Journal of the Ghana Institution of Engineering (2024) 24:1
https//doi.org/10.56049/jghie.v24i1.144

CASE STUDY (Presented at 2023 GhIE Annual Conference & AGM)

Experimental studies on fillet weldment joints by artisans in Ghana's Western Region

Joseph Sekyi-Ansah [1,*], Emmanuel Acquah[1]

Received: 8th August, 2023 / **Accepted:** 25th November, 2023
Published online: 28th February, 2024

Abstract

Constant progress, demand in the manufacturing of mechanisms parts, and the ability to join parts together is another critical aspect of manufacturing for assemblers. Joining methods plays a significant role and welding must be constantly improved, experimented with, and upgraded due to its increasing use in all aspects of manufacturing. The quality of a weld joint is highly dependent on the process parameter. Welds are examined to ensure that they meet specifications through various experimental processes ranging from computational networks, evolutionary algorithms, non-destructive testing (NDT) and destructive testing (DE) to ascertain the quality of joints. The main objective of the study was to ascertain the quality of welded joints through non-destructive evaluation (NDE). To achieve this goal, an experimental method of four (4) NDE methods were employed to evaluate the quality of weldment joints on a mild steel material joined using manual metal arc welding (MMAW) process in selected fabrication shops in Takoradi-Kokompe, Ghana. Steel specimens were prepared and taken to the artisans to be created into corner joints using the fillet method. The specimens were tested using non-destructive testing techniques. The results on the welded joints were evaluated using the AWS D1.1 code of acceptance for structural steels. The results revealed that all welded joints from fabricators failed to meet the AWS D1.1:2000 acceptance criteria and, thus, had to be rejected. The results implies that through the artisans have worked for many years in the welding trade, their lack of competence and skills in the selection of right input welding parameters contributed to the results. The results implies that, the finished artefacts may look fine but internal structures may contribute to future failure of the fabricated artefacts.

Keywords: Takoradi-Kokompe, Radiographic Testing, Weldment Joint, Welding Defects

Introduction

With the continuous development and demand for various parts such as automotive, aerospace structures, various machine components, and so on, and the high rate of production of those parts, automation and accuracy are two of the most desired demands that needs to be met to ascertain quality in production (Kim et al., 2015). Joining is a critical manufacturing requirement for assembling operations. Material joining methods are important technologies in many manufacturing industries (Lee, 2011).

Most products, machines, or structures are assembled and fastened from parts to create highly reliable devices, and the joining of these parts may be accomplished through rivets, seaming, clamping, soldering, brazing, welding, and the use of adhesives (Ahmadnia *et al*., 2015).

Many factors influence those decisions, ranging from production costs to mechanical properties like strength, vibration damping, durability Ahn et al., (2018), Resistance to corrosion or erosion, as well as the ability to correct flaws. The three main types of joining processes are mechanical joining, welding, and adhesive bonding (Rao *et al*., 2014). Welding techniques include fusion welding, brazing and soldering, and solid -state welding. During fusion welding, the zone being joined melts and solidifies (Varun Kumar *et al*., 2021). For metals and plastics, melting occurs in both the workpieces and the filler material. Brazing and soldering are methods of joining materials in which melted filler material is added between the joined surfaces (Kah *et al*., 2013). Solid-state welding does not require the melting of the filler material's base because it only involves plastic deformation and diffusion (Yun *et al*., 2019; Sekyi-Ansah *et al*., 2020). Welding technology is now available in all areas of manufacturing, including rail, roads, shipbuilding, large dam construction, and various projects, pipelines, various power plants, and the automobile industry. Welding must be constantly improved, experimented with, and upgraded due to the constant increase in its use in all aspects of manufacturing. Every manufacturing process must be improved and innovated in light of modern technologies and rising product quality demands. When one considers the welding process, one immediately considers the Arc, Spatter, Weld bead, and surface finish (Srivastava and Sharma, 2017)

The optimum processing parameter has a significant impact on the quality of welded joints (Cooley *et al.*, 2011). Controlling the input process parameters was a frequent problem for the manufacturer in order to achieve a good, welded joint with the required weld quality. Historically, skilled operators or engineers chose parameters by trial and error, which took time for each new welded product to obtain a welded joint that met the required specifications. The welds are examined to see if they meet the specifications (Liu *et al.*, 2021). Design of experiment (DoE), evolutionary algorithms, and computational networks are commonly used today to develop mathematical relationships between welding process input parameters and weld joint output variables in order to determine the welding input parameters that lead to the desired weld quality (Kolahan and Heidari, 2010).

