中国科学院
苏州纳米技术与纳米仿生研究所

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Durable Anti-Corrosion Solutions for Marine and Heavy-Duty Infrastructure

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COATIME 涂创时代

Marine/Offshore Structures

- Oil & Gas Rigs
- Offshore Wind Turbine
- Ships
- Cooling systems
- Onshore and offshore facilities

Anti-corrosion Coating- the 1st protection barrier
（Function + Durability）

- **Harsh Corrosion**
- **Fouling submerged**

Norway Takes Drone Inspections of Offshore Oil Platform to New Level - Global Energy Network

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Heavy-duty Infrastructure

Heavy Duty Corrosion Protection

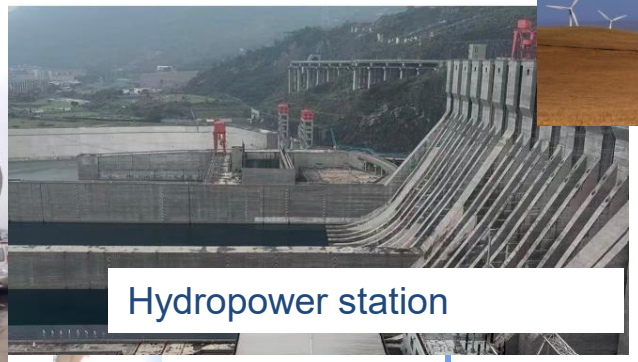
- **Heavy asset (facilities)**
- **Long duration protection (>15 Year)**


Port Machinery


Bridge


Wind Power


Municipal facilities


Hydropower station


Pipeline


Power station


Petrochemical refinery

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Key Features for Heavy-duty Anti-Corrosion Coatings

BSI Standards Publication • **ISO12944-2017/2018**

Paints and varnishes — Corrosion protection of steel structures by protective paint systems

Part 2: Classification of environments

For Highly Corrosive Environment

- C1 very low corrosivity
- C2 low corrosivity
- C3 medium corrosivity
- C4 high corrosivity
- C5 very high corrosivity
- CX extreme corrosivity

