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Investigations of Weldment Joints of Exhaust Pipes Using Non-Destructive Testing (NDT)

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ABSTRACT

Exhaust pipe components are especially vulnerable to accelerated degradation. Cracks are identified during the scheduled inspection and repaired by weld-filling procedure or by more invasive approaches like cutting and replacing sections. Such small defects can develop into fatigue or stress corrosion cracks in service, which can be extremely difficult to detect. The input parameter has a significant impact on weldment joint quality. Welds are checked to determine whether or not they meet specifications. The study was carried out to inspect and assess the quality of the weldment joints of exhaust pipes using non-destructive testing (NDT). An experimental approach methodology was adopted to achieve the aim of the study. Specimens of car exhaust pipes were welded and tested using some selected non-destructive testing techniques. Six (6) samples were selected for testing, with a serious fault or discontinuity in the artisan-made welded seam. The results showed that the principal fault signs were lack of fusion, surface porosity, crater fractures, linear indication, and undercuts, all of which were below the allowable standards of the AMSE B31.3 Stainless-Steel pipe code and therefore must be rejected.

Keywords: Visual inspection: Liquid penetrant inspection: Weldment joint: Exhaust Pipe.

I. INTRODUCTION

Welded pressure vessels are an important part of the equipment used in many industrial branches, including process, chemical, and petrochemical industries, car exhaust[1], as well as refineries, nuclear and thermal power plants, and so on but welded structures are essential in modern industrial production[2]. Maintenance and repair are two distinct operations with many similarities. Both require individuals with a broad understanding of welding and materials[3]. Material joining is an important technology in many manufacturing industries. Most products, machines, or structures are assembled and fastened from parts, and these parts can be joined together using rivets, seaming, clamping, soldering, brazing, welding, or adhesives[4, 5]. According to[6], welding is used to create a permanent joint between two metals by using a localized application of a suitable combination of temperature, pressure, and metallurgical conditions, resulting in a wide range of welding processes. Welding is the primary method of fabricating and repairing metal products, and it is used in all industries. Welding is widely used in the automotive industry, which is one of the major areas of application[7]. Resistance spot welding (RSW), resistance seam welding (RSEW), metal inert gas welding (MIG), tungsten welding inert gas welding (TIG), laser beam welding (LBW), friction welding (FW), and plasma arc wading (PAW) are the most commonly used welding methods for automotive applications[8].

Weld joint quality is strongly influenced by the input process parameter[9]. The manufacturer frequently struggled with controlling the input model parameters to produce satisfactory welded joints with the required weld quality. Since the dawn of time, skilled workers or engineers have chosen parameters through trial and error for each new welded product to produce a welded joint that complies with the necessary specifications. Welds are inspected to ensure they adhere to the requirements [10]. To establish mathematical relationships between welding process input parameters and weld joint output variables and to identify the welding input parameters that result in the desired weld quality, design of experiment (DoE), differential evolution, and computational networks are frequently used. [11]. There are many applications for non-destructive methods in the evaluation of materials, metals, and engineering material components. [12]. The identification and characterization of damages on a welded portion's surface is known as non-destructive testing (NDT)[13, 14].

Welding heat sources are typically arc flames produced by the welding power source's electricity. Welding techniques are used to join together a wide range of automotive body components[15]. To meet the new material combinations for automotive body parts, there is an increasing need for the development of new welding techniques for automotive applications[16]. With automotive manufacturers focusing on lighter yet strong and fuel-efficient vehicles while employing light weight alternative materials, the demand for innovative welding processes has grown significantly in recent years. [6].

