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# Abrasion testing of organic corrosion protection coating systems with a rotating abrasive rubber wheel

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## ABSTRACT

The abrasive wear performance of six organic offshore coating systems is investigated at two temperature levels (0 °C and 20 °C) with a rotating wheel abrasion tester. The relationship between exposure time (in terms of number of revolutions) and coating thickness reduction follows a linear relationship:  $\Delta h = C_1 \cdot n_R + C_2$ . The reverse of the progress parameter ( $1/C_1$ ) is defined as abrasion resistance. This parameter is found to be sensitive to the testing temperature; it decreases for most of the coatings for the lower temperature. Combined SEM/EDX analyses reveal a number of material removal modes. The separation and pull-off of filler/pigment particles contribute notably to the material abrasion on all coating systems at the two temperature levels. Type, distribution and hardness of filler materials are important design parameters. A model of Bello and Wood (2005) [33] for filled polyamides is adapted and extended in order to systematically register different material removal modes. Image analysis is applied to quantify filler particle distribution and size.

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## 1. Introduction

Two promising scenarios for future energy delivery are the installation of offshore wind power farms and the exploitation of offshore oil and gas resources in the Arctic. Both scenarios provide challenges to protective coating systems, whereby a central one is the operation at low temperatures. Offshore wind power constructions in the North Sea and the Baltic Sea are frequently subjected to low temperatures, and this is even more pronounced for constructions operated under Arctic conditions. Mechanical damages to coatings are a critical issue in the offshore industry. Systematic inspections on offshore wind power constructions have shown that up to 40% of all coatings damages can be contributed to mechanical loads [1,2].

Abrasion deteriorates the performance of coatings, even if the coating is not fully abraded. Rossi et al. [3,4] noted a decrease in barrier properties if organic coatings were subjected to abrasion. Worn coatings also deteriorate aesthetic properties, namely gloss and color, of organic coatings [5], which is a serious safety issue for offshore operations. Yellow luminous signaling color is very important to offshore wind parks regarding visibility and collision risk [6]. Offshore regulations consider abrasion resistance as an

important design parameter, and recommendations how to test protective coating systems are provided [7]. Bjoergum et al. [8] performed limited tests on four organic coatings with a sliding alumina ball (10 N force, 5 cm/s sliding speed) at 0 °C. They noted a low resistance of glass-flake reinforced polyester compared with polyurethane and epoxy. A summary of related investigations is provided in Table 1. As can be seen, systematic investigations into the abrasion resistance of organic coatings, particularly at different temperatures, have not been performed. It is the objective of this paper to investigate and assess the performance of typical offshore coating systems, designed for corrosion protection, under abrasive load at two temperature levels, namely at a moderate temperature (20 °C) and a low temperature (0 °C).

## 2. Materials and experimental set-up

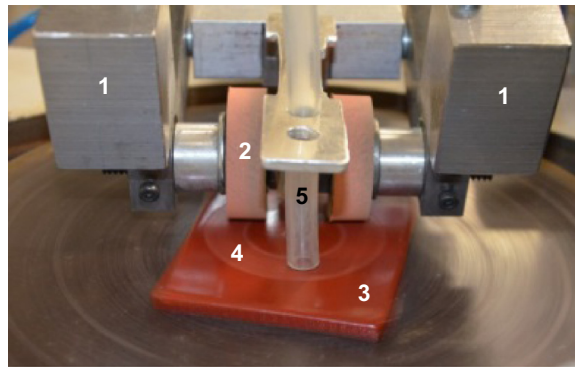
Six offshore coating systems were selected for the investigations. Their basic compositions and properties are listed in Table 2. They included 1-pack and 2-pack systems, coatings with different hardeners and generic types, materials with different filler materials, low- and high-solid materials, and systems with different layer compositions. The total dry film thickness numbers for the systems ranged from 375 μm to 1500 μm. The coatings were selected for offshore splash zone and offshore atmospheric zone conditions [15,16]. They were designed for high-strength

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**Table 1**  
Review of abrasive wear investigations on organic coatings.

Method	Coatings	Results	References
Rotating sand paper disc; 600 cycles; room temperature	Acrylic-melamine	Weight loss increases with cycles in a square-root mode Alumina particles improve abrasion resistance	[9]
Taber test; 1000 cycles; room temperature	Phenolic, epoxy, novalac	Filler material and resin chemistry determine resistance	[10]
Taber test with abrasive sand and electrolyte; 600 cycles; room temperature	Coil coatings (hot dip galvanized zinc + polyester)	Abrasion reduces pore (barrier) resistance	[11]
Taber test with abrasive paste; 1000 cycles; room temperature	Powder coating (epoxy polyester)	Abrasion reduces gloss	[5]
Taber test; rubber wheel with abrasive sand; 700 cycles; room temperature	Powder coating (epoxy polyester)	Thickness loss increases linearly with cycle number (small grit particles)	[12]
Taber test; 4000 cycles; room temperature	Powder coating (epoxy polyester)	Abrasion reduces pore (barrier) resistance Thickness loss increases linearly with cycle number Abrasion increases coating electrical capacity	[3]
Taber test; rubber wheel with abrasive particles; 2000 cycles; room temperature	Powder coating (epoxy polyester)	Abrasion reduces pore (barrier) resistance Abrasion reduces barrier resistance Coarser grit is more abrasive Round grit is less abrasive	[4]
Taber test; room temperature	Sol-gel films	Definition of Abrasion-Index Sol-gel owns high abrasion resistance	[13]
Taber test; room temperature	Clearcoats (isocyanate/polyol)	Abrasion reduces gloss Nano-silica increases abrasion resistance	[14]
Sliding test with alumina ball; 0 °C	Polyurethane, epoxy, polysiloxane	Polysiloxane has high abrasion resistance Glass flakes reduce abrasion resistance	[8]



**Fig. 1.** Set-up for abrasion resistance tests; 1-weight; 2-abrasive wheel, 3-coated specimen, 4-wear track, 5-suction nozzle.

**Table 2**  
Investigated coating systems.

System	Layer	Generic type	Hardener	Solids in vol%	Density in kg/l	DFT in $\mu\text{m}$	Roughness in $\mu\text{m}$	
							Ra	Rz
1	1	Epoxy	Polyamine	88	1.34	400		
	2							
	3							
2	1	Polyurethane	Aliphatic	67	1.29	400	0.6 ± 0.1	3.2 ± 0.4
	2							
	3							
3	1	Polyurethane	(moisture-hardened)	65	2.80	50	0.4 ± 0.05	2.4 ± 0.3
	2							
	3							
4	1	Epoxy	Phenalkamine	95	1.50	500	0.8 ± 0.2	4.1 ± 1.5
	2							
	3							
5	1	Epoxy	Amine	47	1.53	40	0.2 ± 0.05	0.9 ± 0.2
	2							
	3							
6	1	Epoxy	Phenalkamine	60	1.23	150	0.5 ± 0.1	2.5 ± 0.6
	2							
	3							

carbon-steel structures exposed to the corrosivity categories C5-M (atmospheric exposure) and Im2 (immersed exposure). All coating systems were applied according to the specifications of the

suppliers. Steel substrates were prepared by blast-cleaning [17]. The roughness of the substrates was between  $R_z=50\ \mu\text{m}$  and  $75\ \mu\text{m}$ . The surface profile parameters of the top coats were

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