Non-destructive methods are a significant category with numerous applications for evaluating materials, metals, and engineering material components (Fahr, 2013). The recognition and classification of damages on a welded portion's surface is known as non-destructive evaluation (NDE) or non-destructive testing (NDT) Hung *et al*. (2013), surface and layout of material without severing or otherwise modifying it (Rausche, 2004). In other words, NDT is the method of assessing and inspecting engineering materials components in order to characterize or find defects and flaws in comparison to some standards without changing the original attributes or causing harm to the object being tested (Brierley *et al*., 2014; Sekyi-Ansah *et al*., 2022). The NDT techniques are a reduced method of testing a specimen for individual investigation or for checking the entire material in a quality control system in a manufacturing facility (Dobmann *et al*., 2010). Work on assessment of local welding

*Corresponding author: joseph.sekyi-ansah@ttu.edu.gh

[1]Department of Mechanical Engineering, Takoradi Technical University, Takoradi, Ghana

artisans has been carried out by researchers. The results of Birir (2015) on plates and pipes welded by local artisans in Kenya, using NDT showed a significant failure in most of the samples collected when tested using radiography and visual testing. In a recent study conducted by Sekyi-Ansah *et al*. (2023) on exhaust pipes welded by artisans also failed the code of acceptance for ASME B31.3 when tested with NDT. The design, manufacturing and fabrication students' projects are associated with various fabrication processes, including welding. The majority of student projects at Takoradi Technical University (TTU) are created outside of the campus by welding artisans from Takoradi Township. These artifacts are held together by a series of welded joints. The operations of these artifacts are related to vibrations, rotations, and so on. If the welded joints have internal defects during fabrication, deformation is likely to occur within the defected zone. As a result, an assessment of the quality of weldment joint using NDT techniques on the weldment done by artisans at Kokompe in Sekondi-Takoradi Metropolis is required. A variety of NDT methods are used in the testing of materials (Gholizadeh, 2016). Even though similar experimental research using NDT has been conducted by Sekyi-Ansah *et al*. (2022) on Tee joints on local welding artisans in Kokompe-Takoradi, it did not consider corner fillet joint. Since there is constant increase in the use of welding in all aspects of manufacturing, it must be constantly improved, experimented with, and upgraded. In this that, this study seeks to evaluate the welding quality of welded fillet joints by artisans from some selected fabrication shops at Kokompe in Ghana's Western region. The study's objectives were to use NDT to identify defects in the weldment joint and to determine whether the weldment joint met the the AWS D1.1 code of acceptance.

Experimental Materials and Methods

Experimental design

The experiment welded three (3) joint specimens (corner joints) using a manual metal arc welding (MMAW) process with an alternating current machine (AC). For the measurement and analysis tool chosen to assess the quality of the welded joint, the materials samples chosen for the experiment were Ferromagnetic. According to AWS D1.1 and D1.2 code of guideline for welding structural steels, the acceptable thickness of the material should be between 6 mm > T < 20 mm (OSNDT, 2023; Perdhana, 2023). Mild carbon steel material samples with dimensions of 75mm x 50mm x 10mm were chosen for the experiment's specimen joint formation based on the guidelines. The experiments used four non-destructive methods: visual testing (VT), liquid penetrant testing (LPT), magnetic particle testing (MPT), and radiography inspection or testing (RT). Three of the measuring devices (VT, LPT, and MPT) produce results when the discontinuities or flaws are visible and open to the surface, while one (RT) produces results when the discontinuity is visible and open to the surface on both the surface and the subsurface. Based on the material, type of weld, welding current, and voltage, the experiment considered E6013 and E4310 electrodes.

Table 1 Chemical composition of mild steel (experimental specimen) (Adigun *et al*., 2021)

Element	Content
Carbon, C	0.14 – 0.20 %
Iron, Fe	998.81 – 99.26% (as remainder)
Manganese, Mn	0.60 – 0.90 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %
Carbon, C	0.14 – 0.20 %

Material properties

Mild steel with a carbon content of 0.16 % to 0.29 % and a relatively high melting point of 1450 °C to 1520 °C was chosen for the analysis. Tables 1 and 2 show the chemical composition and mechanical properties of the selected material sample (Bodude *et al*., 2020).

Material preparation

To facilitate the cutting of the material samples, a power hacksaw machine Ercole 280 (PS01) with the following specifications was chosen. Weight approx. 900 kg, saw blades number: 5, angular cut degrees: +45, saw blade length: 575 mm, motor 380 volt, power: 3 ps, cut range round diameter: 320 mm, strokes per minute number: 6, machine width/depth/height approx.: 1850 x 800 x 1600 mm, a speed of 7 strokes per minute. The material dimensions were 150 mm x 100 mm x 10 mm.

