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Defect Detection of Topside Offshore Platform Structure Using Non-Destructive Testing Methods

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Abstract

Non-destructive testing on offshore rigs involves multiple sections. The topside platform structure, which consists of the main deck, cellar, and sub-cellar deck, is one of the most important sections. The purpose of this research is to use appropriate nondestructive testing (NDT) methods to assess the internal and surface defects as well as identify the material properties of the selected structure at the topside platform structure. Various NDT technologies can be utilized to detect faults on the topside of the offshore platform. The NDT techniques used in this study are ultrasonic, magnetic particle, and dye penetrant testing. To describe the material in the samples, a different method known as positive identification material is employed. Four tasks are involved in this process: identifying the material properties of each sample, identifying surface and interior faults, and comparing the two types of defects. The results of the analysis revealed that a 316L stainless steel specimen contained as much as 19.2% chromium, 11.8% nickel, and 3.0% molybdenum. Magnetic particle inspection was recommended for surface and subsurface inspection. In contrast, the ultrasonic testing examination yielded the best outcome for the topside offshore platform's interior problem.

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1. Introduction

Offshore installations in the oil and gas sector are high-risk buildings due to their exposure to dangerous and combustible hydrocarbon chemicals [1–2]. An extreme scenario on the platform involves a hydrocarbon explosion resulting in blast loading. The Piper Alpha catastrophe occurred on July 6, 1988, when a gas leak occurred in one of the platform's condensate pipelines. Only 61 of the 226 workers on the platform at this point would survive the catastrophe. Two rescuers perished during the rescue operation, and it required a span of three weeks to successfully suppress the fire [3]. Therefore, it is important to have an inspection strategy and risk assessment in place to monitor the structural integrity of offshore platforms [4–6]. The NDT methods commonly used for inspecting oil and gas offshore plants include positive material testing, dye penetrant testing, magnetic particle testing, and ultrasonic testing [7–11]. The objective of this study is to examine many categories of welding defects, encompassing porosity, slag inclusion, lack of fusion, and lack of penetration. Additionally, it will demonstrate the significance of welding proficiency and the crucial role of non-destructive testing (NDT) inspection in ensuring the reliability of structures. Porosity is a common welding defect that is characterized by the presence of gas pockets or cavities inside the weld metal. On the other hand, slag inclusion happens when non-metallic substances get caught in the weld metal during the welding process [12].

The inspection of topside offshore platforms utilizes three primary non-destructive testing (NDT) techniques: dye penetrant testing (DPT), magnetic particle testing (MPT), and ultrasonic testing (UT) [13–14]. DPT and MPT are utilized for surface defects, whereas UT is used for internal defects [15]. In this research, the characteristics of 316L welded pipe and the carbon steel structure of the topside platform are analyzed using a specific NDT technique on the pipe material. Then we employed DPT, MPT, and UT approaches to detect defects in the structure of the topside offshore platform. The PMI method was employed to determine the material characterization of 316L stainless steel. There are two types of defects: internal defects (UT) and surface defects (MPT and DPT). One of the mechanisms investigated in this study is the effect of gain settings on UT results. Finally, the results of defect measurement were compared between surface and internal inspections.

2. Material and Research Method

The materials used in this study are stainless steel (grade 316L) and carbon steel structure. The NDT method applied is discussed in the following sections.

2.1 Positive Material Identification

Optical Emission Spectroscopy (OES) is a non-destructive testing technique that uses a spark or arc to excite the atoms in a sample, causing them to release photons of light at predetermined energies. Software interprets the data collected by a spectrometer to reveal the elemental composition of the sample. To determine the start of the making of the material, the computer program performs an analysis of the data and then checks it against a database containing the known elemental compositions. The program should be able to determine whether the welded joint contains 316L stainless steel when it is present. The examination will allow the program to establish the alloy grade and decide whether the material in question is stainless steel grade 316L or carbon steel.

2.2 Surface Inspection Setup

The purpose of this research is to identify and determine defects in the surface of the welding joint. In addition, this research uses each of the three different types of carbon steel used in the structure of the topside of the offshore platform. Surface defects can be detected by using visual inspection, dye penetration testing, and magnetic particle testing. Table 2.1 shows the three types of samples that will be used in this research.

