

# COMPREHENSIVE EVALUATION OF ROBOTIC STORAGE TANK BLASTING AND COATING TECHNOLOGY CAPABILITY

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## ABSTRACT

*The maintenance of storage tanks involves complex and labour-intensive processes, particularly in blasting and coating operations. Conventional methods often require extensive scaffolding, manual labour, and exposure to hazardous environments, leading to increased safety risks and higher operational costs. Moreover, conventional approaches are typically slower, which prolongs downtime and negatively impacts overall productivity. Robotic technology may offer a solution to the above issues. Robotic tank blasting and coating technology refers to the use of automated robotic systems to perform surface preparation and coating applications, typically complemented with manual methods. This paper explores the effectiveness of robotic technologies with the primary objective of assessing robotic ultra high-pressure water jetting (UHP WJ), robotic wet abrasive blasting (WAB), and robotic coating capability to achieve quality outcomes equivalent to or surpassing those of conventional methods while giving other benefits such as higher productivity and safety improvement. The results from the testing indicated that robotic technologies for surface preparation could meet the standards of blasting methods. The coating robot was able to apply coatings according to quality requirements, producing results comparable to those of conventional coating methods and demonstrating its effectiveness in delivering consistent, high-quality coating applications. By implementing the best practices outlined in this paper, robotic blasting and coating can become a viable alternative to conventional methods. The findings from this study support the broader adoption of robotic technology in the storage tank blasting and coating industries. The study recommends pilot projects to explore additional applications, understand the nuances of execution, and optimise the performance of these robotic technologies.*

**Keywords:** *Robotic wet abrasive blasting, robotic ultra high-pressure water jetting, robotic coating, robotic blasting and painting.*

## INTRODUCTION

### Objective

The primary objective of this evaluation is to validate the feasibility and effectiveness of robotic technology in maintaining industrial storage tanks, with a specific focus on robotic ultra high-pressure water jetting (UHP WJ), robotic wet abrasive blasting (WAB), and robotic coating applications. The study aims to assess whether these robotic technologies can achieve quality outcomes equivalent to or surpassing those of conventional methods while also providing additional benefits such as enhanced productivity and improved safety. By conducting a comprehensive evaluation, the study

seeks to validate the capability of robotic systems to address the challenges associated with traditional manual labour methods, including safety risks, prolonged downtime, and operational inefficiencies. The findings from this study support the broader adoption of robotic technology in storage tank blasting and coating, recommending pilot projects to explore further applications, understand execution nuances, and optimise the performance of these robotic technologies.

**Pain Point**

Industrial storage tanks play a critical role in various sectors, including oil and gas, chemical processing, and water treatment. Over time, these tanks are subjected to harsh environmental conditions and operational demands, leading to deterioration and corrosion of their structural integrity. Consequently, tank maintenance is essential to maintain optimal tank performance. Conventional methods, which involve manual labour for tasks such as blasting and coating, present inherent safety risks to workers.

The conventional method of abrasive blasting involves the use of abrasive media propelled at high velocity onto the tank surface to achieve the desired cleaning and profiling results [1]. While effective, conventional abrasive blasting presents several challenges, including dust emissions and substrate damage and poses safety risks to workers.

Scaffolding structures are erected around the tank periphery to provide access to workers for blasting and coating works, introducing additional safety hazards, such as the risk of falling objects, falls from heights, and structural instability. Furthermore, scaffolding erection is time-consuming and labour-intensive and adds complexity to tank refurbishment.

Prolonged tank downtime emerges as another critical concern, particularly for industries that rely on continuous storage and processing operations. The cessation of tank functionality for refurbishment purposes results in significant production losses, revenue impacts, and logistical complexities. Extended downtime disrupts supply chains, prolongs project timeliness, and diminishes customer satisfaction.

**Robotic Technology As a Potential Solution**

As industries grapple with the challenges inherent in conventional methods of tank maintenance, there is a growing recognition of robotic technology as a potential solution to revolutionise these operations. Robotic technology promises to address key pain points such as safety concerns, prolonged downtime, and complexities associated with scaffolding and dust emissions. By automating tasks such as blasting and coating, robots can effectively minimise worker exposure to hazardous environments while enhancing productivity, efficiency, and reliability in refurbishment processes.

