perpendicular to the weld surface and sometimes appearing as a branch of tree. They can be caused by use of wet powdered flux, inadequate welding current or wet welding electrodes (Khan, 2001). Shrinkage cavities on the other hand are cavities that are caused by thermal shrinkage. During solidification of molten metal, the volume decreases (shrinkage) hence thick sections of components that solidify last will likely form these shrinkage cavities.

Inclusions are rounded cavities containing slag or other foreign matter. Examples of inclusions include non-metallic inclusions and tungsten inclusions. Non-metallic inclusions may be caused by failure to adequately clean the surface of the joint, failure to remove slag from previous deposit, incorrect edge preparation, incorrect manipulation of the electrode and insufficient arc shielding (Baughurst and Vosnaks, 2009). Tungsten inclusions on the other hand are caused by excessive welding current, incorrect polarity of electrode using direct current (DC) source, dipping electrode into the melt or touching electrode with filler rod during welding. It frequently occurs at the start of weld when electrode is cold.

2.1.1.3 Cracks

Cracks are narrow separations in weld or base metal. Poor workmanship during fabrication contributes significantly to the formation of cracks (Otegui et al., 2009). They can also be caused by presence of hydrogen, sulphur or phosphorus (Devletian and Dyke 2008; Grieve, 2003). Figure 2.2 shows different types of cracks located in and around a welded joint.

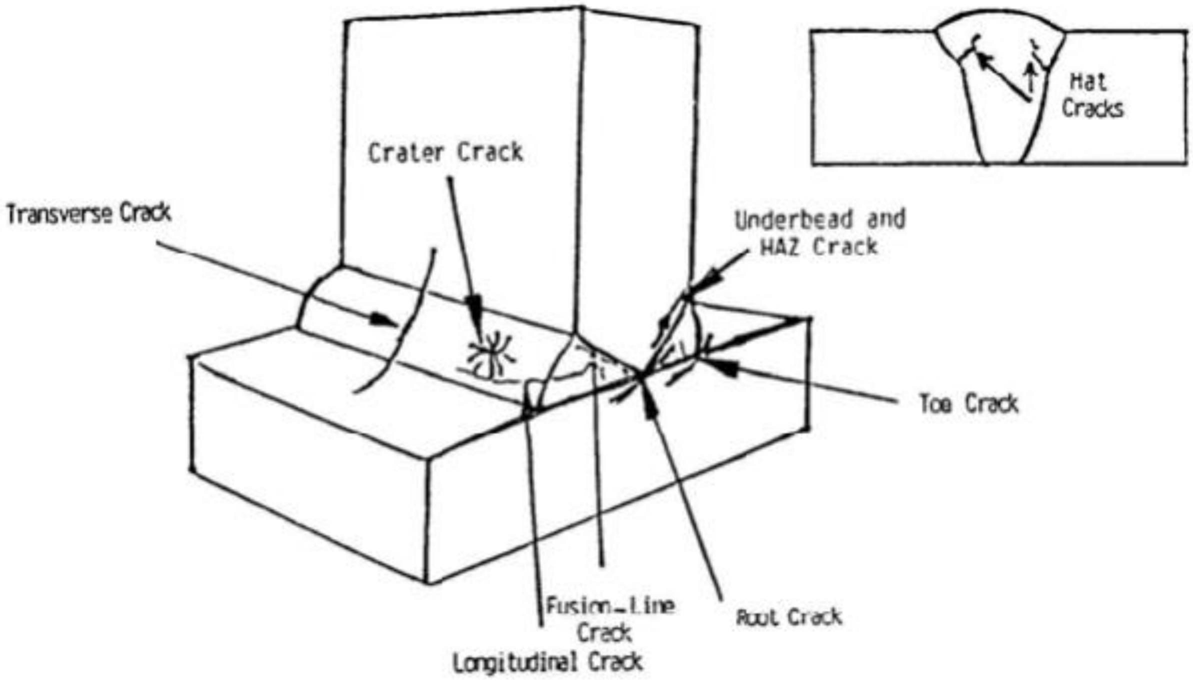


Figure 2.2: Cracks (Were et al., 2011)

Initiation of cracks happens either at the welded zone (weld metal cracks) or at the heat affected zone (HAZ) of the parent metal (base metal cracks) (Exworthy et al., 2002). Weld metal cracks include transverse cracks, longitudinal cracks, crater cracks and hat cracks. Base metal cracks include transverse cracks, lamellar tearing, delamination, under-bead cracks and fusion line cracks (Bernasovsky, 2009). In the weld metal, transverse cracks result when the contraction stresses are in the direction of weld axis. These weld metal transverse cracks lie perpendicular to the weld axis as indicated in figure 2.2 above. Transverse cracks in the base metal on the other hand occur at the heat affected zone (HAZ) and are due to residual stresses induced by thermal cycling during welding, high hardness, excessive restraint and presence of hydrogen. Under-bead cracks follow the contour of the HAZ and form due to high hardness, excessive restraint, and presence of hydrogen (Khan, 2001). Longitudinal cracks form perpendicular to the face of weld and run along the plane that bisects the welded joint. These longitudinal cracks can be in the form of check cracks, root cracks or centerline cracks. Check cracks are open to the surface and extend only partway through the weld. Check cracks are caused by high contraction stresses in the final passes or by hot-cracking (Baughurst and Vosnaks, 2009). Root cracks extend from the root to some point within the weld. The root cracks are often associated with poor quality welds (Hopkins and Benac, 2001) and form as a result of relatively small thickness and size of root pass. Higher heat input and lower wire feed rate generates more hot-cracking at the root of weld. The cracks in the root of weld are also produced when the gap between parts being welded is zero (Iida et al., 1996). Welding in JKS is commonly done with zero-gap between parts being joined and the root cracks are therefore expected to be present. Centerline cracks extend from the root to the surface of weld metal. They are caused by poor fit-up, overly rigid fit-up, or a small ratio of weld metal to base metal. Crater cracks occur in weld crater formed at the end of a welding pass. It is formed by failure to fill the crater before breaking the arc or by rapid withdrawal of the welding electrode following a short weld run. Hat cracks are formed due to high voltage or low welding speed. They occur half way up through the weld and extend into the weld metal from the fusion line of the joint (Otegui et al., 2009; Khan, 2001).

Lamellar tearing on the other hand is a form of cracking that takes places at the parent metal below the weld joint due to high stress levels (Figure 2.3). The tearing occurs in plates that have low ductility and laminar segregation (Grieve, 2003). Lamellar tearing results from shrinkage of weld bead stressing the base metal through its thickness. The tearing may also be caused when inclusions elongate due to rolling, forming stringers and then these stringers crack due to weakness along its plane (Hellier, 2003).

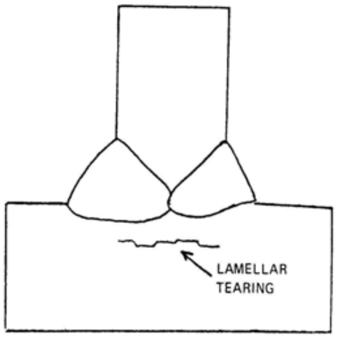


Figure 2.3: Lamellar-tearing (Were et al., 2011)

2.1.1.4 Undercut, Overlap and Burn-through

Other defects visible on the surface of a weld are undercuts, overlaps and burn-through. Undercutting is when there is a groove along the edge of a weld that results in reduced cross-section of the parent metal at the weld toe (Figure 2.4). They are caused by inaccurate welding parameter settings, poor procedure, high welding current, excessive welding speed and improper welding electrode angle (Baughurst and Vosnaks, 2009; Martikainen and Moisio, 1993). Undercuts are corrected by depositing additional weld metal to fill the grooves. On the other hand, overlapping is when weld metal protrudes beyond the toe or root of joint without fusing with the parent metal (Figure 2.4). It is caused by incorrect welding electrode angle, low weld speeds, or too high current. Overlaps can be removed my machining operations such as grinding. Finally burn-through defects have features similar to overlap and undercut which may require grinding off then re-welding respectively. The burn-through refers to when too much penetration of weld metal occurs due to excessive temperatures (Figure 2.4). Burn-through is caused by high current, low weld speed or incorrect weld electrode manipulation, leading to high heat in one area (Khan, 2001). All the welding defects discussed above can be detected by non-destructive testing techniques.

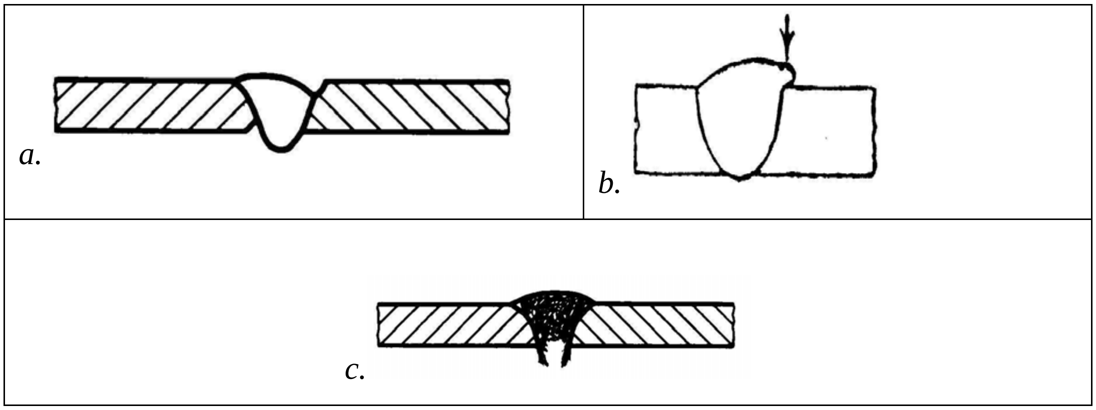


Figure 2.4: (a.) Undercut, (b.) Overlap, (c.) Burn-through (Were et al., 2011)

2.2 Non- destructive testing

Non-destructive testing (NDT) is a test done on an object to determine presence or absence of discontinuities and to determine other mechanical properties without damaging or changing its durability and serviceability (Alcala, 2001). NDT can be applied on raw materials, work in progress, finished product and the item after it has been put to use (Einav, 2005). NDT gives information on the nature, size and location of flaws. The information obtained is then evaluated and decisions made based on severity and danger of flaws in their current state. Decision options to be considered will be whether to repair, to scrap, or to allow the affected component to continue in service for a given duration without any comprise on safely (Khan, 2001).

The application of NDT techniques in inspection ensures the safety of products, reduces safety factors in design, reduces production costs, and guarantees reliability of item in service (Mohd and Mohammed, 2013; Alcala, 2001). According to Einav (2005) the culture in the older designs of structures and plant equipment was to over-design by including a factor of safety in product design so as to take care of any unknown discontinuities. However due to increased competition, scarcity of resources and desire for lighter products the emphasis in current designs is to use as little material as possible so as to reduce the cost and material of the product. The presence of flaws in these products therefore are no longer tolerated, hence the need for NDT as a quality assurance tool (Maximedia, 1997). For components which were overdesigned, NDT is being used to predict its remaining life beyond initial design estimation (Kang and Kupca, 2009). This has maximized profits without any compromise on safety and reliability of the plant equipment for industries that make use of NDT techniques in their processes (DiMeglio, 1995).

NDT techniques are extensively used in power plants (Cheng and Mandula, 2010; Einav, 2005; Iida et al., 1996), space exploration (DaSilva et al., 2005; Lee et al., 2010), transport (Pohl et al., 2004), petroleum and chemical industries (Sun et al., 2005) to assess current conditions and to predict remaining life of industrial equipment, processing lines, pipes, vessels and structures (Khan et al., 2002). During periodic preventive maintenance operations, NDT helps in identifying defects that would otherwise cause reactors and heat exchangers to fail, planes to crash, trains to derail, pipelines and boilers to burst, or bridges and other structures to collapse (Joon et al., 2009). Core components of research reactors are examined for aging characteristics with great success on ensuring the safety of nuclear reactors (Alcala, 2001).

Some of the common NDT techniques include visual inspection, dye penetrant testing, magnetic particle testing, radiographic testing, ultrasonic testing, and eddy current testing (Hellier, 2003; Alcala, 2001). Many of these methods are portable for site inspections, and the costs are relatively low making them potentially useful in the “Juakali” sector. Mutuli (1989) emphasizes the need of availing appropriate NDT technology to the JKS to enhance the growth of the industry. In this study two of the above NDTs namely visual testing and radiographic testing were used to investigate the quality of welds.

2.2.1 Visual testing

Visual testing is the primary method of inspection that makes use of the naked eye (Hellier, 2003). Simple equipment may also be included to improve on factors such as accuracy, repeatability, reliability and efficiency of inspection (Pohl et al., 2004). Examples of optical equipment that can be used to aid in visual inspection include; magnifying glasses, fiberscopes, bore-scopes, fillet gauges, flashlights, mirror, rulers, tape measures, and calipers (Einav, 2005; Alcala, 2001). The method is economical and capable of evaluating discontinuities which can be seen on the surface of the item. It is most effective when it is performed at all stages of any new fabrication and repair, and is the main method used during the inspection of pressure equipment to check for any visible flaws (Einav and Jin, 2008). Visual inspection is capable of revealing many weld discontinuities open to the surface such as incomplete penetration, undercuts and cracks (Khan, 2001) present in plate, pipe and fillet welds.

2.2.2 Radiographic testing

Radiographic testing is used to detect volume defects by making use of radiation (Hellier, 2003). The object being inspected is placed between a radiation source and a recording device. When the radiation passes through the material, some of it will be absorbed by dense material, some will be scattered and some will be transmitted through (Ditchburn et al., 1996). Resultant radiation energy transmitted will be varied and will be recorded accordingly on the image detector. The recording devices can be a film, photosensitive paper or fluorescent screen (Ahonen, 2008). Selection of recording medium to use between film and film-less radiography depends on availability, cost, time and resolution requirements (Kersting et al., 2010; Sun et al., 2005; Trimm, 2003). Common image detector available in Kenya for industrial radiography is film. Film radiography involves using radiation and gamma-film to obtain a good readable radiograph of the object being inspected and then interpretation of the radiograph images to determine the presence or absence of defects (Valavanis and Kosmopoulos, 2010).

There are two types of radiation source commonly used in industrial radiography namely, x-rays generated from x-ray tubes and gamma rays produced by radioisotopes (Alcala, 2001; Oresegun, 1999). The x-ray and radioisotope sources have unique advantages and find a wide range of application in industry in detection of flaws. The main advantage of radioisotope sources is that the associated equipment tends to be cheaper and more portable than x-ray sets, and does not rely on the availability of electricity and water supply (DaSilva et al., 2005) making it ideal for inspections at remote sites. On the other hand x-ray sources have the advantage of being switched off when not in use hence safer and also are capable of producing high quality radiographs of the component being tested (Einav, 2005; Khan et al., 2002). Typical applications of both x-ray and radioisotope radiography in industry include the inspection of welds for defects during manufacture of pipelines, boilers, pressure vessels, and in the examination of insulated pipelines for corrosion and blockages (Einav, 2005). In this study x-ray tube was used as radiation source for inspection.

2.3 Tensile testing

Tensile tests are destructive mechanical tests in which a specimen is subjected to a tensile load until the specimen fails. Failure is considered to have occurred if the material elongates beyond a given limit or when it breaks. When a metal is subjected to tensile loads, it increases in length. The elongation is elastic and recoverable on removal of load if the stresses are below yield strength. Permanent plastic deformation begins when applied stresses exceed the yield strength of the material. This rise in stress levels will eventually result in fracture of component (Bernasovsky 2009).

