COLD COMFORT

SINTEF's Odd M Akselsen discusses the importance of materials for the increasing levels of working undertaken in the Arctic climate

Materials for topside and subsea need further development to achieve robust solutions before exploration and production of oil and gas in the arctic region. This has been recently shown in a research project carried out in Norway. Current structural steels may fail to possess robustness, so is also the case for many polymers.

Resources in the North

The fact that the Arctic region may contain as much as 30% of the remaining gas and 13% of the remaining oil reserves makes it very interesting for future exploration and production. Thus, the offshore industry is moving north. The operating environment becomes colder and the distance to civilisation and infrastructure is widening. Activities are increasing in Alaska, North Canada, and Greenland, the Norwegian and Russian parts of the Barents Sea, as well as eastern parts of Russia.

Extreme challenges

The environmental conditions in these regions are quite different from those normally met by the industry, and this may create some major new challenges. Examples are low temperatures, icing and icebergs, frost heave, thaw settlement, lack of infrastructure, long transport distances and extended periods without daylight. Heavy operations under installation may have to be performed within limited time window in summer. Although maintenance free solutions should ideally be strived for, it is not possible to accomplish in practice. As operation in many cases is located in remote areas, the cost of maintenance and repair is more expensive, and the need for repair, maintenance and replacements should be minimised.

Fig. 1 The author equipped for cold climate "adventures"

The research project "Arctic Materials – Materials technology for safe and cost effective exploration and operation under arctic conditions", supported by the Research Council of Norway, is now finished. The five-year project (2008-2012) was carried out by SINTEF, NTNU and DNV in co-operation with Statoil, ENI Norge, Total E&P Norge, Scana Steel Stavanger, Trelleborg Offshore, Bredero Shaw, GE Oil & Gas, Aker Solutions, Kværner Verdal, Miras, Technip, JFE Steel Corp., Nippon Steel Corp. and Brück Forgings.

Low ambient temperature

The outmost challenge for materials is the low ambient temperature. For steels, this is due to the so-called 'transition' from stable, slow ductile crack growth to unstable, unpredictable brittle fracture.

Structural steels and steel for piping and pressure vessels for operating temperatures down to -60°C are needed, and the steel industry has a challenge to meet such requirements, at least to provide materials at reasonable costs. Furthermore, substantial toughness reserves must be built into steels because fabrication welding will reduce the initial toughness severely. Project results based on extensive experimental testing may indicate that toughness of welds may appear with large scatter. Therefore, test methods that provide reliable data, together with a scheme to deal with scatter, will be necessary.

Non-existent body of rules

Currently, a body of rules for design for use in the Arctic region are lacking. In Norway, the NORSOK is valid down to -14°C, and there is huge gap from -14°C to the lowest Arctic temperature. The coldest field is Goliat, where the design temperature is -20°C. To

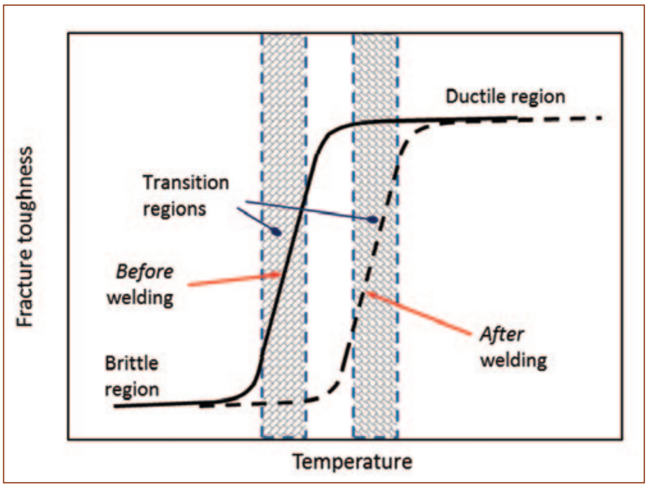

Fig. 2 Transition from ductile to brittle fracture in steel

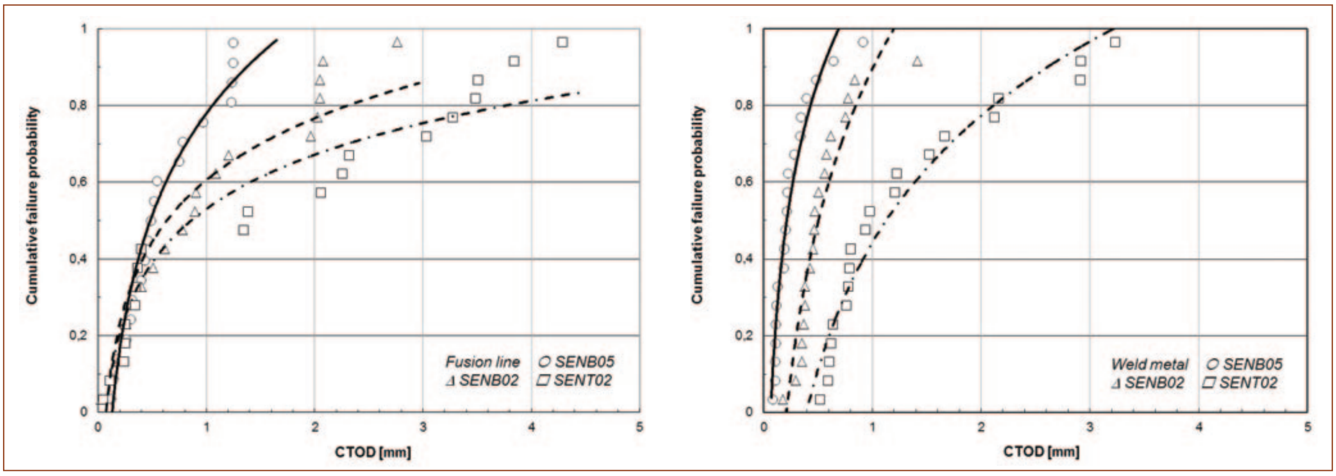

Fig. 3 Scatter in fracture toughness of heat affected zone (left) and weld metal (right)