Surface preparation of samples

The obtained samples were taken to the workshop and held in a bench vice with soft jaws to prevent dents on the material surface. Initially, a smooth file with a single cut was used to deburr square corners and remove rust from the surface. After a DESC Blue Emery Clothe Sheet, a surface finish of 230 280 mm (9" 11") Grit P60 (Grade 2) was applied.

Welding procedure of sample material

Figure 1 shows the graphical illustration of the welded sample joint specimen and figure 2 shows how the sample materials

Table 2 Mechanical properties of mild steel (experimental specimen) (Cil and Alshibli, 2012)

Mechanical properties	Metric	Imperial
Tensile Strength, Ultimate	440 MPa	63800 psi
Tensile Strength, Yield	370 MPa	53700 psi
Elongation at Break (In 50 mm)	15.0 %	15.0 %
Reduction of Area	40.0 %	40.0 %
Modulus of Elasticity (Typical for steel)	205 GPa	29700 ksi
Bulk Modulus (Typical for steel)	140 GPa	20300 ksi
Poisson's Ratio (Typical For Steel)	0.290	0.290
Machinability (Based on AISI 1212 steel. as 100% machinability)	70 %	70 %
Shear Modulus (Typical for steel)	80.0 GPa	11600 ksi

were taken to welding artisans for welding. The Corner-joint welding process MMAW was chosen for the weldment. For the Arc welding process, the artisans used two different types of electrodes. AWS E4310 defines carbon steel electrodes/low alloy steel electrodes. 2.5 mm/3.2 mm/4.0 mm/5.0 mm diameter, 300 mm, 350 mm, 400 mm length, titanium electrode coating, welding current 80-90 a, voltage DC+. ii. AWS E6013 - Electrodes made of carbon steel or low alloy steel. 2.5 mm/3.2 mm/4.0 mm/5.0 mm diameter, 300 mm, 350 mm, 400 mm length, welding current: 50-90A, voltage: AC 50V, DC+. The current and voltage of the machines were set based on the material and electrode. The sample materials were held on a welding plate, and the arc welding process was successfully completed at all shops visited, with an engineering square used to check for correct edges.

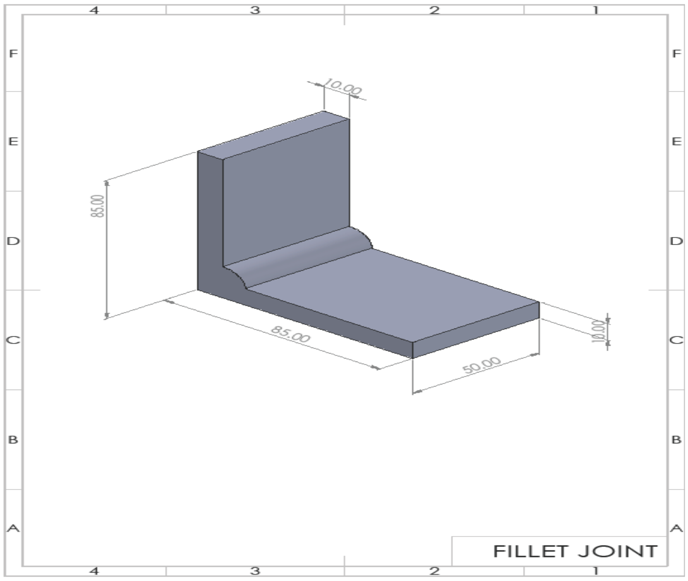

Figure 1 Graphical illustration of the welded sample joint specimen

Experimental method and testing flow chart

Figure 3 describes the sample preparation and the methodology flow chart for the experiment conducted on the fillet welded joint to ascertain the desired results. Following the cutting process, six (6) 75 x 50 x 10 mm material samples were chosen to produce corner welded joints. Three (3) welded samples were produced from the six (6) samples chosen.

a b

Figure 2 The (a) preparation process before welding, and (b) sample aligned for welding

