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METHODS FOR TESTING AND QUALITY CONTROL OF MATERIALS IN OIL AND GAS FACILITY CONSTRUCTION

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Abstract
Methods of testing and quality control of materials in the construction of oil and gas industry facilities play a key role in ensuring the safety, reliability, and durability of structures. Both destructive and non-destructive methods are used in construction, each of which has its advantages and limitations. Destructive methods allow a deeper study of the mechanical properties of materials, but their use leads to damage to samples. At the same time, non-destructive methods such as ultrasound diagnostics and laser scanning ensure monitoring of the condition of objects without destroying their integrity. Hybrid and combined test methods allow for more accurate results, which is critically important for the oil and gas industry. The use of modern technologies in the field of quality control significantly reduces operational risks and increases the service life of facilities.

Keywords Quality control, destructive methods, non-destructive methods, ultrasound diagnostics, laser scanning, oil and gas industry, operational risks, durability.

INTRODUCTION

Quality control of materials in the construction of oil and gas industry facilities is one of the most important components in ensuring the safety and durability of infrastructure. Given that the oil and gas sector is a critically important segment of the global economy, any defects or shortcomings in construction materials can lead to catastrophic consequences for both economic stability and environmental safety. Therefore, the implementation of reliable and accurate testing and quality control methods is a mandatory requirement in this field.

The relevance is driven by the increased demands for the reliability and safety of oil and gas infrastructure in the context of the global economy's growing dependence on energy resources. With the increasing intensity of the operation of such facilities as drilling platforms, pipelines, and processing plants, it is essential not only to detect defects promptly but also to predict their occurrence. This minimizes the risk of accidents and extends the service life of structures. Modern testing and quality control methods, such as ultrasonic diagnostics and laser scanning, make it possible to assess the condition of materials without damaging them, significantly improving the effectiveness of preventive measures.

This work aims to study the methods of testing and quality control of construction materials used in the construction of oil and gas industry facilities, as well as to evaluate their effectiveness in the context of ensuring the safety and durability of such facilities.

1. Classification of Testing Methods for

Construction Materials

The oil and gas industry forms the foundation of the modern world and plays a significant role in shaping the global economy. Daily oil production reaches impressive volumes of approximately 100 million barrels, highlighting the scale and widespread importance of this resource. The industry's primary activity is the processing of crude oil extracted from various fields worldwide, which undergoes a complex transformation process [1].

Currently, several testing methods exist, which can be divided into two main categories: destructive and non-destructive methods. Each category includes various technologies and approaches applied depending on the specific material and testing objectives.

Destructive testing methods involve subjecting the material to external forces until it fails or is destroyed. These methods provide precise data on the strength and mechanical properties of the material, but they result in damage, rendering the material unusable. The application of destructive methods is limited to situations where full knowledge of the material's properties is required, to justify its destruction. Table 1 describes the main methods of material testing within the framework of destructive methods.

Table 1. The main methods of testing materials in the framework of destructive methods [1].

Method	Description
Compression Testing	Determines the maximum load a material can withstand before failure. Used to assess the strength of concrete, metals, and other solid materials.
Tensile Testing	Evaluates the material's ability to withstand elongation under axial load. Determines the tensile strength and elongation limit before rupture.
Bending Testing	Used to assess the strength of materials under bending loads. Helps identify the flexibility limit and resistance to deformation.

Non-destructive testing methods, in turn, allow for diagnosing the condition of construction materials without damaging or compromising their integrity. These methods are particularly important for oil and gas industry facilities, where it is necessary to monitor the condition of structures during operation while avoiding downtime and additional costs. The application of Non-Destructive Testing (NDT) enables the timely detection of defects and the implementation of corrective measures.

The main non-destructive methods include:

- Ultrasonic testing: Ultrasonic waves are used to determine the internal structure of the material and identify defects such as cracks or voids.

- Radiographic methods: Applied for internal inspection of materials and structures, particularly metals, to detect cracks, corrosion, and other defects.

- Eddy current testing: Used for inspecting metal structures, especially pipelines, to detect cracks, corrosion, and thickness changes.

- Radiation control methods (gamma and neutron

radiography): Used to monitor the density and integrity of materials, particularly important for massive structures.

- Laser diagnostics: Used for highly accurate assessment of geometric parameters and deformation monitoring of structures.

- Thermography: Helps identify hidden defects, such as areas with insufficient thermal insulation or cracks, using infrared radiation.

Additionally, hybrid methods are emerging in scientific literature. These approaches compensate for the limitations of individual methods and provide a more accurate and comprehensive assessment of the condition of construction materials.