Railways use welding extensively for the fabrication of coaches and wagons, the repair of wheels, the laying of new railway tracks by mobile flash butt welding machines, and thermite welding to repair cracked/damaged tracks[17]. Welding is required in the production of automobile components such as the chassis, body and its structure, fuel tanks, and the joining of door hinges and excavator buckets [18]. Welding technology is now available in every aspect of manufacturing, including shipbuilding, large dam construction, various projects, pipelines, various power plants, and automobile industries[19]. Because of the constant increase in the use of welding in all aspects of manufacturing, it must be constantly improved, experimented with, and upgraded. [20]. This study aims to determine the response of various NDT techniques for detecting weldment defects and also assesses the welding quality of welded exhaust pipe joints by some selected fabrication shops, finally, the objective of the study is to assess and identify defects in the weldment joint using NDT and determine whether the weldment joint meets the approved standards code of acceptance.

II. EXPERIMENTAL METHODS AND MATERIALS

2.1 Experimental design

The experiment took into account three welded joints of a sampled excavator bucket thus; Butt, Tee and Fillet joints and welded them using the manual metal arc welding (MMAW) process with a machine that uses alternating current (AC). The materials samples for the experiment selected were ferrous magnetic materials because of the chosen measurement and analysis tool that would be used to assess the quality of the welded joint. Stainless steel material samples with dimensions 75mm x 50mm x 10 mm were chosen for the formation of various joints used for the equipment. The measurement and analysis tools chosen for the experiment were three non-destructive test procedures; Visual Testing (VT), Liquid Penetrant Testing (LPT) and Magnetic Particle Testing (MPT). The measurement tools give results when some discontinuities or flaws are open to the surface. The electrode chosen by the researchers was E6013 based on the material, type of weld to be done, welding current and voltage, in table 1 and 2 show chemical and mechanical properties whilst figures 1 and 2 show a detailed view of butt joints on exhaust pipes.

Table 1 : Chemical Composition of Stainless-Steel Material

Element	*Content*
Carbon	0.16-0.18%
Silicon	0.40%
Manganese	0.70-0.90%
Sulphur	0.040%
Phosphorus	0.040%

Source:[21]

Table 2: Mechanical Properties of Stainless-Steel

Mechanical Property	*Value*
Yield strength	345N/mm^2
Tensile strength	485N/mm^2
Elongation	20%
Hardness	105 Vicker-HV

Source:[21]