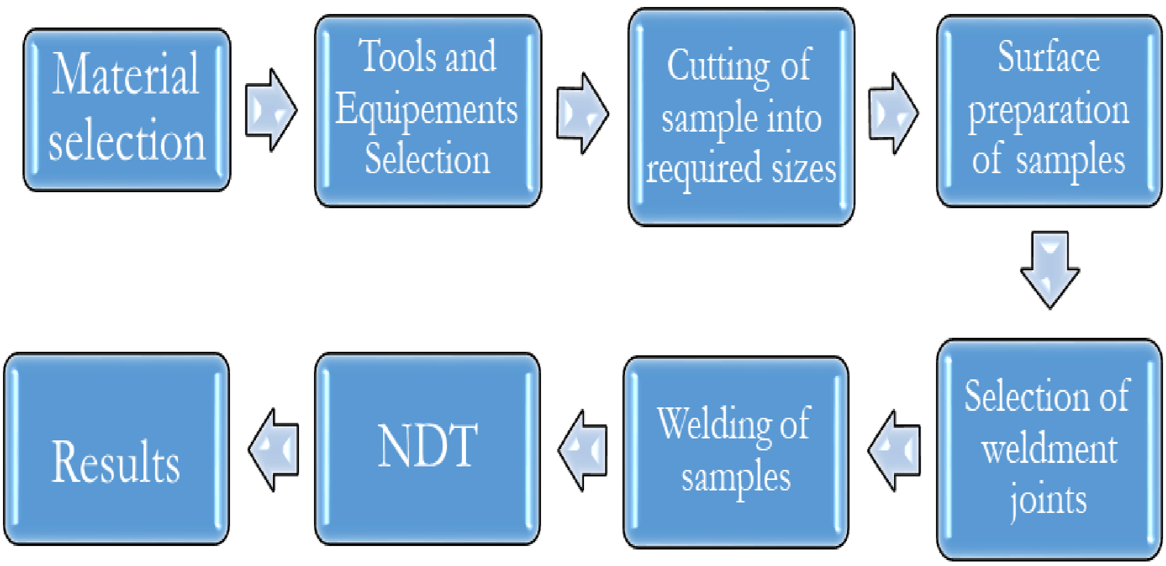

Figure 3 Experimental method and testing flow chart

Measurement and analysis tools

Measurement processes

For quality and dependability, the welded joint must be inspected and measured. Undercuts, uncertified craters, surface cracks, lack of fusion, flows, and other defects can be detected using visual inspection. The size of the joints, joint width and height, bevel angle, preparation depth and width, including angle, root gap, root face depth, convexity, and leg length were all determined using welded joint meters and welding templates. Four of the six commonly used NDT evaluation methods were used in the experiment: visual, liquid penetrant, magnetic particle, and radiography.

Analysis tools

The NDT analysis tools are chosen based on the type of joint and flaw to be detected. For the experiment, four different methods for evaluating samples were used, and the tools for each test method were also different.

Visual testing

Visual inspection (VT) is the detection of surface imperfections with the naked eye. VT is normally applied without the use of any additional equipment, but its effectiveness and scope can be improved by using aids such as a magnifying glass. To be able to recognize problems, VT requires good vision, good lighting, and experience. After the welded samples C1, C2 and C3 were collected, physical observations were made on the sample for conformance with the acceptance criteria, and visual testing tools were used to measure the defect and the results compared with standard.

Liquid penetrant testing

Additional testing with liquid penetrants produced more concrete results. A water-soluble visible penetrant was used in the experiment. For liquid penetrant testing, ABRO products were chosen. ARDOX 907 PB 400ml water washable red dye penetrant; ARDOX 9PR5 400ml penetrant remover/solvent cleaner; ARDOX 9D1B 400ml non-aqueous developer. The surface of the pre-cleaned welded samples was sprayed with ARDOX 907 PB penetrant. The penetrant was allowed to sit on the surface for five (5) minutes. The penetrant was then sprayed with an ARDOX 9D1B non-aqueous developer for a maximum of ten (10) minutes to aid in the detection of flaws. A visual inspection is performed to determine flaws. Finally, ARDOX 5319 remover was used to clean the welded samples.

Magnetic particle inspection

Magnetic particle inspection can detect surface and subsurface flaws up to 6mm in depth. The magnetic dye pigment ARDOX 8903W white contrast paint was chosen. To able to obtain both a longitudinal and circular magnetic field, an alternating current (AC) and direct current (DC) yoke was used to generate the magnetic field for the experiment. For creating subsurface and surface flaws, half-wave direct current (HWDC) is the most effective. The following was the test procedure: Magnetic media (magnetic dye pigment) was applied to the welded samples, magnetic particles were introduced by the yokes, and magnetic particle indication was visually interpreted.

