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A comment on the impact resistance of organic offshore coatings at low temperatures

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ABSTRACT

The Communication reconsiders impact testing results on organic offshore coatings published in *Cold Regions Sci. Technol., 127 (2016), 109–114*. A contact mechanical approach, based on ball indentation, is applied to the problem in order to discuss the decrease in impact resistance at low temperatures. The approach covers qualitative trends and orders of magnitudes for the temperature-dependent impact resistance of organic coatings.

1. Introduction

Coatings protect structures exposed to low temperatures against numerous loads, namely corrosion, wear, impact, radiation and icing. In previous issues of this journal, the author and his co-workers have reported about investigations into the response of offshore coatings to impact loads (Momber et al., 2016a, 2016b) at varying temperature values (−60 to 20 °C). Although the authors could demonstrate that impact resistance decreased with a decrease in temperature, no hypothesis was delivered to explain the trend. It is the objective of this Short Communication to provide an explanation for the temperature-dependent impact resistance of the coatings.

The impact resistance tests in Momber et al. (2016a, 2016b) were performed according to ISO 6272-1 (2011) by means of a falling 2 kg-weight with a 20 mm tip diameter. The weight was dropped from different heights, which corresponded to different impact energies. Impact energy is simply given as follows:

$$E_I = m_B \cdot g \cdot H = \frac{m_B}{2} \cdot v_B^2 \tag{1}$$

In the equation, $m_B = 2$ kg is the mass of the impinging ball, H is the height of the weight fall, v_B is the ball impact velocity, and $g = 9.81\ m/s^2$ is the gravity. The impact height was successively increased in 5-cm-steps. All impact sites were visually evaluated by means of an optical stereo microscope at ×10 magnification. The failure criterion was the impact energy value (in J) that caused radial cracking in the coating system. The experimental set-up is in detail described in Momber et al. (2016a).

2. Impact site inspections

Different damage morphologies are displayed in Fig. 1 and in Table 1 for different coating systems at different temperatures. Inspections of the impinged sample surfaces revealed three damage types, which depended on the temperature for a given weight fall height. For a given temperature (Fig. 1), the damage type depended on the height of the weight fall. In Figs. 1 and 2, the damage types are categorized as follows: (i) plastic deformation, associated with material pile-up around the impact site (Figs. 2a and 1, lower left impact mark); (ii) elastic-plastic deformation and the formation of radial cracks (Figs. 2b and 1, upper impact mark); (iii) elastic-plastic response with lateral cracking and severe coating detachment (Figs. 2c and 1, lower right impact mark).

Fig. 2d to f illustrate deformation and fracture features in brittle thin glass coatings (Qasim et al., 2005; Rhee et al., 2001). More recently, these particular damage types are also reported for the ball indentation of thin brittle diamond coatings (Wang et al., 2014). The similarity between the damage morphologies of the organic coating systems and the glass coatings is obvious. The damage types can be categorized as follows:

(i) $E_I < E_Y$ → no damage
(ii) $E_I > E_Y$ → plastic response (Fig. 2a and d) [Fig. 2d actually shows the situation immediately before cracking, which occurred in the marked section (Rhee et al., 2001)]
(iii) $E_I > E_R$ → elastic-plastic response with radial cracking (Fig. 2b and e)
(iv) $E_I \gg E_R$ → elastic-plastic response with radial and lateral cracking (Fig. 2c and f)

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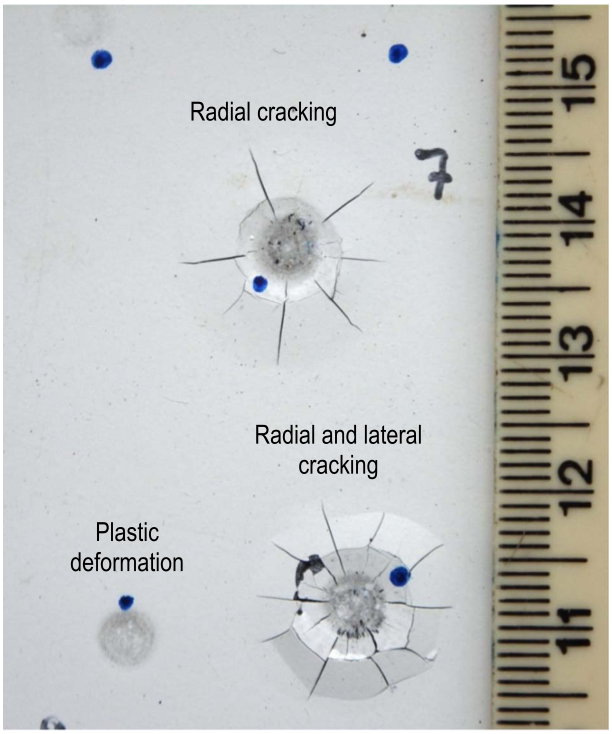


