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Performance characteristics of protective coatings under low-temperature offshore conditions. Part 2: Surface status, hoarfrost accretion and mechanical properties

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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°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 2 discusses the results of 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 μm), consisting of two glass-flake reinforced epoxy coats and a polyurethane topcoat.

4. Surface status

4.1. Surface profile

The results of the profile measurements are illustrated in Fig. 9 in terms of Ra and Rz. All numbers are integral numbers, averaged (arithmetic mean) over about 150 measurements each. The surfaces feature values between Rz = 1 μm and 5.3 μm. This corresponds to a 530% data range. All samples exhibit notable standard deviations, ranging from 0.04 μm to 0.25 μm. The large standard deviations characterize roughness to be a strongly localized parameter even at the small-size specimens. The primary reason is the different techniques and different equipment parameters used to apply the different coating materials.

4.2. Contact angle

Results of contact angle measurements are summarized in Fig. 10 for the wetting liquids used. These are integral numbers, averaged (arithmetic mean) over about 150 measurements each. All data for water are less than 90°. Therefore, all surfaces show a hydrophophilic behavior. The values range from $\theta_C = 80°$ to 86°, which is a 108% data range only. Thus, although the surfaces notably vary in surface profile, their contact angles vary in a very narrow band only. It can be concluded that – at least in the range of small roughness numbers – effects other than profile dominate contact angle formation. This fact is further illustrated in Fig. 11 showing relationships between surface roughness and contact angle for two coating systems. There is no definite trend between the two parameters. More advanced profile parameters, or profile parameter combinations, must be considered in order to install relationships between topography and wettability of engineering surfaces (Kubiak et al., 2011; Momber, 2012). Effects of local wettability are illustrated in Fig. 3 and Fig. 12. These results clearly show the limitations of an integral wettability evaluation. Contact angle is a strongly localized parameter, associated with the local geometrical and energetic situation. The graphs in Fig. 3 and Fig. 12 show "wettability topographies". Contact angle varied over the individual measurement fields. This particular problem will be investigated in a subsequent study. Fig. 13 shows results of the surface energy measurements. The numbers for the total surface energy range from 33.4 mN/m to 38.6 mN/m, which is the data range of 116%. This range is moderately higher than that for the contact angle values. Surface energy seems to be more sensitive to surface properties than contact angle. For all systems, the dispersive part dominates the energy. It covers between 87% (system 6) and 91% (system 2) of the total energy.

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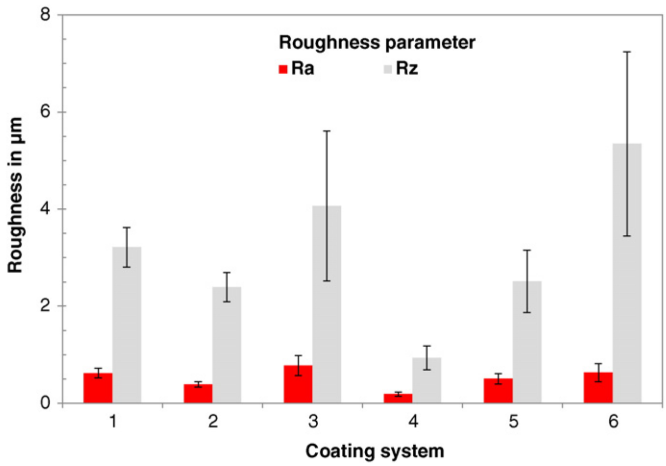

Fig. 9. Effect of coating systems on roughness parameters.

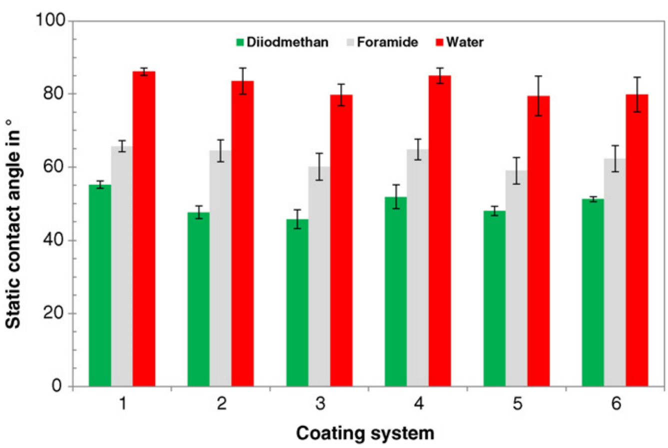

Fig. 10. Effects of coating system and wetting liquid on static contact angle.

