



Performance characteristics of protective coatings under low-temperature offshore conditions. Part 1: Experimental set-up and corrosion protection performance



A.W. Momber^a, M. Irmer^b, N. Glück^b

^a Muehlhan AG, Schlinckstraße 3, 21103 Hamburg, Germany

^b Fraunhofer Application Center for Large Structures in Production Engineering, Albert-Einstein-Straße 30, 18059 Rostock, Germany

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ABSTRACT

Six organic coating systems are investigated according to their performance under Arctic offshore conditions. Four performance groups are considered: corrosion protection performance, performance under mechanical loads, surface status and icing performance. The investigations involve the following tests: accelerated corrosion protection/ageing tests, tests for coating adhesion, hoarfrost accretion measurements, impact resistance tests, abrasion tests, and wettability tests. The test conditions are adapted to Arctic offshore conditions, which mainly cover low temperatures down to $-60\text{ }^{\circ}\text{C}$. A testing facility for hoarfrost performance tests is developed. The coating systems are organic coating systems which differ in generic coating material, hardener, number of layers, dry film thickness and application method. Part 1 describes the testing programme and discusses the results of the corrosion protection performance tests. Part 2 discusses the results of the surface topography measurements, wettability assessment, hoarfrost formation and mechanical testing. A procedure for the ranking of the coating performance is developed. The best performing system in the scope of evaluation is a three-layer system with high thickness ($1400\text{ }\mu\text{m}$), consisting of two glass-flake reinforced epoxy coats and a polyurethane topcoat.

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1. Introduction

Oil and gas exploration in Arctic regions is a future scenario for energy delivery. In due of this development, protective coating systems will face a number of challenges, mainly caused by the harsh environment. The environment is characterized by violent wind, high waves, very low air temperatures, infrared radiation, floating and pushing ice, rime and snow. The latter issues, in particular, will have effects on the performance of surface protection systems. It is known that steel corrosion will not be accelerated in low-temperature sea water (Melchers, 2002) or low-temperature atmosphere (Mikhailov et al., 2008), although the water may show increased oxygen contents. It is not an increase in corrosivity, but rather the question how surface protective coatings will respond to the harsh environment, that will determine the performance of organic coatings. This would specifically include the following items:

- corrosion protection capacity;
- icing and de-icing behaviour;
- response to mechanical loads.

In terms of corrosion protection capacity, the low air temperatures may be a special challenge to the coatings. Temperatures as low as $-60\text{ }^{\circ}\text{C}$ can be expected in Arctic regions. Standard testing scenarios for offshore coatings (ISO 20340, 2009; Norsok M-501, 2012) request air temperatures up to $-20\text{ }^{\circ}\text{C}$ only, and it is not known how organic coatings may perform at lower temperatures. The response to mechanical loads, namely to impact, will also be affected at low temperatures. It is known that the response of organic materials changes from plastic response to elastic, or elastic-plastic, response (Hainsworth and Kilgallon, 2008), and to higher rigidity modulus at low temperatures (Murase and Nanishi, 1985). This would, among others, induce a susceptibility to cracking (Bjoergum et al., 2011). Mechanical near-surface parameters, such as scratch hardness, are also affected at low temperatures (Hainsworth and Kilgallon, 2008). These modifications are also considerable for the entire system “substrate-coating”, which may react in a modified way if exposed to very low temperatures. A parameter describing this response is the adhesion strength between substrate and coating.

Icing and de-icing are crucial processes in terms of efficiency and safety of offshore structures (ISO 12949, 2001; ISO 19906, 2010; Ryerson, 2011). ISO 12949 (2001) distinguishes between two types of atmospheric ice: glaze and rime, whereby the formation of either ice type depends mainly on air temperature and wind speed. Glaze, which forms in the splash water zone, is caused by freezing water; it

E-mail address: momber@muehlhan.com (A.W. Momber).

features a high density and rather high adhesion/cohesion strength numbers. Rime typically forms in the atmospheric zone due to in-cloud icing; it has a moderate density, and it is usually vane-shaped. Another phenomenon is hoarfrost, which forms due to direct phase transition from water vapour into ice; it is common at low temperatures. Hoarfrost is of low density and strength (Fikke, 2006). On offshore platforms, either type of ice may be found. Although active icing prevention strategies, such as heating, are powerful, they cannot be used elsewhere on a platform. Passive icing prevention in terms of ice-phobic coating surfaces is a very attractive alternative. The same is true for anti-icing. Active methods, such as vibrations, heating or mechanical scraping, could be replaced or supported through coating surfaces that promote a weak adhesion to adhering ice (Antonini et al., 2011).