Radiography testing

The study used x-ray radiation with a current of 5 mA and a voltage source of 250 kVA because it poses a lower radiation risk than gamma rays. The density and thickness of the material dictated an x-ray exposure time of 0.4 minutes with a geometrical unsharpness of 0.51. In addition, a focal spot size of 22 was chosen with a 600 mm source to film distance. The ASME SEC V specification was chosen, with a single weld single image technique (SWSI). A KODAK AA 400 film with a lead screen size of 100 125 mm and a density range of 1.8 - 4 was chosen. Moreover, an ASTM 1A06 penetrometer was used in the development of the X-ray film at a developing time of 5 minutes at 20 °C. On a wire-type image quality indicator, film sensitivity is 2 % (IQI).

Welding code acceptance criteria

The investigational specimen was steel, and the study's defect acceptance criteria were the AWS code for structural steels. This code specifies the specifications for welded steel structure fabrication and erection. This code applies to steels with a thickness of 1/8 inch (3.2mm) or greater. When specified in a contract, the majority of the provisions in this code are mandatory.

The code parts used are AWS D1.1/D1.M 2010 clause 6, inspection for VT, MPI, and DPI, and AWS D1.1:2000. Inspections are carried out in accordance with structural steel code 6.0 (part C) and 6.12 for radiographic inspection.

Results and Discussion

Data presentation for tee joint

Table 3 displays Tee joint visual inspection results for visual inspection. The result indicates that all the three welded speci-

Table 3 Visual inspection results of corner joint

Specimen	Location from 0 (mm)	Length (mm)	Defect	Results
C1	0-35	8	Lack of fusion/slags	
	0-22	20		Reject
	0		Surface depression	Reject
	0-23	11	Overlap	Reject
			Root undercut	Reject
C2	0	45	Undercut	Reject
	0-15	26	Slags	Reject
	0&5		Overlap	Reject
	0	15	Slags	Reject
	0-35	15	Lack of fusion	Reject
	0-2		Spatter	Reject
C3	0-8	41	Spatters	Reject
	0		Lack of fusion	Reject
	0-45	5	Lack of fusion/slags	Reject

Keys: C1- Corner joint specimen 1, C2- Corner joint specimen 2, C3 - Corner joint specimen 3

(a) (b) (c)

Figure 4 Visual testing sample (a) C1, (b) C2 and (c) C3

mens and both parts labelled A (front side) and B (backside) showed defects for analysis under the acceptance code. Also, C1 joint, both parts showed a lack of fusion, slags, and surface depression. Joint C2, had both faces showing overlaps, undercut, and surface depression. Finally, joint C3 had faces recording under fill, undercut, and depressions. In comparison with the acceptance criteria code adopted, all three tees welded joints were unacceptable per the welding standard code and must be rejected.

Data presentation for corner joint

Table 3 and Figure 4 portrays the results obtained from the visual inspection of the corner welded joint. From the table, the various welded specimen joints were labelled with specific numbers to differentiate each joint for easy presentation of results after performing the NDT inspection. From the table, all three specimens inspected visually showed a significant defect; thus, C1 showed a lack of fusion, slags, surface depression, overlap, and root undercut.

Again, C2 showed undercut, slags, overlap, lack of fusion, and spatters. Furthermore, C3 also showed spatters, lack of fusion, and slags as a defect. However, these defects were compared with the acceptance criteria adopted for the study, and per analysis under the code for acceptance, all three corner joints visually inspected must be rejected. This is an indication that the three welded corner joints visually inspected falls below acceptance and are not standard.

Dye penetrant inspection

Table 4 and Figure 5 describes the results obtained from the dye penetrant test conducted on three corner joints. C1, C2, and C3 which represents the codes given to the various specimen. The test results in table 4 shows clearly that all the results obtained indicate a rejection of the weldment joints defects which were lack of fusion, undercuts, and under fill per the code for acceptance. There is a clear indication that the corner weldment joint analysis with the dye penetrant test and assessed with the AWS D1.1/D1.M 2010 clause 6 of structural steel code of acceptance does not meet the standard of welding processes

Magnetic particle inspection

Table 5 and figure 6 presents the results of a magnetic particle inspection test performed on three butt welded joints in an experiment to determine the quality of their welded joints. From the results obtained and analysed with AWS D1.1/D1.M 2010 clause 6 of structural steel code for acceptance for the welded parts, all the welded specimens failed the acceptance criteria and had to be rejected for further corrections, because of lack of fusion, undercuts and cracks showed as defects as displayed.