Part 1: Genera introduction

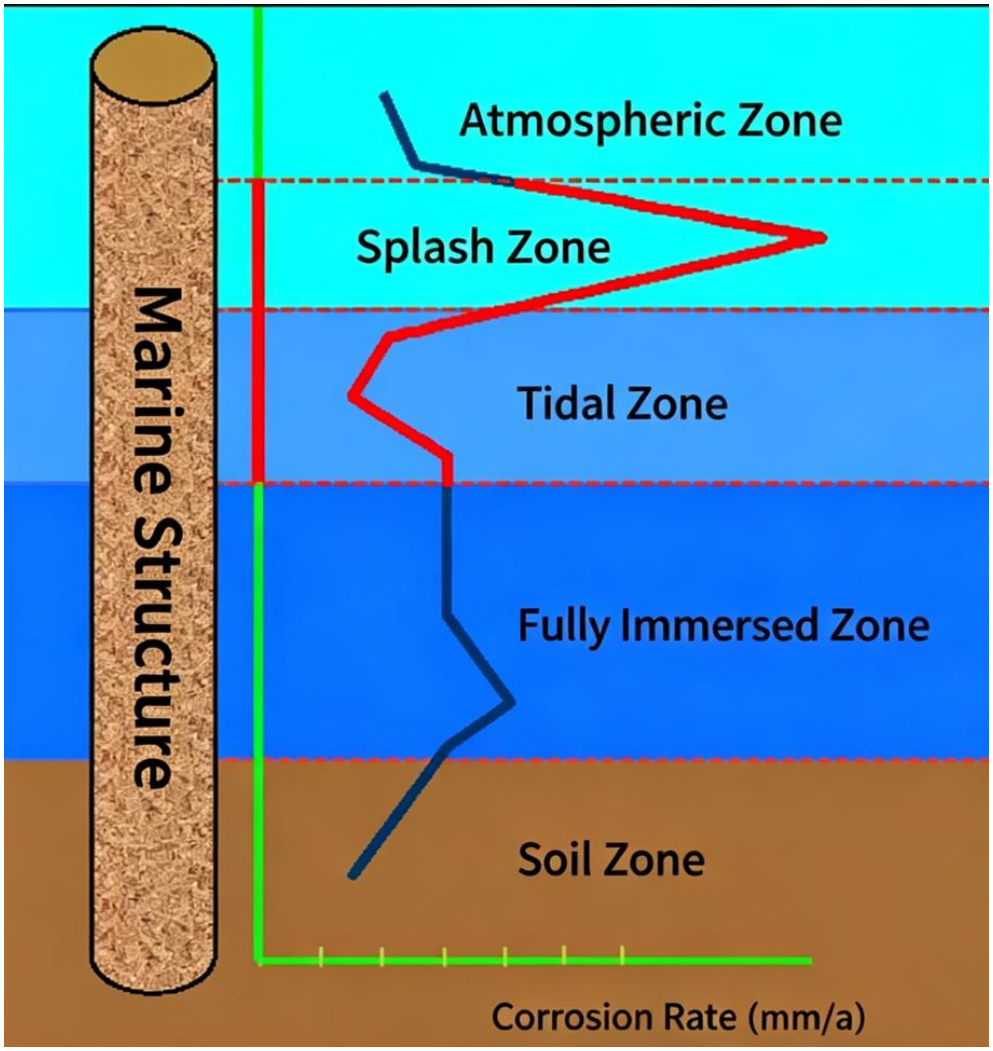
For High or VH durability

- low (L) up to 7 years;
- medium (M) 7 years to 15 years;
- high (H) 15 years to 25 years;
- very high (VH) more than 25 years.

Durability is a technical consideration/planning parameter that can help the owner set up a maintenance programme.

Marine Corrosion Zones

- **ISO12944-9: 2018**



CX offshore zone

CX (offshore) and Im4

Im - Immerssion Zone

Marine/Offshore Anti-Corrosion Technology and Technical Specifications

- **Internationally Recognized Standards**
- **National Standards**
- Industrial Codes
- Owner's Design Specifications
- Association Standards

NORSOK M501 Surface Preparation and Protective Coatings

Norwegian Oil and Gas Association, Federation of Norwegian Industries, Norwegian Shipowners' Association. Managed and published by Standards Norway.

- 1993 1st draft, 1995 1st Edition
- 2022 7th edition, incorporating the latest industry insights.
- The world's most accepted standard for specifying protective coatings in the marine engineering and offshore oil & gas sector.
- Rigorous certification of coating performance under real-world

The drafting committee stakeholders:

- End-users from the marine energy and offshore oil & gas industry, ensuring practical relevance.
- Internationally renowned coating suppliers such as International, Jotun, and Carboline.
- Professional coating application contractors with extensive on-site experience.
- Independent third-party testing laboratories to guarantee objectivity and accuracy.

M501 Appendix A - CSDS for Offshore Structures

CSDS - Coating System Data Sheet

These are pre-qualified coating systems, with a total of **35 CSDS** systems covering various offshore structural requirements.

Substrate Type	Temperature Range	Insulation Requirement	Fire Protection Requirement
• Carbon Steel • Stainless Steel • Aluminum	• Standard range: -50°C to 80°C. • High-temperature range to 200°C	• Insulated • Non-insulated	• for fire-rated specifications • for non-fire-rated structural protection

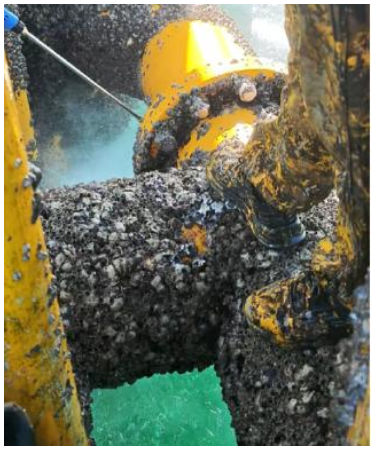
The CSDS systems are rigorously tested to meet the durability and performance criteria for harsh marine and subsea operating conditions, simplifying specification and procurement processes.