**STANDARDS IN SURFACE PREPARATION AND COMPARISON OF VARIOUS SURFACES**

**Preparation Methods**

The effectiveness of protective coatings when applied to steel substrates is affected by the state of the steel surface prior to coating. The primary determinants recognised to impact this efficacy include: 1) the presence of rust, mill scale, and previous coatings; 2) the existence of contaminants, including salts, dust, oils, and greases; and 3) the degree of surface roughness.

This study covers two surface preparation methods: Ultra High-Pressure Water Jetting (UHP WJ) and Wet Abrasive Blasting (WAB).

**UHP WJ**

UHPWJ uses water pressure above 210 MPa (30,000 psi) to remove rust, old coating, and water-soluble salts from surfaces, preparing them for subsequent coating applications. Unlike abrasive blasting, water jetting lacks the capacity to generate a roughness profile on metallic substrates. Consequently, its application is primarily suited for maintenance, targeting areas with intact coatings utilising available profiles from previous applications. Table 1 lists four definitions of surface cleanliness in terms of visible contaminants, and the surface shall be prepared to one of these four visual conditions before coating.

**WAB**

WAB involves the introduction of water into the abrasive blasting process, resulting in a slurry. This process entails several methodologies as follows:

1. Injection of water into the abrasive stream either internally or externally as the abrasive stream exits the blast nozzle;
2. Injection of abrasive into pressurised water; or
3. Use an abrasive slurry under pressure to achieve the specified WAB degree of cleanliness.

This process is suitable for both new construction and maintenance projects, offering the advantage of creating a surface profile alongside cleaning. Table 2 lists definitions for the five degrees of WAB cleaning.

**Table 1** NACE No. 5/SSPC-SP 12 visual surface preparation definitions for UHP WJ [2]

Term	Definition
<b>WJ-1</b>	<b>Clean to Bare Substrate</b> A WJ-1 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible rust, previous coatings, mill scale and foreign matter. Discoloration of the surface may be present.
<b>WJ-2</b>	<b>Very Thorough or Substantial Cleaning</b> A WJ-2 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5% of the surface.
<b>WJ-3</b>	<b>Thorough Cleaning</b> A WJ-3 surface shall be cleaned to a matte (dull, mottled) finish which, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 33% of the surface.
<b>WJ-4</b>	<b>Light Cleaning</b> A WJ-4 surface shall be cleaned to a finish which, when viewed without magnification, is free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Any residual material shall be tightly adherent.

**Table 2** NACE/SSPC visual surface preparation definitions for WAB [3]

Term	Definition
NACE WAB-1/ SSPC-SP 5 (WAB)	<b>White Metal WAB</b> When viewed without magnification, a white metal WAB surface shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, corrosion products, and other foreign matter.
NACE WAB-2/ SSPC-SP 10 (WAB)	<b>Near-White Metal WAB</b> When viewed without magnification, A-white metal WAB-cleaned surface, the Random staining shall be limited to no more than 5% of each unit area of the surface (approximately 5,800 mm <sup>2</sup> [9.0 in <sup>2</sup> ]; i.e., a square 76 mm x 76 mm [3.0 in x 3.0 in]) and may consist of light shadows, slight streaks, or minor discolourations caused by stains of rust, stains of mill scale, or stains of previously applied coating.
NACE WAB-3/ SSPC-SP 6 (WAB)	<b>Commercial WAB</b> A commercial WAB-cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, corrosion products, and other foreign matter. Random staining shall be limited to no more than 33% of each unit area of the surface (approximately 5,800 mm <sup>2</sup> [9.0 in <sup>2</sup> ]) (i.e., a square 76 mm x 76 mm [3.0 in x 3.0 in]) and may consist of light shadows, slight streaks, or minor discolourations caused by stains of rust, stains of mill scale, or stains of previously applied coating.
NACE WAB-8/ SSPC-SP 14 (WAB)	<b>Industrial WAB</b> When viewed without magnification, an Industrial WAB-cleaned surface shall be free of all visible oil, grease, dirt, dust, loose mill scale, rust, and coating. Traces of tightly adherent mill scale, rust, and coating residues are permitted to remain on up to 10% of each unit area of the surface. Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife after the cleaning of abrasive blast. Shadows, streaks, and discolourations caused by stains of rust, stains of mill scale, and stains of previously applied coating may be present on the remainder of the surface.
NACE WAB-4/ SSPC-SP 7 (WAB)	<b>Brush-Off WAB</b> A brush-off WAB-cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Tightly adherent mill scale, rust, and coating may remain on the surface. Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife after abrasive blast cleaning has been performed.

