

Evaluation of Thermal Spray Aluminum Coating Implementation Based on Procedure Qualification Test (PQT) Inspection Data for Offshore Steel Structures

Fitriani,^{a,*}, Fardin Hasibuan,^b and Dwi Cahyadi Putra,^c

^{a,b}Program Studi Teknik Mesin, Fakultas Teknik, Universitas Riau Kepulauan, Indonesia

^cTSA, PT. Vinnex Coatindo, Indonesia

*Corresponding author: fitri0606@gmail.com

Paper History

Received: December 22th 2025

Received in revised form: March 23th 2026

Accepted: April 21th 2026

ABSTRACT

Thermal Spray Aluminum (TSA) coating is widely applied for corrosion protection of offshore steel structures operating in aggressive marine environments. In practical offshore projects, the quality of TSA coating implementation is primarily verified through inspection activities conducted during Procedure Qualification Tests (PQT). In this study, an inspection-based evaluation of TSA coating implementation was performed using documented PQT inspection records obtained from an offshore steel structure, without additional laboratory testing. TSA coating was applied using a twin wire electric arc spray process, and coating quality was assessed based on dry film thickness (DFT) measurements recorded at five inspection points. The measured DFT values ranged from 216 μm to 357 μm , with an average thickness of 284.8 μm . To ensure general applicability, the thickness distribution was interpreted using inspection-derived statistical indicators, including a thickness uniformity index and coefficient of variation. The results indicate a uniform coating build-up and stable application characteristics typical of arc-sprayed aluminum coatings. It is concluded that PQT inspection data provide a practical and reliable basis for evaluating TSA coating implementation and thickness consistency in offshore steel structure applications.

KEY WORDS: *Thermal Spray Aluminum, Procedure Qualification Test (PQT), Arc Spray Coating, Coating Thickness Distribution, Inspection-Based Evaluation*

NOMENCLATURE

TSA Thermal Spray Aluminum
PQT Procedure Qualification Test
DFT Dry Film Thickness (μm)
t_{avg} Average dry film thickness obtained from PQT

measurements (μm)
t_{min} Minimum measured dry film thickness (μm)
t_{max} Maximum measured dry film thickness (μm)
U_t Thickness uniformity index, defined as the ratio of minimum to average thickness (-)
 σ Standard deviation of dry film thickness measurements (μm)
CV Coefficient of variation of thickness distribution (-)
 μm Micrometer

1.0 INTRODUCTION

Thermal Spray Aluminium (TSA) coating is widely applied for corrosion protection of offshore steel structures operating in aggressive marine environments. Exposure to high humidity, salt-laden atmosphere, and cyclic wet-dry conditions significantly accelerates corrosion of carbon steel components[1]. TSA coatings are commonly selected for offshore applications due to their combined barrier protection and sacrificial anodic behaviour, which provide long-term corrosion resistance when properly applied and inspected in accordance with recognized thermal spray practices such as ISO 2063 and AWS C2.23M.

In practical offshore projects, the quality of TSA coating implementation is primarily verified through inspection activities conducted during fabrication and installation stages. Procedure Qualification Tests (PQT) are used to demonstrate conformity between defined coating procedures and actual field application results[2]. PQT inspection records typically document surface preparation, environmental conditions, and coating thickness measurements; however, such data are rarely analysed quantitatively in academic studies, which tend to focus on laboratory-scale investigations and material characterisation (Pawlowski, *The Science and Engineering of Thermal Spray Coatings*). This study addresses this gap by presenting an inspection-based evaluation of TSA coating implementation using documented PQT inspection data, with emphasis on coating thickness distribution and application consistency under field conditions.

2.0 METHODOLOGY

This study was conducted using an inspection-based approach to evaluate the implementation of Thermal Spray Aluminum (TSA) coating applied to an offshore steel structure[3]. The methodology relied exclusively on documented Procedure Qualification Test (PQT) inspection records to reflect actual field application conditions[4]. No additional laboratory testing or experimental coating application was performed. The evaluation focused on coating application process description, inspection data acquisition, and quantitative interpretation of coating thickness distribution.