Harsh Industrial and Marine Corrosion Environment

01. Salt Spray & UV/Humidity
- High salt spray corrosion
- High UV aging
- High humidity
- High temperature

02. Physical & Biological Stress
- Impact stress from wave vibration
- Operation Damage
- Biocorrosion to material surfaces.

03. Dynamic Environmental Cycles
- Under alternating wet-dry
- High-low temperature cycles.

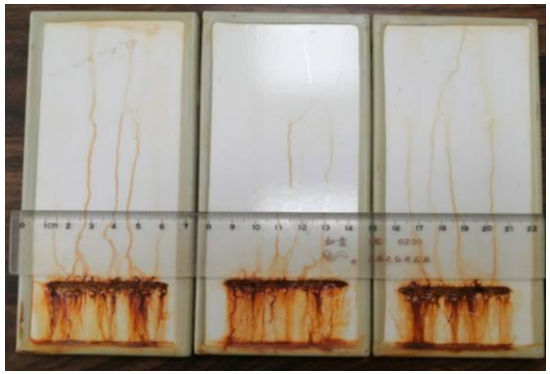


Key to Evaluate Durability of a Coating and Coating System : Integrate multi-factor coupling tests to reproduce the real marine service environment and ensure the accuracy of aging assessment.

Cyclic Ageing Testing to Test Durability under a Combined Corrosion Factors

ISO 12944 Part 9 defines a rigorous cyclic test

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
UV/condensation — ISO 16474-3			Neutral salt spray — ISO 9227			Low-temp. exposure at (−20 ± 2) °C



7 days (168h)- One Cycle
6mth (4200h) -25 Cycles

A scribe of 2.0mm wide to simulate real-world damage, accelerating the evaluation

To complete the qualification testing of the Coating systems for Atmospheric 、 Splash and Tidal Zones

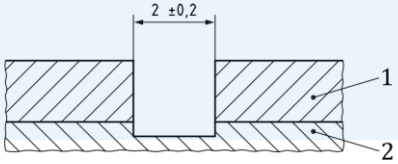


Figure A.1 — Cross section of scribe line

How to Evaluate Anticorrosion Durability Rapidly and Accurately: Testing Methods

中性盐雾测试 1440 小时后划痕处的锈蚀	Norsok M501 4200 小时测试后划痕处的锈蚀	南海岛礁暴晒 12 个月划痕处的锈蚀
1440h Salt Spray	4200h M501 cyclic	12 mth Island South China Sea

Comparison of laboratory and field tests by Dr. Wei's team

- The neutral salt spray test alone insufficient to evaluate corrosion in the real marine environment.

highlighting the importance of multi-factor testing

Coating Systerm Qualification Testing Requirements M501 vs. ISO 12944-9:2018

ISO 12944-9:2018	ZONES	NORSOK M 501: 2022
• 4200h cyclic aging test • Creep width: Zn CS ≤ 3mm; no-Zn CS ≤ 8mm • Blistering allowed up to max 8mm	Atmospheric	• 4200h cyclic aging; Zn CS ≤ 3mm; no-Zn CS ≤ 8mm • **NO corrosion permitted** • **NO blistering allowed**
• 4200h cyclic exposure test • 4200h cathodic disbond test	Splash / Tidal	• 4200h cyclic test & cathodic disbondment • **ADDITIONAL: Impact resistance ≥ 5.6 J**
• 4200h full seawater immersion • 4200h cathodic disbondment test	Immersed	• Identical to ISO: 4200h immersion & 4200h cathodic disbondment test

Typical Coating System
Case Studies for Offshore Structures

The coating systems are required to comply with design requirements for offshore anti-corrosion.