**Surface Preparation Standards Comparison**

While both UHP WJ and WAB can achieve desired surface cleanliness, they have distinct characteristics that make them suitable for various applications. Understanding the different surface preparation

methods and standards is important to ensure that the appropriate methods and level of cleanliness are selected based on project requirements, surface conditions, and coating system compatibility (as summarised in Table 3).

**Table 3** Comparison of cleanliness standards [4]

ISO 8501-1 Dry Abrasive Blasting	NACE Dry Abrasive Blasting	NACE WAB	SSPC Dry Abrasive Blasting	SSPC WAB	ISO 8501-4 Water Jetting	NACE/SSPC 12 Water Jetting
Sa 3	1	WAB 1	SP-5	SP-5 WAB		WJ-1
Sa 2 ½	2	WAB 2	SP-10	SP-10 WAB	Wa 2 ½	WJ-2
Sa 2	3	WAB 3	SP-6	SP-6 WAB	Wa 2	WJ-3
	8	WAB 8	SP-14	SP-14 WAB		
Sa 1	4	WAB 4	SP-7	SP-7 WAB	Wa 1	WJ-4

Upon being subjected to UHP WJ or WAB, steel substrates are vulnerable to the formation of flash rust. This rapid oxidation process occurs when the high-pressure water used during UHP WJ or WAB removes protective coatings, exposing the bare metal to oxygen and moisture in the environment. As a result, iron oxide forms on the surface almost immediately, creating a

reddish-brown discolouration known as flash rust. If not adequately addressed, flash rust can reduce the adhesion of coatings, leading to premature coating failure. Table 4 lists four definitions of flash-rusted surfaces.

**Table 4** Flash rusted surface definitions [2]

Term	Definition
No Flash Rust	A steel surface which, when viewed without magnification, exhibits no visible flash rust.
Light (L)	A surface which, when viewed without magnification, exhibits small quantities of a yellow-brown rust layer through which the steel substrate may be observed. The rust or discolouration may be evenly distributed or present in patches, but it is tightly adherent and not easily removed by lightly wiping with a cloth.
Moderate (M)	A surface which, when viewed without magnification, exhibits a layer of yellow-brown rust that obscures the original steel surface. The rust layer may be evenly distributed or present in patches, but it is reasonably well-adherent and leaves light marks on a cloth that is lightly wiped over the surface.
Heavy (H)	A surface which, when viewed without magnification, exhibits a layer of heavy red-brown rust that hides the initial surface condition completely. The rust may be evenly distributed or present in patches, but the rust is loosely adherent, easily comes off, and leaves significant marks on a cloth that is lightly wiped over the surface.

**Robotic Technology**

**UHP WJ**

The crawler is a modular, magnetic, 4-wheel drive carrier used for application on flat or slightly curved steel surfaces. For closed water blasting, a vacuum dome is installed in front of the carrier, allowing both water and debris to be collected without leakage. Since the vacuum dome is installed in front of the carrier (Figure 1), it leaves a clean driving path for the carrier, ensuring that the carrier would not slip and stays firmly attached to the steel surface.



**Figure 1** UHP WJ robot with vacuum dome

**Table 5** Technical specifications for UHP WJ robot

Cleaning Path	370 mm
Dimensions (L x W x H)	720 x 510 x 370 mm (carrier) 685 x 630 x 450 (vacuum dome)
Total Weight	105 kg [80 kg (Carrier) + 25 kg (vacuum dome)]

**WAB Single Nozzle System**

For the WAB with a single-nozzle system (Figure 2), a swing arm is attached to the crawler. The swing speed, drive speed, and step size can be controlled, and the standard swing arm is equipped with a swivel and a rotating manifold capable of withstanding pressures up to 3000 bar.



