Degradation mechanisms of Arctic offshore topsides equipment: Risk based inspection perspective*

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Introduction

As oil and gas companies in the Arctic attempt to maximize the value of each project and optimize their portfolio of investment opportunities, it has become vital to evaluate the integrity of topsides static mechanical equipment. Effective and regular inspection activity play a crucial role in avoiding business interruption and, reducing the risk of failure. It provides a knowledge about the condition of the topsides static mechanical equipment. In addition, it helps to keep a plant in "as-built" condition and consequently continuing to have its original productive capacity [1]. Increasingly, innovative asset integrity strategies such as risk-based inspection (RBI) methods and tools are being implemented to meet these goals. RBI, in general, is a process that identifies, assesses and maps industrial risks, which aids in the identification of high priority items (i.e., those with high risk) vs. low priority items (i.e., those with low risk). The main aim of RBI tool is to achieve safe operating conditions at minimum inspection cost, and protect human life and the environment from any possible damage during operation.

When we operate in Arctic region, however, it is prudent to accept that operational loads may vary beyond design levels, and that material degradation may be greater than anticipated. Moreover, degradation mechanisms (failure modes) in cold climate are different comparing with 'normal' operating environment. The safety factors used at the design stage may not, therefore, guarantee through-life plant integrity [2]. Hence, probabilistic consideration of the ''peculiar'' mode of failures, due to the Arctic condition, as additional risk, should be carried out to determine the most probable levels of damage, and to check the adequacy of the design loads and resistance values. Further, there are no specific standard/ recommended practices for carrying out RBI analysis for equipment operating in the harsh Arctic conditions. RBI strategies, especially in Arctic region, must take account of the risk of equipment failure due to icing phenomenon and low temperature, in addition to the 'conventional' risk of equipment failure; that is, both the probability of failure and its consequences have to be considered. Using traditional RBI approaches to equipment operating in the harsh Arctic conditions, risk tends only to be considered implicitly. There is thus a real concern that high-risk and low-risk areas may not be clearly identified. This may then mean that low-risk areas are monitored to an excessively high level which leads to needlessly high inspection costs, while high-risk areas may not all be afforded sufficient attention and priority. Without the explicit consideration of risk, it may not therefore be possible to demonstrate that the equipment integrity of the plant has been satisfactorily characterized.

This article discusses the peculiar modes of failure in the Arctic climate and, suggests solutions to fill the gaps that are available in the current RBI practices.

Peculiar modes of failure in the cold Arctic climate

A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent [3]. Examples of potential failure modes include corrosion, embrittlement, torque fatigue, deformation/ buckling (due to compressive overloading), cracking/ fracture (due to static overload, the fracture being either brittle or ductile), failure due to the combined effects of stress and corrosion, failure due to excessive wear, etc.

The peculiar operational conditions of the Arctic, such as ice and snow, cold temperature, polar low, snowdrift, etc. will cause significant challenges if inspection/ maintenance is needed. For instance, many materials experience a shift from ductile to brittle behaviour if the temperature is lowered below a certain point. The temperature at which this shift occurs varies from material to material. It is commonly known as the "ductile-to-brittle-transition" temperature (DBTT), or the "nil-ductility transition" temperature [4]. Further, low temperatures can adversely affect the tensile toughness of many commonly used engineering materials. Tensile toughness is a measure of a material's brittleness or ductility; it is often estimated by calculating the area beneath the stress-strain curve [4]. Ductile materials absorb significant amounts of impact energy before fracturing, resulting in tell-tale deformations. Brittle materials, on the other hand, tend to shatter on impact. Materials with high ductility (i.e. a tendency to deform before fracturing) and high strength have good tensile toughness [4]. Depending on the material, tensile toughness can be very sensitive to temperature changes.

