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CASE HISTORY—PEER-REVIEWED

Positive Material Identification Procedure Development to Prevent Valve Corrosion Failures

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Abstract Valves are essential parts of piping systems in the oil and gas industry. The failure of a valve due to corrosion is an adverse event with several negative consequences. One of the causes of valve corrosion is material mismatch. A PMI test is conducted as part of the project to verify the material of valves, pipes, joints, and pressure vessels. PMI testing of valves has not been studied previously. It is the goal of this study to focus on PMI requirements and case study for valves in order to prevent the negative consequences of its absence, such as corrosion, which can both be costly and unattractive. The purpose of this study is to develop a suitable approach for the development of PMI procedures for industrial valves used in the oil and gas industry. A case study is also described briefly in which the PMI for offshore valves has been forgotten, as well as how the mitigation approach has been implemented. This case study examines the absence of PMI for some dual-plate check valves in an offshore Norwegian project called Edvard Grieg (EG). The project specifications required that 50% PMI be applied to the pressure-retaining parts of a number of these valves made of 22Cr duplex material. The total number of dual-plate check valves is 80. The bodies are made from 22Cr duplex steel. Therefore, 40 valves must be tested for PMI, although only three valves of the 4 inch size and class 150 have already been tested. Consequently, PMI must be conducted on 37 remaining valves during fabrication, which are selected from smaller valve sizes to avoid stopping the fabrication work. According to the PMI results, all of the tested valves were manufactured from 22Cr duplex stainless steel.

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Introduction

Valves are integral components of piping systems, serving a variety of functions including stopping and starting fluid flow, controlling fluid flow, preventing backflow, and providing safety [1–4]. Failure of valves in the offshore sector of the oil and gas industry is a significant risk and a costly event. This results in severe negative consequences, including loss of assets, loss of production due to plant shutdowns, health, safety, and environmental (HSE) concerns, including hydrocarbon spills, environmental pollution, and human death [5–10].

Corrosion is a costly and undesirable phenomenon that has a significant economic impact [10]. A study conducted by the National Association of Corrosion Engineers (NACE) estimated the global cost of corrosion to be US$2.5 trillion, or 3.4% of the global gross domestic product (GDP) [11]. Mixing of materials is one of the most common causes of corrosion. Imagine, for example, that the valve body in corrosive offshore environments is selected in duplex material, but by mistake austenitic stainless steel is used during manufacturing. When this error is made in material handling, it could lead to severe pitting and chloride stress cracking of the valve body in an offshore environment [12]. Positive material identification (PMI) is a method of preventing the mixing of materials and corrosion.

Positive material identification refers to the determination that the chemical composition of a mechanical component is as specified and ordered. In PMI testing, materials are physically examined or tested to ensure that they meet the requirements of the standard related to the material, such as the American Society for Testing and Materials (ASTM), in order to ensure that they conform to the alloy steel material selected. The term alloy steel refers to any steel (including filler metals for welding alloy materials) that contains specified quantities of elements, such as chromium, nickel, or molybdenum, in order to enhance mechanical and physical properties and/or corrosion resistance. Stainless steels of different types, including duplex and austenitic stainless steels, are classified as alloy steels. The majority of alloys used in refineries and petrochemical operations are chromium-molybdenum steels, stainless steels, and nickel-based alloys such as Hastelloy and Inconel. In the petroleum refining and petrochemical industries, positive material identification, or PMI, is an essential component of process safety management. Since the late 1970s, the requirement for PMI of alloy materials has increased dramatically in refinery systems and petrochemical plants. Following a series of accidents caused by material mix-ups, many companies have implemented rigorous PMI programs. In 1993, a major fire at a Louisiana refinery was caused by an inadvertent substitution of a carbon steel elbow for an alloy steel elbow, resulting in a premature rupture due to hot sulfide corrosion. An elbow is a piping component that is used to change the route of piping. PMI is also necessary in the valve industry on the valve components in order to prevent corrosion and costly failures of the valves during operation mainly. It is important to note that PMI is not limited to oil and gas valves, but is also used on pressure vessels, pipelines, piping and piping components or even weld joints. Figure 1 shows a PMI device used to determine the chemical composition of a valve body.