Examples of combined methods include:

- Ultrasound + Radiography: Combining these methods provides both surface and in-depth data on defects.

- Eddy currents + Thermography: This combination provides data on the magnetic properties of metal and thermal characteristics, which is especially important for monitoring pipelines and storage tanks.

Thus, testing methods for construction materials in the construction of oil and gas industry facilities play a crucial role in ensuring the reliability and durability of structures. The choice of a specific method or combination depends on the type of material, operating conditions, and safety requirements. Destructive methods provide precise data on mechanical properties, while non-destructive methods enable continuous monitoring and prevention of potential defects without compromising the integrity of structures [2].

2. Features of Non-Destructive Testing

Non-destructive testing (NDT) methods play a crucial role in assessing the condition of materials and components across a wide range of industries, from aerospace to oil and gas. Their primary advantage lies in the ability to detect defects and integrity issues without damaging or destroying the object being inspected.

The significance of these methods is particularly evident in ensuring the safety and durability of critical infrastructure, including pipelines, bridges, buildings, aircraft, and nuclear power plants. The skilled application of various non-destructive testing methods enhances the reliability of equipment operation and helps prevent accidents.

Non-destructive testing involves the use of technologies to diagnose the quality and condition of an object without causing damage. It is widely used in industries such as manufacturing, construction, aerospace, and oil and gas, where safety and economic efficiency are priority factors. Table 2 outlines the possibilities of applying non-destructive testing methods in various industries.

Table 2. The possibilities of using the non-destructive testing method in various industries [3].

Industry	Application of NDT
Oil and Gas	Quality control of pipelines, tanks, and other system components. Helps detect external and internal defects, including corrosion and mechanical damage, ensuring operational safety.

Aerospace	Inspection of structural elements of aircraft, such as wings and turbine blades, for hidden cracks, preventing accidents and breakdowns.
Manufacturing	NDT helps control the quality of raw materials and finished products, detecting defects at early stages, and reducing the risk of producing defective or substandard goods.
Nuclear Energy	NDT ensures the safety of critical components such as reactor vessels and pipelines by assessing their reliability throughout the operational lifecycle, preventing accidents.
Construction	Used to monitor the quality of buildings, bridges, and other structures, identifying cracks, voids, and other defects that may affect the safety and integrity of the structures.

Control in the oil and gas industry, in turn, holds particular significance, as inspection activities aim to ensure that products comply with established standards and regulations. This guarantees the safety of workers and the reliability of infrastructure. Inspections cover a wide range of components, including oil, fuel, and other hydrocarbons, whose compliance is confirmed by international standards. Table 3 presents quality control methods in the oil and gas industry.

Table 3. Quality control methods in the oil and gas industry [3].

Method	Description
Visual Inspection	The first and most economical method used to assess the condition of equipment. Allows for the quick detection of visible defects such as corrosion, cracks, or leaks.
Factory Equipment Inspection	A detailed analysis of equipment for malfunctions and compliance with operational specifications, helping to identify issues before operation begins.
Final Random Inspections	Conducted to assess product compliance with client requirements. Based on random tests, a quality report is generated before product acceptance.
Pre-shipment Inspections	Ensures the quality and safety of products before shipment. Random tests are conducted to confirm compliance with standards and technical requirements.
Acoustic Emission Testing	An innovative non-destructive testing method using acoustic waves to detect leaks or other structural issues such as cracks or defects.

In turn, when discussing the regulatory requirements and standards governing non-destructive testing (NDT), they play a crucial role in maintaining a unified approach to testing methodologies across various industries. Compliance with these standards ensures product

integrity and safety for both personnel and equipment.

International organizations that develop standards for non-destructive testing methods include:

- The American Society for Nondestructive Testing (ASNT),

- The American Society of Mechanical Engineers (ASME),

- The American Society for Testing and Materials (ASTM),

- The American Petroleum Institute (API),

- The Confederation of Nondestructive Testing (COFREND),

- CSA Group,

- The Canadian General Standards Board (CGSB).

The unified standards developed by these organizations promote the use of consistent criteria when testing various materials and products across different sectors of the economy.

The features of NDT in this field can be examined through several key aspects:

Thus, non-destructive testing in the oil and gas industry is an essential tool for ensuring safety, increasing the reliability of construction projects, and extending their service life. The use of modern diagnostic technologies and intelligent analysis systems allows for the timely detection of defects, significantly reducing operational risks in the oil and gas complex.