Presence of defects affects the strength of a component. Rounded defects such as inclusions and voids reduces the cross-sectional area hence the load-carrying capacity of a component. Linear defects such as cracks, incomplete penetration and lack of fusion act as stress concentration points whereby stresses are multiplied by several factors in regions of defect. As a result, failure of a component will occur at these points of reduced cross-sections and stress concentrations at stresses much lower than the yield strength of the material (Khan, 2001).

Tensile tests gives information on how and where a welded component subjected to a tensile load will fail. The presence of defects in welds introduced during the welding process will result in reduced cross-sectional area and stress concentrations that will cause failure to occur at the weld joint (TCR Engineering, 2004). Tensile tests are also used to determine yield strength and ultimate tensile strength on the weld joint (Hellier, 2003). The results can be used generally to compare the strengths between a welding metal and the surrounding base metal. This is attained by noting the location of failure whether it is on the weld or on the base metal.

CHAPTER 3

Methodology

3.0 Area of study

This study investigated the quality of welding in Kenya by evaluating a random sample of fabricated and repaired products from across the country. The work involved collection of "Juakali" (JKS) samples from selected towns namely Ngong (14 samples), Dagoreti (14 samples), Mlolongo (12 samples), City Stadium (12 samples), Mombasa (10 samples), Kisumu (10 samples), Kitale (10 samples) and Meru (10 samples). Additional weld samples (92 plates and 18 pipes) done by the more established welders in the formal SME sector were also collected for purposes of quality comparison with JKS samples. Samples selected for testing were those accessible from both sides of the weld to enable inspection by film radiography. The samples were then transported to the test laboratories at the Kenya Bureau of Standards (KEBS). They were subjected to visual, radiographic and tensile tests to identify flaws and determine failure modes.

3.1 Sampling method

Test samples in this research work were collected from the JKS and SME sectors. Collection of test samples from the JKS was done in two major phases. In the first phase an initial survey was done in which 28 repair welding samples was randomly purchased from various premises. The welding of these samples was witnessed so as to determine the typical thickness ranges of the JKS weld products, joint preparation methods and welding techniques used. These samples were then evaluated by visual and radiographic examination to determine types of defects present. The findings from the first phase were then used as a basis for launching the second phase. In the second phase, two sets of standard test coupons were prepared (following ASME IX guidelines) and submitted to "Juakali" welders across the country for butt welding by the manual shielded-metal-arc-welding method. One set (of 32 samples) of the coupons had a 0 mm gap while the second set (of 32 samples) had 2 mm gap to simulate the welding conditions observed earlier in the first phase of this investigation. Each welder was given two coupons to weld, one with 0 mm gap and the other with 2 mm gap. The entire welding process was witnessed on site as per ASME IX requirements. The test coupons were then taken to the laboratory for evaluation by visual, radiographic and tensile tests. SME test coupons on the other hand were sampled from welders who were applying for new welder certifications or re-certification at KEBS. These samples were prepared and analyzed following ASME IX guidelines. The entire process was similarly witnessed starting from the surface preparations and welding in the field. The SME coupons (92 plates and 18 pipes) were butt welded by the manual shielded-metal-arc-welding method. The samples were then taken to laboratory for visual and radiographic examination. The findings from JKS and SME were then compared. Figure 3.1 shows plate and pipe test coupons analyzed.

Figure 3.1: Plate and pipe test coupons analyzed

3.2 Testing method

3.2.1 Visual testing

Visual testing was done in accordance with Article 9 of ASME V. The standard specifies the minimum luminance required when performing the test, distance and angle of inspection, sample preparation requirements, test report and test equipment. The main items required to perform this test included the test specimens, measuring tape, vernier caliper, magnifying lens and weld gauge (Hellier, 2003). The process involved visually checking for discontinuities on the surface with the help of magnifying glass and then doing appropriate measurements on the defects detected to determine size.

3.2.2 Radiographic Testing

Radiographic testing involved the acquisition of radiographic films, processing, viewing and interpretations of results. Radiographic film acquisition was done in accordance with Article 2 and Article 22 of ASME V. This standard provides for the procedures of sample preparation, selection of proper films and image indicators, determination of x-ray tube voltage and radiation source, calculations of source-to-object distance, taking of radiographs, film processing, setting of film viewing conditions and preparation of test report. Once all the parameters had been set according to the standard, a radiographic image was taken on a film. The film was then unloaded for processing. The entire film processing procedure was accomplished under safelight conditions in a darkroom.

After the processing, radiographic film viewing and interpretation was done in accordance with ASME VIII and ASME IX. These codes specify the acceptance levels for indications from imperfections in welds detected by radiographic testing. The films were first evaluated for artifacts and false indications that are formed either prior to film processing, or during film processing or after film processing. The radiographs were then evaluated for true relevant discontinuities. To assess the quality level, the sizes of imperfections permitted by the standard were compared with the dimensions of indications revealed by a radiograph made of the weld. Safety measures when using ionizing radiation were observed at all stages of this test. Figure 3.2 shows the radiography equipment setup and film viewer setup.

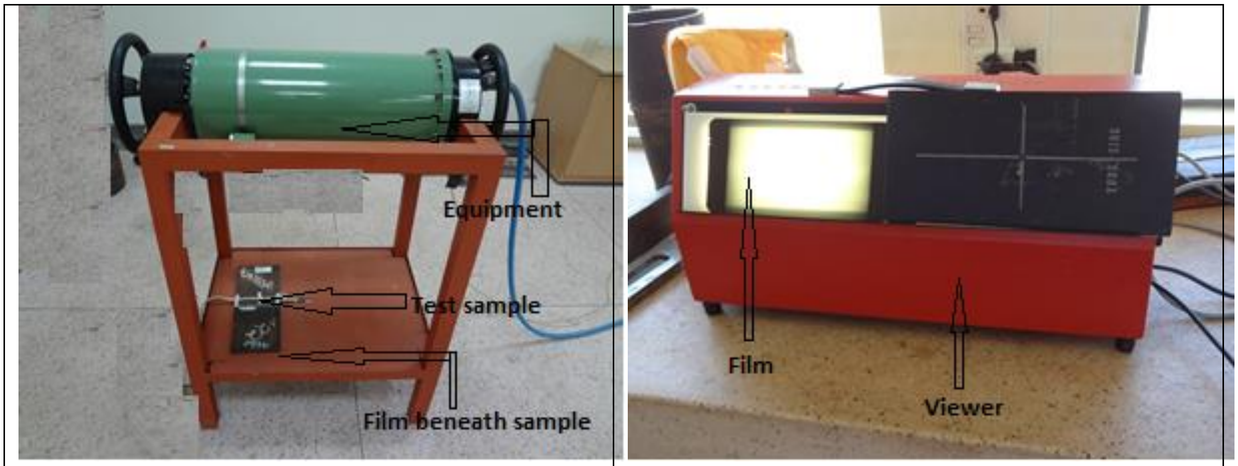


Figure 3.2: Radiography equipment setup and film viewer setup

3.2.3 Tensile tests

A total of 124 tensile specimens were tested. Two tensile specimens were obtained from each of the fabrication samples i.e. 62 tensile specimens from 31 of 0 mm gap samples and another 62 tensile specimens from 31 of the 2 mm gap samples. Tensile tests were conducted according to ISO 6892 on selected JKS products. This standard provides for the method of determination of the shape and dimensions of the tensile-test specimen based on the physical structure of the source metallic item from which the test pieces are taken from. It also provides procedures for the preparation of test specimen, calibration of testing equipment, carrying out the test, measurements of strength and elongation, determination of dimensional changes after fracture and preparation of test reports. The tensile test specimens were subjected to tensile loading until they ruptured. The location of specimen rupture was then noted as failure either on the weld metal or on the parent metal. Figure 3.3 shows the Tensile test setup and fractured tensile specimen.

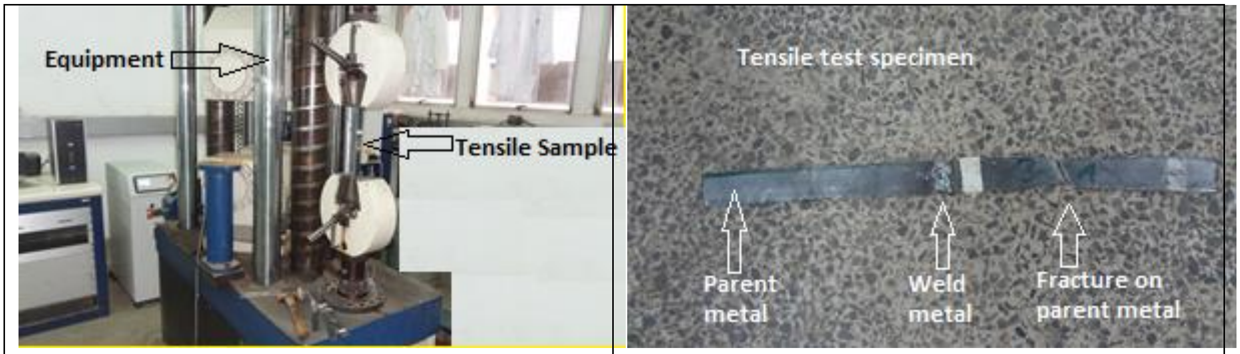


Figure 3.3: Tensile test setup and fractured tensile specimen

Tensile test results were also subjected to paired t-Test analysis to compare the two treatments of welding 0 mm gap at joint and 2 mm gap at joint. The procedure used in t-Test was as follows (Montgomery & Runger, 2011);

a) Calculate the difference between the two observations (0mm gap – 2mm gap tensile strengths)
b) Calculate the mean of difference
c) Calculate standard deviation of difference
d) Calculate standard error of the mean of difference = standard deviation / Square root of sample size

e) Calculate t-statistic = mean difference / standard error
f) Determine degrees of freedom = sample size – 1
g) Use tables of t-distribution to compare t-statistic and t-distribution values

3.2.4 Acceptance criteria

The decision to accept or reject a flaw indication in the welds was done based on ASME VIII and ASME IX guidelines. According to ASME IX, indications in which the length is more than three times its width are referred to as linear indicators. Linear indications include cracks, lack of fusion and incomplete penetration and they appear on the radiograph film as linear. All linear indications in a welding are unacceptable in accordance to ASME IX code. Indications in which the length is less than three times its width are referred to as rounded indicators. Rounded indications include porosity and inclusions such as slag. Rounded indications were evaluated based on size and distribution in a weld volume in accordance to ASME VIII. The quality level of the welding was determined by comparing the size of the rounded indications observed on the test object with the dimensions of imperfections allowed by the standard based on thickness of specimen. Tensile tests on the other hand were evaluated based on location of failure. Tensile specimens that fractured outside of the weld region (i.e. on the parent metal) were considered to be good welds whereas those that fractured in the weld metal were considered to have failed. Tensile strength required to rupture each of the specimens were also recorded.

CHAPTER 4

Results and Discussions

4.0 Data recording and analysis

Informal ("Juakali") sector samples were subjected to visual, radiographic and tensile tests. Additional samples welded by the more established Small and Medium Enterprises (SME) welders were similarly evaluated for purposes of comparison. The data obtained from this investigation has been categorized generally as "Juakali" samples and SME samples. "Juakali" samples are further grouped in terms of repair welds, fabrication welds performed with 0 mm gap and fabrication welds performed with 2 mm gap. SME samples are divided into plate samples and pipe samples. The type of defects identified in each of the above categories is evaluated for their frequency of occurrence. Potential causes of the observed defects are explored, discussed and solutions suggested. Selected photos of film radiographs of "Juakali" welds showing various defects are attached in Appendix 7.

4.1 Defects

The weld samples were analyzed by visual and radiographic inspection and were found to have the following dominant defects; incomplete penetration, undercuts, porosity, lack of fusion and cracks. Figures 4.1, 4.2, 4.3, 4.4 and 4.5 show how the various defects appear in the radiographic film.