**Figure 2** WAB robot with a single-nozzle system equipped with carrier and swing arm

**Table 6** Technical specifications for WAB robot with single-nozzle system

Cleaning Path	1500 mm
Dimensions (L x W x H)	720 x 510 x 370 mm (Carrier) 925 x 217 x 750 mm (Swing Arm)
Total Weight	100 kg [80 kg (carrier) + 20 kg (swing Arm)]
Abrasive	Industrial garnet abrasive with sieve size 30/60

**WAB with Three Nozzles**

The swing arm in the three-nozzle WAB system as shown in Figure 3 is equipped to accommodate and operate all three nozzles simultaneously. It moves automatically in a consistent arc pattern at a preset speed, and the crawler moves forward after each swing. The nozzles are high-productivity blast nozzles with up



**Figure 3** WAB robot with a three-nozzle system equipped with a carrier and swing arm

to 17 dBA noise reduction and up to 45% less nozzle trust, designed to optimise the use of garnet abrasive and improve service life.

**Table 7** Technical specifications for WAB robot (three-nozzles)

Cleaning Width	1500 mm
Dimensions (L x W x H)	650 x 550 x 520 mm
Total Weight	55 kg
Nozzles	1 unit nozzle-1/2" 2 units nozzle -7/16"
Abrasive	Industrial garnet abrasive sieve size 30/60

**Robotic Coating**

The painting robot comes with an accompanying trailer, forming a seamlessly integrated system designed for coating applications (Figure 4). The robot offers advanced capabilities for automated coating, while the trailer provides mobility and support for on-site deployment. The robot is equipped with a spray hood, providing a protective barrier around the spraying area that contains overspray and airborne particles generated during the coating process.

**Robotic Blasting and Coating Deployment**

Robotic technology in blasting and coating has been successfully deployed in various projects worldwide, demonstrating its potential to enhance safety, productivity, and consistency. The reference projects listed in Table 8 showcase the diverse applications and outcomes achieved with robotic technology.



Figure 4 Coating trailer, coating robot crawler and remote control

Table 8 Robotic blasting reference projects

Project	Location	Date	Results (ft <sup>2</sup> /hr)
Brock Storage Tank	Salt Lake City, USA	Nov 2021	400
Civmec New Fuel Storage Tank External	Kwinana, Australia	Oct 2020	600
Graham Industrial Coatings Jet Fuel Tank	Fairbanks, USA	June 2021	260
Quincy Industrial Coating Fuel Storage Tank External	Iowa, USA	May 2022	270
Alphatech Tank Internal	Banting, Malaysia	Apr 2023	332
BP Diesel Storage Tank Floor	QLD, Australia	Jan 2020	290
BHP 100ft Tank Internal	Olympic Dam, Australia	June 2020	100
Bunchen International Storage Tank Inner Walls	Antwerp, Belgium	June 2023	484

The results from robotic blasting reference projects highlight the effectiveness of this technology in achieving desired surface cleanliness and productivity. Projects like Brock Storage Tank in Salt Lake City, USA, and Alphatech Tank Internal in Banting, Malaysia, achieved significant blasting results in terms of speed and surface area covered. This process demonstrates the ability of robotic blasting to perform large-scale tasks efficiently.

Robotic coating reference projects illustrate the benefits of automated coating technology. Projects such as the protective coating application on Tank A331 at Shell Deer Park in Texas, USA, and the Protective Coating application at Shell Haven, Stanford-Le-Hope in the UK, demonstrate that robotic coating can achieve consistent quality and productivity. The total surface coated in these projects reflects the efficiency of robotic coating systems.

Table 9 Robotic coating reference projects

Project	Location	Date	Total surface coated (m <sup>2</sup> )
Protective Coating application on Tank A331, Shell Deer Park	Texas, USA	Dec 2021	400
Protective Coating application on Tank 401, MOT Terminal	Rotterdam, NL	Sept 2022	600
Protective Coating application on Tank T553, Chevron Penjuru	Singapore	Nov 2022	260
Protective Coating application at Shell Haven, Stanford-Le-Hope	UK	2022	270

These reference projects reinforce the viability of robotic technology for blasting and coating in various industries. They also suggest that robotic solutions can

offer advantages in terms of safety, reduced downtime, and consistent quality, providing a solid foundation for broader implementation and future research.