Leading international suppliers: **Hempel, International Paint, PPG, Jotun**

Typical three-coat systems in the atmospheric zone (CX）

涂层体系层级	ISO 12944-9:2018 CX	M501:2022 CSCD no. 1B	China GB/T 33423-2024 Offshore Wind CX	China GB/T 31817:2025 Wind Turbine VI Grade
Zn Rich Primer (μm)	80	60	60	80
Epoxy Intermediate Coat (μm)	160	160	200	200
PU topcoat (μm)	80	80	60	80
Minimum Total DFT (μm)	280	300	320	360

M501 requires a thicker DFT than ISO, while the Chinese national standards for wind turbines mandate a higher total DFT, reflecting the specific needs of each application

Typical coating systems in the splash and tidal zone

Coating System	ISO 12944-9:2018 CX & Im4	M501:2022 CSCD no. 7A	GB/T 33423-2024 Marine Wind CX & Im4	GB/T 31817:2025 VI Highly Corrosive Grade	
Epoxy Mastic/Glass Flake Primer (μm)	200	500	400	500	500
Epoxy Mastic/Glass Flake Coat (μm)	400	500	400	500	500
PU Topcoat (μm)			(60)	-	80
Minimum total DFT (μm)	600	1000	800 (860)	1000	980 (1000)

M501 requires a thicker DFT than ISO, while the Chinese national standards for wind turbines mandate a higher total DFT, reflecting the specific needs of each application

Typical coating systems in the submerged zone

Coating System	ISO 12944-9:2018 Im4	M501:2022 CSCD no. 7B	GB/T 33423-2024 China Marine Wind Im4	GB/T 31817:2025 China wind turbine Im4 (full immersion)
Epoxy Mastic/Glass Flake Primer (μm)	≥150	175	400	300
Epoxy Mastic/Glass Flake Coat (μm)	200	175	400	300
Minimum total DFT (μm)	350	350	800	600

M501 requires a thicker DFT than ISO, while the Chinese national standards for wind turbines mandate a higher total DFT, reflecting the specific needs of each application

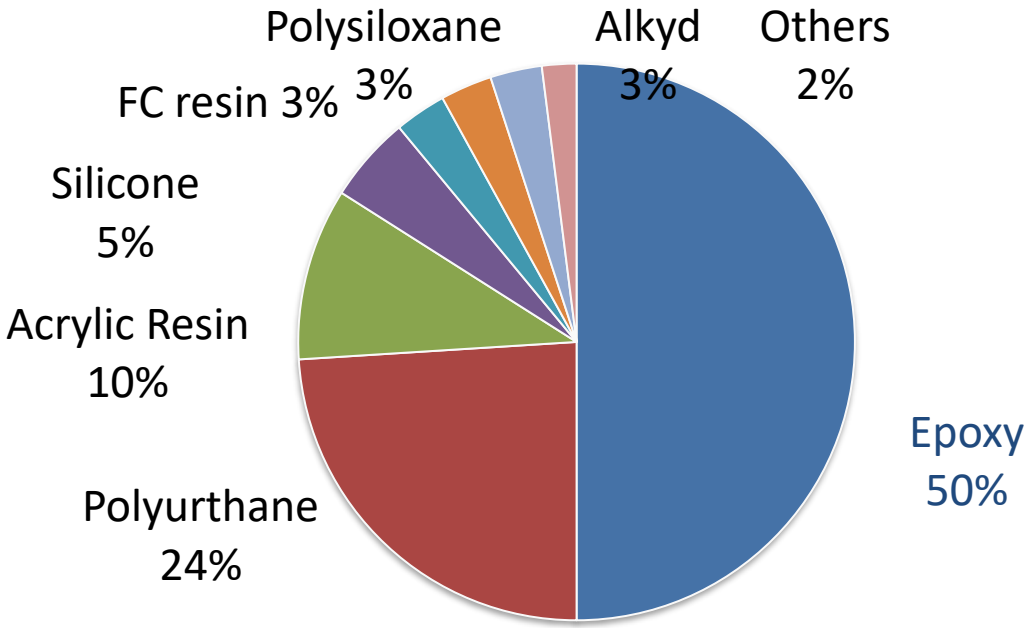
MARINE/HEAVY DUTY COATINGS & COATING SYSTEMS:

TECHNOLOGY & DEVELOPMENT

Typical Coating Technologies for Offshore Structures

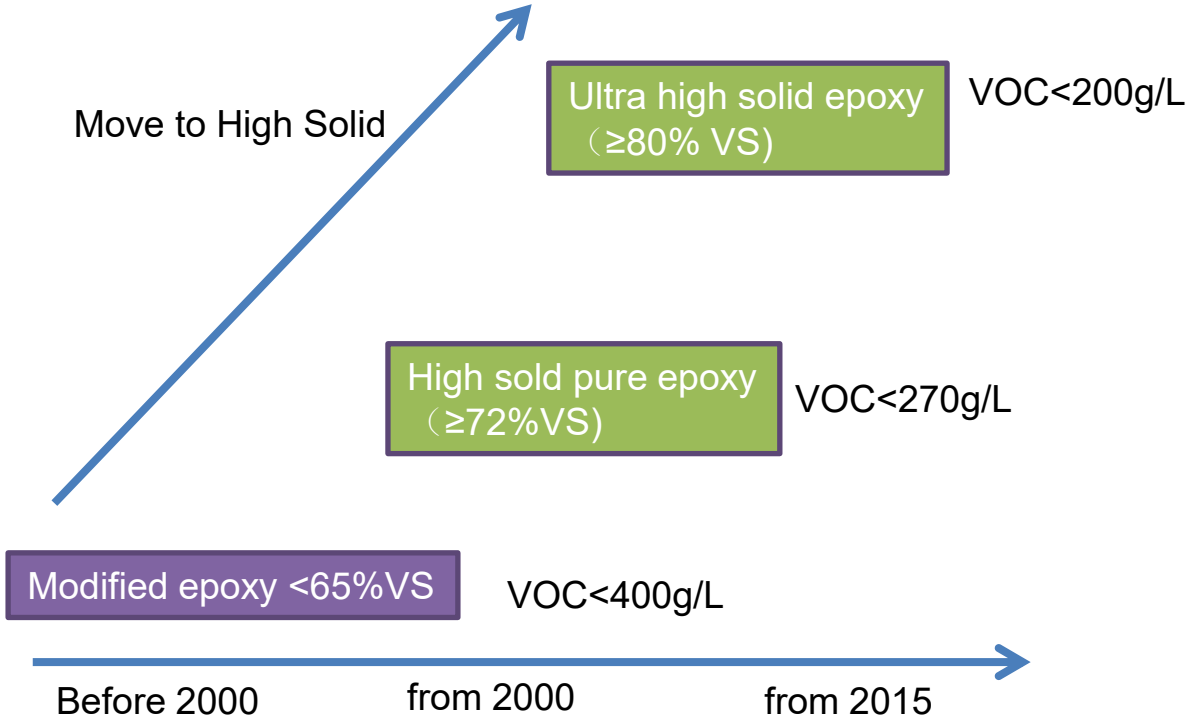
Coating Systems in M501	Protection Parts	Corrosion Category	Coating Technology
No 1	Steel structure in atmospheric environment (≤120° C)	CX	**Zinc-rich primer, epoxy intermediate coat, top PU coat**
No 2	Storage tanks, pipelines (>120° C) 2A Thermal sprayed aluminum or aluminum alloy or sprayed zinc	CX	**Aluminum powder silicone paint**
No 3A-3B	Internal surface of carbon steel storage tank body 3A (Potable water tank) 3B (Ballast tank)	Im4	**Solvent-free epoxy coating** **High-solids epoxy coating**
No 4	(Walkway, deck)	CX	**Anti-slip epoxy mortar coating**
No 5A No 5B	(Epoxy-based fireproofing) (Cement-based fireproofing)	CX	**Epoxy (zinc-rich) primer, epoxy intermediate coat, top coat**
No 6A-C	Stainless steel, galvanized steel	CX	**Epoxy zinc-rich primer, epoxy intermediate coat**
No 7A	Steel structure in splash zone	Im2 & Im4	**Epoxy, polyester (glass flake) coating (≥600μm)**
No 7B	Steel structure in full immersion zone	Im2 & Im4	**Epoxy, polyester (glass flake) coating (≥350μm)**