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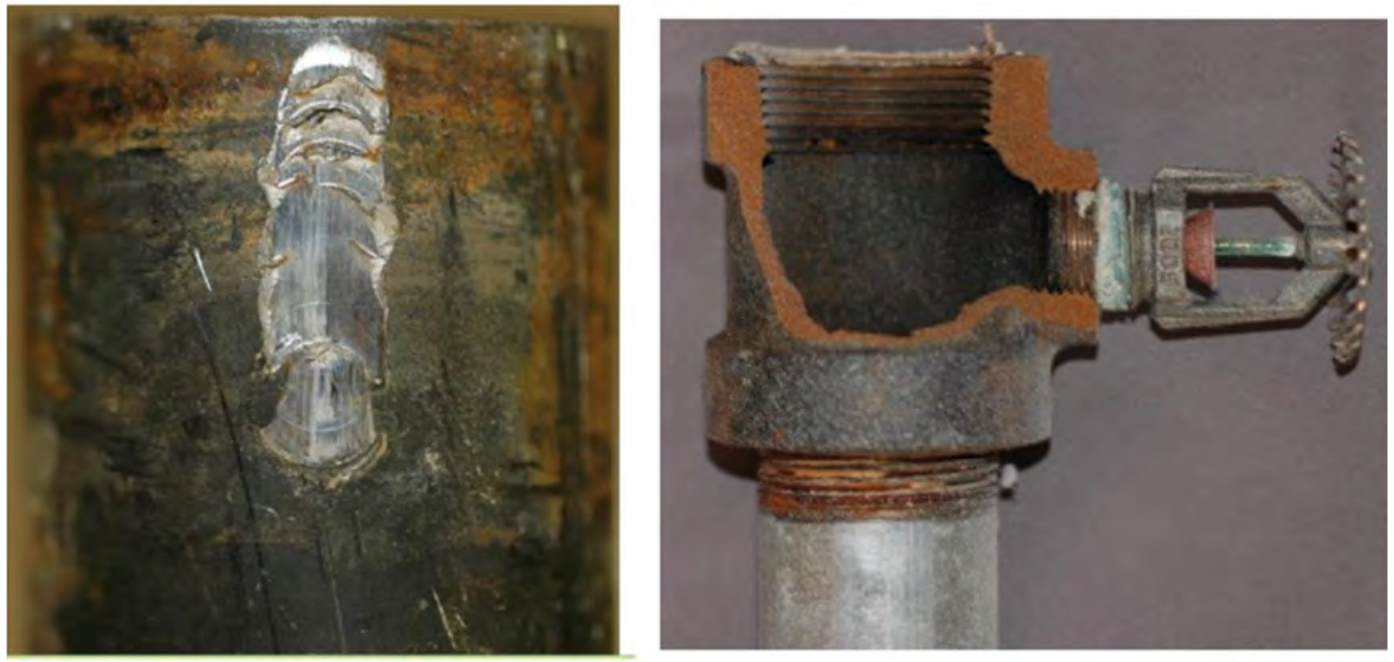

Figure 1. Freeze-up failure. Source: Crane Engineering 2014

The peculiar modes of failure in the cold Arctic climate are (but not limited to):

- *Freeze failure:* Freeze failures is a component failure due to volumetric expansion of freezing water (Fig. 1). Freeze failures often yield multiple cracks. Crack initiations generally are critical and need timely detection. Freeze-up failure can induce large-scale deformation. The main factors that affect the crack/fracture of a material in cold climate are:

- *Low temperature.* For instance, steel may behave as a ductile material above, say, 0°C but below that temperature, it becomes brittle. Embrittlement of steel, plastic and composites causing failures at loads that are routinely imposed without damage in warmer climate.
- *Thermal shock.* Occurs when a thermal gradient causes different parts of an object to expand by different amounts.

Figure 2. Cavitation failure. Source: Corvias

- *Cavitation failure:* Cavitation is caused by the presence of gas bubbles under high pressure being suddenly subjected to a low pressure. In general, there are two principal types of cavitation: vaporous and gaseous. Vaporous cavitation is an ebullition process, which takes place when the bubble grows explosively in an unrestrained manner as liquid rapidly changes into vapour [5]. On the other hand, gaseous cavitation is a diffusion process, which occurs if the pressure falls below the saturation pressure of the non-condensable gas dissolved in the liquid.