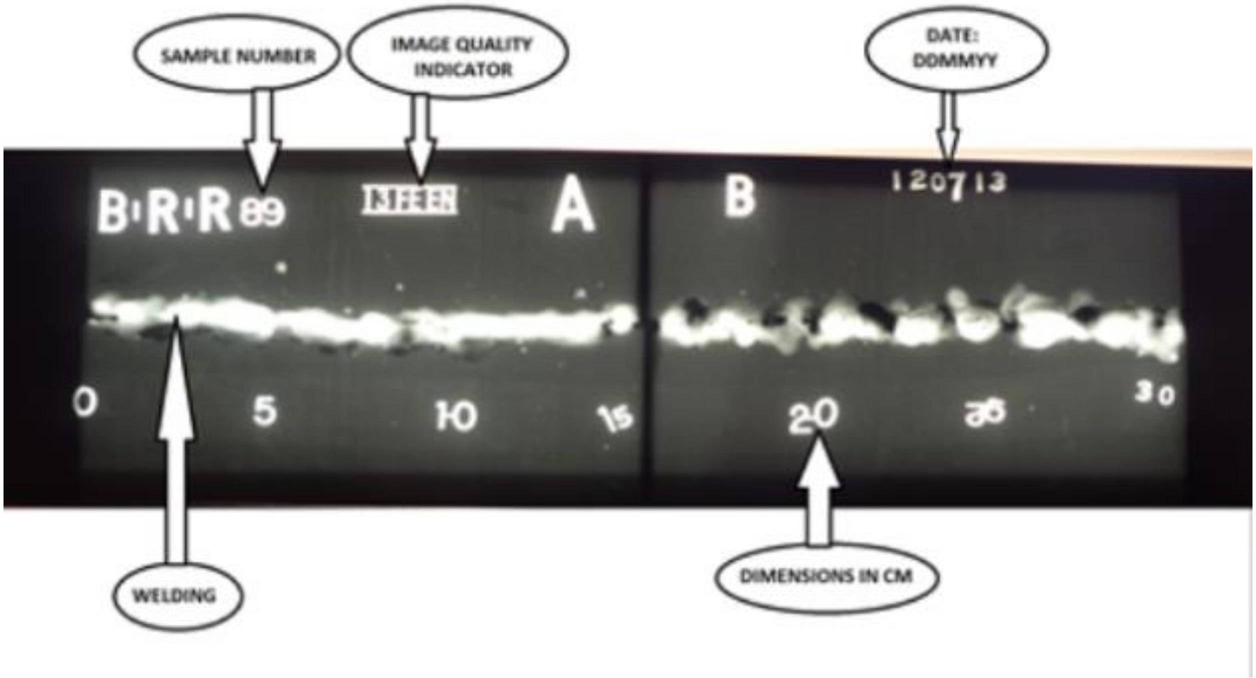


Figure 4.1: Selected photo of film radiographs showing important labels

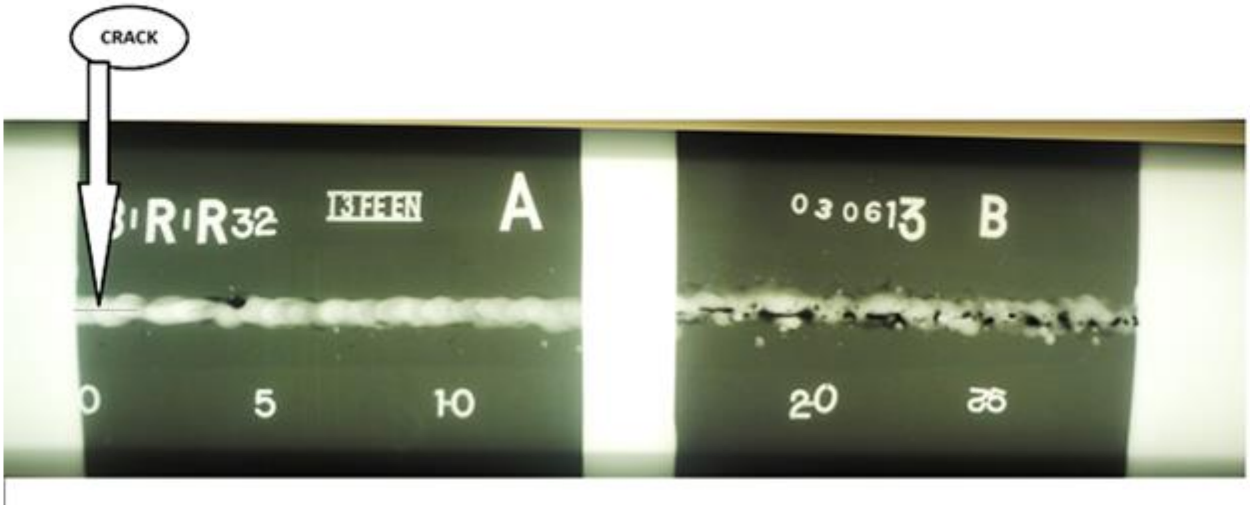


Figure 4.2: Selected photo of film radiographs showing crack

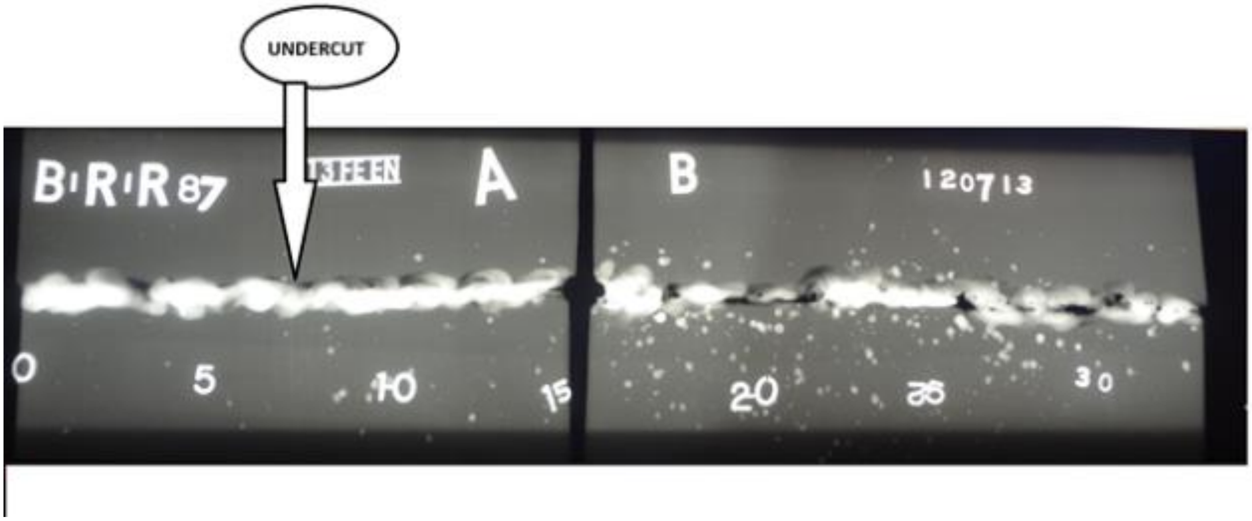


Figure 4.3: Selected photo of film radiographs showing undercut

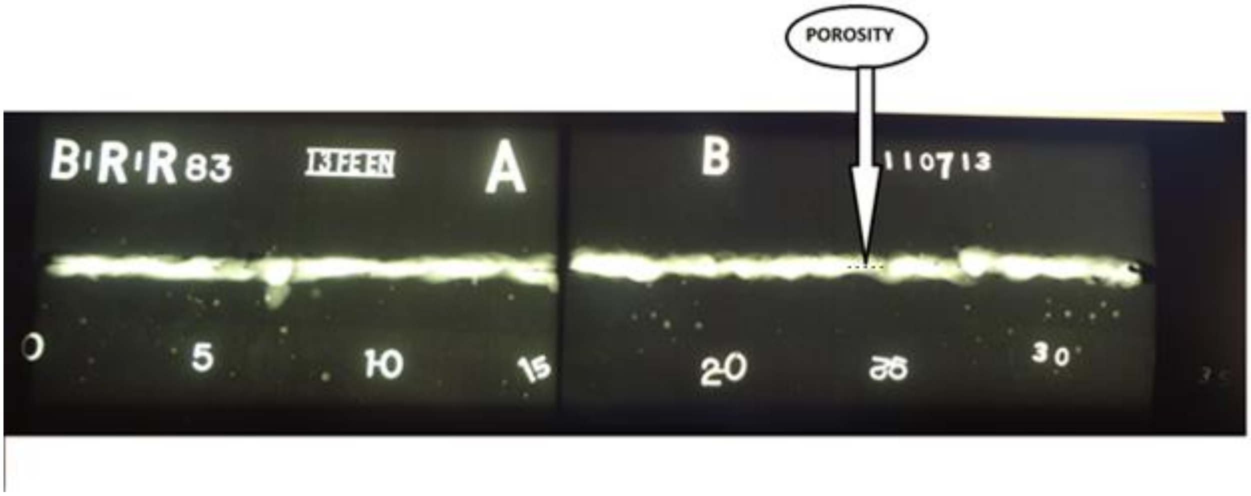


Figure 4.4: Selected photo of film radiographs showing porosity

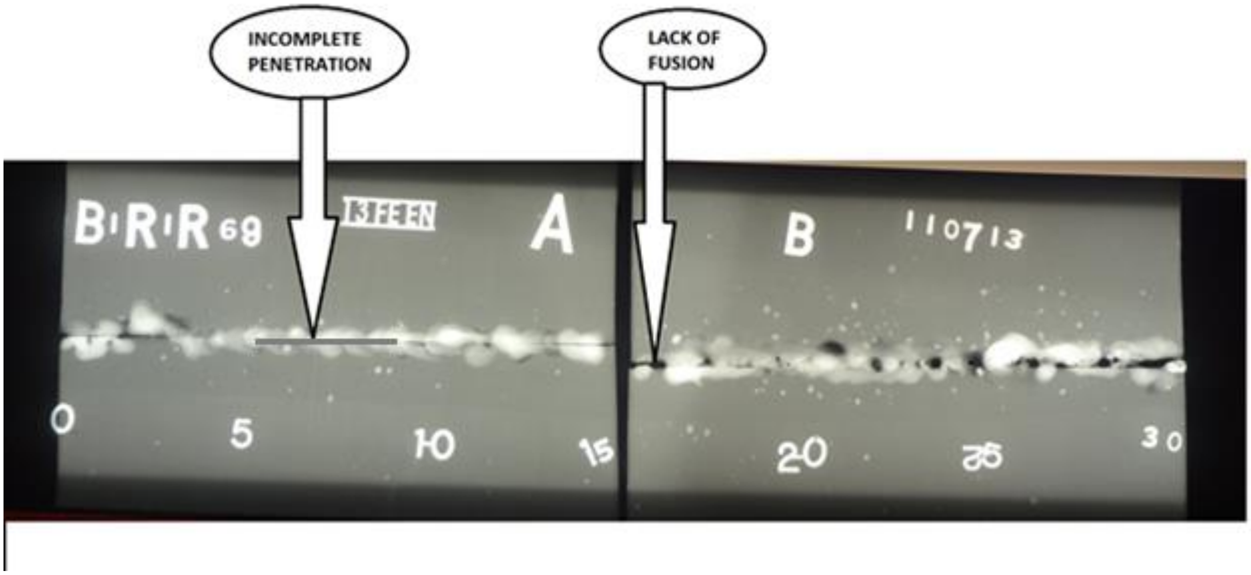


Figure 4.5: Selected photo of film radiographs showing incomplete penetration and lack of fusion

4.2 “Juakali” samples

A total of 92 “Juakali” weld products were subjected to visual and radiographic testing. Out of the 92 samples, 28 were repair samples, 32 were fabrications welded with 0 mm gap at joint while 32 were fabrications welded with 2 mm gap at joint. 124 tensile test specimens were then obtained from 62 of the above “Juakali” fabrication samples and subjected to destructive tensile test to fracture.

4.2.1 Defects in “Juakali” welds

The “Juakali” welds subjected to visual and radiographic inspection were found to have the following dominant discontinuities; incomplete penetration (41 % of the samples), undercuts (12 %), porosity (8 %), lack of fusion (29 %) and cracks (2 %). Figure 4.6 shows graphically the overall defect prevalence in JKS samples.

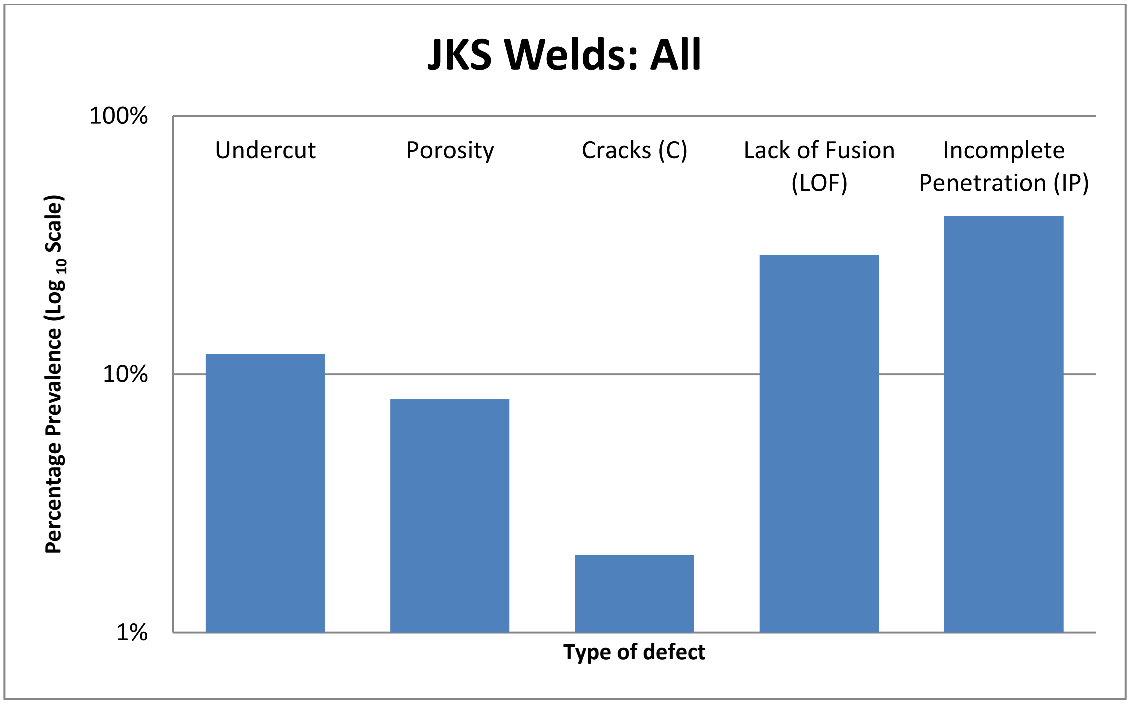


Figure 4.6: Overall defect prevalence in JKS samples

When subjected to tensile loads, 60 % of the specimens fractured at the weld joint while the remaining 40 % fractured at the parent metal. Appendix 1 gives the detailed results for each of the samples. The high percentage of weld failure in tensile tests can be attributed to the high number of samples observed with linear indications namely incomplete penetration and lack of fusion. These linear types of flaws are most critical in a weld due to resulting stress concentration effects and are therefore considered undesirable by most international standards. The lack of fusion occurred on places with slag inclusion. Most of the samples which had indications of lack of fusion also had incomplete penetration. Cracks observed were as a result of having a small volume of weld metal compared to the size of the parent metal and resulted from lack of proper weld joint preparation.

4.2.2 Defects in repaired samples

Specimens from repaired products at "Juakali" sector were subjected to visual and radiographic examination. The following flaws were observed: incomplete penetration (61 % of the samples), undercuts (4 %), porosity (11 %), lack of fusion (18 %) and cracks (4 %). Figure 4.7 shows graphical presentation of defect prevalence on JKS repair samples. Appendix 4 gives the detailed results for each of the samples. The cracks observed were mainly due to the difficulty of welders carrying out proper repair in various welding positions that included vertical and overhead welding. Due to the size and shape of the products in this category it was not possible to perform tensile tests. It was noted also that most repair works were carried out with 0 mm gap at joint which resulted in incomplete penetration of the weld joint.

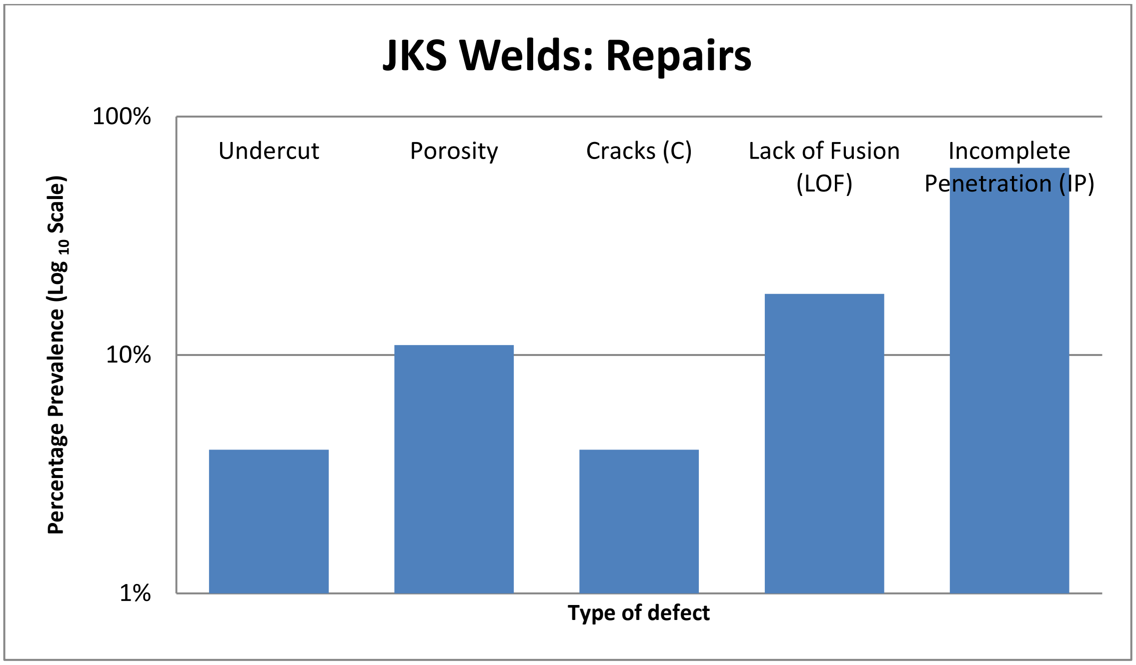


Figure 4.7: Defect prevalence on JKS repair samples

In an attempt to minimize the problem of incomplete penetration observed to be widespread in many “Juakali” welded samples, instructions were issued to have the welders join two sets of similar products, one set had 0 mm gap at joint while the second set had 2 mm gap at joint.

