

Long-Term Performance of a Subsea Wet Insulation Material at 180 °C Continuous Operating Temperature

Eileen Wan
Shawcor Ltd.
25 Bethridge Road
Toronto, Ontario, M9W 1M7
Canada

Espen Ommundsen
Norner Research AS
Asdalstrand 291
NO-3962 Stathelle
Norway

ABSTRACT

As subsea oil and gas exploration goes to deeper water depths, there is a greater need for pipeline wet insulation materials capable of withstanding higher operating temperatures, >150 °C. At these extreme temperatures, the list of suitable polymeric materials is limited. One such material has been assessed in long-term tests for 12 months at elevated temperature and pressure in seawater, according to ISO 12736, as well as 12-month nitrogen exposure tests at elevated temperature. The performance of this new material under this harsh exposure regimen is presented and evaluated.

Key words: high temperature, subsea wet insulation, polyphenylene sulfide, exposure testing, long-term performance, HPHT

INTRODUCTION

As more conventional reserves are depleted, there is an increasing drive to develop challenging high-pressure high-temperature (HPHT) subsea oil and gas reservoirs, which has created a need for subsea pipeline insulation coatings designed to withstand higher operating temperatures for transport of the extracted fluids. For HPHT projects found in deepwater and ultra-deepwater regions, it is preferred for the insulation coatings to be 'wet' coatings, i.e. suitable for direct contact with the surrounding seawater, due to the challenges with installation of alternative heavy pipe-in-pipe systems.

Polypropylene-based wet insulation coating systems have a long track record; they have been utilized for design temperatures of up to 155 °C¹ and are generally accepted for temperatures of up to 300 °F², about 150 °C. There is a need to identify alternative materials with similarly good insulating properties,

mechanical robustness suitable for pipeline installation and handling, and the ability to withstand long-term exposure to temperatures $>150\text{ }^{\circ}\text{C}$ in a subsea environment at water depths of up to 3000 m.

One such material is a modified polyphenylene sulfide (PPS) which has a thermal conductivity of about 0.20 W/mK in the unfoamed state, tensile strength of $>30\text{ MPa}$, and an elongation to break of $>50\%$ strain. Unmodified PPS is known as a high strength material with very good thermal oxidation and chemical resistance but typically low ductility (i.e. $<5\%$ elongation to break).³ To overcome this limitation, an impact-modifier was introduced to provide the needed ductility required during subsea pipeline installation activities. While high temperature polymers are generally much more expensive than commodity resins, such as polypropylene, when utilized as a thermal barrier layer in combination with standard polypropylene based systems, this PPS-based material enables a low-cost subsea wet insulation solution for operating temperatures of at least $180\text{ }^{\circ}\text{C}$ that can be installed via the reel-lay method.

In order to evaluate the risks associated with utilizing this PPS-based material over the typical required lifespan of a subsea insulation coating, 20-30 years, it has been subjected to long-term exposure testing under the worst case scenario of direct contact with hot pressurized seawater at $180\text{ }^{\circ}\text{C}$ and 30 MPa hydrostatic pressure for a period of 12 months, to evaluate for potential failure modes, as per ISO⁽¹⁾ 12736:2014.⁴ Additional exposure testing under conditions more representative of the typical expected service condition, a hot and dry exposure at $180\text{ }^{\circ}\text{C}$ under a deoxygenated atmosphere, has also been performed for a period of 12 months for comparison. This paper presents the results and interpretation of these exposure tests.

EXPERIMENTAL PROCEDURE

Modified PPS samples for exposures were unfoamed injection moulded pieces consisting of 4 mm thick ISO 527-1B dumbbells, 50 mm x 50 mm rectangular prisms at thicknesses of 4 mm and 8 mm, and circular discs 12.5 mm in thickness and 50 mm in diameter.

Hot/Wet Exposures

Hot and wet exposures were performed as per ISO⁽¹⁾ 12736:2014⁴, Clause 7.2, in specialty pressure vessels capable of long-term high pressure and temperature operation. Exposures were performed under hydrostatic conditions in simulated seawater prepared in accordance with ISO⁽¹⁾ 15711.⁵ Dissolved oxygen content of the test fluid was measured at each vessel closing and opening and was typically 8-9 ppm at vessel closing and $<2\text{ ppm}$ at vessel opening. The exposure media was replaced at each vessel opening. Exposure temperatures of 4, 150, 165, and $180\text{ }^{\circ}\text{C}$ were evaluated. For each vessel opening, a set of dumbbell specimens was removed for analytical and destructive testing. In addition, rectangular prism samples were removed, evaluated for dimensional and weight changes, and then returned to the vessel for continued exposure. Circular disc samples were removed, evaluated for thermal conductivity, and then returned to the vessel for continued exposure. At $4\text{ }^{\circ}\text{C}$ exposure, only rectangular prism samples were evaluated.