In cold climate, extremely low temperature causes many fluids to congeal, which means that it cannot flow through mechanical systems efficiently. This fluid immobility can starve a pump, which causes potentially harmful vaporous cavitation in the system. Further, cavitation failure also results in high fluid and mechanical friction, as well as lubricant starvation for bearing surfaces. Fig. 2 shows the impact of extremely low temperatures wreak havoc on mechanical systems.

- *Freeze-thawing failure:* The other peculiar mode of failure in the cold climate is the freeze-thaw failure. The freeze-thaw conditions cause random cracking, surface scaling and joint deterioration. Fig. 3 illustrates the process of freeze-thawing failure.

- *Fretting wear failure:* Cold climates cause failure of lubricant to perform adequately, thereby resulting in increased wear rates. Increased loss of lubricants and coolants can cause fretting wear. In general, fretting is a wear phenomenon that occurs between two contacting surfaces; initially, it is adhesive in nature and vibration or small-amplitude oscillation is an essential causative factor [6].

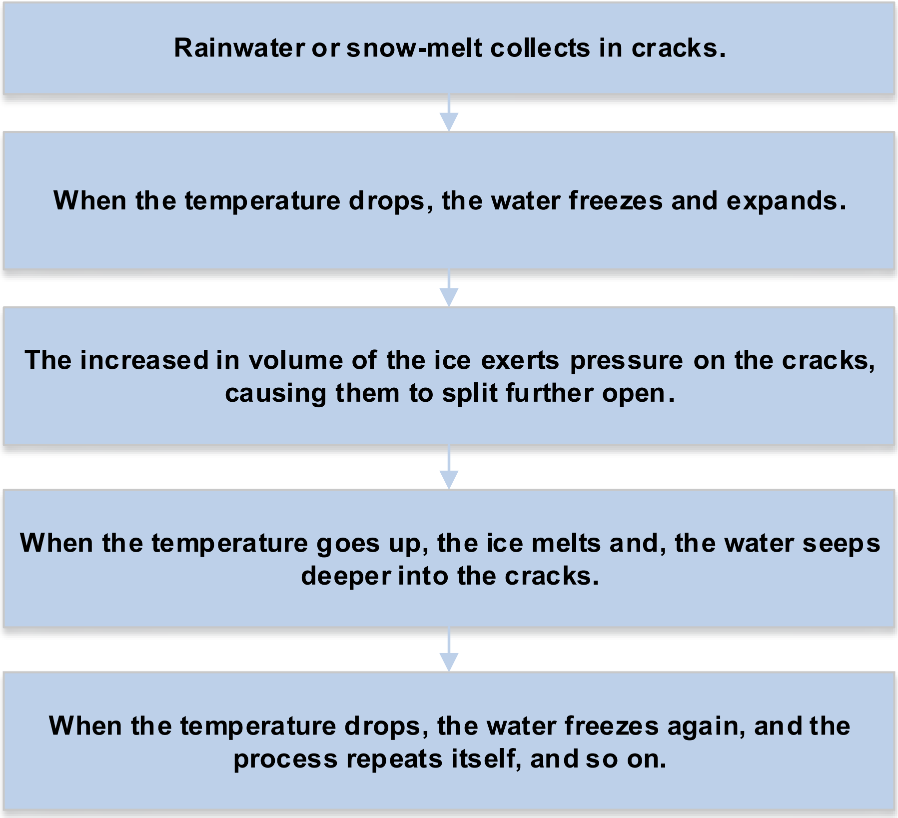

Figure 3. Freeze-thawing failure process

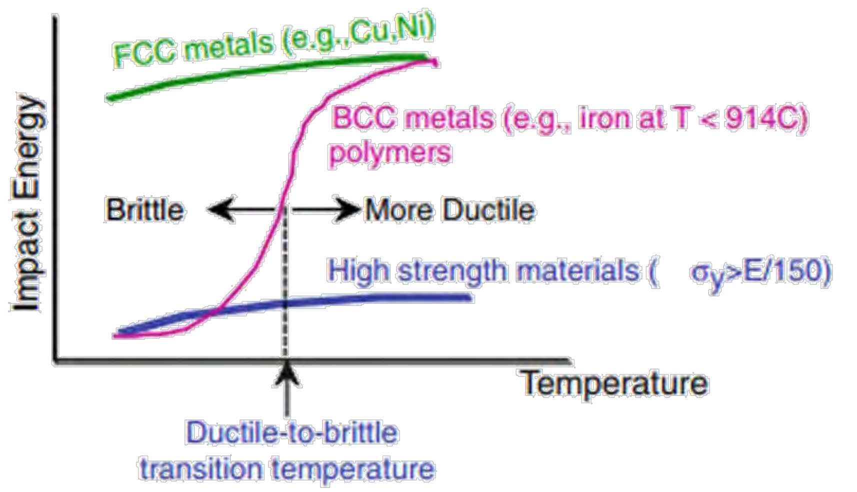

Figure 4. DBTT curve. Source: Callister and Rethwisch [7]

Proposed solutions

- ***Selecting proper alloys:*** The transition temperature of steel is affected by the alloying elements in the steel. For instance, manganese (Mn) and nickel (Ni) reduce the transition temperature. Thus, for low-temperature work, a steel with manganese and nickel alloying elements is preferred. Fig. 4 illustrates the ductile–brittle transition temperature (DBTT) curve for various metals.

- ***Inspect equipment regularly:*** Since Arctic and sub-Arctic, regions possess large variation in temperature during a short period of time; it might be beneficial to consider increasing inspection intervals in these regions. Frequent periodic inspection to look for cracking, nicks, or chipping will help prevent accidents. In addition, increased frequency of monitoring processes such as non-destructive testing (NDT) may also help, if the risk of failure is severe. Moreover, to reduce the fretting failure, using oxidation inhibitors in oil or using oil of lower viscosity, and re-lubricating frequently can be beneficial.