Table 1 *Types of samples*

No	Type of samples	Code of material
1	CS (I)	EN10255 S355G7 +M
2	CS (II)	EN10255 S355G8 +MZ35
3	CS (III)	S355MLO
4	SS (A)	Grade ASTM A312
5	SS (B)	Grade ASTM A312
6	SS (C)	Grade ASTM A312

2.2.1 Dye Penetrant Testing (DPT) Process

During the DPT process, a liquid penetrant is applied to the surface of the welded joint. After allowing 10 to 15 minutes for the penetrant to seep into any visible defects on the surface, the test findings are examined and analyzed. Subsequently, operators remove any remaining penetrant and administer a developer onto the surface. The developer aids in extracting the penetrant that is trapped within the faults, which reveals the defects in the structure.

2.2.2 Magnetic Particle Testing Process

Magnetic particle testing (MPT) is a technique that makes use of a magnetic field to discover surface and subsurface flaws in ferromagnetic materials like carbon. When a magnetic field is applied to a ferromagnetic material, any flaws or discontinuities in the material cause the magnetic field to become distorted. Prior to commencing the testing procedure, the sample must be prepared. The area that needs to be tested must be clearly visible and easily accessible, and the welded joint's surface must be cleaned to get rid of any dirt or debris. Subsequently, a yoke is employed to apply a magnetic field to the surface of the recently formed welded connection.

2.3 Internal Inspection Setup

An area or extent of a defect located inside the internal structure of an item being studied is referred to as an internal area. The NDT procedure is used to find and assess defects that may be concealed or internal to an object that is being tested.

2.3.1 Ultrasonic Testing Process

The Sonatest Sitescan D59 is the instrument employed for the purpose of defect detection in the topside offshore platform's structure. Ultrasonic testing (UT) must be performed on a test surface that is devoid of any coatings, dirt, or debris that may interfere with the transmission of ultrasonic waves. Prior to performing the testing, it is necessary to calibrate the equipment properly and apply a couplant, typically a gel or liquid, to the surface of the test object [4]. For this study, two types of bevels, namely single bevels and double bevels, have been employed for the purpose of testing.

Single bevels usually refer to a specific kind of weld joint design. Weld joints are extensively used in a variety of sectors to connect two or more metal components. A single bevel weld joint can be identified by a V-shaped groove formed by cutting one of the workpieces. The bevel angle is normally between 30 and 60 degrees; however, it might vary based on the welding technique and code requirements. The other workpiece is typically flat or has a small incline to aid in the welding operation. A single bevel is classified as CS (I) or CS (II) carbon steel. In reality, these two materials have distinct flaws.

3. Results and Discussion

The results and discussion of the research work are presented in this paper. The positive material identification result is used to determine the characteristics of three different sizes of 316L stainless steel pipe. The first sample, referred to as sample A, has a pipe size of 150 mm and a thickness of 10.97 mm. In comparison, the second sample, sample B, has a pipe size of 200 mm and a thickness of 12.7 mm. Lastly, the third sample, sample C, has a pipe size of 250 mm and a thickness of 15.08 mm. This process is very important in this research to ensure that the results obtained, either from the structure of the topside platform, can be used for the dye penetrant testing method or the magnetic particle method. Next, the results obtained for the detection of defects in the surface area using selected non-destructive testing methods, which are magnetic particle testing and dye penetrant testing. Furthermore, the detection of defects in the internal structure of the topside platform structure. The types of material and different types of sizes have been discussed to identify the best method to detect defects. Finally, ultrasonic testing is the method that is used to detect defects in the internal area. Thus, it would be divided into two sections: a single-bevel welding area and a double-bevel welding area.

3.1 Positive Material Identification Result

This section describes positive material identification as a necessary process to justify the selection of an NDT method. For example, DPT is based on the material composite of the inspection parts or structure. Throughout this technique, the material type of the parts or structure can be identified, such as metals or alloys.

In this experiment, positive material identification is used to identify the composition of the 316L stainless steel pipe material, while the metal or alloy composition is also graded according to the ASTM A312 standard. The findings indicate that each sample has the four characteristic composite elements of molybdenum, nickel, chromium, and carbon. The sample contains several composite results based on observations.