4.2.3 Defects in samples fabricated with 0 mm gap at joint

Visual and radiographic inspection of the samples welded with 0 mm gap at joint revealed the presence of the following dominant flaws; incomplete penetration (59 % of the samples), undercuts (22 %), porosity (3 %) and cracks (3 %). Figure 4.8 shows a graphical presentation of defect prevalence on JKS samples with 0 mm gap at joint. When these samples were subjected to tensile tests, 55 % of them failed at the weld joints. Appendix 2 gives the detailed results for each of the samples. The high percentage of samples with insufficient penetration was due to improper weld joint gap and was a common problem with a majority of “Juakali” welders. Undercuts were due to poor manipulation of the welding electrode. It was observed that most of the welds done in the “Juakali” sector are done with with 0 mm gap at joint and was the main reason for incomplete penetration defects.

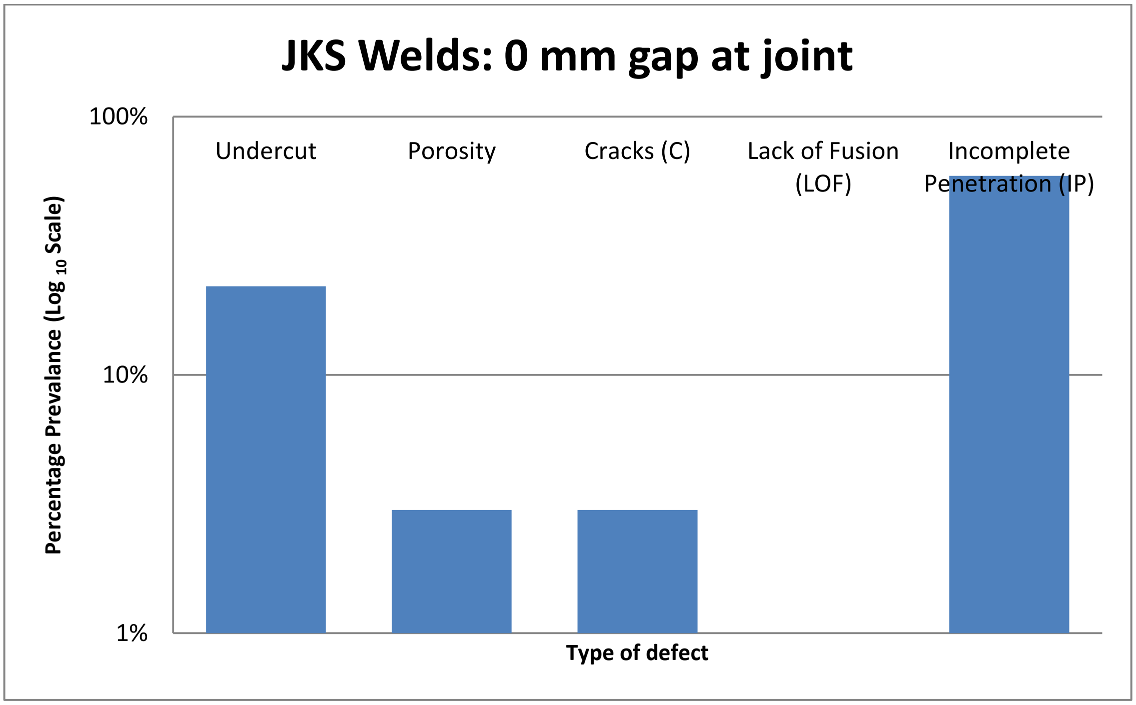


Figure 4.8: Defect prevalence on JKS samples with 0 mm gap at joint

4.2.4 Defects in samples fabricated with 2 mm gap at joint

For the samples welded with 2 mm gap at joint, the following flaws were observed upon visual and radiographic inspection; incomplete penetration (6 % of the samples), undercuts (9 %), porosity (9 %) and lack of fusion (69 %). Figure 4.9 graphically show the defect prevalence on JKS samples with 2 mm gap at joint. When subjected to tensile tests, 66 % of these samples failed on the weld joints. Appendix 3 gives the detailed results for each of the samples. The failure in tensile tests was attributed to lack of fusion which rose to 69 % up from 0 %. Lack of adequate skills and workmanship of welders on manipulation of welding electrode was observed when performing these welds on samples with 2 mm gap at joint. The difficulty observed here when welding 2 mm gap joint explains why “Juakali” welders preferred and did most of their welding by having no gap at the joint. The zero gap enabled them achieve a nice looking weld at the surface but with no penetration through the entire thickness of part. With 2 mm gap at joint on the other hand they were able to achieve full penetration. However the welders lacked proper skills required to make proper weld joint when the gap was introduced hence leading to a lack of complete fusion at the joint.

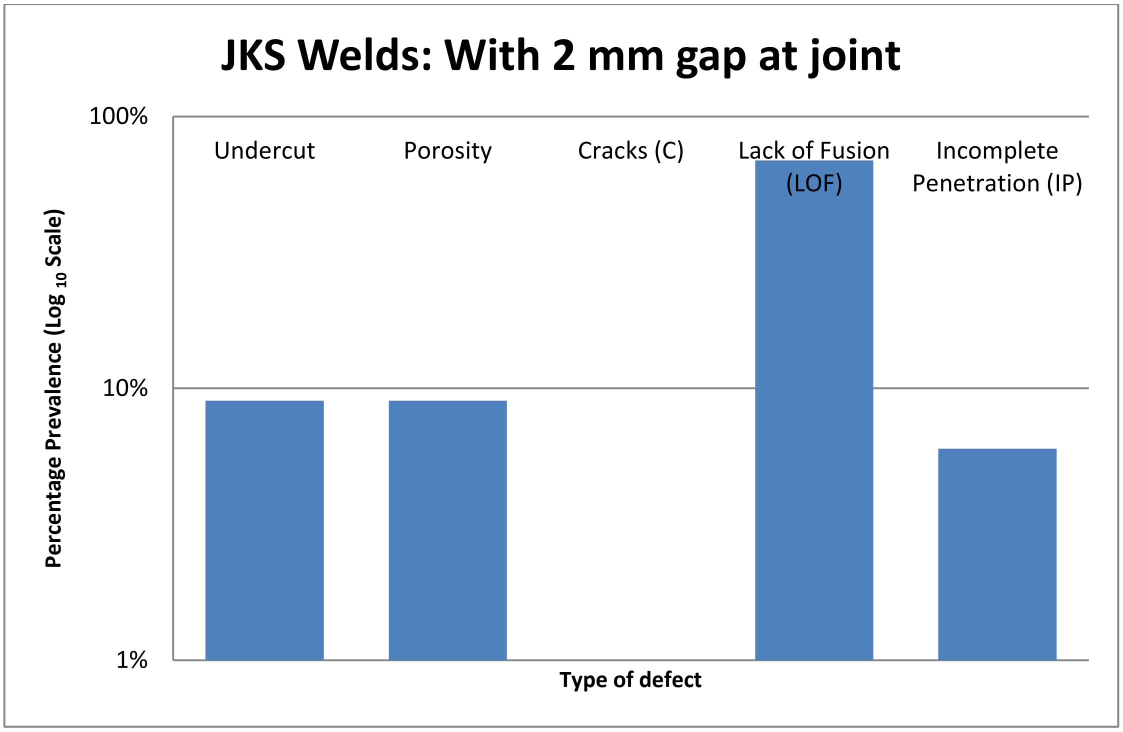


Figure 4.9: Defect prevalence on JKS samples with 2 mm gap at joint

It was noted that with adequate training the necessary knowledge and skills can be gained by the “Juakali” welders so as to produce better quality welds. For instance the number of items with incomplete penetration decreased from 59 % to 6 % of the samples when the welders were guided on what to do by means of welding instructions aimed at reducing incomplete penetration. Figure 4.10 graphically shows the prevalence of incomplete penetration on the various sample categories.

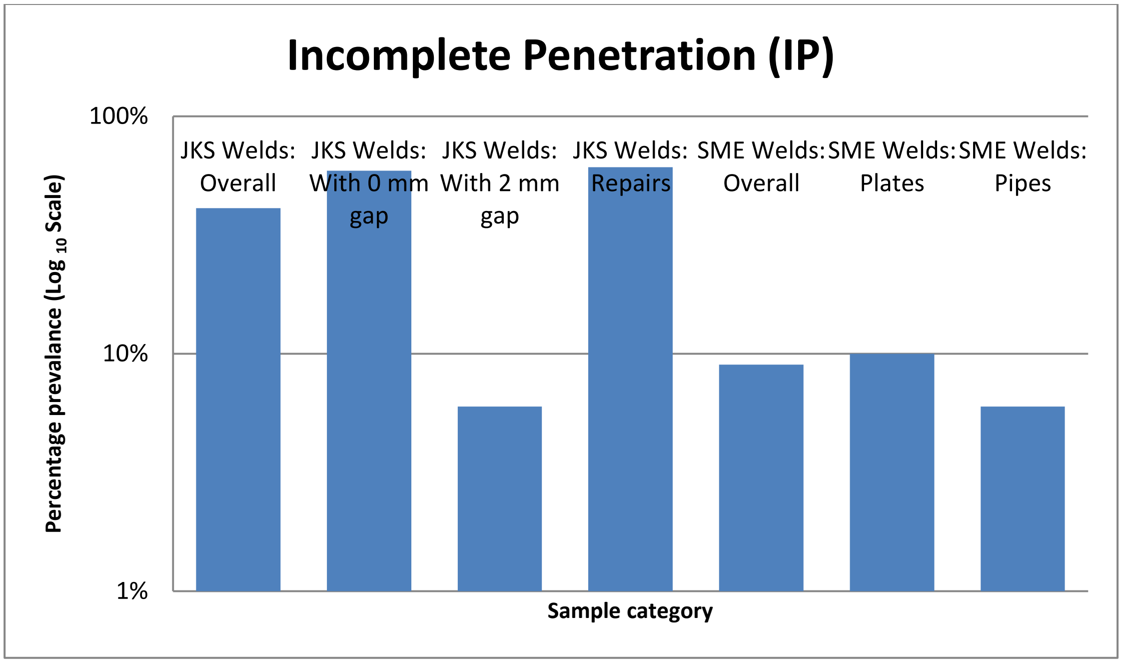


Figure 4.10: Incomplete Penetration prevalence on various sample categories

This significant gain in penetration was attributed to having a proper joint gap before welding as specified in the welding instructions (i.e. welding with 2 mm gap between the parts being joined), gap size being based on welding rod size. These instructions were developed based on theoretical knowledge of the dominant welding defect observed (i.e. incomplete penetration), how the defects are formed and how they can be minimized. This observation agrees with that of Hopkins and Benac (2001) who concluded in their work that in order to achieve better quality of welding it was necessary to implement some welding procedures and improve on welder skills through training.

4.2.5 Tensile test results

A total of 124 tensile specimens were tested. These specimens were obtained from the fabrication samples above (i.e. with 0 mm gap at joint, and with 2 mm gap at joint). The average tensile strength for the samples subjected to tensile test was obtained as 325 N/mm^2. Appendix 1 shows tensile strengths for each of the test specimens. Figure 4.11 shows graphical plot of the tensile strengths for each of the samples tested.

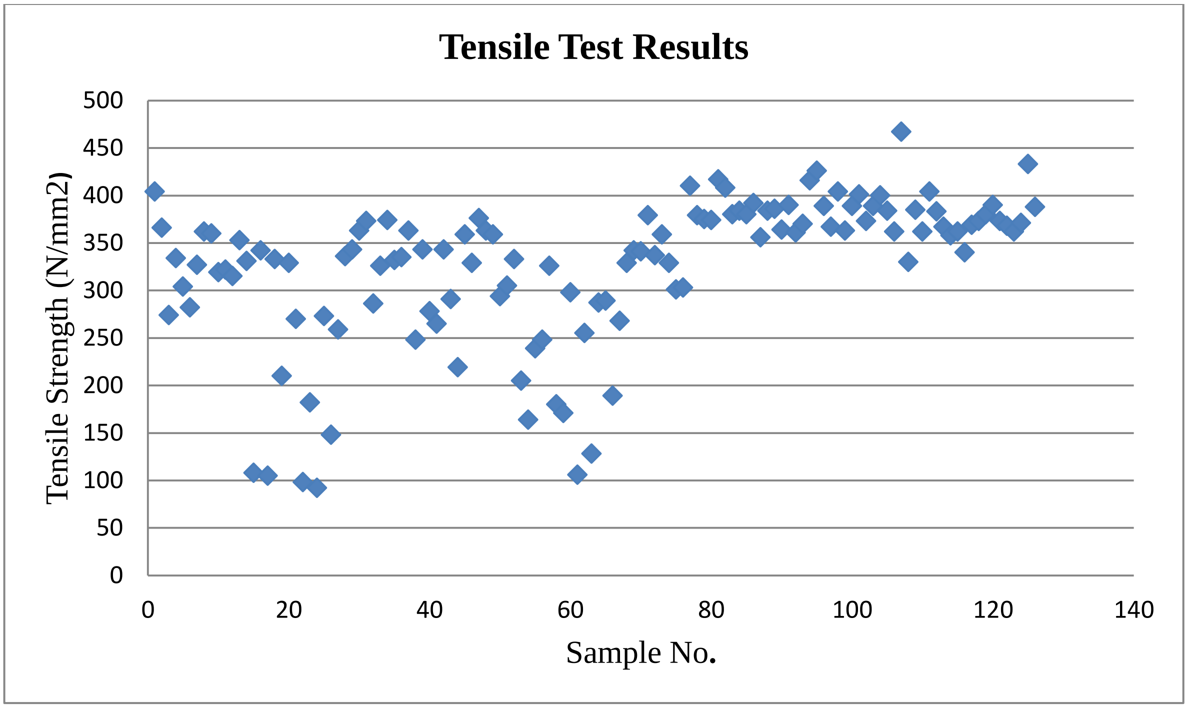


Figure 4.11: Tensile Test results

A paired sample t-Test at 95% confidence interval was carried out to compare mean tensile strengths for samples welded with 0 mm gap and samples having 2 mm gap at joint. Table 4.1 shows mean tensile strengths for two treatments given to 31 different welders which were subjected to t-Test. Table 4.2 shows a summary of t-Test results obtained. Due to the means of the two tensile strengths and the direction of the *t*-value, we can conclude that there was no statistically significant difference in the two tensile strengths at 0 mm gap and 2 mm gap, hence any differences between the two is due to chance and not manipulation of the gap. The margin of error for the difference in strengths is obtained as 24 N/mm^2. This lack of difference in strength is attributed to the fact that even though introduction of a 2 mm gap led to significant reduction in defect of lack of penetration, the gap also introduced a lack in proper fusion defects due to weak skills of welders which could not be simply solved by introducing gap at the joint. The welders need to be given comprehensive training on proper workmanship skills so as to achieve proper quality welds of significant strength.

Table 4.1: Mean tensile strengths (N/mm^2) for 31 welders subjected to two treatments

Welder No.	1	2	3	4	5	6	7	8	9	10
0mm gap	397	368.5	390	382.5	354.5	331	358.5	367.5	361.5	342.5
2mm gap	357	420.5	369	326	318	392	284.5	286.5	301.5	372.5
0mm gap-2mm gap	40	-52	21	56.5	36.5	-61	74	81	60	-30

Welder No.	11	12	13	14	15	16	17	18	19	20
0mm gap	345.5	363	360	331	351.5	268	290.5	195	284	218.5
2mm gap	368	376.5	306.5	310	361	136	176.5	250	102	110
0mm gap-2mm gap	-22.5	-13.5	53.5	21	-9.5	132	114	-55	182	108.5

Welder No.	21	22	23	24	25	26	27	28	29	30	31
0mm gap	280	224	305.5	398	381	354	327	374	351	338.5	416.5
2mm gap	218.5	354.5	346	408	357.5	391.5	350	381.5	313.5	380	360
0mm gap-2mm gap	61.5	-130.5	-40.5	-10	23.5	-37.5	-23	-7.5	37.5	-41.5	56.5

Table 4.2: Paired samples t-Test results

	Paired Differences					T	Degrees of Freedom	Significance (2-tailed)
	Mean	Standard Deviation	Standard Error of Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1: 0mm gap – 2mm gap	20.161	65.980	11.850	-4.040	44.363	1.701	30	0.099

4.3 SME samples

92 plates and 18 pipes were sampled from the more established welders in the SMEs. These samples were subjected to visual and radiographic examination.