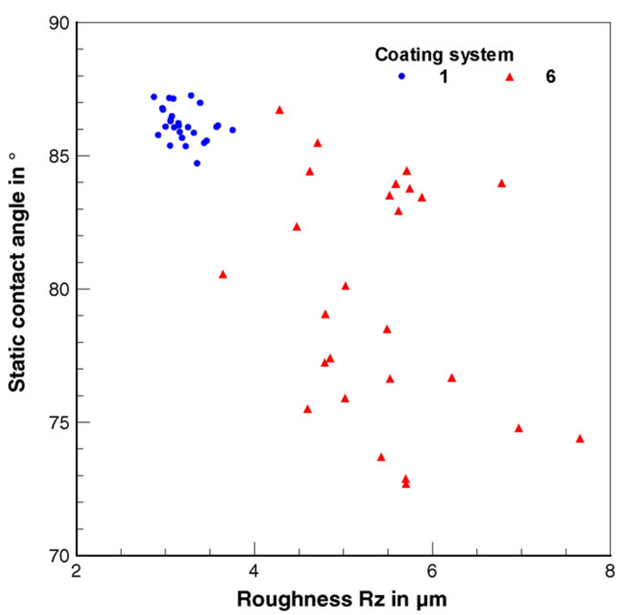

Fig. 11. Relationships between roughness and static contact angle for two coating systems. Each data point corresponds to a measurement field (see Figs. 3a and 12).

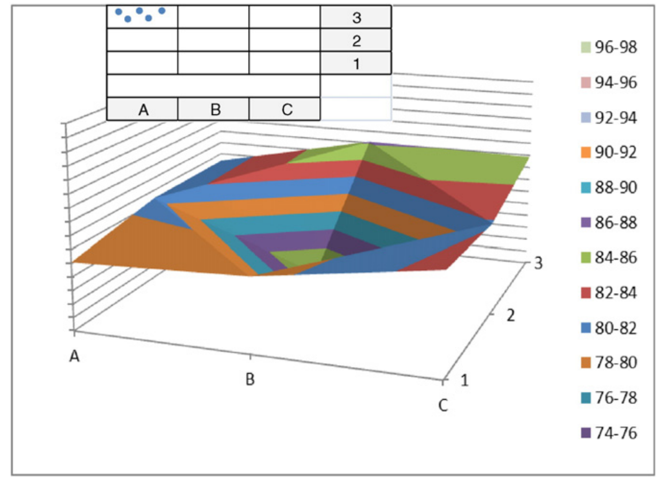

Fig. 12. Example of an inhomogeneous wettability topography; right column: static contact angle ranges (water) in °.

5. Hoarfrost accretion

Results of hoarfrost thickness measurements are provided in Table 5 and in Fig. 14. The images in Table 5 visually illustrate the development of the hoarfrost layers over time. Quantitative evaluations were not possible based on the images. Measured hoarfrost layer thickness values, plotted in Fig. 14, range from 180 µm to 425 µm, which is a 136% data range. Rather thick layers are found on system 3. There is a trend for polyurethane coatings to own slightly higher thickness numbers. All samples exhibit notable standard deviations in the range between 29 µm and 132 µm. With respect to other surface parameters, neither contact angle not roughness uniquely affects hoarfrost formation. Hoarfrost formation is not connected to liquid film formation, which would explain why contact angle is not a governing parameter. Again, hoarfrost thickness, as measured in this study, is an integral parameter and is not linked to the local situation of the test plates.

6. Mechanical properties

6.1. Impact resistance

Results of impact test results are provided Fig. 15. The critical energy numbers vary in a wide range between 5.3 J and >32 J. The latter number was the highest number to be realized with the testing equipment.

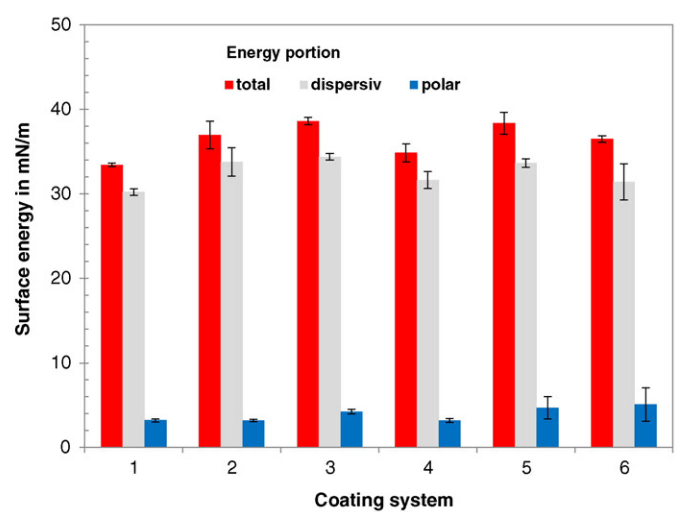

Fig. 13. Effect of coating systems on specific surface energy parameters.