3.1.1 Characteristics of Positive Material Identification

According to the table of stainless-steel pipe grades (ASTM A312), the typical range of molybdenum values in a stainless-steel pipe of grade 316L is between 2.0% to 3.0%. The results show that the element molybdenum is between 2.74% to 2.83%. In that case, molybdenum elements are still within the acceptable range of chemical composites. Furthermore, the typical range for nickel percent value in stainless steel pipes of grade 316L is somewhere between 10.0% to 14.0%. This information is derived from the article Stainless Steel and Duplex Pipe (ASTM A312, A790) [15]. Based on Table 1, the results show that the value of a nickel is between 11.5% to 11.7%. This demonstrates that this grade of pipe is appropriate for the material that it is made of and that it maintains its chemical composition within an acceptable range without any issues. Next, the range of carbon elements according to the table of stainless-steel pipe grades (ASTM A312) is 0.035%. Based on the observation of the results, the range of the element carbon in 316L stainless steel between samples A, B, and C is 0.012% to 0.019%. Finally, the range of composite elements in chromium is between 16.0% and 18.0%. But the results show the composite element in between three samples of 316L stainless steel is higher than the standard range of chemical composition because each welding in the three samples differs in terms of capping size and voltage temperature used for welding.

Table 2 *Characteristic of 316L stainless steel in elements composited results*

No	Sample	Elements Composites in (%)			
		Molybdenum	Nickel	Chromium	Carbon
1.	A	2.83	11.5	19.2	0.012
2.	B	2.69	11.8	18.5	0.017
3.	C	2.74	11.7	19.0	0.019
Range of Characteristic from ASTM A312		2.0-3.0	10.0-14.0	16.0-18.0	0.035

Fig. 1 shows the comparison characteristics between three samples of 316L stainless steel. For molybdenum, nickel, and carbon, these three samples have slightly different results compared to chromium. Moreover, chromium has exceeded the chart table that is supposed to be in the range of 16% to 18%, but in this research, it reaches 19.2%. Furthermore, chromium is the highest element when compared to other elements. This is because the element chromium acts as an alloying agent, imparting corrosion resistance while also increasing the strength and longevity of the steel. Chromium is also utilized in superalloy production, which is used in jet engines, gas turbines, and other high-temperature applications.

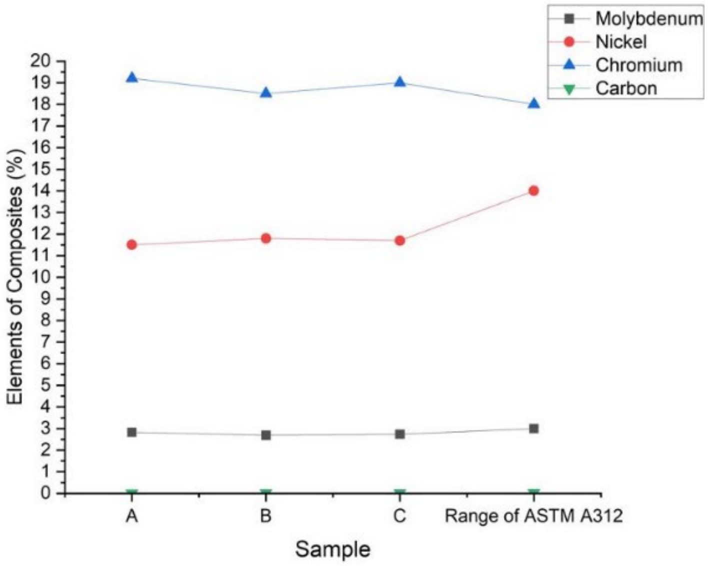


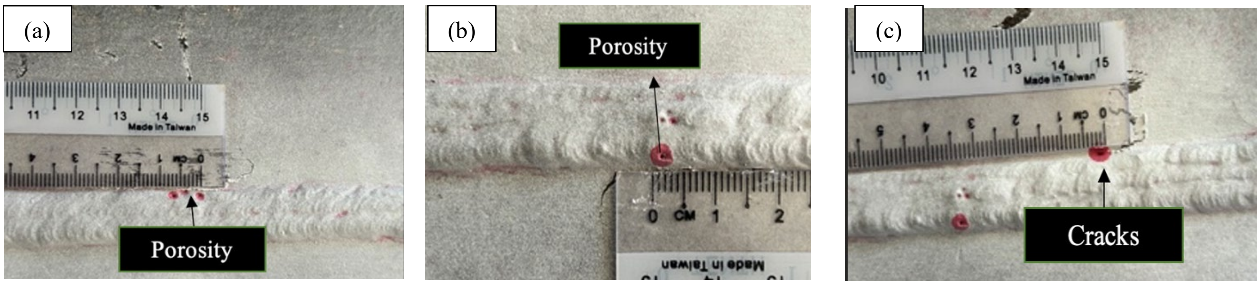
Fig. 1 *Characteristic comparison between three samples of 316L stainless steel pipe with range of ASTM A312*

3.2 Surfaced-Based Defect Detection Results

This section discusses the results obtained from the fabrication structure using two NDT techniques on the surface area. The findings identified two defects in the fabrication structure: porosity and cracks. Both NDT methods detect two types of defects in carbon steel. Several types of material have been used in this process, including EN10255 S355G7 +M for material type I, EN10255 S355G8 +MZ35 for material type II, and S355MLO for material type III.