Hot/Dry Exposures

Hot and dry exposures were performed in a static nitrogen environment in specialty sealed vessels at a temperature $180\text{ }^{\circ}\text{C}$ under a slight overpressure of 0.04 MPa. Residual oxygen content was measured to be $<1\text{ ppm}$. For each vessel opening, a set of dumbbell specimens was removed for analytical and destructive testing. Circular disc samples were removed, weighed, measured for dimensions, evaluated for thermal conductivity, and then returned to the vessel for continued exposure.

Specimen Analyses

Specimens were analyzed for tensile properties at ambient temperature as per ISO⁽¹⁾ 527 at 2 mm/min for modulus and 50 mm/min to rupture.⁶ Shore D hardness was measured on tensile dumbbell tabs as per ISO⁽¹⁾ 868.⁷ Weight change over time was measured on rectangular prism samples by weighing, immediately after removal from the exposure media and patting dry, to the nearest 4th decimal place. Volume measurement of the samples was then performed via densimeter as per ISO⁽¹⁾ 1183.⁸ Dimensional measurements were performed with calipers. Thermal conductivity was tested on the circular disc samples as single thickness tests as per ISO⁽¹⁾ 8301 utilizing a Fox 50⁺ instrument at 23 °C.⁹ As there was a risk for changes to sample surface condition or warping of specimens over time during long term exposure tests, which may have affected measurements as per ISO⁽¹⁾ 8301⁹, parallel thermal conductivity tests utilizing a Hot Disk Transient Plane Source⁺ instrument as per ISO⁽¹⁾ 22007-2 were also performed to confirm the observed trends.¹⁰ DSC analysis was performed on specimens taken from exposed dumbbells according to ISO⁽¹⁾ 11357-3 at heating and cooling rates of 10 °C/min.¹¹ DMA analysis was performed on specimens taken from exposed dumbbells according to ISO⁽¹⁾ 6721 in single cantilever mode at 2 °C/min, 1 Hz, and 0.05% strain.¹² Scanning electron microscopy, at 15 kV acceleration voltage with a back-scatter electron detector, and FTIR analysis, on 20 µm thick microtomed slices with an aperture of 100 x 100 µm, were performed on small specimens taken from the edges of circular disc samples.

RESULTS AND DISCUSSION

In evaluating the expected long-term performance of a modified-PPS material for service as part of a subsea wet insulation system, the strategy provided in ISO⁽¹⁾ 12736:2014⁴ was followed, which presents a means of evaluating long-term performance via failure mode and risk analysis.¹³ Collection of data for small-geometry material samples under exposure to a conservatively harsh, hot and wet, environment is meant to simulate a worst-case scenario of hot, wet, and deoxygenated conditions. Test results allow for the identification of potential material failure modes under those circumstances.

Collection of data for small-geometry material samples exposed under dry, deoxygenated conditions was additionally performed, which is more representative of normal service where underlying hot material is protected from direct contact with seawater by outer jackets and cold surrounding material layers.

Material Response to Exposure – Potential Effects of Exposure in Operation

The effect of exposure over time at 180, 165, 150, and 4 °C in simulated seawater under 30 MPa of hydrostatic pressure on physical and mechanical properties is found in Figure 1. Results demonstrated that, under these conditions at elevated temperature, there was an initial change in the material which then stabilized after some time; at 180 °C this stabilization of properties occurred after ~3-6 months and the rate of change slowed at 165 and 150 °C. The nature of the change was an increase in the mechanical strength of the modified PPS material, with some increase in modulus, and reduction in ductility that stabilized at a measured elongation to break of >20 % strain. There were only minor changes to the material weight or volume at elevated temperatures although the shape of the curve indicates some initial water uptake/swelling followed by leaching. Pressurized water exposure at ambient seawater temperature, 4 °C, resulted in no measurable sample volume change and <0.3 wt.% water uptake.