4.3.1 Overall defects in SME samples

On average the SME samples had the following defects; undercuts (5 % of samples), porosity (13 % of samples), lack of fusion (6 % of samples) and incomplete penetration (9 % of samples). Figure 4.12 graphically shows the overall defect prevalence on SME samples. The SME samples were composed of plates and pipes.

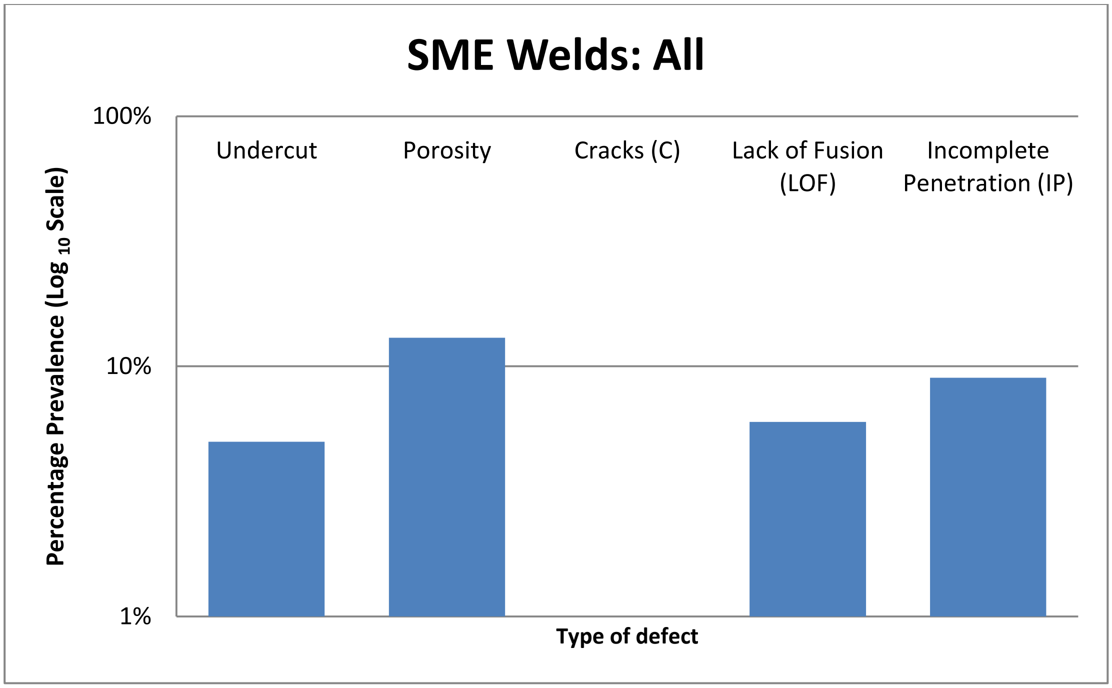


Figure 4.12: Defect prevalence on overall SME samples

4.3.2 Defects in SME plate samples

Specimens from the welded SMEs' plates had the following flaws: incomplete penetration (10 % of the samples), undercuts (5 %), porosity (15 %) and lack of fusion (8 %). Figure 4.13 shows graphically the defect prevalence on SME plate samples. Appendix 5 gives the detailed results for each of the samples. The levels of incomplete penetration and lack of fusion were significantly lower as compared to "Juakali" samples. The sizes of these critical defects were also relatively smaller. The reason for the low levels of defects was due to the fact that this category of welders were better trained on welding and are also subjected to annual assessment on competency and quality of their work through welder qualification programs. It was observed that most of the defects observed were from works done by welders who were new in the SME sector and doing their first welder qualification evaluation as opposed to more experienced SME welders whose quality had improved significantly over the years.

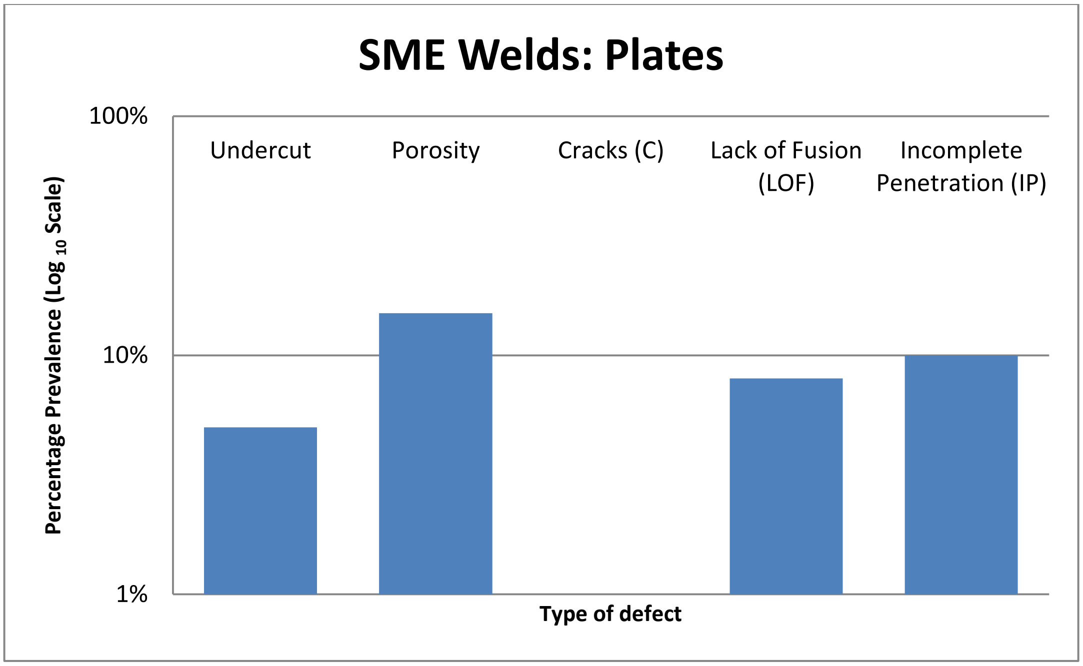


Figure 4.13: Defect prevalence on SME plate samples

4.3.3 Defects in SME pipe samples

For the sampled welded pipes from SMEs, slight incomplete penetration was observed in just 6 % of the samples. Figure 4.14 shows graphically the defect prevalence on SME pipe samples. Appendix 6 gives the detailed results for each of the samples. Due to the complexity of pipe welding, it is believed that welders chosen to perform this kind of work of welding have received more training and experience as compared to welders of the plate samples. This could be the reason for the quality differences observed between welders of SME plate and SME pipe welds.

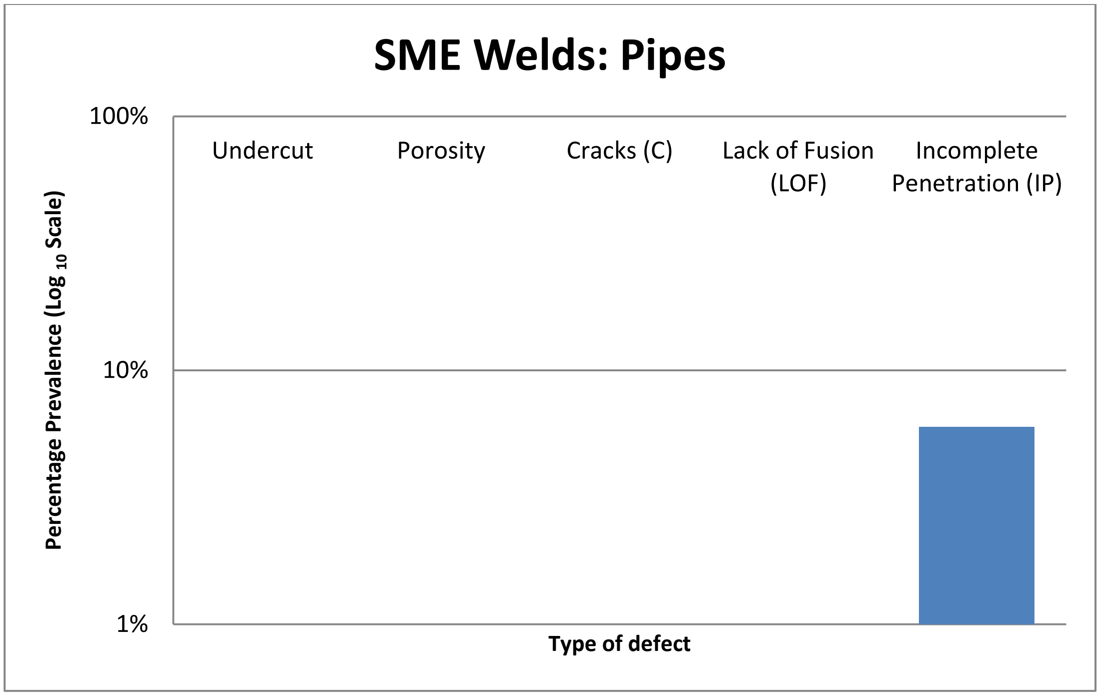


Figure 4.14: Defect prevalence on SME pipe samples

4.4 Comparing Juakali and SME samples

When “Juakali” sector (JKS) and SME test results were compared (Table 4.3), defects in SME samples were significantly low. Figure 4.15 graphically shows the comparison of test results for JKS and SME Welds. The lower level of critical defects on the SME samples as opposed to “Juakali” samples was in general attributed to the fact that the welders in SME category had received better technical trainings and acquired more skills on welding. The majority of SME welders were also assessed periodically through practical evaluation tests and certification in accordance with the requirements of ASME IX.

Table 4.3: Comparison of Test Results for JKS and SME Welds

	Type of Discontinuity:							
Welds	Undercut	Porosity	Cracks (C)	Lack of Fusion (LOF)	Incomplete Penetration (IP)	Total Discontinuities	Tensile Weld Failure	C+ LOF+ IP
JKS Welds: All	12 %	8 %	2 %	29 %	41 %	92 %	60 %	72 %
JKS Welds: No Instructions	22 %	3 %	3 %	0 %	59 %	87 %	55 %	62 %
JKS Welds: With Instructions	9 %	9 %	0 %	69 %	6 %	93 %	66 %	75 %
JKS Welds: Repairs	4 %	11 %	4 %	18 %	61 %	98 %	_	83 %
SME Welds: All	5 %	13 %	0 %	6 %	9 %	33 %	_	15 %
SME Welds: Plates	5 %	15 %	0 %	8 %	10 %	38 %	_	18 %
SME Welds: Pipes	0 %	0 %	0 %	0 %	6 %	6 %	_	6 %

Note:

i. The % indicated represents the percentage of total samples tested having the given defect or failure.
ii. The – (dash) indicated that no tensile tests were done on those samples.

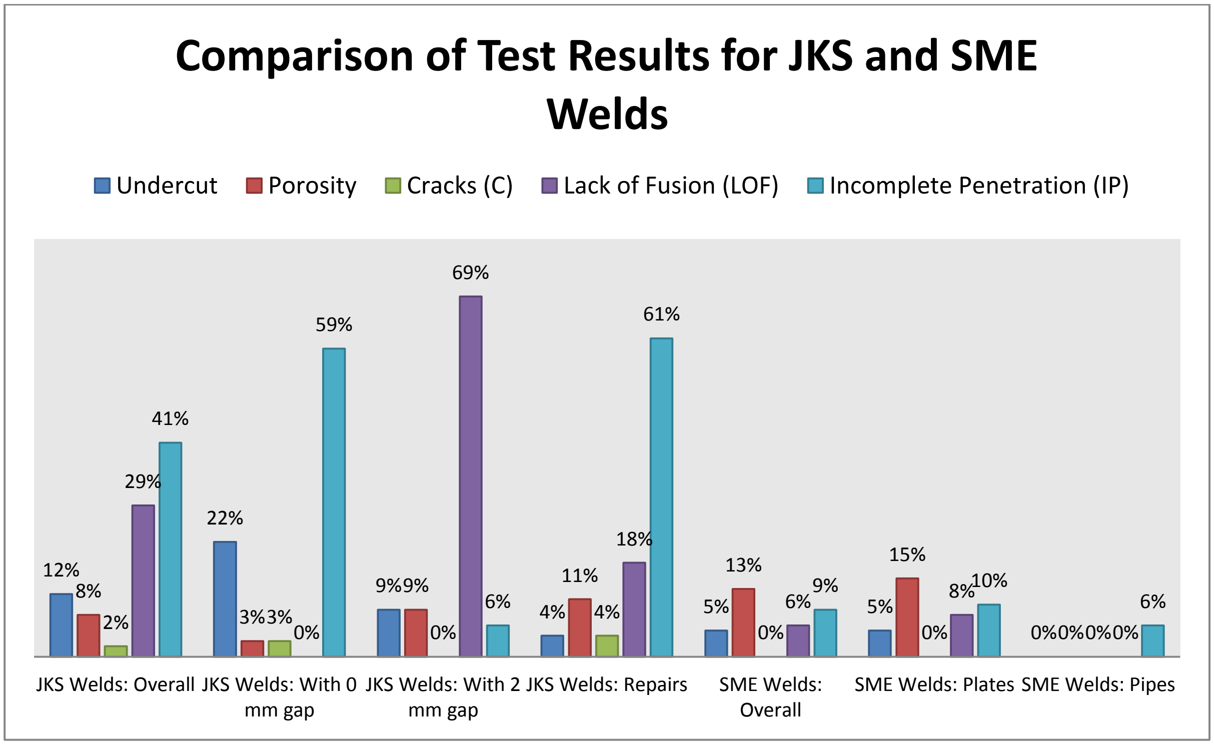


Figure 4.15: Comparison of Test Results for JKS and SME Welds

CHAPTER 5

Conclusion and Recommendations

5.1 Conclusion

This study investigated the quality of weld products in the “Juakali” sector by carrying out visual, radiographic and tensile tests on a sample of 92 welds. It was found that the quality is very wanting in the “Juakali” with various surface and volume defects detected. The surface defects detected by visual inspection were undercuts (12 % of the samples) and cracks (2 % of the samples) whereas volume defects detected by radiographic tests were incomplete penetration (41 % of the samples), lack of fusion (29 % of the samples) and porosity (8 % of the samples). For the “Juakali” samples subjected to tensile tests, 60 % of them fractured on the weld. Samples from the more established SME’s were also evaluated for purpose of quality comparison with “Juakali”. From the 110 SME samples analyzed the defects found by visual and radiographic tests were porosity (13 % of the samples), incomplete penetration (9 % of the samples), lack of fusion (6 % of the samples) and undercuts (5 % of the samples). It was observed that the quality in the SME was much better than in JKS. This difference in quality levels between JKS and SME was attributed to the fact that the SME artisans had received more training and were subjected to periodic welder qualification examination and certification. There is therefore a need for improvement aimed at providing products of acceptable quality levels. One of the ways to achieve this improvement is by training and assessment. During the first phase of this investigation it was observed that most of the JKS welders investigated welded all work with 0 mm gap irrespective of thickness which led to 59 % of the sampled work not attaining required penetration. However when welding thicker materials, proper welding procedure requires that joint preparation should be done and a gap comparable in size with the welding rod in use is to be set in order to achieve full penetration. When samples with 2 mm gap were given to “Juakali” for welding, there was significant drop in incomplete penetration defects from 61 % (for samples with 0 mm gap) to 6 % (for samples with 2 mm gap). However with 2 mm gap it was observed that most welders had problems manipulating the welding electrode and therefore ended up producing more different defects such as lack of fusion despite achieving full penetration. This indicated a lack in welding skills to deal with various conditions. It is therefore concluded the quality of “Juakali” welding skills and weld products is currently poor and that with adequate training and periodic assessment, it is possible to eliminate or reduce significantly the high levels of observed defects.