3.2.1 Dye Penetrant Testing Results

There are two different defects in the weld joint after applying the DPT method to the topside platform supporting the fabrication structure. Porosity and cracking are two such defects. Figure 2 shows a close-up of the defect in the fabrication structure on the topside platform. Besides that, Table 4.2 also shows the length of the defect. The first defect found was porosity in material type I; the value of the length defect is 7 mm. The second material, type II, also has porosity in two different locations with different lengths of defects, which are 4 mm and 3 mm. Finally, in material type III, the defect found is a crack with a length of 3 mm.



Material I	Detection of Defects	Length of Defects
EN10255 S355G7 +M	Porosity	7 mm

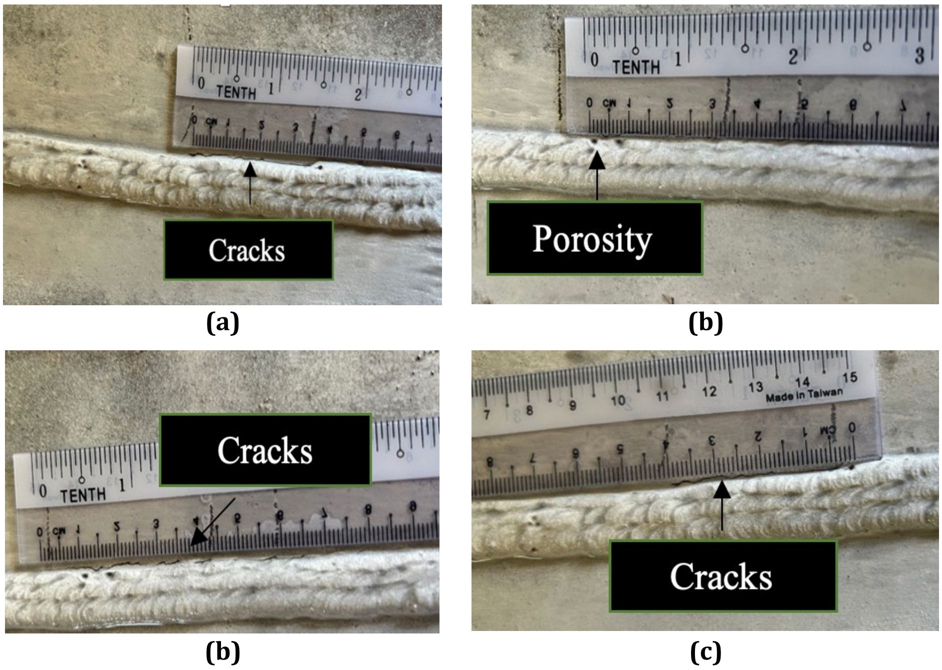
Material II	Detection of Defects	Length of Defects
EN10255 S355G8 `+MZ35	Porosity Porosity	4 mm 3 mm

Material III	Detection of Defects	Length of Defects
S355MLO	Cracks	3 mm

Fig. 2 *Type of defects in DPT with different lengths*

3.2.2 Magnetic Particle Testing Results

There are two different defects in the weld joint after applying the MPT method to the topside platform supporting the fabrication structure. Figure 3 shows a close-up of the defect in the fabrication structure on the topside platform. Besides that, Figure 3 also shows the length of the defect. The first defect found was a crack in material type I; the value of the length defect is 350 mm. For the second material type II, the results show there are two defects, which are porosity and crack, in two different locations with different lengths of defects, which for porosity are 1 mm and 650 mm for crack defects. Finally, in material type III, the defect found is a crack with a length of 400 mm.



(a) **(b)**

(b) **(c)**

Material I	Detection of Defects	Length of Defects
EN10255 S355G7 +M	Cracks	350 mm

Material II	Detection of Defects	Length of Defects
EN10255 S355G8 +MZ35	Porosity Cracks	1 mm 650 mm

Material III	Detection of Defects	Length of Defects
S355MLO	Cracks	400 mm

Fig. 3 *Type of defects in MPT with different lengths*

3.3 Internal-Based Defect Detection Results

This section presents the findings of the ultrasonic testing (UT) technique on the internal structure of carbon steel. Based on the available findings, four defects have been identified: porosity, lack of fusion, lack of penetration, and slag inclusion. Both single and double bevels can exhibit any of these four defects.