Fig. 1 A PMI device is used to determine the chemical composition of a valve body

Research Problem, Novelty, Motivation, and Contribution

There have been a number of past studies that address PMI, which are briefly reviewed in this section. The oil and gas industry sometimes experiences non-conformances and a lack of quality control, such as a mix-up of materials during component fabrication or repair, which may go unnoticed for several years until a problem arises [13]. As a result of fabrication defects, which may open up after years of service, major failures will occur, which can result in unscheduled shutdowns, production loss, environmental contamination, as well as safety and health risks [13]. In summary, the reviewed paper provides two case studies in which PMI is missed for a fitting in a pipeline system and for the welding of a piping system which caused sour corrosion and cracking as a result of service fluid [13]. Materials used in sour services containing considerable amounts of hydrogen sulfide must meet the requirements of NACE MR0175/ISO 15156 [14, 15]. Based on these two standards, chemical composition of materials is one of the most important requirements. Nevertheless, the materials used for the fitting and welding in these case studies failed to meet the standard requirements and PMI was not applied. As a matter of fact, sour corrosion is very dangerous due to the release of toxic hydrogen sulfide into the atmosphere, which can kill humans in short periods of time, even at a low dose [16]. It is important to recognize that lack of PMI, especially in these two cases, is associated with lack of quality control plans. Accordingly, the second study in this review uses a PMI approach to recognize the grade of pipeline material in carbon steel produced in accordance with API 5L specifications for line pipes [17]. A noteworthy aspect of this study is that the developed PMI method can also determine the mechanical properties of pipe materials, such as yield and tensile strength, in addition to their chemical composition [17]. In spite of the fact that PMI is commonly applied to alloys, this study shows that it may also be used on carbon steels. Furthermore, another essential and prominent feature of this type of PMI that is used to determine the mechanical properties of the pipe is that it is a non-destructive test. This means that there is no need to damage the material. Nevertheless, it is important to note that the methods used to determine the mechanical strength of pipeline materials prior to the establishment of PMI methods were all destructive in nature [17]. The third study in this review focuses on the use of X-ray fluorescence (XRF) technology for PMI testing of stainless steel materials (austenitic and 22 Chromium (Cr) duplex) in the welded joint and heat-affected zone (HAZ) [18]. A heat-affected zone (HAZ) is a non-melted area of metal that has undergone changes in its material properties as a consequence of being exposed to high temperatures. A change in material property is usually caused by welding or high-heat cutting [19]. Following the testing, the results were compared with the applicable standards, namely ASME Section II Part A for pipe materials and ASME Section II Part C for welding electrodes. As a result of the results, it can be concluded that the materials used are compliant with the standards. As a result, the PMI results are acceptable. Most XRF analyzers provide software for analyzing the X-ray spectrum obtained by the instrument's detector [20]. A test is initiated by placing the instrument (or instrument probe) on the surface to be analyzed, and then either pulling a trigger or pressing a button to open a safety shutter. Aside from activating the electronics, this process also initiates the acquisition of spectral data by the system. In most cases, the results are displayed on an LCD screen, and they include both the chemical composition and the common trade name of the identified alloy grade. The surface of the material is subjected to a brief radiation from an X source in X-ray fluorescence spectroscopy. During the test, the atoms of each element in the metal emit secondary X-rays characteristic of the element. By measuring the intensity of the X-rays in each region, a detector separates these X-rays into categories of energy. In another study, PMI was used to test the coating of thermal spray aluminum (TSA) on stainless steel 316L [21]. TSA is a type of robust coating that is used to protect carbon and alloy steels from external corrosion in marine environments [22]. In the last study, the root cause analysis (RCA) of stainless steel cladding cracking due to sour corrosion was examined. On a carbon steel base metal, the cladding was applied in a gas scrubber. PMI results indicated that the cracking of the cladding was caused by the mixing up of materials due to the use of SS321 instead of SS316L [23].