Radiography inspection

Table 6 and Figure 7 show the results for three specimens of corner joints tested with radiography inspection, the three specimens C1, C2, and C3 all recorded flaws such as lack of fusion, undercuts, and slag inclusions at specified distances measured from a reference on the weldment. After careful examination of the defects and compared with the acceptance criteria of AWS code for structural steels, all the welded specimen was rejected based on the acceptance criteria.

Table 4 Dye penetrant inspection results of the Corner joint

Specimen	Location from 0 (mm)	Length	Defect	Results
C1	0	10	Lack of fusion	Reject
	0-5	15	Lack of fusion	Reject
	0-5	42	Undercut	Reject
C2	0	10	Lack of fusion	Reject
	0-47	10	Lack of fusion	Reject
	0	15	Lack of fusion	Reject
	0-30	15	Undercut	Reject
C3	0	5	Lack of fill	Reject
	0-50	10	Lack of fusion	Reject
	0-10	15	Undercut	Reject

Keys: C1- Corner joint specimen 1, C2- Corner joint specimen 2, C3 - Corner joint specimen 3

(a) (b)

Figure 5 Sample with (a) dye penetrant applied and (b) results after developer applied

Table 5 Magnetic particle inspection results of the Corner joint

Specimen		Location from 0 (mm)	Length (mm)	Defect	Results
C1	a	0-7	8	Lack of fusion	Reject
	b	0	10	Depression	Reject
		0-16	23	Undercut	Reject
C2	a	0-4	43	Undercut	Reject
	b	0	15	Lack of fusion	Reject
		0-30	12	Undercut	Reject
C3	a	0	5	Lack of fusion	Reject
	b	0-40	10	Lack of fusion/crack & depression	Reject

Key: C1- Corner joint specimen 1, C2- Corner joint specimen 2, C3 - Corner joint specimen 3

(a) (b)

Figure 6 Magnetic particle inspection on (a) C2 and (b) C1

Table 6 Radiography inspection results of the Corner joint

Joint code	Sch/wt	Density	Observations	Result
C1	10 mm	2.03 – 2.86	Lof and slag@0-5cm, uc@4cm	Rejected
C2	10 mm	2.14 – 2.72	Lof and slag@0-5cm	Rejected
C3	10 mm	2.0 – 2.88	Lof@0-5cm, lof@5cm	Rejected

Key: C1- Corner joint specimen 1, C2- Corner joint specimen 2, C3 – Corner joint specimen

Defects on weldment joint using selected NDT techniques

The selected NDT techniques discovered a total of rejected and accepted defects, as shown in Table 7. NDT was performed using VT, MPI, DPI, and RT. Three of the techniques are only capable of detecting surface defects, while the fourth can detect subsurface defects. Nil for VT and MPI, 1 and 3 for DPI and RT, respectively. The steel specimen chosen for the experiment was classified as structural steel by the code used to analyse the defects.

According to AWS D1.1/D1.M 2010 clause 6, majority of defects discovered during VT, MPI, and DPI testing must be rejected based on the code. Undercuts, under fills, lack of fusion, and lack of penetration, porosities, surface depressions, and rounded and linear indications that were roughly above the

(a) (b)

Figure 7 Radiographic inspection results of (a) sample C1 and (b) sample test results for C2

Table 7 Summary of rejected and accepted defects based on AWS standards

NDT Test Technique	Joints	Accepted	Rejected
Visual Inspection	Corner	Nil	13
Dye penetrant inspection	Corner	Nil	10
Magnetic particle inspection	Corner	Nil	8
Radiography inspection	Corner	Nil	3

code's acceptance value were discovered during the test. The ASME section V and AWS D1.1:2000 acceptance codes were used once more. Code 6.0 structural steel (part C) and 6.12 radiographic inspection were used to compare flaws such as lack of fusion, undercuts, slag inclusions, and porosities to the code chosen for analysis. Overall, due to defects exceeding the AWS D1.1:2000 structural steel code 6.0 inspection (part C) and 6.12 radiographic inspection acceptance code, all welded samples collected and tested must be rejected.

Determining whether the weldment joint specimen meets the acceptance specifications

According to the assessment criteria code AWS D1.1/D1.M 2010 clause 6 used for VT, MPI, and DPI and AWS D1.1:2000 Structural steel code 6.0 inspection (part C) and 6.12 radiographic inspection, the welded joints specimen from the various shops failed after the assessment of the various welded joints in the course of conducting the research practical. Thus, it was discovered from the welding of the specimen at the various selected workshops that majority of welders do not keep their welding electrodes in ovens as required by welding processes. In accordance with the material and electrode to be used, the artisans do not adjust the current and voltage. The material to be welded determines the choice of electrode and insufficient ability.

