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Common Defects and Treatment Measures for Pressure Vessels

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Abstract: Pressure vessels play a critical role in industrial production. However, their manufacturing, installation, and operation are influenced by numerous factors such as materials, processes, and environmental conditions, making them highly susceptible to defects that pose significant safety risks. This paper provides a detailed analysis of common defects arising during the manufacturing and installation stages, including welding imperfections, geometric dimensional deviations, and surface quality issues, along with targeted mitigation measures. Additionally, it discusses approaches for addressing defects that occur during the operational phase, such as corrosion and cracking. The study emphasizes the necessity of stringent quality control to ensure the safe operation of pressure vessels.

Keywords: Pressure Vessels; Common Defects; Treatment Measures

Introduction

Pressure vessels, as special equipment widely used in industrial production, are highly susceptible to various defects during manufacturing, installation, and operation due to factors such as materials, processes, and environmental conditions. These defects act like hidden "time bombs," posing serious threats to personnel safety and property security. Therefore, gaining an in-depth understanding of common defects in pressure vessels and mastering effective treatment measures are crucial for ensuring their safe operation. This article will elaborate on the common types of defects that occur during the manufacturing and installation stages as well as the operational phase of pressure vessels, and propose corresponding solutions.

1. Overview of Common Defects in Pressure Vessels

Pressure vessels, as special equipment widely used in industrial production, are highly susceptible to various defects during manufacturing, installation, and operation due to the interplay of factors such as materials, processes, and environmental conditions. These defects act like "time bombs" hidden within the vessels, posing serious threats to human life and property safety. In the manufacturing process, welding is a critical stage and a high-risk area for defects. Improper selection of welding parameters—such as excessive current, high voltage, or overly fast welding speed—can result in poor weld formation, leading to defects like undercut, lack of fusion, and incomplete penetration^[1]. Undercut reduces the effective cross-sectional area of the base metal, diminishing its load-



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bearing capacity, while lack of fusion and incomplete penetration create gaps in the weld, becoming sources of stress concentration and crack initiation. Material quality issues cannot be overlooked either; inherent defects such as laminations or porosity in the material can compromise the overall strength and toughness of the vessel. The installation phase may also introduce defects. Failure to strictly adhere to specifications during installation—such as uneven foundations or improper support structures—can subject the vessel to additional stress, causing local deformation. Collisions or scratches during installation may damage the vessel's surface and the anti-corrosion coating, and accelerate corrosion. During operation, pressure vessels are continuously exposed to harsh conditions, including high temperature, high pressure, and corrosive environments. The internal medium may cause chemical or electrochemical corrosion on the vessel walls, gradually thinning them and reducing strength. Cyclic loading can lead to fatigue cracks, which may start as tiny defects but propagate over time, potentially resulting in vessel rupture. These common defects in pressure vessels, regardless of the stage at which they occur, can lead to severe consequences. Therefore, it is essential to prioritize quality control throughout the entire lifecycle of pressure vessels—from manufacturing and installation to operation—by strictly adhering to relevant standards and specifications, enhancing inspection and testing, and promptly identifying and addressing defects to ensure that pressure vessels remain in a safe and reliable operating condition.

2. Common Defects and Treatments During Manufacturing and Installation

2.1 Welding Defects

Welding is the core process in the manufacturing of pressure vessels, and the welding quality directly determines the overall performance of the vessel. However, various defects often occur during the actual welding process, significantly affecting the quality of the welded joint. Incomplete penetration is one of the more common welding defects, referring to the lack of complete fusion between the weld metal and the base metal, or between weld layers. This condition reduces the effective load-bearing area of the joint, thereby significantly weakening its strength. When subjected to pressure and loads, areas with incomplete penetration can easily become stress concentration zones, leading

to the initiation and propagation of cracks, which may ultimately result in vessel rupture. Lack of fusion occurs when the edges of the weld or between layers are not fully fused together, similarly creating stress concentration points, reducing the mechanical properties of the welded joint, and increasing the risk of vessel failure. Porosity refers to cavities formed within the weld when gases fail to escape in time during the welding process. The presence of porosity disrupts the continuity of the weld metal, reduces the effective cross-sectional area of the weld, and weakens its strength. Slag inclusions are non-metallic residues trapped in the weld, which hinder the plastic deformation of the weld metal, reduce the toughness and fatigue resistance of the weld, and pose a potential threat to the safe operation of the vessel. To address welding defects, non-destructive testing methods, such as radiographic testing and ultrasonic testing, should first be used to accurately determine the location and severity of the defects. For defects like incomplete penetration and lack of fusion, methods such as carbon arc gouging or grinding with a grinding wheel are generally employed to remove the defective areas thoroughly before re-welding. During re-welding, welding parameters must be strictly adjusted to ensure quality. For porosity and slag inclusions, if the number is small and the size is minor, the defective areas can be ground smooth and then repaired by welding. If the defects are numerous or large in size, it is necessary to redevelop the welding procedure, optimizing factors such as welding materials, current, voltage, and speed to prevent the recurrence of defects.