Key Resin Systems for Marine/Heavy-Duty Anti-Corrosion Coatings



Epoxy is Dominant Resin for Anti-corrosion Coatings

Development of Environmental-Friendly Technologies for Heavy-duty Epoxy Coatings



Green Heavy-duty Anti-Corrosion Coatings

Volume Solids	Classification	Typical VS %	VOC (g/L)
100%	Solvent-Free Epoxy	100	0
90-99%	Ultra-High Solids Epoxy	95	35
80-89%	High Solids Epoxy	80	200
70-79%	Medium Solids Epoxy	70	280-300
60-69%	Average Solids Epoxy	65	320-350
50-59%	Medium Solids Epoxy	55	>420
40-49%	Low Solids Epoxy	42	>500
~50%	Waterborne Epoxy	50	20-100

Low VOC
Green Coatings

Pros and Cons for High Solid and Solvent Free Heavy-Duty Anticorrosion

Coating Type	Pros	Cons
High-Solid Solvent-Borne (≥70% VS)	• Provides excellent long-term anticorrosion performance. • Currently the most common and widely adopted anticorrosive Tech. • Balanced performance.	• Still has VOC (200-300g/L); Relatively high viscosity; • Has a risk of cracking over time.
Solvent-Free Coatings	• Zero VOC, extremely eco-friendly; • Safe application in enclosed environment and in poor ventilation • The greenest option for heavy-duty marine use	• Fast reaction requires twin-pump spray or heating up; • Poor wetting on substrate and difficult to overcoat • Limited application currently.

Epoxy Glass Flake Coatings for Splash and Tidal Zone，Submerged Zone

- Technical Breakthrough: **using reactive diluents**, resulting in extremely low VOC emissions.
- Performance Advantages: **Solids can go up to 99%**, with significantly improved durability.
- Key Applications: **Splash zone protection** for offshore platforms and wind power facilities.


油气平台

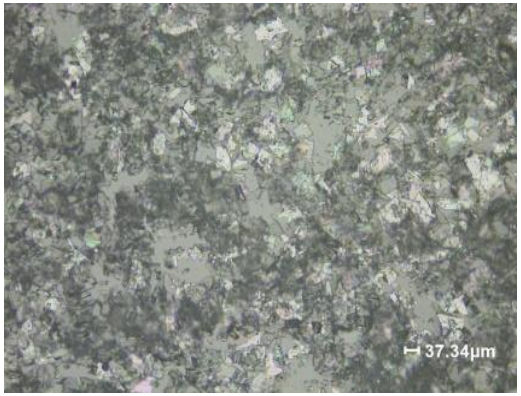

跨海大桥

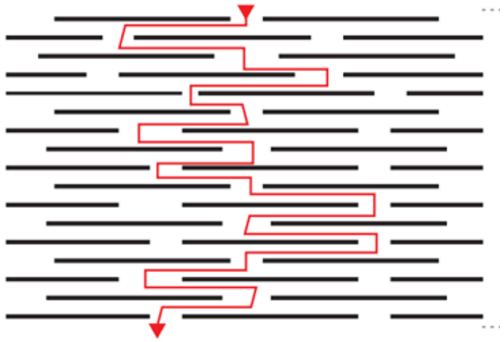

海上风电


船舶舰艇

Durable Epoxy Glass Flake Technology

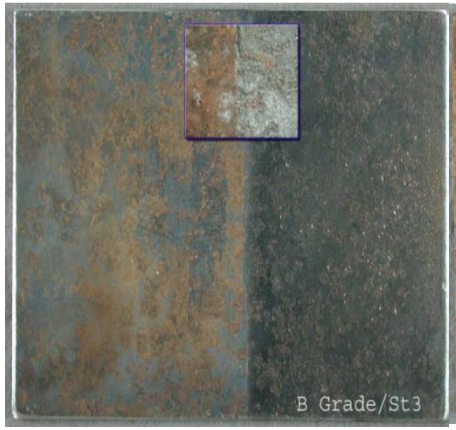
- Glass flakes with a specific length/thickness ratio at a defined proportion in a formulation,
- Zigzag path effect to block the ingress of water, oxygen, and salt.
- Performance: resistance to abrasion, to impact , to cyclic temperature and to cathodic disbondment.
- Solve Application Problems: Anti-settling, anti-sagging, and spray-friendly.
- **Extended service durability for harsh marine environments**
- Environmental friendly: High-solids and solvent-free.