**MATERIALS AND METHODS**

**Scope of Evaluation**

The effectiveness of the robotic technology was quantified by inspecting the results of the blasting and coating. The inspection was conducted using the same standards and methods of conventional blasting and coating.

This technology evaluation covered several methodologies in blasting and coating works as follows:

1. Robotic blasting using UHP WJ
2. Robotic blasting using single-nozzle WAB
3. Robotic blasting using three nozzles WAB
4. Robotic coating

A test panel was prepared to a specification that represents a typical storage tank surface coated with a three-coat coating system before evaluation. Subsequently, the test panel was cleaned and inspected using the specified robotic technology. The surface was then coated using the robotic coating and inspected. The observation was taken and will be discussed in the next section.

**Inspection Method for Blasting And Coating**

Prior to coating, a surface must be prepared according to specified standards and acceptance criteria. This technology evaluation aimed to verify that the surface prepared using robotic technology meets the specified criteria. The same is also true for robotic coating. The primary criteria for the evaluation is listed in Table 10.

**RESULTS AND DISCUSSION**

The results from the inspection after the blasting and coating were tabulated and will be discussed in this section.

**Test Panel Initial Condition**

The test panel's initial condition serves as a benchmark for evaluating the effectiveness of subsequent blasting and coating processes (Table 11). It serves as a reference point for comparing the test results with the final outcomes, allowing for a precise evaluation of the performance and quality achieved through robotic blasting and coating.

These initial conditions are critical for establishing a baseline. The surface preparation standard, achieved through blasting to ISO 8501 Sa 2.5, indicates that the test panel was cleaned to remove rust, scale, and contaminants, providing a suitable surface for coating application. The surface profile, averaging 75.6 μm, suggests a level of roughness which acts as anchor points for proper coating adhesion.

**Table 10** Inspection method and acceptance criteria [5]-[7]

Step	Inspection Method	Standard acceptance criteria	Tools
<b>Blasting Inspection</b>			
1	Surface cleanliness [3]	NACE No. 5/SSPC-SP 12 WJ2 NACE WAB-2/ SSPC-SP 10 (WAB)	SSPC/NACE visual comparator
2	Surface profile measurement	50-75 microns	Surface profile gauge
3	Dust contamination	Min Level 2	Dust tape
4	Soluble salts	Max 20 mg/m <sup>2</sup>	Chloride test kit
5	Flash rust level	Light flash rust	Visual and dust tape
<b>Coating Inspection</b>			
5	Wet film thickness measurement	As per the coating system	WFT gauge
6	Dry film thickness measurement	As per the coating system	DFT gauge
7	Adhesion	Min 5 MPa	Pull-off adhesion tester
8	Holiday	No holiday	Low voltage holiday tester

**Table 11** Test panel initial condition

Inspection Activity	Acceptance Criteria	Test Panel Initial Condition
Surface preparation standard achieved	ISO 8501 Sa 2.5	Achieved ISO 8501 Sa 2.5
Surface profile	50-75 µm	Average: 75.6 µm
Dry Film Thickness (DFT)	400 µm	700 µm
Adhesion test	5 MPa minimum	6 MPa

The Dry Film Thickness (DFT) of 700 µm represents the thickness of the existing coating, indicating the amount of material to be removed during robotic blasting. This measure helps in understanding the efficacy of the robotic blasting methods in achieving desired results.

The adhesion test, with a minimum requirement of 5 MPa and an initial condition of 6 MPa, underscores the coating’s strength and its ability to adhere to the substrate. This case is an essential criterion for the test panel to evaluate the capability of robotic blasting to remove existing coatings that strongly adheres to the steel surface, as would be encountered in actual applications.

While these initial conditions provide a close approximation to real-world scenarios, certain factors, such as weather variations and natural degradation over time, cannot be simulated in this test.

This detailed assessment of the test panel’s initial condition allows for a comprehensive understanding of the starting point for subsequent tests. It establishes a clear framework for evaluating the results from robotic blasting and coating, ensuring that the outcomes are analysed in the context of their baseline conditions.

**Robotic Ultra High-Pressure Water Jetting**

**Inspection Result**

The robotic blasting using UHP WJ was performed on the test panel, and the results are presented in Table 12.