- ***Winterization:*** To reduce the frequency of equipment failure in the cold climate, winterization measure can be implemented. In general, winterization is a process of enclosure of the most susceptible areas (equipment). By implementing winterization measures, materials and equipment shall be adequately protected by the provision of heating or insulation; and consequently, reducing the failure frequency. This can ensure the safe operation of all systems and equipment. It shall also ensure that personal can conduct the required tasks in an ergonomically sound way, with respect to temperatures, wind, visibility and restrictions imposed by personal protective equipment.

- ***Uncertainty reduction:*** To reduce the uncertainty during RBI process, various approaches can be employed. For instance, the probability of failure and the consequence associated with a failure, estimates shall be made by integrating the probability distributions of air temperatures. Moreover, the lowest anticipated service temperature shall be defined. Further, the effects of thermal changes on mechanical/structural behaviour and human capability shall be considered as part of the design and operation of the topsides static mechanical equipment.

Concluding remarks

To date, there are no specific standards and, recommended practices or software tools for carrying out RBI analysis for equipment operating in the harsh Arctic conditions. Moreover, due to lack of experience and data, there are a wide range of sources of uncertainties, such as model, parameter, and incompleteness uncertainty. Hence, it is concluded that for safe Arctic offshore operation, development of RBI procedures that are specifically intended for the analysis of topsides static mechanical equipment installed in Arctic area is vital. That means that revising the current RBI standards, recommended practices and technical documents, by considering the peculiar Arctic operating environments are necessary. Further, understanding the peculiar modes of failure in the cold climate can help to establish risk ranking among individual equipment items in order to optimise inspection efforts and reduce costs. It can also help to extend inspection intervals beyond statutory requirements.

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