Visually, the material was not changed as a result of the exposure, as seen in Figure 2, which presents dumbbell samples after wet hydrostatic exposure at 180 °C and destructive tensile testing. As can be seen by the nature of the tensile rupture, which showed some local necking near the point of failure, the failure mode remained ductile. The modified PPS material is shown to be hydrostable and non-hygroscopic.

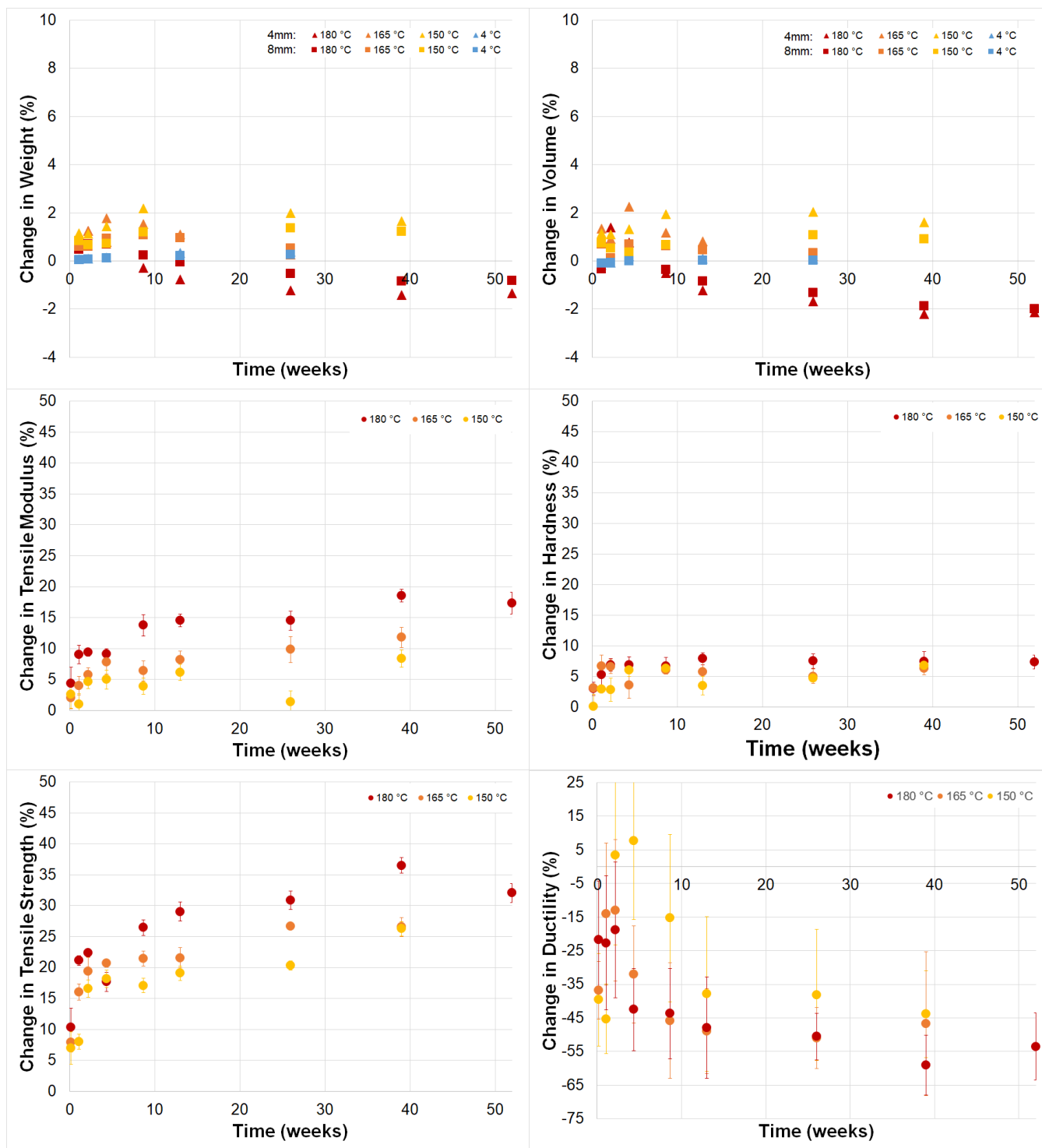


Figure 1: Change in Physical/Mechanical Properties with Time Under Direct Hydrostatic Thermal Exposure