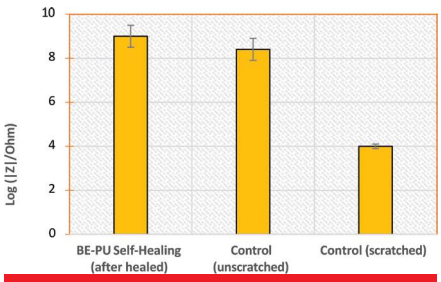

FIGURE 4 EIS testing for control and BE-PU self-healing coating.

Salt Spray Corrosion Resistance Test: The researchers tested the corrosion resistance of the self-healing and control coatings by exposing them to continuous salt spray for 3,000 h. The coatings were scratched with an X-cut pattern and then placed in the salt spray chamber at 35 °C, with the self-healing coatings undergoing a 24-h healing process before exposure.

Result: After 3,000 h, the control coatings showed severe rusting at the scratched areas. In contrast, the self-healing coatings showed no rusting, indicating that the healing process effectively restored the protective barrier and prevented corrosion. The self-healing coatings achieved a 97% healing performance after 24 h, with the scratch depth significantly reduced from 301 µm to 8 µm (Figures 5 and 6).

Cyclic UV/Salt Spray Test: To simulate real-world exposure conditions (sunlight and rain), the coatings were subjected to alternating UV and salt spray cycles for 4,200 h. The UV exposure was conducted for one week, followed by one week of salt spray exposure, to mimic the environmental conditions experienced in offshore oil and gas applications.

Result: The self-healing coating showed no signs of rust, blistering, or delamination after 4,200 h, demonstrating its outstanding durability under harsh conditions. On the other hand, the control coatings showed slight blistering, suggesting the self-healing coating's superior long-term performance.

"The self-healing reaction has remained effective even after 4,200 h of cyclic UV/salt spray, indicating that the technology is highly reliable under conditions that would typically challenge conventional coatings," Norfadilah says.

Adhesion Test: To evaluate how well the self-healing coating adhered to the substrate, the researchers performed a pull-off adhesion test according to ASTM D4541. The self-healing coating was scratched, healed for 24 h at 60 °C and 80% RH, and then subjected to the adhesion test.

Result: The self-healing coating showed strong adhesion to the substrate, with adhesion strength values higher than the minimum requirement of 300 psi. The adhesion strength was comparable to that of the control sample, indicating that the self-healing coating remained stable and intact after healing (Figure 7).

Abrasion Test: The abrasion resistance of the self-healing coating was tested by subjecting it to 1,000 cycles of wear with a 1,000-gram load on an abrasion tester. The weight loss of the coating was measured before and after the test to evaluate its mechanical durability.

Result: The self-healing coating exhibited significantly lower weight loss compared to the control coating, demonstrating superior abrasion resistance. The weight loss was well below the PETRONAS internal standard of 150 mg per 1,000 cycles, confirming the self-healing coating's excellent wear resistance (Figures 8 and 9).

FIGURE 5 Condition of control and BE-PU self-healing specimens after 3,000 h of long-term salt spray exposure testing.

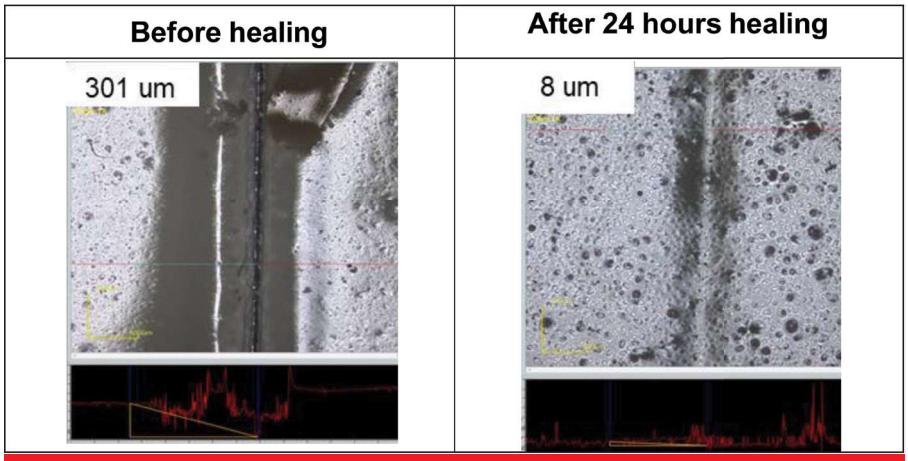

FIGURE 6 Healing performance of BE-PU self-healing specimen before and after 24 h.

Real-World Applications

The durability of self-healing coatings in real-world applications can vary significantly based on a multitude of factors, such as the specific type of

FIGURE 7 Condition of control and BE-PU self-healing specimens after 4,200 h of cyclic UV and salt spray tests testing.

coating being used, the environmental conditions to which the coating is exposed, and the inherent characteristics of the surfaces onto which the coatings are applied, Norfadilah says.

Generally, self- healing coatings are designed to provide a lifespan that can range from several months to multiple years, depending on these influencing elements. In more stable environments, where conditions are less demanding, the longevity of these coatings may be notably extended. Conversely, when self-healing coatings are subjected to severe conditions, their lifespan can be significantly compromised. To maximize the performance and durability of self-healing coatings, consistent maintenance and correct application methods are crucial.

"By adhering to best practices in application and maintenance," Norfadilah says, "users can ensure that self-healing coatings deliver their intended benefits, providing effective protection for an extended period.

The researchers will continue to rigorously examine and enhance the chemical formulation of these coatings, with the primary goal of maximizing their healing efficiency, longevity, and resistance to various environmental factors. This involves not only refining the existing formulations but also exploring innovative materials and additives that can contribute to improved performance.

"To facilitate the successful commercialization of this technology, we intend to collaborate with industries that could benefit from the application of self-healing coatings such as paint manufacturers, asset owners, and additive manufacturers," Norfadilah says. "This collaborative approach will enable us to tailor our formulations and application methods to specific use cases, ensuring that our self-healing coatings provide maximum value and effectiveness in real-world applications." MP

FIGURE 8 Adhesion strength of control and BE-PU self-healing.

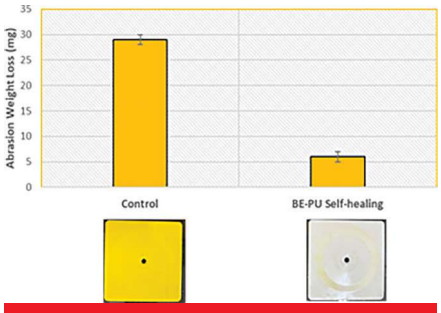

FIGURE 9 Abrasion test of control and BE-PU self-healing.