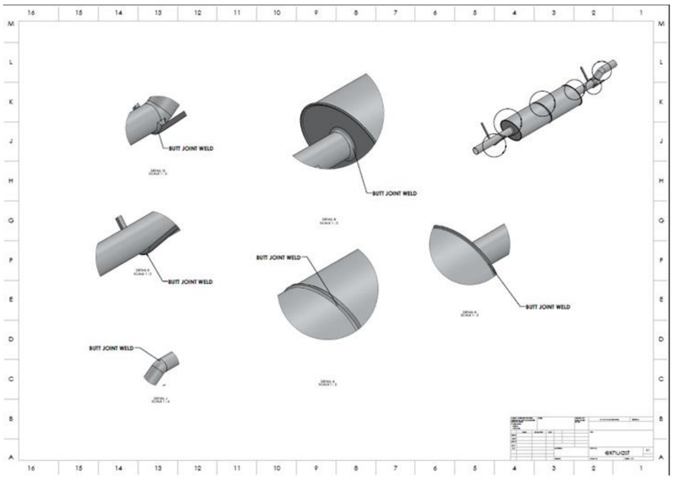

Figure 1. Detail view of Butt Joints on Exhaust pipes

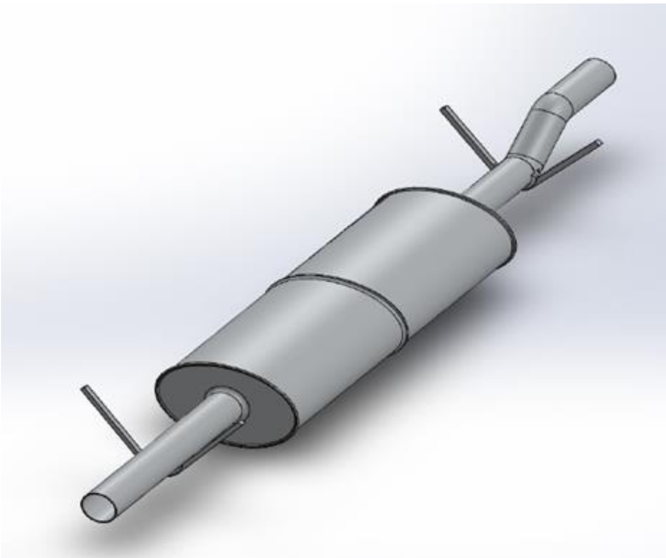

Figure 2 View of an exhaust pipe with butt joint

2.2. Material preparation

2.2.1. Cutting Procedure of Sample Material

The initial material size was 150mm x 100mm x 10mm. A power hacksaw machine Ercole 280 (PS01) with the following specifications: Weight Approx: 900kg, Saw Blade Number: 5, Angular cut degree: +45, Length of Saw blade: 575mm, Motor 380-volt, power: 3PS, Cut range round diameter: 320 mm, Stroke per unit number: 6, Size of machine width/depth/ height approx.: 1850x800x1600 mm. A speed of 7 strokes per minute was selected to facilitate the fast cutting of the material samples. The final material sample dimension was 75 mm x 50 mm x 10 mm

2.2.2 Surface Perpetration Procedure of Samples

The sample obtained was taken to the workshop and held in a bench vice in support of soft jaws to prevent dents on the material surface. A smooth file single cut was initially used to deburr for square corners and remove the rust on the surface first. After a DESC Blue Emery clothes sheet, 230 x 280 mm (9” x 11”) Grit P60 (Grade 2) was used for the surface finish. For the butt joint, a hack saw blade of 12” – 300mm 18 Teeth per inch (TPI) was selected based on the thickness of the material for creating the single Vee groove.

2.2.3 Welding Procedure of Sample Material

The sample materials were taken to welding artisans for welding. The welding process chosen for the weldment was MMAW. One joint was chosen thus; the Butt joint. Two electrodes were used by the artisan for the Arc welding process. This is, AWS 4303 thus - Carbon Steel Electrodes, Diameter – 2.5 mm/ 3.2 mm/ 4.0 mm/5.0 mm Length – 300 mm, 350 mm, 400 mm, Electrode Coating – Calcium-Titanium, Welding Current – 90 -130 A, Voltage – AC 50V, DC+, AWS E6013 – Carbon Steel Electrodes/ Low Alloy Steel Electrode, Diameter – 2.5 mm/ 3.2 mm/ 4.0 mm/5.0 mm, Length – 300 mm, 350 mm, 400 mm, Electrode Coating – Titanium, Welding Current – 90 - 130 A, Voltage – AC 50V, DC+

The current and voltage for the machines were set based on the material and electrode. The sample materials were held on a welding plate and using Engineering Square to check the correct edges, the arc welding process was done successfully at all shops visited.

2 .2. 4. Sample preparation and testing flow chat

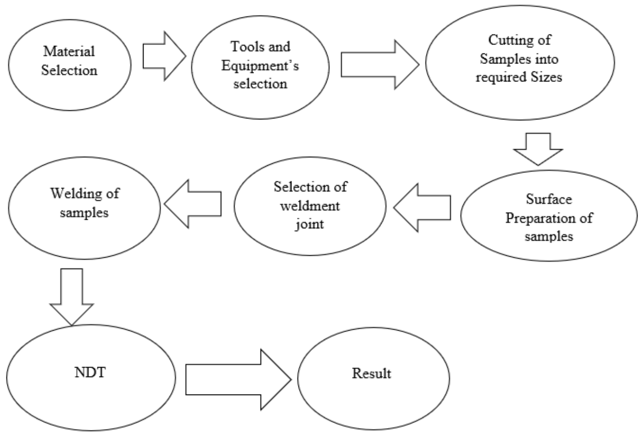

Figure 3 Sample preparation and testing flow chart

2.2.5 Sample of jointly selected

A total of nine (9) 75 x 50 x 10 mm material samples were selected after the cutting process for one type of welded joint. Out of the nine (9) samples selected, a total of six (6) welded sample was produced, and six (6) butt joint was selected in figure 4 show a cut sample butt joint.