2.1 Thermal Spray Aluminum Application Process

The TSA coating was applied using a twin wire electric arc spray process. In this process, an electric arc formed between two aluminum consumable wires was used to melt the feedstock, while compressed air atomized and propelled the molten aluminum particles onto the prepared steel substrate. Coating deposition was performed in multiple overlapping passes to achieve uniform surface coverage. Surface preparation prior to coating application was carried out by abrasive blasting to achieve a cleanliness level equivalent to Sa 3 in accordance with ISO 8501-1. The coating application process followed recognized thermal spray practices as defined in ISO 2063 and AWS C2.23M.

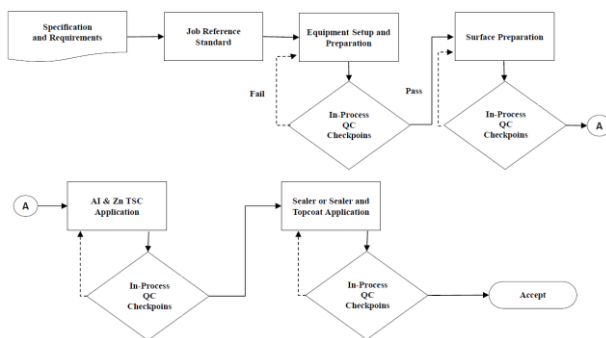


Figure 1: Thermal Spray Process

2.2 Inspection-Based Evaluation and PQT Data

Coating quality was evaluated based on inspection activities conducted during the PQT. Inspection records included dry film thickness (DFT) measurements obtained from five inspection points on the coated test panel. These measurements were used to represent the achieved coating thickness distribution. The inspection data were treated as primary input for analysis and were not modified or supplemented by assumed values. Quantitative evaluation was performed using inspection-derived statistical indicators, including average thickness, minimum and maximum thickness, thickness uniformity index, and coefficient of variation.

2.3 Repair and Surface Reconditioning Procedure

Localized damage to Thermal Spray Aluminum (TSA) coatings may occur during fabrication or handling prior to inspection. When coating damage results in exposure of the steel substrate, repair and surface reconditioning are performed as part of standard field implementation practice[5]. The damaged area is

reconditioned by localized abrasive blasting to achieve a cleanliness level equivalent to Sa 2½ with a medium surface profile of approximately 50–85 µm, and the prepared area is extended beyond the visibly damaged zone to ensure adequate overlap with the surrounding intact coating. TSA coating is then locally re-applied using a spot repair approach, with gradual feathering at the overlap region to maintain coating continuity and minimize stress concentration. Substrate preheating is not applied during repair activities, as moisture control in electric arc spray processes is achieved through environmental monitoring rather than substrate heating, consistent with qualified coating procedures and applicable international thermal spray standards.

3.0 RESULT

3.1 Table and Figure

The Procedure Qualification Test (PQT) was conducted using a flat carbon steel test panel with dimensions of 500 × 500 × 12 mm, as documented in the PQT inspection report. The selected panel size provides a sufficiently large surface area to evaluate coating build-up uniformity, spray overlap consistency, and thickness variation under practical arc spray application conditions. A panel thickness of 12 mm was selected to ensure adequate thermal mass, thereby minimizing thermal distortion and excessive heat accumulation during coating deposition.

Prior to coating application, the test panel was subjected to abrasive blasting in accordance with the qualified surface preparation procedure to achieve the specified surface cleanliness and profile. Thermal Spray Aluminium (TSA) coating was applied using a twin wire electric arc spray system with recorded spray parameters of 32 V voltage, 400 A current, 90 psi air pressure, and a spraying temperature of 55 °C. Aluminium wire material Al 99.5 (EN AW 1050) with a diameter of 2.0 mm was used as the coating feedstock. Coating deposition was performed through multiple overlapping spray passes to ensure full surface coverage across the panel.

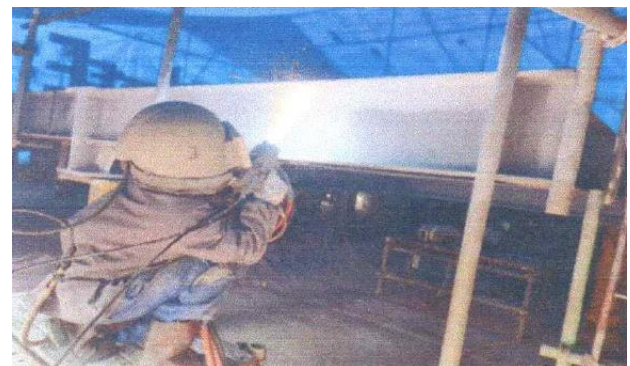


Figure 2: TSA application using electric arc spray

Dry film thickness (DFT) measurements were obtained at five designated locations distributed across the coated panel surface to capture representative thickness variation. The recorded DFT values were 234 µm, 349 µm, 267 µm, 357 µm, and 216 µm, resulting in an average thickness of 284.8 µm, with minimum and maximum values of 216 µm and 357 µm, respectively. These measurements represent the actual coating thickness

achieved during execution of the qualified TSA application procedure and form the basis for subsequent quantitative analysis of thickness distribution.