2.2 Geometric Dimension Deviation

In the manufacturing process of pressure vessels, geometric dimensional deviations are also relatively common issues. These include excessive straightness deviation of the cylinder, oversized ovality, and exceeding the misalignment tolerance between the head and the cylinder. Excessive straightness deviation of the cylinder can affect the overall stability and installation accuracy of the pressure vessel. If the straightness deviation is too large, it may prevent the vessel from being properly positioned during installation, increasing the difficulty and cost of installation^[2]. During the operation of the vessel, excessive straightness deviation can also lead to localized stress concentration, reducing the fatigue life of the vessel. Oversized ovality is equally concerning, as

excessive ovality can cause uneven distribution of local stresses when the vessel is subjected to internal pressure, leading to localized stress concentration and increasing the risk of vessel rupture. Exceeding the misalignment tolerance between the head and the cylinder can reduce the strength and sealing performance of the joint. Excessive misalignment alters the stress distribution at the joint, making it prone to cracking under pressure, and can also compromise the sealing performance of the vessel, leading to medium leakage. For geometric dimensional deviations, appropriate corrective measures should be taken based on the specific situation. For cylinders with excessive straightness deviation, flame straightening or mechanical straightening methods can be employed. Flame straightening utilizes localized plastic deformation induced by flame heating to restore the cylinder to the correct straightness, while mechanical straightening involves applying external mechanical force to correct the cylinder. When ovality is excessive, the forming process should be inspected for potential issues, and if necessary, the forming operation should be repeated to ensure the ovality of the cylinder meets design requirements. For cases where the misalignment between the head and the cylinder exceeds the tolerance, if the deviation is minor, grinding and correction methods can be used to smooth out the misaligned area; if the deviation is significant, rework involving reassembly and welding is required.

2.3 Surface Quality Defects

Surface quality defects in pressure vessels include cracks, scratches, pits, etc. Cracks are the most serious surface quality defects and may be caused by material defects, improper welding processes, stress concentration, and other factors. The presence of cracks significantly reduces the strength and toughness of the vessel. Under pressure and load, cracks can rapidly propagate, eventually leading to vessel rupture and causing serious safety accidents. Although scratches and pits are less hazardous compared to cracks, they also reduce the surface strength and corrosion resistance of the vessel. Scratches and pits tend to accumulate corrosive media, accelerating the corrosion process and shortening the service life of the vessel. Once surface cracks are detected, the pressure vessel should be immediately taken out of service, and non-destructive testing methods should be used to accurately determine the extent and depth of the cracks. For cracks, repair by excavation or replacement

of components is generally adopted. During excavation repair, the welding quality of the repaired area must be strictly ensured in accordance with process requirements. For scratches and pits, if the depth does not exceed the specified value and does not affect the normal use of the vessel, grinding can be applied to smooth the area and eliminate stress concentration. If the depth exceeds the specified value, repair welding or component replacement is necessary to ensure the surface quality and safety performance of the vessel.

3. Common Defects and Treatments During the Usage Phase

3.1 Corrosion Defects

Corrosion is one of the most common defects in pressure vessels during operation. Due to the wide variety of media contained in these vessels, often with diverse chemical properties, and the combined effects of temperature, pressure, and other conditions, various types of corrosion can easily occur. Common forms of corrosion include uniform corrosion, pitting corrosion, intergranular corrosion, and stress corrosion. Uniform corrosion refers to the even distribution of corrosion across the inner surface of the vessel, leading to a uniform thinning of the wall thickness. Although this type of corrosion progresses relatively slowly, it continuously reduces the vessel's load-bearing capacity. If not addressed promptly, it may ultimately cause the vessel to rupture due to insufficient strength^[3]. Pitting corrosion, on the other hand, forms small pit-like cavities on localized areas of the vessel's surface. These pits can become stress concentration points, potentially initiating and propagating cracks, thereby posing a serious threat to the vessel's safety. Intergranular corrosion occurs along the boundaries of metal grains, significantly weakening the bonding force between grains. This results in material embrittlement, making the vessel prone to brittle fracture under load. Stress corrosion is a form of corrosion that occurs under the combined action of tensile stress and specific corrosive media. It is highly hazardous and often leads to sudden vessel failure without obvious warning signs. To address corrosion defects, the first step is to accurately measure the remaining wall thickness of the vessel and comprehensively assess whether it can continue to be used based on the extent of corrosion and remaining service life. For uniform corrosion, if the remaining

wall thickness meets design requirements and relevant standards, measures such as reducing operating pressure can be implemented, along with shortening inspection intervals and enhancing monitoring of corrosion conditions. If the remaining wall thickness does not meet requirements, the vessel must be taken out of service for repair or replacement. For pitting corrosion, if the affected area is small and shallow, the corroded region can be ground clean and repaired by welding. If the pitting is extensive or deep, the corroded components should be replaced. Due to the severe hazards associated with intergranular corrosion and stress corrosion, continued use is generally not advisable. A comprehensive safety assessment should be conducted, and if necessary, the entire vessel should be replaced.