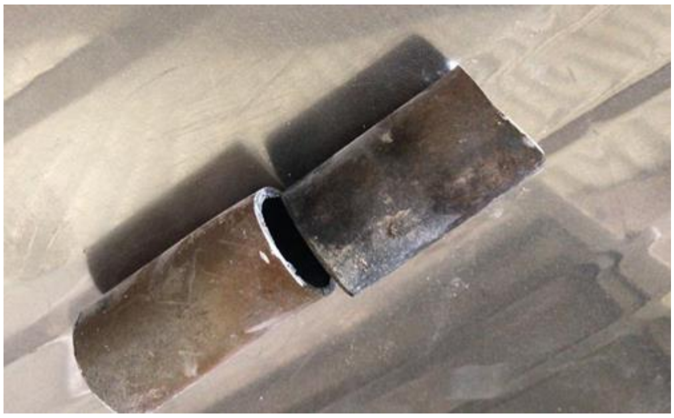

Figure 4 : Sample of the selected Butt Joints

2.2.6 Tools for measurement and analysis

The experiment adopted three NDT evaluation methods out of the six (6) common ones the selected method was: (1) Visual Testing (2) Liquid penetrant testing and (3) Magnetic penetrant Testing. The results obtained were compared with the inspection standard criteria and conclusions were made on whether the welded joint is to be rejected or selected.

2.2.7. Analysis tools

The analysis tools for NDT evaluation are selected based on the kind of joint and flaw to be detected. However, for the experiment, four different methods were used for the evaluation of the samples, and the tools for each test method were also different.

2.2.8. Visual testing

Visual inspection (VT) relies upon the detection of surface imperfections using the eye. VT is generally applied without the use of any other equipment, but its effectiveness and scope can be enhanced by using aids such as a magnifying glass. The basic requirement of VT is good vision, good lighting, and experience, to be able to recognize problems.

2.2.9. Liquid penetrant testing

Further testing with liquid penetrants yielded more concrete results. The experiment used a water-soluble visible penetrant. ABRO products were chosen for liquid penetrant testing. Moreover, water washable red dye penetrant – ARDOX 907 PB 400ml, Penetrant remover/solvent cleaner – ARDOX 9PR5 400ml, and non-aqueous developer – ARDOX 9D1B 400ml were considered in this study. The ARDOX 907 PB penetrant was sprayed on the surface of the pre-cleaned welded samples. The penetrant was allowed to dwell on the surface for approximately five (5) minutes. Afterwards, an ARDOX 9D1B non-aqueous developer was sprayed onto the penetrant for a maximum of ten (10) minutes to help detect flaws. Besides, after a visual inspection is applied for flaw determination. Finally, the welded samples were cleaned with ARDOX 5319 remover.

2.3 Welding code of acceptance

The defect acceptance criteria adopted for the study was the ASME B31.3 code for steel pipes since the experimental specimen was stainless steel pipes. This code contains the requirements for fabricating and erecting steel structures. The specifications for pipes in chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants, as well as other processing facilities and terminals, are specified in ASME B31.3. It encompasses piping design, fabrication, assembly, erection, examination, inspection, and testing. It also covers materials and components. This Code applies to all fluids in pipework, such as unprocessed, process-ready, and finished chemicals; petroleum-based goods; air, water, steam, and gas; liquefied solids;

III. Experimental Data Result and Discussion

The data acquired from the experiment is presented in the table forms according to the joint and NDT technique used. The table below contains the results obtained from the NDT test conducted.