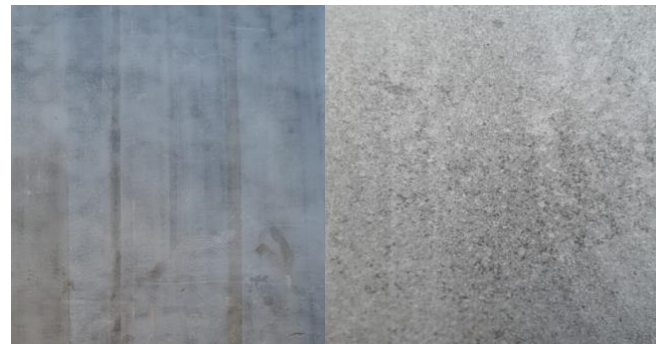
**Discussion**

1. Robotic UHP WJ blasting successfully removed most of the initial coating on the test panel. During

**Table 12** Results for robotic UHP WJ inspection

Inspection Activity	Acceptance Criteria	Results
Surface cleanliness	NACE No. 5/SSPC-SP 12 WJ2	NACE No. 5/SSPC-SP 12 WJ2
Surface profile	50-75 µm	Average: 80.5 µm
Dust contamination	Min Level 2	Level 1
Soluble salts	Max 20 mg/m <sup>2</sup>	Average: 9.1 mg/m <sup>2</sup>
Flash rust	Light flash rust	Light flash rust
Productivity rate	10 m <sup>2</sup> /hr/nozzle	28.8 m <sup>2</sup> /hr
Dust particles during blasting	Visual observation	No dust particles were observed

the testing, it was observed that the blasted surface did not form any flash rust even after several hours post-blasting (Figure 5). It was also observed that the steel surface gets warmer immediately after UHP WJ due to the high pressure used in the process. This increase in surface temperature, coupled with the use of a vacuum system to immediately remove standing water, has significantly delayed flash rust formation.



**Figure 5** Test plate surface post-robotic UHP WJ blasting (Left: Normal view. Right: Magnified view)

- Surface cleanliness for water jetting is defined in NACE No. 5/SSPC-SP 12. NACE/SSPC quantified the allowable remaining coating of 33% for WJ3 and only 5% for WJ2. However, the inspection method defined by the standard only uses visual inspection assisted by the visual comparator. As such, the approximation of the remaining coating is purely based on the inspector’s experience and estimation.
- A higher cleanliness level can be achieved by increasing the water pressure hitting the surface. This outcome can be achieved by closing some of the active nozzles and reducing the clearance

between the blasting arm and the blasting surface. Alternatively, slowing down the movement of the robot and reducing the rotation of the blasting arm can be implemented to increase the duration of blasting for each unit area. Both will have detrimental effects on blasting productivity and, subsequently, project costs.

4. It is recommended that the optimal configuration between the number of active nozzles, robot speed, cleanliness level target, and productivity target be determined prior to performing full blasting works at the site.
5. Robotic UHP WJ blasting demonstrated the cleanest blasting operation environmentally, as it was equipped with a closed dome system attached to a vacuum truck, which eliminates dust emissions during the blasting process. This effort represents a significant improvement in workers' safety, as exposure to crystalline silica inside blasting garnet can cause an irreversible but preventable lung disease known as silicosis. The closed system also eliminated the need for protection screens to prevent airborne particles from contaminating equipment and environments. We also observed that the closed system eliminated the need for post-blasting clean-up and drying. In actual work, this will significantly increase productive blasting hours at the site.
6. The productivity of a robotic UHPWJ was almost equivalent to three conventional manual blasters, with the advantage of safer, cleaner, and longer

productive blasting duration. While the speed per robot is slower compared to four teams of conventional blasting, the longer productive hours will make up for it.

7. The surface profile obtained from robotic UHP WJ depends on the existing surface profile and level of cleanliness. Water jetting standards allow for the leaving of some adherent coating (WJ2, WJ3 and WJ4) on the surface. As such, the coating system selection must adapt to this condition. As the surface was not thoroughly cleaned to the bare substrate, a surface-tolerant epoxy primer is more suitable compared to a typical zinc-rich coating. A surface-tolerant epoxy coating is also more suitable for water-jet cleaned surfaces, as it can be applied to damp surfaces.
8. The use of robotic UHP WJ also produces a surface that is dry to the touch, which is optimum for coating. In actual implementation, this feature enables back-to-back blasting and coating, thereby increasing the productivity of the work.