Using the literature review, this paragraph summarizes what is known about PMI based on the available researches. Based on the literature review described in the previous paragraph, the following information is known:

- In oil and gas projects, PMI could be part of the quality control plan to ensure that materials are not mixed.
- PMIs can be missing as a result of a lack of quality control.
- Mixing the materials can occur during various phases of a project, including manufacturing, fabrication, and repair.
- A PMI is not limited to the base materials of pipes, valves, and vessels; it can also apply to welding, overlay cladding, and painting.
- In order to ensure compliance with NACE requirements regarding chemical compositions, PMI can be applied to materials intended for use in souring services.
- It has been developed an advanced PMI method to determine the mechanical strength values without damaging the material, including yield and tensile
- PMI is primarily applicable to alloy steels, but it can also be applied to carbon steel materials. As an example, PMI is applied to API 5L grade pipeline in order to determine its grade.
- In one project, PMI was applied to the TSA coating to ensure that its chemical composition was correct.
- In one study, the X-ray method of PMI was described as follows: The surface of the material is exposed to a brief beam of X-ray radiation from an X source. Every element in the metal emits secondary X-rays characteristic of its atoms during the test. A detector separates X-rays into categories of energy based on the intensity of their X-rays in each region.
- In a scrubber, SS321 was used instead of SS316L as a weld overlay and PMI was missed, resulting in sour corrosion cracking

There have been no studies to investigate missing PMI and its consequences in an offshore oil and gas project on industrial valves, as well as to develop a procedure for establishing PMI. Based on the gaps identified, the following points have been highlighted:

- An overview of valves used in an offshore project for which PMI was forgotten;
- Detailed analysis of the case study in which PMI for valves was missed on an offshore project;
- Establishment of a procedure for PMI establishment;

This study is motivated by the objective of focusing on PMI so as to prevent negative consequences of its absence, such as corrosion, which can be both costly and unattractive. A lack of PMI can result in the use of inferior materials for piping, valves, and pressure vessels, which can lead to the failure of these costly facilities. It is important to note that the cost of valve failure caused by corrosion and a lack of PMI is not limited to the cost of the valve itself. When some important valves in the plant fail, such as control valves, expensive equipment such as pressure vessels and reactors can be damaged or destroyed. There are some valves that are installed on the final product or lines which contribute to the overall production process of the final product. If the valve malfunctions, the plant will be shut down and production will be lost, which is much more costly than the cost of the valve itself. Additionally, failure of the valve could result in leakage from the valve, and many fluids in the oil and gas plant are toxic and flammable, including hydrocarbons (oil and gas). The leakage of flammable liquids can result in fires and explosions, which can result in the loss of human life and the pollution of the environment. Similarly, leakage of toxic fluids, such as those containing hydrogen sulfide, can result in human death. As a result of these series of severe negative events, engineering companies as well as operators may be fined and suffer loss of reputation.

To acknowledge the importance of PMI in oil and gas plants, including industrial valves as expensive and critical assets, the following contributions have been made to this study.

- The implementation of an approach to define a complete PMI procedure;
- Assuring the safety of humans and the environment through the implementation of PMI in an appropriate manner;
- Providing protection against fires, explosions, and other adverse events caused by corrosion of valves lacking PMI;
- Protecting expensive and essential valves from damage and failure;
- As a result, the company will avoid fines and reputational damage.

Research Aim and Objectives

This study aims to develop a suitable approach for developing PMI procedures for industrial valves in the oil and gas industry. In order to develop such an approach, a specific and detailed approach must be taken. In addition, a case study is discussed briefly in which the PMI has been forgotten for offshore valves and how the mitigation approach has been implemented. A number of objectives have been developed to fill the gaps identified in previous studies.

1. An overview of valves used in an offshore project for which PMI was not taken into account;
2. An analysis of a case study where PMI for valves was not performed on an offshore project;
3. Setting up a procedure for establishing a PMI for valves in an oil and gas project;

Figure 2 summarizes the research question, aim, and objectives.