5.2 Recommendations

The knowledge on the types of welding defects, how the defects are formed and how the defects can be eliminated is necessary for the production of a quality weld. These knowledge and associated welding skills can only be transferred by means of adequate training and experience. It is therefore recommended that the “Juakali” welders should be assisted to acquire the necessary welding knowledge and skills, as well as safety, through investments on training. It was also observed that SME welders who are subjected to an annual welder approval examination produced good quality welds. It is therefore recommended that the “Juakali” welders should be additionally and after proper training be subjected to periodic welder qualification examinations and certification based on ASME IX or similar standard for the appropriate range of welding position and size of the welding products they deal with. The periodic examination will ensure consistency in the production of quality products and will raise customer confidence while increasing job opportunities. Refresher training opportunities for welders should also be provided. The costs involved in the training and periodic certification are not affordable to most artisans in the “Juakali” and therefore it is recommended that they should be facilitated by relevant authorities to access these services as part of vision 2030 agenda. Additional studies also need to be taken to determine other variables that may have an impact on the quality of welding such as type of equipment, materials used, experience of artisans and level of education of “Juakali” welders.

References

Aalami, A. M. E., & Rashidi, A. M. (2012). Correlated macrostructural parameters of weld and weld current in the SMAW of small pipes. *Journal of Mechanical Science and Technology, vol. 26*(1), pp. 181-185.

Ahonen, S. M. (2008). Radiography – A conceptual approach. *Radiography, vol. 14*(4), pp. 288–293.

Alaknanda, Anand, R.S., & Pradeep, K. (2006). Flaw detection in radiographic weld images using morphological approach. *NDT and E International, vol.* 39, pp. 29–33. Elsevier Inc.

Alcala, R. F. (Ed.). (2001). *Application of non-destructive testing and in-service inspection to research reactors.* IAEA-TECDOC-1263. International Atomic Energy Agency (IAEA), Vienna, Austria.

ASME V (2010). *Boiler and pressure vessel code : Section V - Nondestructive examination.* ASME press, USA.

ASME VIII (2010). *Boiler and pressure vessel code : Section VIII - Rules for construction of pressure vessels.* ASME press, USA.

ASME IX (2010). *Boiler and pressure vessel code: Section IX - Welding and brazing qualifications.* ASME press, USA.

Baughurst, L., & Vosnaks, G. (2009). Welding defects, causes and correction. *Australian Bulk Handling Review*. July/August Issue, pp. 26-28.

Bernasovsky, P. (2009). Failure analysis of welded components: Importance for technical practice. IIW International congress in central and European region. Slovakia, high tatras stara Lesna, October issue, pp. 14-16.

Berry, A. (2002). The role of small and medium enterprise sector in Latin America and similar developing economies. *Seton Hall Journal of Diplomacy and International Relations.* Winter/Spring Issue, pp. 104-119.

Berry, A., Blottnitz, M., Cassim, R., Kesper, A., Rajaratna, B., & Seventer, D. E. (2002). The economics of SMME's in South Africa. Trade and Industrial Policy Strategies (TIPS) Report, Johannesburg. Retrieved on 15/03/2015 from www.tips.org.za/files/506.pdf

Campbell, J. (2011). *Complete casting handbook: Casting metallurgy. Vol. 1*, pp. 391-597. Elsevier publishers, UK.

Cheng, H., & Mandula, J. (Eds.). (2010). *Risk informed in service inspection of piping systems of nuclear power plants: Process, status, issues and development*. International Atomic Energy Agency (IAEA), nuclear energy series, no. NP-T-3.1, STI/PUB/1452. IAEA press, Vienna, Austria.

Dalziel, L. (2006). SMEs in New Zealand: Structure and dynamics. Retrieved from http://www.med.govt.nz

Dana, L.P. (1988). More small business is not the answer for Peru. J. Small Bus. Manage., vol 26. York, M. 2009

Dar, N. U., Qureshi, E. M., & Hammouda, M. M. I. (2009). Analysis of weld-induced residual stresses and distortions in thin-walled cylinders. *Journal of Mechanical Science and Technology, vol. 23,* pp. 1118-1131.

DaSilva, R. R., Siqueira, M. H. S., de Souza, M. P. V., Rebello, J. M. A., & Caloba, L. P. (2005). Estimated accuracy of classification of defects detected in welded joints by radiographic tests. *NDT and E International, vol. 38*(5), pp. 335–343.

Daugherty, W. L., & Cannell, G. R. (2003). Analysis of porosity associated with “Hanford-3013” outer container welds. *Practical Failure Analysis, vol. 3*(4), pp. 56-62. ASM International.

Devletian, J. H. & Dyke, D. V. (2008). Failure analysis of steel welds. *Failure Analysis of Heat Treated Steel Components*, pp. 503-519. ASM International.

DiMeglio, F. A., & Alcala, R. F. (Eds.). (1995). *Management of research reactor ageing*. IAEA-TECDOC-792. International Atomic Energy Agency (IAEA). IAEA press, Vienna, Austria.

Ditchburn, R. J., Burke, S. K., & Scala, C. M. (1996). NDT of welds: state of the art. *NDT and E International, vol. 29*(2), pp. 111-117. Elsevier Inc.

Einav, I., & Jin, J. H. (Eds.). (2008). *Training guidelines in nondestructive testing techniques*. IAEA-TECDOC-628/Rev. 2. International Atomic Energy Agency (IAEA). IAEA press, Vienna, Austria.

Einav, I. (Ed.). (2005). *Nondestructive testing for plant life assessment*. IAEA-TCS-26. International Atomic Energy Agency. IAEA press, Vienna, Austria.

Exworthy, L. F., Little, W. J. & Flewitt, P. E. J. (2002). Diagnosis of cracking in the boiler shell seam welds at “Sizewell A” Power Station. *International Journal of Pressure Vessels and Piping, vol. 79*, pp. 413–426. Elsevier science Ltd.

Feeney, L. S. & Riding, A. L. (1997). Business owners fundamental tradeoff. Finance and the vicious circle of growth and control. Canadian Business Owners.

GoK, Government of Kenya (1992). Sessional paper no. 2 of 1992 on small enterprise and Jua kali development in Kenya. Government press.

GoK, Government of Kenya (1996). Sessional paper no. 2 of 1996 on industrial transformation to the year 2020. Government press.

GoK, Government of Kenya (1999). National micro and small enterprise baseline survey 1999 (05). Government press.

GoK, Government of Kenya (2005). Sessional paper no. 2 of 2005 on development of micro and small enterprises for wealth and employment creation for poverty reduction. Government press.

GoK, Government of Kenya (2007). Vision 2030. Government press.

GoK, Government of Kenya (2012). Economic survey, 2012. Government press.

Grieve, D. J. (2003). Welding defects. www.tech.plym.ac.uk/sme/strc201/wdefects.htm. Retrieved in September 2012.

Grieve, D. J. (2009). Welding processes. www.tech.plym.ac.uk/sme/strc201/weldI.htm. Retrieved in September 2012.

Harvie, C., & Lee, C. B. (2003). The role of SME’s in national economies in East Asia: Studies of small and medium sized enterprises in East Asia. *Asian Economic Bulletin, Volume II.* Cheltenham, UK: Edward Elgar, pp. 404.

Hellier, C. J. (2003). *Handbook of non destructive evaluation*. McGraw Hill publishers.

Hopkins, D. N., & Benac, D. J. (2001). Investigation of fatigue induced socket welded joint failures for small bore piping used in power plants. *Practical Failure Analysis, vol. 1*(2), pp. 71-82. ASM International.

Horn, P. (1995). Self employed women’s union: Tackling the class-gender intersection. *South Africa Labour Bulleting, vol. 9*(6), pp. 34-38.

Iida, K., Matsuda, F., Sato, M., Nayama M., & Akitomo, N. (1996). Study on crack generation at root of socket welds. *Nuclear Engineering and Design, vol. 166,* pp. 85-98. Elsevier Inc.

ISO 6892-1:2009. Metallic materials tensile testing: Part 1 - Method of test at room temperature. International Standard. ISO press, Geneva, Switzerland.

Joon, H. J., Einav I., & Khan A. A. (Eds.). (2009). *Guidebook for establishing a sustainable and accredited system for qualification and certification of personnel for nondestructive testing*. IAEA-TCS-34. International Atomic Energy Agency. IAEA press, Vienna, Austria.

Joon, H. J., Khan, A. A., & Rao B. P. C. (Eds.). (2012). *Training guidelines in nondestructive testing techniques: Leak testing at level 2*. IAEA/TCS/52. International Atomic Energy Agency. IAEA press, Vienna, Austria.

Kang, K., & Kupca, L. (Eds.). (2009). *Integrity of reactor pressure vessels in nuclear power plants: Assessment of irradiation embrittlement effects in reactor pressure vessel steels*. IAEA Nuclear energy series No. NP-T-3.11, STI/PUB/1382. IAEA press, Vienna, Austria.

Kersting, T., Schonartz, N., Oesterlein, L., & Liessem, A. (2010). High end inspection by filmless radiography on LSAW large diameter pipes. *NDT and E International, vol. 43*, pp. 206–209. Elsevier Ltd.

Khan, A. A. (Ed.). (2001). *Guidebook for the fabrication of nondestructive testing (NDT)test specimens*. IAEA Training course series no. 13, IAEA-TECDOC-TCS-13. International Atomic Energy Agency. IAEA press, Vienna, Austria.

Khan, A. A., Abd, N. I., & Singh, G. (Eds.). (2002). *Guidebook on nondestructive testing of concrete structures*. IAEA–TCS–17. International Atomic Energy Agency. IAEA press, Vienna, Austria.

Lee, H. J., Zhang, S., Luo, J., Li, F., & Shrout T. R. (2010). Thickness dependent properties of “Relaxor-PbTiO3” ferroelectrics for ultrasonic transducers. *Advanced Functional Materials, vol. 20*(18), pp. 3154–3162.

Longley, R. (2006). How small business drives U.S. economy: Provides jobs for over half of nation’s private workforce. Retrieved on 15/03/2015 from usgovinfo.about.com/od/smallbusiness/a/sbadrives.htm.

Martikainen, J. K., & Moisio, T. J. I. (1993). Investigation of the effect of welding parameters on weld quality of plasma arc keyhole welding of structural steels. The Welding Journal, Welding Research Supplement, pp. 329-340.

Matthews, C., (2001). *ASME engineer's data book*. pp 211. ASME Press, USA.

Maximedia (1997). NDT: An indispensable tool for industry. *INSIDE Technical Cooperation, vol. 3*(1). IAEA press, Vienna, Austria.

Mephokee, C. (2004). The Thai SME's development policies: Country report. Faculty of Economics, Thammasat University, Bangkok.

Mohd, A. W., & Mohammed F. (2013). An investigation of nondestructive testing of pressure vessel. *International Journal of Emerging Technology and Advanced Engineering, vol. 3*(1), pp. 243-248.

Montgomery D.C., & Runger G.C. (2011). *Applied statistics and probability for Engineers,* 5ed, John Wiley & Sons Inc., USA.

Mukole, K. (2010). Job creation versus job shedding and the role of SME's in economic development. *African Journal of Business Management, vol. 4*(11), pp. 2288-2295. Academic Journals.

Mutuli, S. M. (1989). The future of NDT in Kenya. A paper presented at the NDT seminar held in Kenyatta International Conference Centre, Nairobi, Kenya.

Neumark, D., Wall, B., & Zhang J. (2008). Just the facts: Small businesses and job creation - Do small businesses create more jobs? Public Policy Institute of California (PPIC). Retrieved on 15/03/2015 from http://www.ppic.org.

Ntsika (1999). State of small business in South Africa. SARB Quarterly Bulleting and Statistics SA Releases. Ntsika Enterprise Promotion Agency, Pretoria, South Africa. www.resbank.co.za.

Odero, W., Meleckidzedeck, K., & Heda, P. M. (2003). Road traffic injuries in Kenya: Magnitude, causes and status of intervention. *Injury Control and Safety Promotion, vol. 10*(1-2), pp. 53–61.

OECD, Organisation for Economic Cooperation and Development (1997). Globalisation and small & medium enterprises. Synthesis Report. Retrieved from www.oecd.org.

Oresegun, M. (Ed.). (1999). *Radiation protection and safety in industrial radiography*. IAEA Safety reports series, No. 13, STI/PUB/1066. International Atomic Energy Agency. IAEA press, Vienna, Austria.

Otegui, J. L., Fazzini, P. G., & Marquez, A. (2009). Common root causes of recent failures of flanges in pressure vessels subjected to dynamic loads. *Engineering Failure Analysis, vol. 16*, pp. 1825–1836, Elsevier Inc.

Pang, P. (2008). The role of SME’s in Asian development. Statement by the Asian Development Bank head of delegation, Hong Kong and China at the 41st Annual Meeting, Madrid, 5-6 May.

Pohl, R., Erhard, A., Montag, H. J., Thomas, H. M., & Wustenberg, H. (2004). NDT techniques for railroad wheel and gauge corner inspection. *NDT and E International, vol. 37*(2), pp. 89–94.

Ramesh, S. (2012). Applied welding engineering: Section 3 - Nondestructive testing. pp. 247-327. Elsevier Inc.

Shen, S., Oguocha, I. N. A., & Yannacopoulos, S. (2012). Effect of heat input on weld bead geometry of submerged arc welded ASTM A709 Grade 50 steel joints. *Journal of Materials Processing Technology, vol. 212*, pp. 286–294.

Sun, Y., Bai, P., Sun, H., & Zhou P. (2005). Real time automatic detection of weld defects in steel pipe. *NDT and E International, vol. 38*(7), pp. 522–528.

Sungho, K., Keunchan, J., Wan, S., & Soowoo, N. (1994). Effect of lack of penetration on the fatigue strength of high strength steel butt weld. *KSME Journal, vol. 8*(2), pp. 191-197.

TCR Engineering (2004). Investigating material and component failure. Failure and root cause analysis white paper published by TCR Engineering services technical team, India. Retrieved from www.tcreng.com on 3/6/2013.

Thornburg, L. (1993). IBM agent’s of influence. *Human Resource Magazine, vol. 38*(2), pp. 25-45.

Trimm, M. (2003). An overview of nondestructive evaluation methods. *Practical Failure Analysis, vol. 3*(3), pp. 17-31.

Tulus, T. (2008). Development of SME’s in ASEAN with reference to Indonesia and Thailand. *Chulalongkorn Journal of Economics, vol. 20*(1), pp. 53-83.

UNCTAD, United Nations Conference on Trade and Development (2003). Improving the competitiveness of SME's through enhancing productive capacity. Retrieved on 15/03/2015 from unctad.org/en/docs/iteteb20051_en.pdf

Valavanis, I., & Kosmopoulos, D. (2010). Multiclass defect detection and classification in weld radiographic images using geometric and texture features. *Expert Systems with Applications, vol. 37*(12), pp. 7606–7614.