Fig. 1. Damage morphologies in coating system 5 at −20 °C (different weight fall heights); three different damage types can clearly be distinguished.

Here, E_I is the impact energy according to Eq. (1), E_Y is the energy required to introduce plastic deformation (yielding), and E_R is the energy required for the formation of radial cracks (= coating failure). The case (iii) corresponds to the impact resistance of the coating. Fig. 1 and Table 1 reveal that the cases (iii) and (iv) could be detected at the lower temperature levels.

3. Ball indentation

Based on the similar damage morphologies for polymeric coatings and glass coatings in Fig. 2, threshold criteria for deformation and fracture of brittle coating materials during ball indentation may be applied to discuss the results. Ball indentation test on thin brittle coatings reveal the following criterion for the initiation of radial cracks (Miranda et al., 2003):

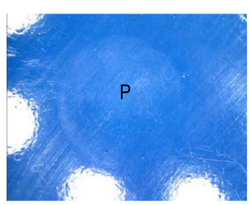
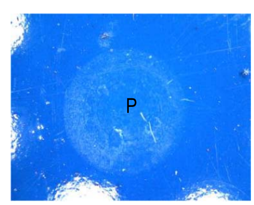
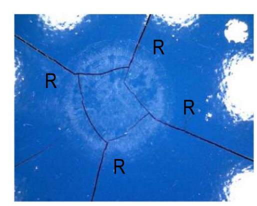
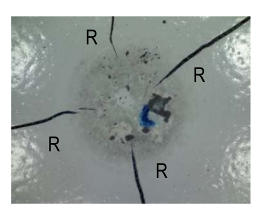
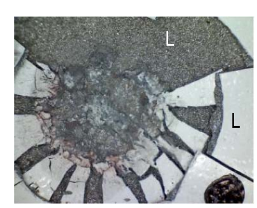
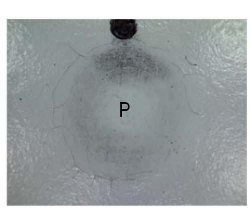
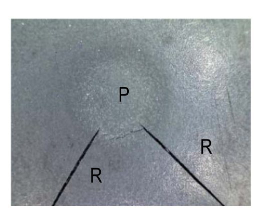
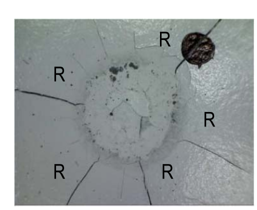
$$\frac{P_R}{P_Y} \propto \frac{\sigma_T}{H_C} \tag{2}$$

Here, P_Y is the indentation load required for plastic deformation, P_R is the threshold indentation load for radial crack initiation, H_C is the coating hardness, and σ_T is the tensile strength of the coating material. With $P \propto v_B^{6/5}$ (Knight et al., 1977; Momber, 2008) and introducing Eq. (1), the relationship can be rewritten as follows:

$$\frac{E_R}{E_Y} \propto H_C^{-5/3} \tag{3}$$

If the ratio is larger than unity, the response is plastic (no failure), and if the ratio is smaller than unity, the response is elastic-plastic (failure). If coating hardness decreases, higher impact energy is required to form radial cracks (failure).

Table 1
Effects of testing temperature on damage morphologies ("P" denotes plastic deformation; "R" denotes radial cracking; "L" denotes lateral cracking).

Coating system[a]	Weight fall height	Temperature in °C		
		+20	−20	−60
4	30 cm			
5	40 cm			
2	50 cm			

[a] Coating system numbers correspond to numbers in Momber et al. (2016a).

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