Methods and Materials

There are two parts in this section: The first one is about handling check valves in an offshore project where PMI was not utilized, and the second one is about developing a PMI procedure for industrial valves in the oil and gas industry.

Valve PMI Missing Case Study

In this brief case study, we will discuss PMI being missing for dual-plate check valves in an offshore Norwegian project called Edvard Grieg (EG). The Edvard Grieg field is located in the North Sea 35 kilometers south of the Grane and Balder fields, and its water depth is 110 meters. EG jacket platform after installation is shown in Fig. 3. Dual-plate check valves are used to prevent the flow from returning [24]. Most of these valves were in 22Cr duplex materials, and it was required by the project specification to apply 50% PMI on the pressure containing (retaining) of the valves including dual plate valves. The most important pressure-retaining part of the dual-plate check valves is the body of the valve. Pressure-containing parts of the valve refer to the parts which failure to function leads to the leakage from the valve. The valve supplier missed PMI test on almost all of the valves on 22Cr duplex valves that should be tested. This was discovered when the valve supplier sent the PMI procedure and report to the contractor company. Based on the PMI procedure and report only three valves in 22Cr duplex were under PMI test while the test was missed. About 77 valves were estimated to have been missed by PMI. At that point, the valves were sent to the fabrication yard for installation. Most of these valves ranged in size from 3“ to 16”. Therefore, it was necessary to apply PMI to 50% of the valve bodies constructed from 22Cr duplex stainless steel. As a general rule, fabrication of piping systems, including valves, begins with large sizes and ends with small sizes. In this regard, it would be more effective to apply PMI to small size valves that had not yet been installed in order to avoid stopping and delaying the fabrication of large piping systems. Also, many of the 22Cr duplex valve bodies were coated with phenolic epoxy or TSA coatings, which required the coating to be removed from the area of the valve body that was to undergo PMI testing and again repaired or touched up. Lastly, the PMI test was performed on the required valve bodies and the coating was repaired. Based on the PMI tests, 22Cr duplex material was selected for all the tested valves.

PMI Procedure

This procedure prescribes the requirements for positive material identification (PMI) for valves to verify that alloy materials are of acceptable chemical composition independent of any certificate and marking that may exist, and to assure that the correct alloy materials are used at the places intended. There are several sections in a PMI procedure, including personnel qualification, definition and calibration of equipment and tools, preparation for the test, extent of the test, parts extends to be tested, acceptance