Mainstream protection coating for Marine Splash/Tidal Zone

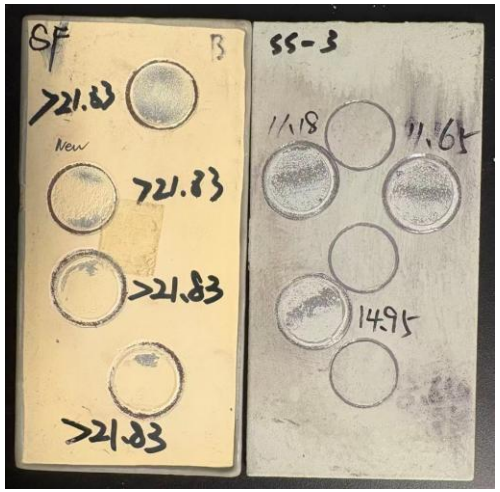
Surface Tolerant Epoxy Coating Technology for Onsite Maintenance & Repair



Rust grade B to ST3

Rust grade C to ST3

Rust surface abraded to St3 substrate for overcoating



Adhesion on Sa2.5 substrate

Adhesion on ST3 substrate

China Standard HG/T 4564-2013, Epoxy Coatings with High Tolerance to Inadequate Surface Preparation.

- On Sa 2.5 blast-cleaned surfaces, the adhesion strength between the coating and the substrate ≥ 21 MPa.
- On St 3 power-tool-cleaned surfaces，the adhesion strength between the coating and substrate is ≥ 11 MPa.

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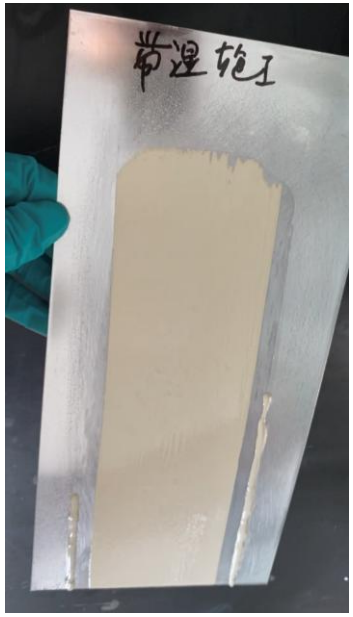
Surface Tolerant Epoxy Coating Technology for Onsite Maintenance & Repair

- Suitable for recoating onsite in harsh environment
- To be applied on damp surfaces and even cures underwater.
- Surface tolerant on St 3 substrate to provide a good adhesion.
- High-build and abrasion-resistant
- Can cure at low temperatures. 。

Moisture-tolerant Epoxy Coating Technology

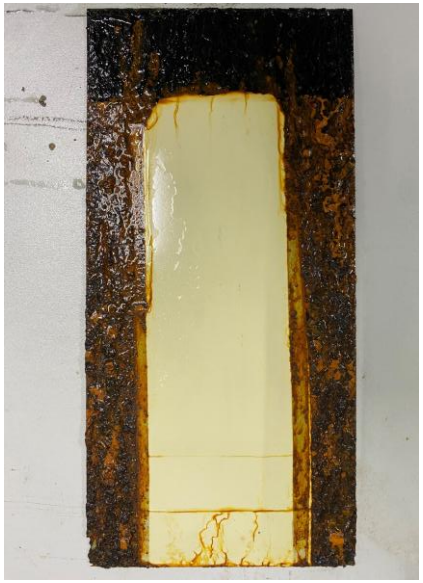
Spray water on substrate

Draw down coating on the Moisture substrate



Coated panel for testing

Moisture-tolerant Epoxy Coating Technology



Salt Spray 720h

Salt Spray 1000h

Salt Spray 1440h

the coating was cured underwater. Panels put to a neutral salt spray test. After 1440 hours of testing, **the coating remains intact with no signs of corrosion**. The uncoated edges of the panel are completely corroded.