There are no studies known dealing with the above discussed problems in a systematic way, particularly not for offshore conditions. In due of a long-term (13 years) exposure study, Hattori et al. (1991) investigated the response of 12 coating systems on an Alaska site at temperatures between -25°C and $+16^{\circ}\text{C}$. The coating systems included inorganic zinc-rich paint, thermally sprayed zinc and aluminium, rubber, epoxies and polyurethanes. The authors measured adhesion strength, top coat chalking, coating thickness and steel corrosion. Coating deterioration due to freezing and thawing could not be detected, neither due to UV radiation. In terms of corrosion protection, the authors found that vinyl chloride and chlorinated rubber coatings did not perform well at low temperatures. Zinc-rich paints and zinc-sprayed coatings along with epoxy/polyurethane systems were found to perform suitably. The performance of high-performance composite coatings (HPCC), suitable for protecting pipelines, under a wide range of temperatures (-50°C to $+95^{\circ}\text{C}$) was investigated by Singh et al. (2005). The authors found that the impact resistance decreased with a decrease in temperature. Shore hardness, in contrast, increased moderately if temperature dropped. Coating flexibility was not affected in the temperature range between -30°C and -40°C . More recently, Bjoergum et al. (2011) investigated the behaviour of five coating systems under temperatures between -10°C and -60°C . They found that polysiloxane topcoats did not perform well under corrosive and mechanical load at low temperatures. Reinforced polyester coatings and vulcanized rubber performed better, whereas a conventional 3-layer system featured very high corrosion creep numbers. Regarding the adhesion strength of the coatings, the authors could not establish a proper trend, because some coating systems showed an increase in pull-off strength at lower temperatures, while others showed a decrease. Impact tests delivered good results, except for the polysiloxane coating. Indentation tests delivered an increase in hardness at lower

temperatures. Ice adhesion tests revealed definite relationships to coating system and temperature: rubber and reinforced polyester showed the highest values, and the values increased with a decrease in water temperature. An effect of the water composition (distilled water versus sea water) was also noted. None of these investigations considered offshore conditions.

It is the objective of this paper to systematically investigate, and to evaluate, the performance of organic coating systems suitable for standard offshore applications under simulated low-temperature offshore conditions.

2. Testing programme

2.1. Coating systems

Six organic coating systems with proven records for the protection of steel structures under offshore splash zone and offshore atmospheric zone conditions were selected for the investigations. Their basic compositions and properties are listed in Table 1. The systems included 1-pack and 2-pack systems. The 2-pack systems consisted of a resin (generic type) and hardener to be mixed together for curing. The 1-pack systems, in contrast, did not contain hardener, but cured due to moisture contained in the surrounding environment. The systems also included coatings with different hardeners and generic types; materials with and without fillers; different filler materials; low- and high-solid materials; and systems with different layer compositions. The total dry film thickness numbers for the systems ranged from $375\ \mu\text{m}$ to $1500\ \mu\text{m}$. The coating systems were supplied by diverse coating material manufacturers. All coating systems were applied according to the specifications of the suppliers. Steel substrates were prepared by blast-cleaning to a surface preparation grade Sa 2½ according to ISO 8501-1 (except system 1, which required Sa 2 only). The roughness of the substrates was between $R_z = 50\ \mu\text{m}$ and $75\ \mu\text{m}$.

2.2. Testing procedures

The testing procedures employed for this study are summarized in Table 2. They consisted of four testing groups, namely (i) corrosion protection, (ii) mechanical properties, (iii) surface status, (iv) icing.

2.2.1. Accelerated ageing test

The corrosion protection performance was investigated by means of an accelerated ageing procedure prescribed in ISO 20340 (2009) for offshore coatings. This procedure includes a combination of UV/condensation, salt spray, and low-temperature exposure cycles. The exposure

Table 1
Investigated coating systems.

System	Layer	Generic type (resin)	Hardener	Filler	Solids in vol.-%	Density in kg/l	DFT in μm
1	1	Epoxy	Polyamine	Glass flakes	88	1.34	400
	2						400
	3						400
2	1	Epoxy	Polyamine	-	79	1.60	175
	2						175
	3						175
3	1	Polyurethane	(moisture-hardened)	Zinc dust	65	2.80	50
	2	Polyurethane	(moisture-hardened)	-	72	1.40	150
	3						150
	4						150
4	1	Epoxy	Phenalkamine	-	95	1.50	500
	2	Epoxy	Amine	-	47	1.53	40
	3	Polyurethane	Isocyanate	-	57	1.21	75
5	1	Epoxy	Phenalkamine	Aluminium	60	1.23	150
	2						150
	3	Epoxy	Amine	-	51	1.34	75
6	1	Epoxy	Phenalkamine	-	95	1.50	500
	2						500
	3						500

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