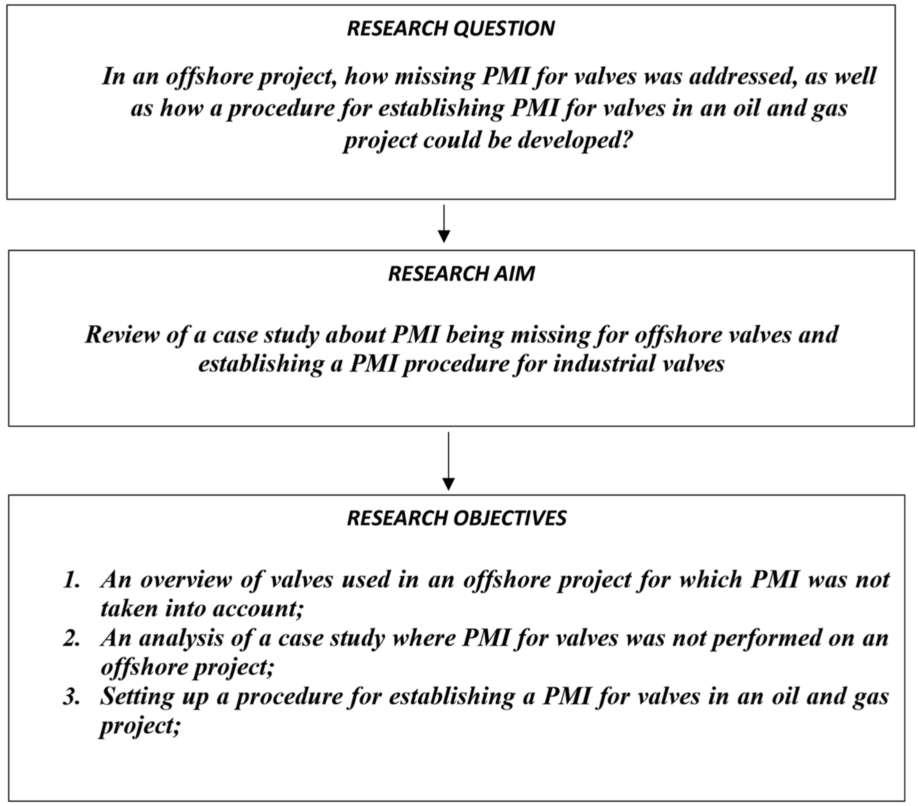

Fig. 2 Formulation and summarization of the research questions, aim and objectives

Fig. 3 Edvard Grieg Field after Jacket Installation

criteria, rejection procedure, reporting, marking and color coding, and safety.

Personnel Qualification

PMI personnel should have a comprehensive understanding of the PMI requirements. In order to verify the nominal compositions of the alloy pressure-containing components, trained personnel should operate the PMI tool according to the approved procedure and interpret and record the results. It is essential that the operators are qualified to operate equipment on a representative sample of the alloy materials prior to the start of PMI, that is known as assessments of the operator performance. Before commencing work, evidence of training, qualifications, and experience must be provided for review and approval of the client. Records of personnel examinations will be maintained in accordance with the project requirements.

PMI Tools Calibration

The PMI Personnel shall calibrate and/or verify the performance of the test equipment in accordance with the valve manufacturer's recommendations. Generally, equipment should be calibrated periodically (e.g., every six months) using an approved procedure by PMI personnel or by the manufacturer of the equipment. The inspector may request re-calibration of the instrument (PMI device) after a short period of time if he is concerned about the measurement accuracy. In addition, when readings are abnormal due to severe temperature fluctuations or any other adverse conditions on the job site, the equipment should always be re-calibrated.

It is possible to measure PMI using a variety of instruments, such as the SPECTROTEST and XRF analyzers. X-ray fluorescence (XRF) spectrometers are X-ray instruments used for routine, relatively non-destructive chemical analyses [25]. Through the use of various X-rays emitted by various elements of a component that has been subjected to PMI testing, the device has the ability to determine the chemical composition of the component. SPECTROTEST is a portable metal analyzer that is based on optical emission spectroscopy as the principle of analysis.

Extend of Test

Most procedures only require PMI testing on pressure-containing parts of valves, such as the body and bonnet. However, since the trim or internals of the valve are in contact with fluid, they must generally exhibit higher corrosion resistance. It is important to note, however, that failure of valve internals, in contrast to failure of body and bonnet due to corrosion and the absence of PMIs, does not result in external leakage from the valves. Typically, PMI is performed on alloys such as austenitic stainless steels, duplex and super duplex stainless steels, nickel alloys, and 6MO and super-austenitic materials. It has been experienced in the EG project to apply 20% PMI on SS316, 50% PMI on 22Cr duplex stainless steel, 100% PMI on super duplex valves in corrosive sea water and 50% PMI on super duplex in other services other than corrosive sea water, 100% PMI on nickel alloys, 6MO and super-austenitic body valves. In the EG project, there were no requirements for PMI for titanium materials. The provided data pertain to PMI tests conducted in an offshore oil and gas plant where corrosion-resistant alloys (CRAs) were extensively used. Onshore refineries and petrochemical plants typically use lower-cost materials such as carbon steel. It is therefore more important for offshore valves to comply with the requirements of PMI. The materials used in onshore valves consist primarily of austenitic stainless steel and 22Cr duplex and nickel alloys, which are subject to PMI, and these materials can also be tested to the same extent as offshore valves. However, it is worth noting that in some PMI procedures where the failure of material as a result of mixing and PMI missing will have a greater impact on the product, the extent of PMI should be increased to 100 percent for all types of alloy steels mentioned above. Another possible extension of PMI testing is to determine the percentage (e.g., 50% or 100%) of each material's heat number. The present author proposes applying PMI testing to titanium and nickel aluminum bronze (NAB) materials as well as other alloys. The two types of materials discussed above are used in corrosive sea water services [26–28]. In spite of the fact that corrosion and leakage from titanium and NAB lead to the leakage of sea water, which is neither flammable nor toxic, the damage to the property would be costly. Furthermore, sea water can be used as a fire extinguishing medium provided that it is supplied in sufficient quantities (capacity) and at sufficient pressure to effectively extinguish the fire.