Were, P. D., Sukasam, K., Jin, J. H., & Khan A. A. (Eds.). (2011). *Eddy current testing at level 2*. IAEA Training course series no. 48. IAEA press Vienna, Austria.

Appendices

Appendix 1: Overall Test Results for “Juakali” Welds

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Under cut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
1	-	-	-	-	0	0	1	0	0
2	-	-	-	-	1	0	0	0	0
3	-	-	-	-	0	0	0	1	0
4	-	-	-	-	0	0	0	0	0
5	-	-	-	-	0	0	0	0	1
6	-	-	-	-	0	0	0	1	0
7	-	-	-	-	0	0	0	0	1
8	-	-	-	-	0	0	0	0	1
9	-	-	-	-	0	1	0	0	0
10	-	-	-	-	0	0	0	0	1
11	-	-	-	-	0	0	0	0	1
12	-	-	-	-	0	0	0	0	1
13	-	-	-	-	0	0	0	0	1
14	-	-	-	-	0	0	0	0	1
15	-	-	-	-	0	0	0	0	1
16	-	-	-	-	0	0	0	0	1
17	-	-	-	-	0	0	0	0	1
18	-	-	-	-	0	0	0	0	1
19	-	-	-	-	0	0	0	0	1
20	-	-	-	-	0	0	0	0	1

Appendix 1: Overall Test Results for "Juakali" Welds (cont')

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Under cut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
21	-	-	-	-	0	0	0	0	1
22	-	-	-	-	0	0	0	1	0
23	-	-	-	-	0	0	0	1	0
24	-	-	-	-	0	0	0	0	1
25	-	-	-	-	0	0	0	1	0
26	-	-	-	-	0	1	0	0	0
27	-	-	-	-	0	1	0	0	0
28	-	-	-	-	0	0	0	0	1
29	-	-	-	-	0	0	0	0	0
30	X	X	410	384	0	1	0	0	0
31	X	335	379	X	0	0	0	0	1
32	X	X	375	362	0	0	1	0	0
33	X	X	374	467	0	0	0	1	0
34	X	363	417	X	0	0	0	0	1
35	X	X	408	330	0	0	0	1	0
36	X	X	380	385	0	0	0	0	1
37	404	248	X	X	0	0	0	1	0
38	366	343	X	X	0	0	0	0	1
39	274	X	X	362	0	0	0	1	0
40	X	278	384	X	0	0	0	0	1

Appendix 1: Overall Test Results for “Juakali” Welds (cont’)

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Under cut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
41	X	X	380	404	0	0	0	1	0
42	334	X	X	383	1	0	0	0	0
43	304	265	X	X	0	0	0	1	0
44	X	343	392	X	1	0	0	0	0
45	282	291	X	X	1	0	0	0	0
46	X	X	356	367	0	0	0	0	0
47	X	219	384	X	0	0	0	0	1
48	327	X	X	358	1	0	0	0	0
49	X	359	386	X	0	0	0	1	0
50	362	329	X	X	1	0	0	0	0
51	360	376	X	X	0	0	0	1	0
52	X	X	364	362	0	0	0	0	1
53	X	363	390	X	0	1	0	0	0
54	X	359	361	X	0	0	0	0	1
55	319	294	X	X	0	0	0	1	0
56	322	X	X	340	0	0	0	0	1
57	315	305	X	X	0	0	0	1	0
58	X	333	370	X	0	0	0	0	1
59	353	X	X	369	0	1	0	0	0
60	331	205	X	X	0	0	0	0	1

Appendix 1: Overall Test Results for “Juakali” Welds (cont’)

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Under cut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
61	108	164	X	X	0	0	0	1	0
62	342	239	X	X	0	0	0	0	1
63	105	248	X	X	0	0	0	1	0
64	-	-	-	-	0	0	0	0	1
65	333	326	X	X	0	0	0	1	0
66	210	180	X	X	0	0	0	0	1
67B	329	171	X	X	0	0	0	1	0
67A	270	298	X	X	0	0	0	0	1
68	98	106	X	X	0	0	0	1	0
69	182	255	X	X	0	0	0	0	1
70	92	128	X	X	0	0	0	1	0
71	273	287	X	X	0	0	0	0	1
72	148	289	X	X	0	0	0	1	0
73	259	189	X	X	0	0	0	0	1
74	336	X	X	373	0	0	0	1	0
75	343	268	X	X	0	0	0	0	1
76	363	329	X	X	0	0	0	1	0
77	X	X	416	380	0	0	0	0	0
78	X	X	426	390	0	0	0	0	0
79	X	X	389	373	0	0	0	0	0

Appendix 1: Overall Test Results for “Juakali” Welds (cont’)

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Undercut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
80	373	342	X	X	1	0	0	0	0
81	X	341	367	X	0	0	0	0	0
82	X	379	404	X	0	0	0	0	0
83	286	X	X	368	0	0	0	0	1
84	X	337	363	X	0	1	0	0	0
85	X	359	389	X	1	0	0	0	0
86	X	X	401	362	0	0	0	1	0
87	X	329	373	X	1	0	0	0	0
88	326	301	X	X	0	0	0	1	0
89	374	303	X	X	0	0	0	0	1
90	X	X	389	371	0	0	0	1	0
91	X	X	400	433	1	0	0	0	0
92	332	X	X	388	1	0	0	0	0
Failure/defect count	76		50		11	7	2	27	38
% of samples having the given defect/ failure mode	76/(76+50) = 60 %		50/(76+50) = 40 %		11/92 = 12 %	7/92 = 8 %	2/92 = 2 %	27/92 = 29 %	38/92 = 41 %

Appendix 2: Test Results for “Juakali” Welds Performed with 0 mm Gap

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Undercut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
30	X	X	410	384	0	1	0	0	0
32	X	X	375	362	0	0	1	0	0
34	X	363	417	X	0	0	0	0	1
36	X	X	380	385	0	0	0	0	1
38	366	343	X	X	0	0	0	0	1
40	X	278	384	X	0	0	0	0	1
42	334	X	X	383	1	0	0	0	0
44	X	343	392	X	1	0	0	0	0
46	X	X	356	367	0	0	0	0	0
48	327	X	X	358	1	0	0	0	0
50	362	329	X	X	1	0	0	0	0
52	X	X	364	362	0	0	0	0	1
54	X	359	361	X	0	0	0	0	1
56	322	X	X	340	0	0	0	0	1
58	X	333	370	X	0	0	0	0	1
60	331	205	X	X	0	0	0	0	1
62	342	239	X	X	0	0	0	0	1
64	-	-	-	-	0	0	0	0	1
66	210	180	X	X	0	0	0	0	1
67A	270	298	X	X	0	0	0	0	1
69	182	255	X	X	0	0	0	0	1

Appendix 2: Test Results for “Juakali” Welds Performed with 0 mm Gap (cont')

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Undercut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
71	273	287	X	X	0	0	0	0	1
73	259	189	X	X	0	0	0	0	1
75	343	268	X	X	0	0	0	0	1
77	X	X	416	380	0	0	0	0	0
79	X	X	389	373	0	0	0	0	0
81	X	341	367	X	0	0	0	0	0
83	286	X	X	368	0	0	0	0	1
85	X	359	389	X	1	0	0	0	0
87	X	329	373	X	1	0	0	0	0
89	374	303	X	X	0	0	0	0	1
91	X	X	400	433	1	0	0	0	0
Failure/defect count	34		28		7	1	1	0	19
% of samples having the given defect/ failure mode	34/(34+28) = 55 %		28/(34+28) = 45 %		7/31 = 22 %	1/31 = 3 %	1/31 = 3 %	0/31 = 0 %	19/31 = 59 %

Appendix 3: Test Results for “Juakali” Welds Performed with 2 mm Gap

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Under cut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
31	X	335	379	X	0	0	0	0	1
33	X	X	374	467	0	0	0	1	0
35	X	X	408	330	0	0	0	1	0
37	404	248	X	X	0	0	0	1	0
39	274	X	X	362	0	0	0	1	0
41	X	X	380	404	0	0	0	1	0
43	304	265	X	X	0	0	0	1	0
45	282	291	X	X	1	0	0	0	0
47	X	219	384	X	0	0	0	0	1
49	X	359	386	X	0	0	0	1	0
51	360	376	X	X	0	0	0	1	0
53	X	363	390	X	0	1	0	0	0
55	319	294	X	X	0	0	0	1	0
57	315	305	X	X	0	0	0	1	0
59	353	X	X	369	0	1	0	0	0
61	108	164	X	X	0	0	0	1	0
63	105	248	X	X	0	0	0	1	0
65	333	326	X	X	0	0	0	1	0
67B	329	171	X	X	0	0	0	1	0

Appendix 3: Test Results for “Juakali” Welds Performed with 2 mm Gap (cont’)

	Mechanical Tensile Test Results Ultimate Strength Under Loading (X 10^6 N/m^2)				Visual And Radiographic Inspection Results				
	Fracture failure:								
	On weld		On parent		0(Zero)=Absence Of Flaw 1(One)=Presence Of Flaw -(dash)=No tensile test done X=Only two tensile test specimens per sample				
Sample No.	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Undercut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
68	98	106	X	X	0	0	0	1	0
70	92	128	X	X	0	0	0	1	0
72	148	289	X	X	0	0	0	1	0
74	336	X	X	373	0	0	0	1	0
76	363	329	X	X	0	0	0	1	0
78	X	X	426	390	0	0	0	0	0
80	373	342	X	X	1	0	0	0	0
82	X	379	404	X	0	0	0	0	0
84	X	337	363	X	0	1	0	0	0
86	X	X	401	362	0	0	0	1	0
88	326	301	X	X	0	0	0	1	0
90	X	X	389	371	0	0	0	1	0
92	332	X	X	388	1	0	0	0	0
Failure/defect count	42		22		3	3	0	22	2
% of samples having the given defect/ failure mode	42/(42+22) = 66 %		22/(42+22) = 34 %		3/32 = 9 %	3/32 = 9 %	0/32 = 0 %	22/32 = 69 %	2/32 = 6 %

Appendix 4: Test Results for Repair "Juakali" Welds

	Visual And Radiographic Inspection Results 0=Absence Of Flaw 1=Presence Of Flaw				
Sample No.	Undercut	Porosity	Crack	Lack of Fusion	Incomplete Penetration
1	0	0	1	0	0
2	1	0	0	0	0
3	0	0	0	1	0
4	0	0	0	0	0
5	0	0	0	0	1
6	0	0	0	1	0
7	0	0	0	0	1
8	0	0	0	0	1
9	0	1	0	0	0
10	0	0	0	0	1
11	0	0	0	0	1
12	0	0	0	0	1
13	0	0	0	0	1
14	0	0	0	0	1
15	0	0	0	0	1
16	0	0	0	0	1
17	0	0	0	0	1
18	0	0	0	0	1
19	0	0	0	0	1
20	0	0	0	0	1
21	0	0	0	0	1
22	0	0	0	1	0
23	0	0	0	1	0
24	0	0	0	0	1
25	0	0	0	1	0
26	0	1	0	0	0
27	0	1	0	0	0
28	0	0	0	0	1
defect count	1	3	1	5	17
% of samples having the given defect	1/28 =4 %	3/28 =11 %	1/28 =4 %	5/28 =18 %	17/28 =61 %

Appendix 5: Test Results for SME Plate Welds

	Visual And Radiographic Inspection Results 0=Absence Of Flaw 1=Presence Of Flaw Discontinuity			
Sample No.	Undercut	Porosity	Lack of Fusion	Incomplete Penetration
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	1	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	1	0	0	0
22	0	1	0	0
23	0	0	0	0
24	1	0	0	0
25	0	1	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0
32	0	0	0	0
33	0	0	0	0

Appendix 5: Test Results for SME Plate Welds (cont’)

	Visual And Radiographic Inspection Results			
	0=Absence Of Flaw 1=Presence Of Flaw			
	Discontinuity			
Sample No.	Undercut	Porosity	Lack of Fusion	Incomplete Penetration
34	0	0	0	0
35	0	0	0	0
36	0	0	0	0
37	0	0	0	0
38	0	0	0	0
39	0	0	0	0
40	0	0	0	0
41	0	0	0	0
42	0	0	0	0
43	0	0	0	0
44	0	0	0	0
45	0	0	0	0
46	0	0	1	0
47	0	0	0	0
48	0	0	0	0
49	0	1	0	0
50	0	0	0	0
51	0	0	1	0
52	0	0	0	0
53	1	0	0	0
54	0	1	0	0
55	0	1	0	0
56	0	0	0	1
57	0	0	0	1
58	0	0	0	1
59	0	1	0	0
60	0	0	0	1
61	0	0	0	0
62	0	0	0	1
63	0	0	0	0
64	0	0	0	1
65	0	0	0	1
66	0	1	0	0

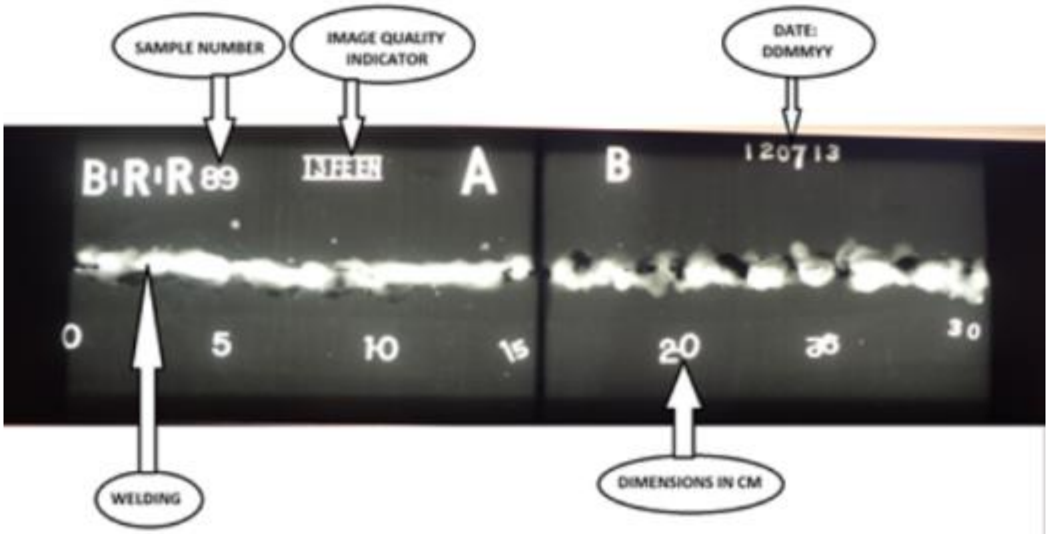
Appendix 5: Test Results for SME Plate Welds (cont')