Table 1: Dry film thickness (DFT) measurements recorded

Measurement Point	DFT μm
DFT Test 1	234
DFT Test 2	349
DFT Test 3	267
DFT Test 4	357
DFT Test 5	216

4.0 DISCUSSION

4.1 Equation

To provide a quantitative interpretation of dry film thickness (DFT) consistency based solely on inspection data, a thickness uniformity index (U_t) was used. The index is defined as the ratio between the minimum measured thickness and the average thickness:

$$U_t = \frac{t_{\min}}{t_{\text{avg}}}$$

where t_{\min} represents the minimum recorded dry film thickness and t_{avg} the average dry film thickness obtained from the PQT measurements. A uniformity index value closer to unity indicates a more uniform coating thickness distribution across the coated surface.

5.0 CONCLUSION

Based on inspection data obtained from the Procedure Qualification Test (PQT), the implementation of Thermal Spray Aluminium (TSA) coating demonstrated consistent coating build-up under practical field application conditions. Dry film thickness measurements recorded at five inspection points on the 500 × 500 × 12 mm test panel ranged from 216 μm to 357 μm, with an average thickness of 284.8 μm. Quantitative interpretation using an inspection-derived thickness uniformity index resulted in a value of 0.76, indicating that the minimum coating thickness remained reasonably close to the average thickness across the coated surface[6].

The results confirm that the TSA coating application, executed in accordance with a qualified procedure and recognized international standards, produced a uniform and continuous coating layer without evidence of discontinuity or exposed substrate. It is concluded that PQT inspection records can be effectively utilised as a reliable data source for applied engineering evaluation of TSA coating implementation, supporting inspection-based assessment of coating thickness consistency for offshore steel structure applications.

REFERENCE

[1] Universitas Sebelas Maret, et al. Effect of the substrate surface profile on the bonding strength of the aluminum thermal sprayed on low carbon steel. JRM. 2021

- Dec;12(3):591–604. doi:10.21776/ub/jrm.2021.012.03.9.
- [2] Setiawan TW, Kristiawan YY. Pengerasan permukaan baja karbon rendah dengan metode thermal spray coating (Surface hardening of low carbon steel using thermal spray coating method). 2020.
- [3] Saidah A, Basri A. Termal dan jarak arc spray pengaruh terhadap sifat mekanik baja karbon (AISI 1045) (Effect of thermal parameters and arc spray distance on mechanical properties of carbon steel AISI 1045). JKTM. 2020 Sep;5(2):116–123. doi:10.52447/jktm.v5i2.4184.
- [4] Riyanto E, Prawara B. Mikrostruktur dan karakterisasi sifat mekanik lapisan Cr3C2-NiAl-Al2O3 hasil deposisi dengan menggunakan high velocity oxygen fuel thermal spray coating (Microstructure and mechanical properties characterization of Cr3C2-NiAl-Al2O3 coating deposited using HVOF thermal spray). J Mechatron Electr Power Veh Technol. 2012 Mar;1(1):1–4. doi:10.14203/j.mev.2010.v1.1-4.
- [5] Pramudya BI, Hastuti S, Budiono HS. Pengaruh tekanan gas pada proses thermal spray aluminium (TSA) terhadap keausan dan morfologi pada baja ST 60 (Effect of gas pressure in thermal spray aluminium process on wear and morphology of ST60 steel). JTMEI. 2024 Oct;3(4):87–94. doi:10.55606/jtmei.v3i4.4391.
- [6] Azhari MR, Purniawan DA, Purwaningsih H, et al. Pengaruh thermal cycle terhadap ketahanan adhesi dan abrasi pada pelapisan SS 304 dengan metode NiCrSiB (Effect of thermal cycle on adhesion and abrasion resistance of SS 304 coating using NiCrSiB method). Thesis, Univesitas Sumatera Utara. 2023.