Typically, valve manufacturers and/or suppliers that supply valve parts to valve manufacturers conduct PMI tests on valves. However, PMI on the welds is typically performed by the fabricator in the construction yard. In the case of valves, some are welded to piping through extended pup pieces that are subject to PMI testing. Furthermore, weld overlays can be applied to the valve internals or inside the valve body and bonnet to prevent erosion and corrosion. As well as the filler welds, weld overlays may also be subject to PMI testing [29]. A PMI test must be conducted on the weld material in the same manner as the adjacent base metal.

Test Preparation

The PMI tool should be calibrated prior to the test, as explained previously. Prior to testing, all extraneous materials, such as scale, rust, dirt, and grease, should be removed from the metallic surface. Light grinding should be performed on all surfaces to be examined in order to ensure proper contact between the surfaces. With a mini-disk grinder, ferritic base materials and weld areas can be prepared for testing; however, excessive removal may reduce the effective material thickness beyond acceptable limits. It is essential to inspect the electrode for cleanliness and for a sharp tip; if the electrode is not clean or sharp, it should be replaced or cleaned properly.

Acceptance Criteria

The number of alloying elements specified in the material specification and the relevant material standard shall be present in the materials. It is necessary to take into account the effects of dilution from the different base metals as well as the filler metal when determining the nominal composition of dissimilar metal alloy welds (other than weld overlays). In the case of weld overlays, the chemistry on the surface of the overlays shall be equivalent to the filler metal composition requirements unless other requirements are specified.

Rejection Criteria

In the event that the PMI testing results fall outside the acceptable range, PMI is rejected. In the event that a component or weld is found to be unacceptable, it should be replaced and the replacement shall be alloy verified according to this procedure. It is necessary to establish procedures to ensure that rejected components are properly identified and segregated so that they cannot be re-used.

Reporting

It is recommended that the report includes the following information at a minimum: Report number, Client/Contractor name, Project, Location, Material under Examination, Identification of Materials for all components and welds, Material Verification, Results, Name and Signature of the Operator with the date of testing. The PMI test report should be reviewed prior to any post-weld heat treatment, painting, insulation, or hydrotest. Prior to final acceptance, the PMI Report will be reviewed by the client inspector.

Marking and Color Coding

The letters 'PMI' should be painted using a water-insoluble material containing no hazardous substances, such as metallic pigments, lead, zinc, sulfur, mercury, chlorides or other halogens, which may attack or adversely affect austenitic or nickel alloy steels at ambient or elevated temperatures.

Result

The result section contains a list of dual-plate check valves in the EG project (Table 1), as well as their size, pressure class, and quantity. This section also specifies which valves were not covered by PMI as well as the scope of the PMI test performed on the missing valves. Further, the results of PMI tests and their comparison with the required chemical composition are presented.

There were a total of 80 valves listed in the table with 22Cr duplex bodies. According to the PMI procedure for the EG project, 50 percent of the duplex stainless steel valves must be tested on their pressure-containing parts, which is the body of the valve in this case. As a result, PMI tests must be conducted on 40 valves, although only three valves in the 4 inch size and class 150 have already been tested. As a result, PMI must be performed on 37 remaining valves during fabrication, which are selected from smaller size valves for the reasons explained above. Consequently, PMI was conducted on the valve bodies of 23 pieces of 3" valves CL150, 300 and 600, 3 pieces of 4" valves CL300, 5 pieces of 6" valves CL150, 300, and 1500, and 6 pieces of 8" and class 1500 valves. There is a duplex body selection of the valves in accordance with American Society for Testing and Materials (ASTM) A890 Gr.4A (22Cr duplex cast material) [30]. Table 2 provides the PMI test results for each group of valves and a comparison with ASTM standards.