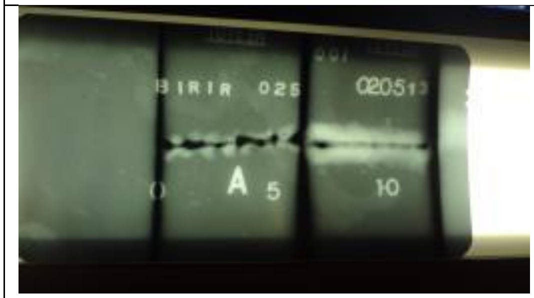
	Visual And Radiographic Inspection Results			
	0=Absence Of Flaw 1=Presence Of Flaw			
	Discontinuity			
Sample No.	Undercut	Porosity	Lack of Fusion	Incomplete Penetration
67	0	0	0	0
68	0	0	0	0
69	0	0	0	0
70	0	0	1	0
71	0	1	0	0
72	0	0	0	1
73	0	0	0	0
74	0	1	0	0
75	0	1	0	0
76	0	0	1	0
77	0	0	0	1
78	0	1	0	0
79	0	0	0	0
80	0	1	0	0
81	0	1	0	0
82	0	0	1	0
83	1	0	0	0
84	0	0	1	0
85	1	0	0	0
86	0	0	0	0
87	0	0	1	0
88	0	0	0	0
89	0	0	0	0
90	0	0	0	0
91	0	0	0	0
92	0	0	0	0
defect count	5	14	7	9
% of samples having the given defect	5/92 = 5 %	14/92 = 15 %	7/92 = 8 %	9/92 = 10 %

Appendix 6: Test Results for SME Pipe Welds

	Visual And Radiographic Inspection Results
	0=Absence Of Flaw 1=Presence Of Flaw
	Discontinuity
Sample No.	Incomplete Penetration
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	1
15	0
16	0
17	0
18	0
defect count	1
% of samples having the given defect	1/18 = 6 %

Appendix 7: Photos of Film Radiographs of “Juakali” Welds Showing Discontinuities





Sample 1

Sample 2

Sample 3

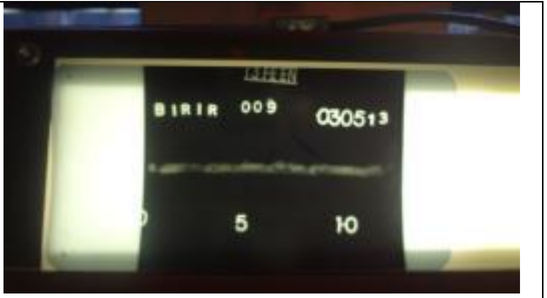
Sample 5

Sample 6

Sample 7

Appendix 7: Photos of Film Radiographs of "Juakali" Welds Showing Discontinuities (cont')

Sample 8

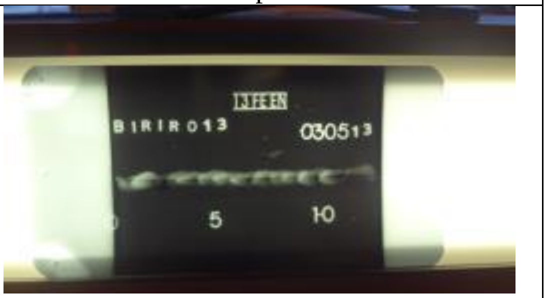


Sample 9

Sample 10

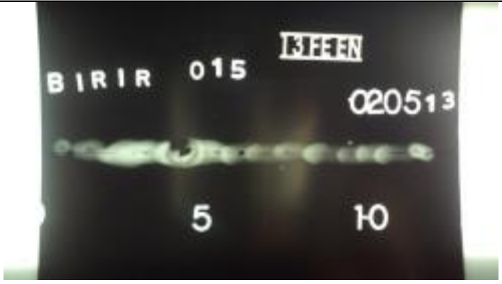
Sample 11

Sample 12



Sample 13

Sample 14



Sample 15

Sample 16

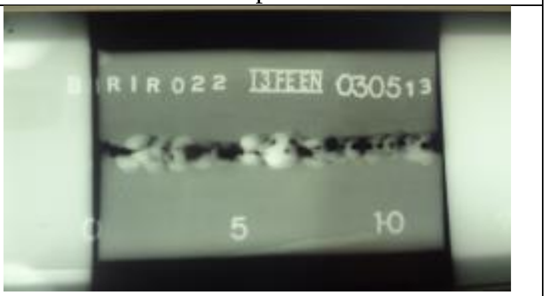
Sample 17

Appendix 7: Photos of Film Radiographs of “Juakali” Welds Showing Discontinuities (cont’)

Sample 19

Sample 20

Sample 21



Sample 22

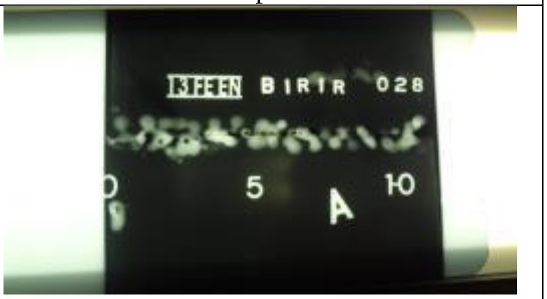
Sample 23

Sample 24

Sample 25

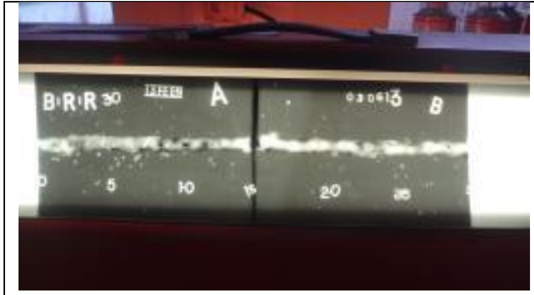
Sample 26

Sample 27

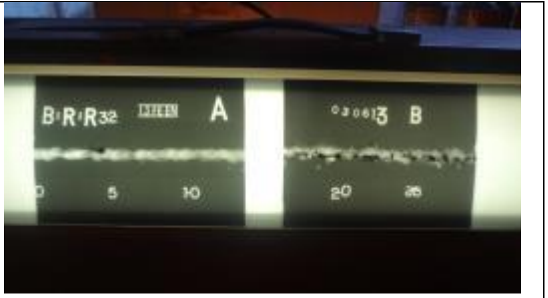


Sample 28

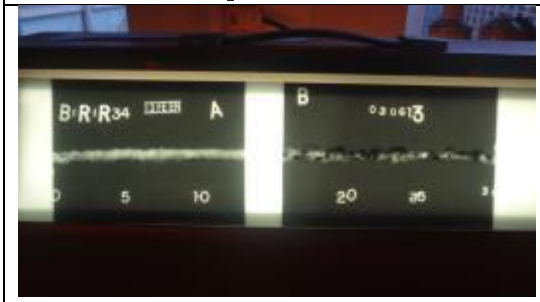
Appendix 7: Photos of Film Radiographs of "Juakali" Welds Showing Discontinuities (cont')



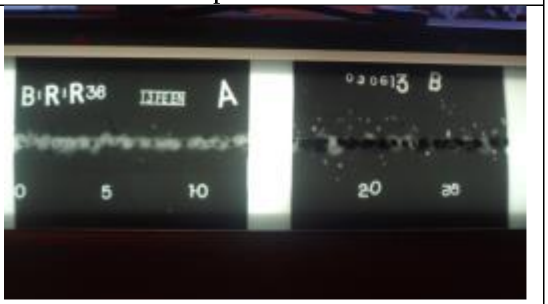
Sample 30 and 31



Sample 32 and 33



Sample 34 and 35



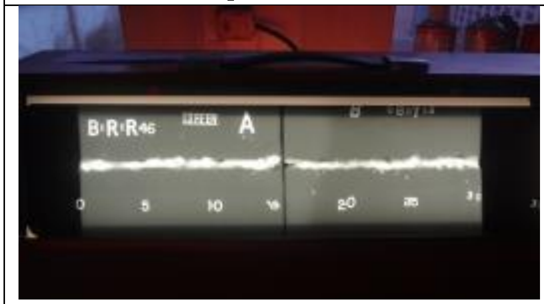
Sample 36 and 37

Sample 38 and 39

Sample 40 and 41

Sample 42 and 43

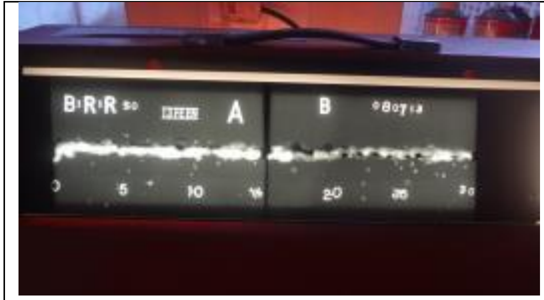
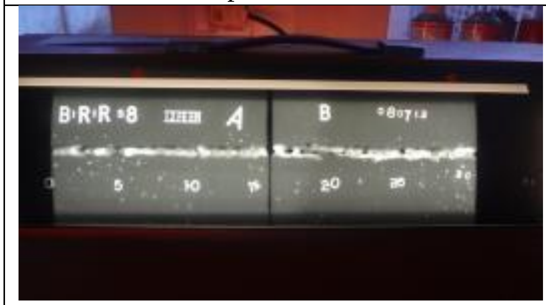
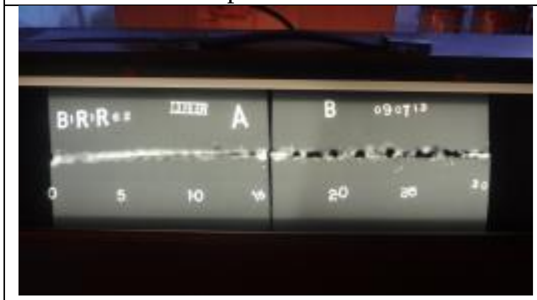
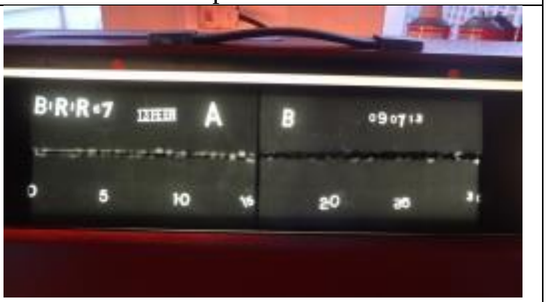
Sample 44 and 45



Sample 46 and 47

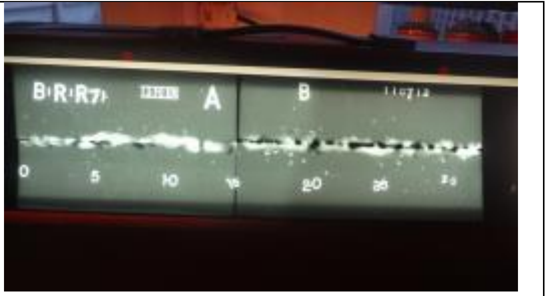
Sample 48 and 49

Appendix 7: Photos of Film Radiographs of “Juakali” Welds Showing Discontinuities (cont’)

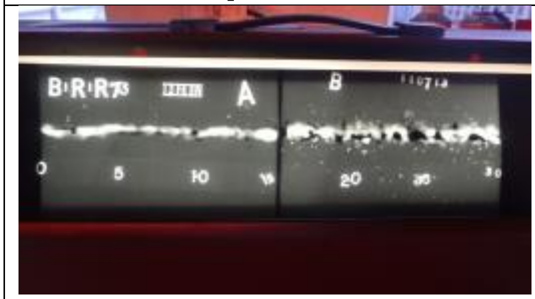
 Sample 50 and 51	 Sample 52 and 53
 Sample 54 and 55	 Sample 56 and 57
 Sample 58 and 59	 Sample 60 and 61
 Sample 62 and 63	 Sample 64 and 65
 Sample 66 and 67B	 Sample 67A and 68

Appendix 7: Photos of Film Radiographs of "Juakali" Welds Showing Discontinuities (cont')

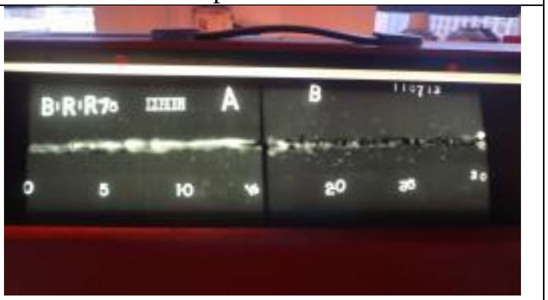
Sample 69 and 70



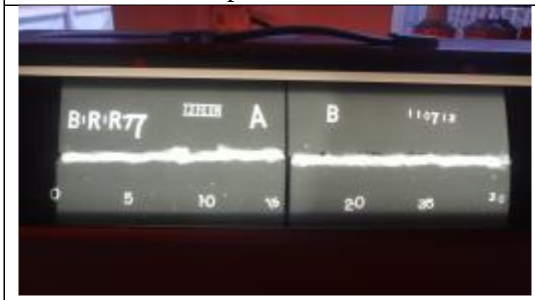
Sample 71 and 72



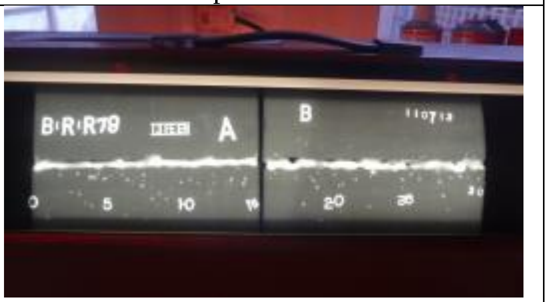
Sample 73 and 74



Sample 75 and 76



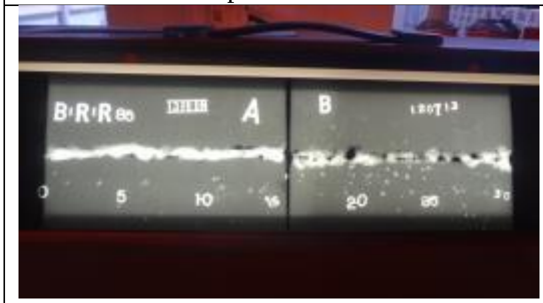
Sample 77 and 78



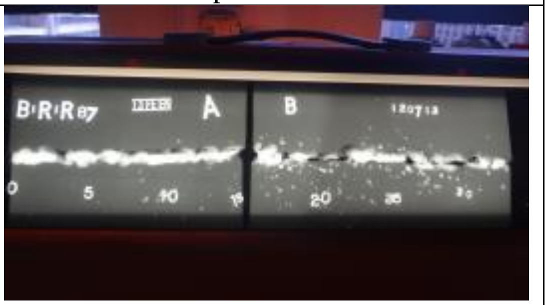
Sample 79 and 80

Sample 81 and 82

Sample 83 and 84

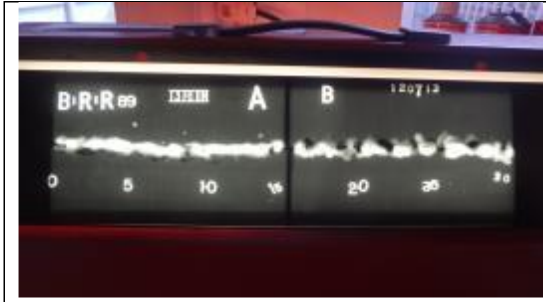
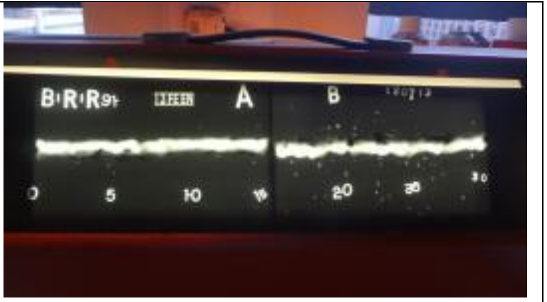


Sample 85 and 86



Sample 87 and 88

Appendix 7: Photos of Film Radiographs of "Juakali" Welds Showing Discontinuities (cont')

	
Sample 89 and 90	Sample 91 and 92