**Robotic Wet Abrasive Blasting**

**Inspection Result**

The robotic wet abrasive blasting using a single nozzle and three nozzles was performed on the test panel, and the following results were obtained:

**Table 13** Results of robotic WAB inspection

Inspection Activity	Acceptance Criteria	Results	
		Single nozzle	Three nozzles
Surface cleanliness	NACE WAB-2/ SSPC-SP 10 (WAB)	NACE WAB-2/ SSPC-SP 10 (WAB)	NACE WAB-2/ SSPC-SP 10 (WAB)
Surface profile	50-75 micron	Average: 48 µm	Average: 62 µm
Dust contamination	Level 2	N/A	Level 1
Soluble salts	Max 20 mg/m <sup>2</sup>	24.5 mg/m <sup>2</sup>	19.0 mg/m <sup>2</sup>
Flash rust	Light Flash Rust	Light Flash Rust	Light Flash Rust
Productivity rate (blasting, wash down and blow-dry)	10 m <sup>2</sup> /hr/nozzle	6.7 m <sup>2</sup> /hr	38 m <sup>2</sup> /hr
Dust particles during blasting	Visual observation	A mixture of dust and mist splattering was observed around the blasting area.	A mixture of dust and mist splattering was observed around the blasting area.

**Discussion**

The primary findings from the technology testing indicated the following:

1. WAB successfully removed all existing coating to the bare substrate and created a new surface profile (Figure 6). This situation is a major difference compared to UHP WJ technology, which only removes the existing coating and resurfaces the surface profile.



**Figure 6** Test plate surface post-Robotic WAB (single nozzle)  
(Left: Normal view. Right: Magnified view)

2. The surface prepared for WAB appears to exhibit higher soluble salts compared to UHP WJ. This condition could be due to the use of abrasive products, which may contain a higher salt level. The abrasive used must be tested for salt contamination to ensure the desired surface cleanliness is achieved.
3. During this testing, it was observed that the surface profile had been reduced from its initial condition. It is suspected that the WAB tapered the peaks of the surface profile, resulting in a reduction of the surface profile. In actual implementation, the correct abrasive to be used with the WAB should be selected and tested prior to use to ensure the desired surface profile is obtained. The dynamic impact of abrasive hardness and shapes, as well as water and metal surfaces, is empirically understood through experience.
4. Robotic WAB does not employ any vacuum system to capture the dust and slurry produced in the process. Unlike UHP WJ, a wash-down step is necessary to clean the blasted surface of any residue. Additionally, to delay flash rust formation, the blow-drying step must also be performed.

5. The productivity of blasting is comparable to that of the conventional method, especially for WAB, which uses three nozzles, achieving a productivity of around 38 m<sup>2</sup>/hr. In the conventional dry blasting method, the productivity rate is approximately 30 m<sup>2</sup>/hr – 40 m<sup>2</sup>/hr with four teams blasting simultaneously. In Malaysia’s weather, considering the clean-up required after blasting and coating hours, the productive hours for blasting are only around 3.5-4 hours per day. In summary, a single 3-nozzle WAB robot is performing the work of a 4-blasting team.
6. The 3-nozzle WAB is the optimum configuration compared to a single nozzle, as it results in higher productivity. The blasting can be set such that each nozzle performs blasting, washdown and blow dry simultaneously.
7. The sequence of robot movement will also influence productivity, especially for single-nozzle blasting. The robot sometimes must retrace its blasting area to clean up, perform a wash-down and blow dry.
8. It must also be noted that blasting one area from top to bottom will also contaminate the surface area on the sides. Therefore, an efficient strategy must be employed to optimise the robot’s movement, thereby optimising the blasting operation.
9. The dust produced during blasting is significantly less compared to conventional dry abrasive blasting. However, the blasting still produces a lot of airborne particles around the blasting area that flow down the blasted surface. With the correct nozzle angle and abrasive-to-water ratio adjustment, it may be possible to perform the blasting without a protection screen.