3.3.1 Inspection Results at Single Bevel Weld Joining Area

Ultrasonic testing revealed that slag inclusion had formed on the structure for the first defect, which involved the material EN10255 S355G7 +M. The test revealed many discontinuities in the weld, with a thickness of 15.9 mm, after testing with a weld length of 1957 mm. Discontinuities that were generated in the structure include ones that were 80 mm long and those that were 12–14 mm long in terms of defects.

Furthermore, when utilizing material EN10255 S355G8 +MZ35, two distinct types of defects have been identified: lack of fusion and lack of penetration. During testing, it was discovered that the weld, which is 4278 mm in length and has a thickness of 15.9 mm, had several discontinuities. The breaks in question are characterized by a lack of fusion. This lack of fusion might manifest in two ways: breaks that are discontinuous in terms of length and have a distance of 200 mm, and breaks that are discontinuous in values of depth and have a gap of 8-11 mm. Furthermore, another type of defect that may arise is insufficient penetration. Despite the uniform weld length and thickness in all the tests, the results indicate the presence of two types of fractures: one type is characterized by discontinuity in length, with a distance of 220 mm, while the other type is characterized by discontinuity in depth, with a distance ranging from 8 to 15 mm. Both of these forms of fractures are currently present.

Every defect that occurs has its properties at a single bevel. However, single bevel welding defects, including slag inclusion, lack of fusion, and lack of penetration, compromised the strength and reliability of weld joints. For slag inclusion, we need to remove any visible slag by chipping or grinding it away. Repair work is one of the solutions to this problem. For example, the occurrence of slag inclusion can be eliminated through chipping and grinding procedures.

3.3.2 Inspection Results at Double Bevel Weld Joining Area

A double-bevel weld joint is a type of joint configuration commonly used in welding. The process involves the preparation of both surfaces of the base metal through the creation of a V-groove or U-groove, which forms a central groove in the joint. The only defect observed in the material S355MLO is porosity. Following ultrasonic testing on a 16 mm long weld, it was discovered that the 16 mm thick weld had multiple instances of porosity, which are discontinuities. The discontinuities consist of variations in length, spanning a distance of 50 mm, as well as variations in depth, ranging from 7 to 10 mm. Porosity occurs when the base metal or filler material becomes covered with moisture, dirt, and oil, resulting in the formation of gas pockets during the welding procedure.

3.4 Comparison Between Surface and Internal Results

This research utilizes two distinct methods, namely surface detection, and internal detection, to identify faults in welding joints. Despite employing identical materials, these methods differ in their approach. When comparing the surface and internal outcomes, ultrasonic testing (UT) yields higher results than dye penetrant testing (DPT) and magnetic particle testing (MPT). The reason for this is that the outcome of ultrasonic testing is more apparent in contrast to dye penetrant testing (DPT) and magnetic particle testing (MPT). Furthermore, UT can detect the depth of the defect clearly on the surface and inside, but DPT and MPT can only identify the defect on the surface.

4. Conclusion

In conclusion, the detection of defects in topside offshore platforms using NDT methods serves as a critical outcome that guides subsequent actions and decisions. It consolidates the findings and observations made during the inspection process, providing a summary of the condition of the platform, and highlighting any significant issues or areas of concern. The conclusion not only serves as a reference for immediate remedial actions but also informs long-term strategies for the platform's maintenance and integrity management. The defect detection process involves the analysis and interpretation of NDT data obtained from various techniques, such as ultrasonic testing, magnetic particle testing, visual inspection, radiography, or other relevant methods. It involves the integration of inspection results, including the identification of defects, their severity, location, size, and other pertinent characteristics. This can be concluded from the data collected from various research projects that were done on three different tests. UT is more effective than DPT and MPT because UT can detect the depth of the defect clearly on the surface and internally, compared to DPT and MPT, which can only detect the defect on the surface. Hence, overall results may include recommendations for further actions, such as additional inspections, repairs, or monitoring, based on the identified defects and their implications for the platform's integrity.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *F. N Yacub, M. F Mahmod;* ***data collection:*** *F. N Yacub;* ***analysis and interpretation of results:*** *F. N Yacub, M. F Mahmod;* ***draft manuscript preparation:*** *F. N Yacub, M. F Mahmod. All authors reviewed the results and approved the final version of the manuscript.*

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