Figures 1 and 4 show how PMI test is applied on couple of valves in 22Cr duplex material in EG project.

Table 1 This is a list of dual-plate check valves in 22Cr duplex where PMI was not present for most of them

Type of valve	Size	Pressure class	Body material	Quantity	PMI performed
Dual-plate check valve	16"	1500	22Cr duplex	1	No
Dual-plate check valve	14"	600	22Cr duplex	1	No
Dual-plate check valve	12"	150	22Cr duplex	1	No
Dual-plate check valve	12"	300	22Cr duplex	1	No
Dual-plate check valve	12"	1500	22Cr duplex	1	No
Dual-plate check valve	10"	150	22Cr duplex	3	No
Dual-plate check valve	10"	150	22Cr duplex	2	No
Dual-plate check valve	8"	150	22Cr duplex	4	No
Dual-plate check valve	8"	300	22Cr duplex	1	No
Dual-plate check valve	8"	1500	22Cr duplex	32	No
Dual-plate check valve	6"	150	22Cr duplex	3	No
Dual-plate check valve	6"	300	22Cr duplex	1	No
Dual-plate check valve	6"	1500	22Cr duplex	1	No
Dual-plate check valve	4"	150	22Cr duplex	3	Yes
Dual-plate check valve	4"	300	22Cr duplex	2	No
Dual-plate check valve	3"	150	22Cr duplex	6	No
Dual-plate check valve	3"	300	22Cr duplex	13	No
Dual-plate check valve	3"	600	22Cr duplex	4	No

Discussion

The result shows all 22Cr stainless steel dual-plate check valves including those for which PMI is missing. Based on the results, PMI is not available for 77 out of 80 valves. In addition, the results show how to select the required valves for PMI testing. PMI testing is conducted on smaller valves since larger valves were installed on the piping system during fabrication; therefore, PMI testing on larger valves would result in the fabrication being halted. The second part of the result section presents the results of PMI testing in the form of chemical composition measurements of the valve bodies, which are compared with the chemical

Table 2 PMI test result for 22Cr duplex dual-plate check valves

Valve	Carbon	Manganese	Silicon	Phosphorous	Sulfur	Chromium	Nickel	Molybdenum
3” duplex stainless steel CL150 (6 pieces)	0.03	1.5	1	0.039	0.02	22	5	3
3” duplex stainless steel CL300 (13 pieces)	0.029	1.5	1	0.04	0.015	21.5	5	3
3” duplex stainless steel CL600 (4 pieces)	0.03	1.49	1	0.035	0.018	21.5	5	2.7
4” duplex stainless steel CL300 (2 pieces)	0.027	1.48	0.99	0.039	0.019	22	4.6	3
6” duplex stainless steel CL150 (3pieces)	0.03	1.5	1	0.04	0.020	23	5.1	2.5
6” duplex stainless steel CL300 (1 pieces)	0.03	1.5	1	0.04	0.019	22.5	5	3
6” duplex stainless steel CL1500 (1 pieces)	0.029	1.48	1	0.04	0.020	21.5	5	3
8” duplex stainless steel CL1500 (6 pieces)	0.03	1.5	1	0.04	0.020	21	5	3.5
ASTM A890 4A	Max. 0.03	Max. 1.5	Max. 1.0	Max 0.04	Max 0.020	21-23.5	4.5-6.5	2.5-3.5
Result	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept