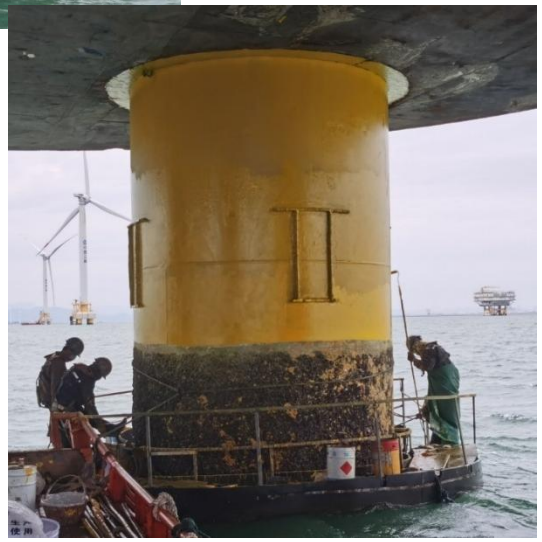
On-site Validation of Glass Flake Surface Tolerant Coatings for Offshore Wind Power

Offshore wind turbine
located in East China Sea

After 6 years in-service

Before M&R
Corroded
Splash and tidal Zone

Coating application
by roller



Finish After recoating

What Required to Enter Offshore Protection Market Pre-qualification as the 1st Key Step for Anticorrosion Coatings Per ISO 12944 and M501

01. Core of Pre-qualification

The pre-qualification process is the cornerstone of the M501 standard. It mandates paint manufacturers to undergo a rigorous screening before their products can be considered for project applications, establishing a fundamental threshold for market access.

02. Independent 3rd-Party Testing

Manufacturers must submit test reports issued by qualified, independent third-party laboratories. This eliminates conflicts of interest, ensuring that all evaluation data is generated from an unbiased and neutral professional perspective.

03. Application & Performance

The third-party verification system builds trust in product data. It strictly confirms that paints meet the demanding performance criteria of M501, guaranteeing reliability and consistency for critical infrastructure and project applications.

Key Takeaway: The M501 pre-qualification mechanism ensures only high-quality, compliant paint products enter the supply chain.

Certification and Qualification Requirements
Heavy-duty Anticorrosion Products

Rigorous Testing

Long testing for 4200 hours (6 months), ensuring thorough verification of material performance under extreme conditions.

Application & Sampling

Takes approximately 2 months for sample submission, report drafting and preliminary review procedures.

Certificate Issuance

The entire cycle from application to final certification approval takes a minimum of 8 months.

Table: Test Items and Testing Duration for Marine Corrosion Environment (CX/Im2/Im4) setup by ISO12944 and M501

Coating Area	Salt Water (h)	Cathodic Disbondment (h)	Adhesion (MPa)	Salt Spray (h)	UV Aging (h)	Cyclic Aging (h)
Offshore atmospheric Zone	-	-	⩾ 5	-	-	4200
Inland atmospheric zone	-	-	⩾ 5	2000	1000	-
Splash and Tidal Zone	-	4200	⩾ 5	-	-	4200
Full immersion zone	4200	4200	⩾ 5	-	-	-

Highlights: These extensive tests (6mth testing) ensure the highest standards for durability and performance in harsh corrosion environments.

Conclusions: The most desirable durable coatings for heavy-duty & marine protection

Core Requirements	Technical & Commercial Targets
Higher Durability and Optimized Cost	• Long-term and Reliable Corrosion Protection • Reduced Repair Scope • Improved Profit Margin
Improved Coating Application Efficiency	• Reduced Number of Coats • Application Friendly • Fast Drying and Low Temperature Curing
Lower Surface Treatment Costs	• Improved Surface Tolerant • Stronger adhesion and On-site Management
More Environmentally Friendly and Harmless	• Reduced VOC, High Solid Solution • Strict Limits on Hazardous Substances • Full Compliance with Relevant Regulations and Standards

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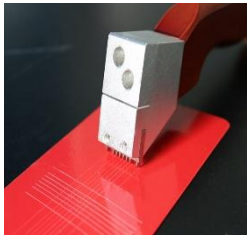

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THANK YOU

QUESTIONS， PLEASE!

敬请指导！