Comparing destructive and non-destructive testing methods, it can be noted that destructive testing involves physically altering or damaging the object to assess its characteristics. In contrast, non-destructive testing does not damage the object, making it preferable for evaluating expensive and rare materials.

Examples of destructive methods include macrosectioning, tensile testing, and bending tests. These methods allow for a detailed study of the material structure but destroy the tested samples, making their reuse impossible.

Non-destructive testing methods, such as ultrasonic diagnostics or radiographic testing, do not alter the material's structure, making them highly sought after in situations where it is necessary to preserve the object's integrity. This is particularly relevant when inspecting expensive or unique objects where minimizing damage is critically important.

The primary advantage of non-destructive testing is the ability to perform diagnostics without damaging the object. Additional benefits include:

- High efficiency: such methods allow for the quick and accurate detection of defects, significantly reducing testing time without sacrificing quality.

- Increased safety: the use of non-destructive methods eliminates the need for interaction with hazardous materials or tools, reducing the risk of incidents.

- Accuracy: modern technologies make it possible to detect defects invisible during a regular inspection, preventing equipment breakdowns or accidents.

- Economic benefit: early defect detection helps avoid the costs of replacing expensive equipment and reduces downtime.

- Accident prevention: regular inspections help identify potential problems promptly, greatly reducing the risk of breakdowns and accidents.

Non-destructive testing remains a key tool for ensuring the safety and durability of objects across a wide range of industries [4].

3. Examples of Applying Modern Testing Methods in the Oil and Gas Industry

Modern testing and quality control methods are widely used by international companies in the oil and gas industry to enhance the reliability of infrastructure and reduce operational risks. Computerized tomography (CT) and laser scanning diagnostics are critical technologies for detecting defects at early stages, which is particularly important for large-scale projects. Below are examples of the implementation of these methods by international companies.

ExxonMobil. The American corporation ExxonMobil actively uses computerized tomography to diagnose equipment at its refining and extraction facilities. At one of the company's key sites in Baytown, Texas, CT is used to inspect equipment such as heat exchangers and storage tanks. This technology allows for an accurate assessment of corrosion and other defects without disassembling the equipment, helping to maintain uninterrupted production and reduce the risk of accidents.

Shell. Shell has implemented laser scanning diagnostics to monitor the condition of its offshore facilities in the North Sea. Laser scanning helps create precise 3D models of drilling platforms, enabling specialists to track potential structural changes and plan maintenance work accordingly. This technology has proven particularly useful for platforms located in remote areas where access to physical inspections is limited. The use of laser diagnostics at Shell has significantly reduced downtime and improved operational reliability.

Chevron. Chevron, one of the world's largest energy companies, employs ultrasonic diagnostics in combination with laser scanning to monitor the condition of pipelines at its facilities in Canada. These methods allow the company to detect microcracks, weld defects, and other structural damage that may occur during operation. At its oil fields in Alberta, Chevron actively uses these methods to enhance the safety of oil and gas transportation in harsh environments, helping to mitigate the risk of accidents and leaks.

BP. The British oil and gas company BP uses computerized tomography for non-destructive equipment inspection at its processing plants and offshore platforms. On one of its major projects in the Persian Gulf, the company utilizes CT to perform detailed analysis of critical infrastructure components such as pumps and compressors. This helps to identify signs of wear early and prevent potential failures, ultimately reducing the risk of incidents and extending equipment life.

TotalEnergies. The French energy company TotalEnergies applies laser scanning at its facilities in Africa to create high-precision 3D models of drilling rigs and oil storage tanks. These models allow for a detailed analysis of structural conditions and early detection of potential defects, helping to reduce repair costs and avoid accidents. Laser scanning is also used during the modernization of older facilities, allowing for the integration of new technological solutions without the need for complete equipment dismantling [5].

Thus, leading international companies such as ExxonMobil, Shell, Chevron, BP, and TotalEnergies actively use modern quality control methods, including computerized tomography and laser diagnostics. These technologies provide a high degree of reliability for oil and gas industry facilities, reducing operational risks and improving the safety of production processes.

CONCLUSION

Testing and quality control methods for materials form the foundation for ensuring the reliability and safety of oil and gas industry facilities. Destructive methods provide precise data on the mechanical properties of materials, while non-destructive methods allow for continuous monitoring without compromising the integrity of structures. The integration of modern technologies, such as

ultrasonic diagnostics and laser scanning, not only helps identify potential defects but also prevents accidents. Thus, the proper application of control methods contributes to risk reduction, increased reliability, and extended operational life of facilities, which is a critical factor for successful operations in the oil and gas industry.

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