Fig. 4 PMI test on a 22Cr duplex gate valve in EG project

composition in the relevant ASTM standard. Results are important since they provide an overview of the scope of PMI testing on specific valves, as well as identifying the chemical composition of the valve bodies in order to verify compliance with international standards. Furthermore, PMI testing is important for ensuring that the correct material is selected for the valve bodies in this case (pressure-containing parts). If the valve body is constructed from carbon steel or austenitic stainless steel rather than 22Cr duplex, severe corrosion damage will result. If the valve is coated, it is likely that choosing carbon steel over 22Cr duplex will not result in external corrosion. The majority of these 22Cr duplex valves are used in environments containing significant amounts of carbon dioxide, which can cause sweet corrosion (carbon dioxide corrosion) in carbon steel [31–33]. Carbon dioxide is a form of metal loss that reduces the thickness of carbon steel materials as corrosion-resistant alloys (CRAs). In contrast, duplex stainless steel is a type of corrosion-resistant alloy that is resistant to carbon dioxide corrosion. As a result of not coating the duplex valve, and choosing carbon steel rather than duplex stainless steel, the valve is at risk of severe corrosion, such as rusting and pitting [34]. When austenitic stainless steel is used for the valve body instead of 22Cr duplex, and the valve body is coated, as with carbon steel, no external corrosion occurs. Otherwise, austenitic stainless steel could be corroded externally in the offshore environment as a result of pitting and chloride stress cracking corrosion (CLSCC) [35]. A unique feature of the case study and its results is that no previous studies have focused on PMI for industrial valves. Further, the results and the case study are consistent with the research’s intended purpose and objectives. These results do not cover PMI tests for other valves than dual-plate check valves and other materials than 22Cr duplex which are subject to PMI tests. The same method can, however, be used to determine the extension of PMI testing to other types of valves and other materials. Moreover, the result does not verify the internal materials of the valve since PMI is only specified for the body as a pressure-containing part. In addition, it should be noted that failure of valve internals due to corrosion or material mismatches may result in internal leaks. According to the present author, PMI testing should be extended to the valve internals in order to minimize the risk of valve internals failing due to material mismatches and corrosion. Based on the data in Table 2, we are able to understand how PMI’s method can show different chemical compositions and how the chemical composition extension can be compared with the values in the standard. It is important to note that in some cases, project specifications may set even stricter limits on the chemical compositions than the standard, so in those cases, PMI report results should be compared with chemical composition values in the project specification rather than the standard.

Conclusion

As an integral part of a piping system, valves are used primarily for controlling the flow of fluid. A valve failure caused by corrosion is a negative adverse event with a number of negative consequences. Material mismatch is one of the causes of valve corrosion. As part of the project, PMI tests are conducted to verify the material of valves, pipes, joints, and pressure vessels. There has been no previous study on PMI testing of valves. The purpose of this study is to focus on PMI in order to prevent negative consequences of its absence, such as corrosion, which can both be costly and unattractive. This study seeks to develop a suitable approach for developing PMI procedures for industrial valves in the oil and gas industry. A specific and detailed approach is required in order to develop such an approach. Also, a case study is discussed briefly in which the PMI has been forgotten for offshore valves and how the mitigation approach has been applied. The purpose of this case study is to discuss the absence of PMI for some dual-plate check valves in an offshore Norwegian project called Edvard Grieg (EG). A dual-plate check valve prevents the flow from returning. Several of these valves were constructed of 22Cr duplex material, and it was required by the project specifications that 50% PMI be applied to their pressure-retaining parts of the valves, including dual plate valves. A total of 80 dual-plate check valves with 22Cr duplex bodies. It is therefore necessary to conduct PMI tests on 40 valves, although only three valves of the 4 inch size and class 150 have already been tested. Therefore, PMI must be performed on 37 remaining valves during fabrication, which are selected from smaller valve sizes for the reasons outlined above. Thus, PMI was conducted on the valve bodies of 23 pieces of 3" valves CL150, 300 and 600, 3 pieces of 4" valves CL300, 5 pieces of 6" valves CL150, 300 and 1500, and 6 pieces of 8" valves and class 1500. According to the PMI results, all of the tested valves were manufactured from 22Cr duplex stainless steel.

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