3.1 Data presentation for butt joint (Visual Inspection)

Table 3 Visual Inspection Result of Butt Joints of the Exhaust Pipes Welded at Workshop

SPECIMEN	*LOCATION FROM 0*	*DEFECT*	*RESULTS*
BA1	0-50mm 0-35mm	Surface porosity Excess weld metal	Rejected
BA2	0-15mm	Burn through	Rejected
BA3	0-40	Surface porosity Spatter	Rejected

Key : BA1- Butt joint Specimen 1, BA2-Butt joint Specimen 2, BA3-Butt joint Specimen 3

Specimens BA1, BA2 and BA3 in Table 3 and Figure 5 represent three samples of welded butt joints at workshop one. The butt joint has two sides, where one side was represented as the root and the front side. Specimen BA1, BA2 and BA3 had all defects which were surface porosity, excess weld metal, burn through and spatter being rejected as per the code of acceptance. This result is a clear indication of improper welding operation as per standard.

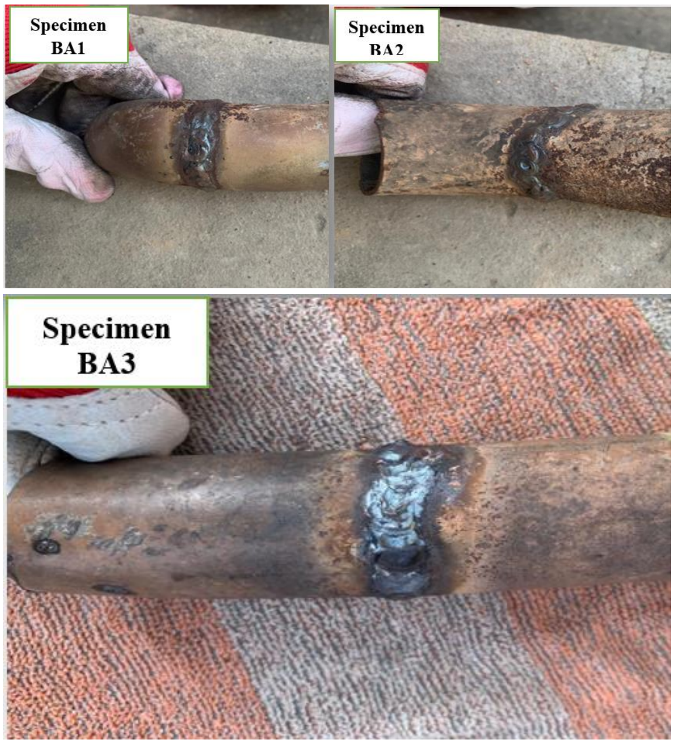

Figure 5 Visual Inspection Result of Butt Joints of the Exhaust Pipes Welded at Workshop

3.1.2 Visual Inspection Result of Butt Joints of Exhaust Pipes Welded at Workshop 2

Table 4 : Visual Inspection Result of Butt Joints of the Exhaust Pipes Welded at Workshop 2

SPECIMEN	*LOCATION FROM 0*	*DEFECT*	*RESULTS*
BAW1	0-50mm 0-35mm	Surface porosity Excess weld metal	Rejected
BAW2	0-15mm	Burn through	Rejected
BAW3	0-40	Surface porosity Spatter	Rejected

Key: BAW1- Butt joint of Workshop 2 Specimen 1, BAW2-Butt joint of Workshop 2 Specimen 2, BAW3-Butt joint of Workshop 2 Specimen 3.

Specimen BAW1, BAW2 and BAW3 in Table 4 and Figure 6 represent three samples of welded butt joints at workshop two. The butt joint has two sides where one side was represented as the root and the front side. Specimen BAW1, BAW2 and BAW3 had all defects which were surface porosity, excess weld metal, burn-through and spatter being rejected as per the code of acceptance. This result is a clear indication of improper welding operation as per standard. The pointer in Figure 6 indicates a typical example of excess weld metal, therefore it was rejected after the visual inspection.