3.2 Crack Defects

During the use of pressure vessels, cracks are primarily caused by factors such as stress concentration, corrosion, and fatigue. Cracks may appear in the weld seam, heat-affected zone, or base metal. Weld cracks are usually due to poor welding quality, such as improper selection of welding process parameters or non-compliant welding materials, leading to defects in the weld seam that initiate cracks under stress. Alternatively, cracks may form in the weld area due to significant stress concentration during the vessel's operation. Heat-affected zone cracks are related to changes in material properties and stress conditions in that region. During welding, the microstructure and properties of the heat-affected zone can alter, and if the stress distribution is unreasonable, cracks are prone to occur. Base metal cracks may result from inherent material defects, such as inclusions or pores, which gradually propagate under the combined action of stress and corrosive media over long-term use. They may also arise from fatigue cracks in the base metal due to the vessel enduring cyclic loads over time^[4]. When cracks are detected, the first step is to accurately determine their location, length, and depth. For shallow cracks, grinding can be used to remove them, with the ground area smoothed to eliminate stress concentration. For deep cracks, carbon arc gouging or grinding wheels are employed to excavate the crack down to its root, followed by repair welding. Before repair welding, a reasonable welding procedure must be established, selecting appropriate welding materials

and parameters to ensure the quality of the repair. After repair welding, non-destructive testing, such as radiographic or ultrasonic testing, should be conducted to check for defects in the repaired area. Additionally, heat treatment is necessary to relieve welding stresses and improve the mechanical properties of the repaired section.

3.3 Deformation Defects

Deformation of pressure vessels includes various forms such as local dents, bulges, and overall expansion. Local dents are usually caused by external impact or compression on the vessel. If the dent is minor and does not affect the strength or sealing performance of the vessel, it generally requires no treatment. However, if the dent is significant, it may alter the stress distribution and compromise the vessel's safety, necessitating repair by cutting out the affected area or replacing components. Bulges often result from corrosion-induced thinning of the vessel wall due to the medium inside or localized overheating that alters the material properties. For bulge defects, the root cause must first be identified. If caused by corrosion, the appropriate treatment method for corrosion defects, as described above, should be applied based on the severity. If caused by localized overheating, the material's property changes need to be assessed, and corresponding measures, such as material replacement or heat treatment, should be taken. Overall expansion occurs when the vessel yields under internal pressure due to overpressure operation or insufficient wall thickness. Vessels exhibiting overall expansion are generally not suitable for continued use and require strength verification and comprehensive safety assessment. The decision to replace the vessel should be based on the evaluation results.

3.4 Material Degradation Defects

Pressure vessels may experience material degradation due to various factors during long-term operation. Under high-temperature conditions, the grains of metallic materials grow, the microstructure changes, and mechanical properties decline. For example, in carbon steel vessels exposed to prolonged high temperatures, spheroidization of pearlite intensifies, leading to reduced hardness and strength. The chemical effects of the medium inside the vessel cannot be overlooked either—oxidizing, reducing, or corrosive

media can react with the metal, altering its chemical composition and microstructure. Radiation, fatigue loads, and other factors can also deteriorate material performance. After material degradation, the vessel's appearance may show no obvious changes, but alterations in performance can be detected through inspections. Hardness testing can provide a preliminary assessment of whether degradation has occurred; a decrease in hardness may signal deterioration. In tensile tests, reductions in yield strength, tensile strength, and elongation indicate a decline in material plasticity. In impact tests, a decrease in impact toughness suggests the material is more prone to brittle fracture under impact loads ^[5]. To address material degradation, detection and evaluation should be prioritized. Regular inspections—such as hardness testing, chemical composition analysis, and mechanical property tests—should be conducted on pressure vessels to accurately assess the extent of degradation and evaluate remaining service life in conjunction with operating conditions and usage requirements. For vessels with mild degradation and sufficient remaining service life, restoration measures may be applied. For instance, carbon steel vessels affected by high-temperature pearlite spheroidization can undergo normalizing heat treatment to partially restore performance; materials subjected to medium corrosion can be sprayed with anti-corrosion coatings to prevent further deterioration. If material degradation is severe, the remaining service life is insufficient for continued use, or restoration costs are prohibitively high, the vessel or severely affected components should be promptly replaced to ensure the safe operation of the pressure vessel.

Conclusion

Pressure vessels play an indispensable role in industrial production, and their safe operation is of critical importance. From manufacturing and installation to the operational phase, the emergence of various types of defects serves as a constant reminder of the need to prioritize quality control. By accurately identifying defect types and implementing timely and effective measures, the risks associated with these defects can be minimized. In the future, with continuous technological advancements, we should persistently optimize detection and treatment methods to provide stronger safeguards for the safe and stable operation of pressure vessels.

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