Conclusions

The study objective is to use NDT to evaluate weldment joint quality in selected fabrication shops in STMA-Kokompe. Three major themes guided the research. The first theme examines weldment joint quality using selected NDT techniques, the second theme compares test results to an AWS code of acceptance, and the third theme investigates the impact of joint type on weldment quality. According to the research findings, the experimental method used produced the required results for the specimen tested. All three (3) samples tested had significant flaws or discontinuities in the artisans' weldment.

Accepted welded parts were minor indications that had no direct impact on the welding part. The AWS structural code flaw indications that were less than acceptable included: a lack of fusion; undercuts; slag inclusion; rounded indications; linear indications; and porosities. These discontinuities, if not detected and corrected, cause internal stress and machine component failure. The following are the flaws in courses, according to the research: Inadequate storage of welding consumables, improper current and voltage regulation to suit the specified material, a lack of understanding of the material and electrode selection criteria inadequate skill sets. Furthermore, the study revealed that most of the artisans' work produced at the chosen shops does not meet the AWS structural steel code of acceptance standards. Furthermore, it is evidence that the students' work at these Kokompe fabrication shops may have similar flaws if tests are conducted on them based on the results obtained.

Acknowledgement

The authors acknowledge Takoradi Technical University for the support toward the research work.

Conflict of Interest Declaration

The authors have no conflict of interest to declare.

References

Adigun, O. D., Bodude, M. A., Adigun, A. R., Obadele, B. A., Adebayo, A. O., Umunakwe, R., Kolawole, F. O., & Borisade, S. G. (2021). Effects of Austempering on the microstructure, corrosion and mechanical properties of AISI 1018 steel. https://doi.org/10.21203/rs.3.rs-861196/v1

Ahmadnia, M., Seidanloo, A., Teimouri, R., Rostamiyan, Y., & Titrashi, K. G. (2015). Determining influence of ultrasonic-assisted friction stir welding parameters on mechanical and tribological properties of AA6061 joints. The International Journal of Advanced Manufacturing Technology, 78(9-12), pp. 2009-2024. https://doi.org/10.1007/s00170-015-6784-0

Ahn, J., He, E., Chen, L., Dear, J., Shao, Z., & Davies, C. (2018). In-situ micro-tensile testing of AA2024-T3 fibre laser welds with digital image correlation as a function of welding speed. International Journal of Lightweight Materials and Manufacture, 1(3), pp. 179-188. https://doi.org/10.1016/j.ijlmm.2018.07.003

Birir, J. K. (2015). Investigation of welding quality in the Kenyan informal sector ("JUAKALI-SECTOR"). Master's thesis report, University of Nairobi, Kenya.

Bodude, M., Adigun, O. D., & Ibrahim, A. (2020). Microstructure and mechanical characterization of Austempered AISI 1018 steel. FUOYE Journal of EngineeringandTechnology, 5(1). https://doi.org/10.46792/fuoyejet.v5i1.424

Brierley, N., Tippetts, T., & Cawley, P. (2014). Data fusion for automated non-destructive inspection. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 470(2167), 20140167. https://doi.org/10.1098/rspa.2014.0167

Cil, M. B., & Alshibli, K. A. (2012). 3D assessment of fracture of sand particles using discrete element method. Géotechnique Letters, 2(3), 161.166. https://doi.org/10.1680/geolett.12.00024

Cooley, L. D., Burk, D., Cooper, C., Dhanaraj, N., Foley, M., Ford, D., Gould, K., Hicks, D., Novitski, R., Romanenko, A., Schuessler, R., Thompson, C., & Wu, G. (2011). Impact of forming, welding, and Electropolishing on pitting and the surface finish of SRF cavity niobium. IEEE Transactions on Applied Superconductivity, 21(3), pp. 2609-2614. https://doi.org/10.1109/tasc.2010.2083629

Dobmann, G., Kurz, J., Taffe, A., & Streicher, D. (2010). Development of automated non-destructive evaluation (NDE) systems for reinforced concrete structures and other applications. Non-Destructive Evaluation of Reinforced Concrete Structures, pp. 30-62. https://doi.org/10.1533/9781845699604.1.30

Fahr A. (2013). Aeronautical applications of non-destructive testing. DEStech Publications, Inc.