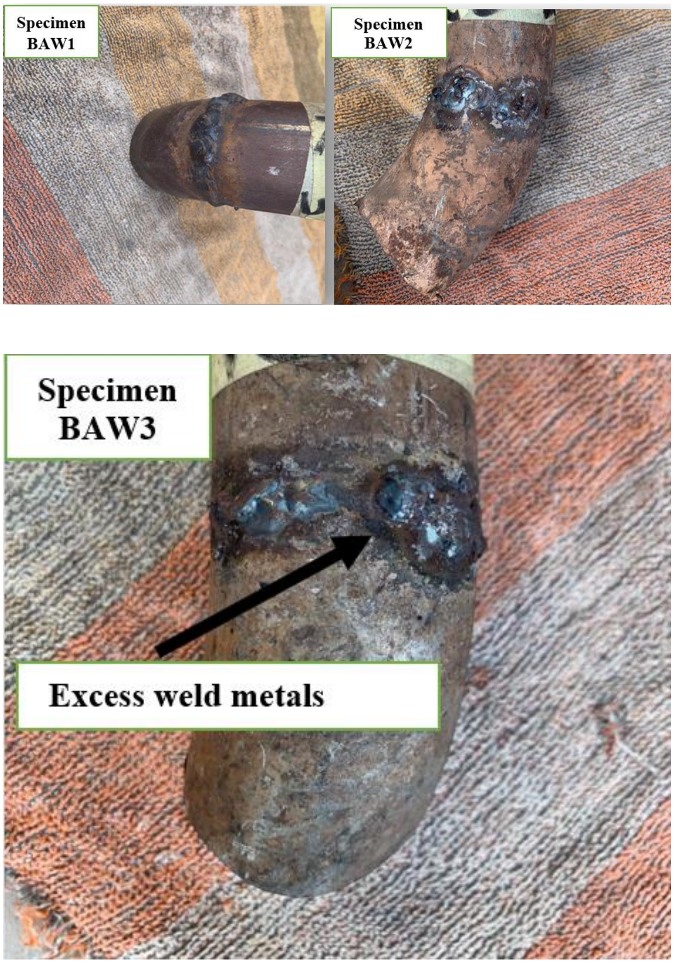

Figure 6: Visual Inspection Result of Butt Joints of the Exhaust Pipes Welded at Workshop 2

3.1.3 Data presentation for butt joint (dye penetrant inspection)

Table 4 Dye penetrant inspection results for butt joint at Workshop One.

SPECIMEN	*LOCATION FROM 0*	*DEFECT*	*RESULTS*
BA1	0-10 0-25mm 0-35mm	Undercut Rounded indication Rounded indication	Rejected Rejected Rejected
BA2	0-15mm	Burn through	Rejected
BA3	0-40 0-43 0-49	Porosity Lack of fusion Lack of fusion	Rejected Rejected Rejected

Key: BA1- Butt joint Specimen 1, BA2-Butt joint Specimen 2, BA3-Butt joint Specimen 3

Table 4 and Figure 7 represent dye penetrant testing results performed on a three-butt weldment specimen. Table 4, three specimens namely BA1, BA2 and BA3. Most recorded flaws in specimens BA1, BA2 and BA3 were rounded and linear indication, undercut, porosity and lack of fusion were rejected based on the ASME acceptance criteria used. In Figure 7 BA1, after the penetrant was applied to the surface of the joint it indicates a welding defect called an undercut. This welding imperfection is the groove formation at the weld toe, reducing the cross-sectional thickness of the base metal. Following a dye penetrant inspection of the first joint, it was discovered that the defects were caused by artisanal welders using excessive weld current. The welding speed was too fast. Incorrect angle, which directs more heat to free edges, incorrect filler metal, and Poor weld technique. This concludes that the weldment is not fit for the standard.

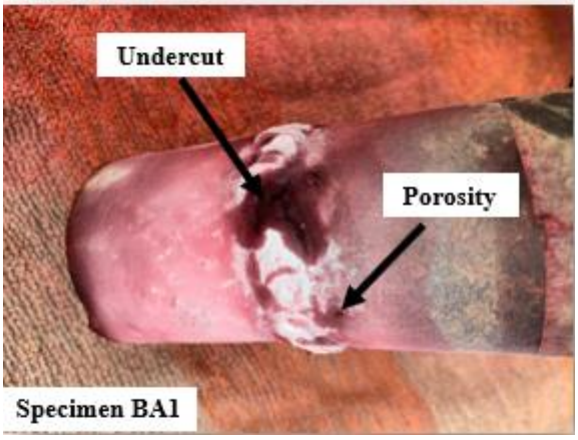

Figure 7: Dye penetrant inspection results for butt joint Workshop one.