**Robotic Coating**

**Inspection Result**

The previously cleaned test panel was subsequently coated with a two-coat system using robotic coating, and the results are presented in Table 14.

**Discussion**

1. The most critical test for blasting and coating is the pull-off adhesion test, as it represents the ability of a coating to bond to a substrate or surface, providing long-lasting corrosion protection. It serves as a measure of the strength and durability

**Table 14** Result of robotic coating inspection

Inspection Activity	Acceptance Criteria	Coating
Wet Film Thickness (WFT)	First Coat: Min 412 µm Second Coat: Min 88 µm	First Coat: Avg 408 µm Second Coat: Avg 200 µm
Final Dry Film Thickness (DFT)	First Coat: Min 350 µm Second Coat: Min 400 µm	First Coat: Avg 357 µm Second Coat: Avg 425 µm
Visual inspection	Absence of coating defect	Acceptable
Adhesion	5 MPa minimum	UHP WJ Prepared Average: 9 MPa  WAB Prepared Average: 10 MPa
Holiday	No holiday	No holiday detected
Productivity rate	Comparable with conventional coating	91 m <sup>2</sup> /hr (based on the first coat)

of this bond, indicating how well the coating will resist separation, peeling, or flaking over time or under specific conditions. The adhesion strength depends on multiple factors such as surface cleanliness, surface profile and coating application. Based on our testing, the coating applied to both WAB and UHP WJ-prepared surfaces demonstrated good adhesion strength.

- Coating is a highly sensitive activity where all robot movements must be meticulously planned, as any mistake will be costly to rectify, unlike robotic blasting. This includes robot movement from the non-blasted area to the blasted area, as this will carry contaminants that can cause coating quality issues. The robot should be attached directly to the blasted area to avoid contamination.
- The robot is equipped with semi-automatic features, including auto lane change, auto alignment, precise speed control, and estimation of WFT based on flow rate and transfer rate. This ensures consistent coating overlaps between lane runs and consistent WFT throughout the process.
- The consistent WFT achieved by robotic blasting results in highly uniform DFT on the coated surface. Issues of under-thickness, typically encountered with manual blasting, which relies on individual painter skills, can be avoided. This is evident from the holiday test performed on the coated surface, where no holiday was detected. Although a holiday test is not normally required for atmospheric coating applications such as storage tank externals, it was performed for this technology evaluation to ensure the highest quality of the finished coating.
- The robot is equipped with a dome and vacuum system to collect and pull coating overspray. No overspray was observed during the coating work. The coating inhalation can lead to serious health issues, which necessitate significant improvement in work safety. This feature also saves the surrounding environment from getting dirty due to the coating, unlike the conventional method. In actual implementation, this feature will avoid the need to erect protection screens, saving costs and time for projects.
- Our testing revealed excellent productivity compared to the conventional method, with the advantages of reduced manpower working at heights and eliminating human exposure to hazardous coating particles. In conventional applications, the primer application depends on blasting productivity, as the blasting speed is typically slower compared to the painting speed. In tank refurbishment, blasting and painting are done course by course from top to bottom. With faster robotic blasting outlined above, it is now possible to perform blasting immediately, followed by painting or even in parallel. However, challenges such as post-blasting inspection, repair activities, and stripe painting requirements remained obstacles to achieving a high productivity rate.

**CONCLUSION**

The comprehensive evaluation of robotic storage tank blasting and coating technology demonstrates its significant potential to revolutionise maintenance

operations by enhancing safety, productivity, and quality. The study confirms that robotic Ultra High-Pressure Water Jetting (UHP WJ) and Wet Abrasive Blasting (WAB) can achieve cleanliness standards comparable to those of conventional methods while offering additional benefits such as reduced human exposure to hazardous conditions and faster turnaround times. Furthermore, robotic coating applications ensure consistent quality and precision, addressing the limitations of manual methods. By validating the feasibility and effectiveness of these robotic technologies, the study supports their broader adoption in storage tank maintenance, recommending pilot projects to explore further applications, understand execution nuances, and optimise performance. This advancement paves the way for broader implementation and further exploration in various industries, ultimately contributing to safer and more efficient maintenance processes.

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