Gholizadeh, S. (2016). A review of non-destructive testing methods of composite materials. Procedia Structural Integrity, 1, pp. 50-57. https://doi.org/10.1016/j.prostr.2016.02.008

Hung, Y., Yang, L., & Huang, Y. (2013). Non-destructive evaluation (NDE) of composites: Digital shearography. Non-Destructive Evaluation (NDE) of Polymer Matrix Composites, 84-115. https://doi.org/10.1533/9780857093554.1.84

K Srivastava, A., & Sharma, A. (2017). Advances in joining and welding technologies for automotive and electronic applications. American Journal of Materials Engineering and Technology, 5(1), pp. 7-13. https://doi.org/10.12691/materials-5-1-2

Kah, P., Shrestha, M., & Martikainen, J. (2013). Trends in joining dissimilar metals by welding. Applied Mechanics and Materials, 440, 269-276. https://doi.org/10.4028/www.scientific.net/amm.440.269

Kim, J., Park, Y., Kim, Y., Shrestha, P., & Kim, C. (2015). Aircraft health and usage monitoring system for in-flight strain measurement of a wing structure. Smart Materials and Structures, 24(10), 105003. https://doi.org/10.1088/0964-1726/24/10/105003

Kolahan F., & Heidari M. (2010). A new approach for predicting and optimizing weld bead geometry in GMAW. *International Journal of Mechanical Systems science and engineering*, *2*, pp. 138-142.

Lee, K. (2011). Integrating carbon footprint into supply chain management: The case of Hyundai motor company (HMC) in the automobile industry. Journal of Cleaner Production, 19(11), pp. 1216-1223. https://doi.org/10.1016/j.jclepro.2011.03.010

Liu, Y., Tsang, K. S., Tan Zhi'En, E., Alagu Subramaniam, N., & Pang, J. H. (2021). Investigation on material characteristics and fatigue crack behavior of thermite welded rail joint. Construction and Building Materials, 276, 122249. https://doi.org/10.1016/j.conbuildmat.2021.122249

OSNDT. (2023). Guidelines for fillet weld sizing in compliance with AWS D1.1 and D1.2. ONESTOP NDT. Retrieved September 24, 2023, from https://www.onestopndt.com/ndt-articles/fillet-weld-sizes-as-per-aws-d11-aws-d12

Perdhana. (2023). Minimum Fillet Weld Size Per AWS D1.1 Table. SCRIBD Inc. Retrieved September 24, 2023, from https://www.scribd.com/document/500642332/Minimum-Fillet-Weld-Size-per-AWS-D1-1-Table

Rao, P. G., Rao, P. S., & Krishna, A. G. (2014). Mechanical properties improvement of weldments using vibratory welding system. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 229(5), pp. 776-784. https://doi.org/10.1177/0954405414531248

Rausche F. (2004). Non-destructive evaluation of deep foundations [Conference session]. Proceedings of the 5th International Conference on Case Histories in Geotechnical Engineering.

Sekyi-Ansah, J., Acquah, E., Edunyah, I., & Eduku, S. (2022). Experimental studies on tee weldment joints (non-destructive testing). International Journal of Engineering Trends and Technology, 70(11), pp. 422-430. https://doi.org/10.14445/22315381/ijett-v70i11p242.

Sekyi-Ansah, J., Dadadzogbor, I., Eduku, S., Atarah, J. J. A., Puoza, J. C. & Morro, A. (2023). Investigations of weldment joints of exhaust pipes using non-destructive testing (NDT). International Journal of Scientific Research in Science and Technology, pp. 146-155. https://doi.org/10.32628/ijsrst229664

Sekyi-Ansah, J., Wang, Y., Quaisie, J. K., Li, F., Yu, C., Asamoah, E., & Liu, H. (2020). Surface characteristics and cavitation damage in 8090Al–Li alloy by using cavitation water jet peening processing. Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 45(1), pp. 299-309. https://doi.org/10.1007/s40997-020-00401-5

Varun Kumar, A., Selvakumar, A., Balachandar, K., Waseem Ahmed, A., & Yashar Arabath, A. (2021). undefined. Engineering Science and Technology, an International Journal, 24(5), pp. 1253-1261. https://doi.org/10.1016/j.jestch.2021.01.017

Yadav, J., & Paswan, M. (2019). Different methods for predicting and optimizing weld bead geometry with mathematical modeling and ANN technique. International Journal of Innovative Technology and Exploring Engineering, 8(10), 2761-2766. https://doi.org/10.35940/ijitee.j9580.0881019

Yun, W., Philip, B., Zhenying, X., & Junfeng, W. (2019). Study on fatigue crack growth performance of EH36 weldments by laser shock processing. Surfaces and Interfaces, 15, pp. 199-204. https://doi.org/10.1016/j.surfin.2018.10.009.