Figure 8 Spatter and Lack of fusion defect after the dye penetrant inspection

In Figure 8 the pointer indicates a welding defect called spatter and lack of fusion; which occurs when small particles from the weld attach themselves to the surrounding surface. It's an especially common occurrence in gas metal arc welding. No matter how hard you try, it can't be eliminated. However, there are a few ways you can keep it to a minimum. After a clear observation during the welding procedure, in Figure 9, the point indicates a defect called slack inclusion. Slag inclusion is a type of welding defect that is usually visible in the weld. Slag is a vitreous material produced by stick welding, flux-cored arc welding, and submerged arc welding. It happens when the flux, and the solid shielding material used in welding, are on the welded zone's surface.

Figure 9 Slag inclusion defect after the dye penetrant inspection

3.2 Discussion

The main aim of the research work was to inspect and assess the quality of weldment joints of exhaust pipes using selected NDT, only the Butt joint was selected based on the type of pipe which was welded. After conducting the NDT test on the butt joint of the various specimen, the results were recorded based on standards that are used to either reject or accept the weld based on the defect. Table 5 shows the summary of all accepted and rejected results obtained based on the standard criteria under the ASME B31.3 codes.

3.2.1 Defects on weldment joint using selected NDT Techniques

Table 5 : Summary of rejected and accepted defects based on AMSE standard.

NDT	*Test Joint*	*Accepted*	*Rejected*
Techniques	Butt		
Visual Inspection		Nil	6
Dye Penetrant Inspection		Nil	3
Total		0	9

Table 5 shows the total number of rejected and accepted defects found in the course of using the selected NDT techniques. The two NDT techniques adopted were VT and DPI. All two techniques can only detect defect when it is opened to the surface. The specimen chosen for the experiment was a stainless-steel pipe, in that, the code chosen for analyzing the defect classifies such specimen under steel pipe criteria. ASME B31.3, inspection for steel pipes was used as the acceptance and the rejection criteria for VT and DPI. Based on the defects found in the course of using the aforementioned techniques, most of the defects found in the test have to be rejected based on the ASME B31.3 code. The indications by the test showed undercut, lack of fusion, porosities and linear indications, which were approximately above the acceptance value based on the code.

3.2.2 Ascertaining whether the welding joint specimen meets the Specification of acceptance

Based on the assessment Criteria code ASME B31.3 which contains requirements for piping and was used for the VT and DPI, the welded joint specimen from the various shops failed after the assessment of the various welded joints in the course of conducting the research practical, the welding of the specimen at the various selected workshops, the researcher observed that;

Most artisanal (Welders) do not have their welding electrodes stored in an oven as required by the welding process.

The artisan does not set the current and voltage as per the and the electrode to be used.

Most of the electrode used is not based on the material to be welded.

Lack of adequate skill.

All these contributed to the flaws that were detected in the test samples like porosity, slag inclusion, lack of fusion and undercut.

IV. CONCLUSION

The project's objective is to use Non-Destructive Testing (NDT) at a few selected welding shops to evaluate the quality of the weldment junction of exhaust pipes. Two key goals were established to direct the research to accomplish the goal. The welded joint was evaluated using VT and DPT to assess its quality, and a second purpose was to ascertain whether it complied with the ASME code of acceptance. The research findings and the experimental method approach adopted produced the appropriate outcomes for concluding the specimen studied. The six (6) samples that were gathered for testing each displayed a severe defect or discontinuity in the artisan-made welded joint. Lack of fusion, surface porosity, crater fractures, linear indication, undercuts and all of which were above the permitted standards of the AMSE Stainless-Steel pipe code the main fault indicators.

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