avoid 'extrapolation' of existing rules for installations in the North, there is a need to build knowledge of materials behaviour under challenging conditions. The on-going work of ISO is very important here[1,2], but also design guidelines and requirements developed in the Arctic Materials project will be a step towards basis for future safe use of materials and structures.

Coating systems

Coating systems with sufficient robustness are required both in the submerged zone, splash zone and topside. However, the operational conditions are somewhat different. In the fully submerged zone, the eventual ice impact needs to be considered. The temperature is stable and not much below zero. In the splash zone a robust coating system is required to minimise maintenance. Particular issues such as adhesion, durability, bending and resistance to impact should be addressed. Topside coatings have to fulfil all the particular needs for the structure or equipment to be coated. In addition, the particular challenges in arctic environment need to be considered; these may be wearing caused by ice formation and mechanical removal, temperature variations including temperature caused by process and eventual heat tracing, and the minimum temperature. During the past decade, R&D on topics such as icephobic or anti-icing coatings has been on-going, but may not be the solution for the most remote areas due to the excessive wear from ice.

Weight savings

Lower weight of structures can be achieved by taking lighter materials into use. Project results show that composites may improve their properties with falling temperature, which may facilitate weight reduction of actual components. A potential challenge is still the joining of composites, either to themselves or to metals. The joining process is usually adhesive bonding, and properties and duration of the adhesive is often questioned. This may be an important part for further study.

Different length scales

In order to obtain reliable models to predict risk of brittle fracture under the prevailing conditions, it is important to understand the materials behaviour at all scales, ranging from atomistic to macroscopic scale.

Atomistic simulations may give important information on how lattice structure, crystallographic orientation and crack shape will influence the behaviour under mechanical loading. Nanomechanical testing, using nanoindenter or picoindenter, marks a new era of scientific laboratory equipment that may be helpful to build new knowledge on materials and their properties at small scale. With *in situ* mechanical testing, the deformation event can be viewed in real-time rather than *post mortem.* The microscale is well established arena for material scientists, but there is still need for more knowledge on low temperature brittle behaviour of steel welds. Moreover, data on fatigue properties at low temperatures are not yet available.

Education

In addition to the R&D work performed in the Arctic Materials project, education was also addressed. The project has fully financed three PhDs, and three PhDs have received financial support in terms of laboratory and equipment costs, as well as materials. A total number of 27 students have been involved in the project performing their project work or master thesis. The PhD and MSc work were linked to varied topics such as:

- Atomistic modelling of iron;
- Quasicontinuum modelling of fracture in bcc material;
- Multiscale materials modelling of cleavage fracture in steel;

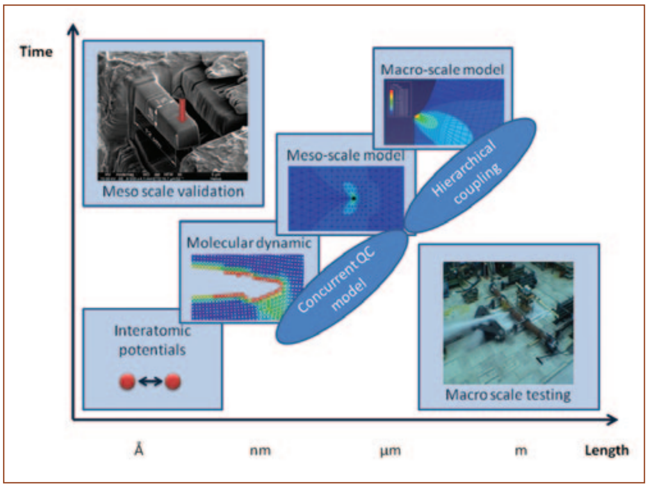

Fig. 4 Multiscale approach

Fig. 6 Project kick-off meeting at Svalbard, April 2008

- Investigation of brittle fracture surfaces of a weld thermal simulated X65 steel;
- Brittle and ductile fracture in X80 steel;
- Brittle fracture initiation of weld simulated F70 steel;
- Brittle fracture characterised by acoustic emission;
- M-A phases and crack growth;
- *In situ* electron back-scattered diffraction characterisation of crack growth at -60°C;
- Nucleation of brittle fracture in weld simulated coarse grained heat affected zone;
- Atomic force microscope studies on fracture surfaces in steel;
- Statistical interpretation of the fracture toughness of structural steel;
- Nanomechanical testing of steel; and
- Arctic materials and lightweight solutions.

Objectives

In order to pursue exploration in Arctic areas it is necessary to develop robust structures which are easy to deploy and maintain. A key factor in this picture is materials technology. Solutions for lightweight structures capable of operating at low temperatures and to resist harsh environmental loads are required. A crucial part of this is development of structural integrity assessment methods and acceptance criteria as well as specification of required qualification testing. Some of the more specific sub-goals are:

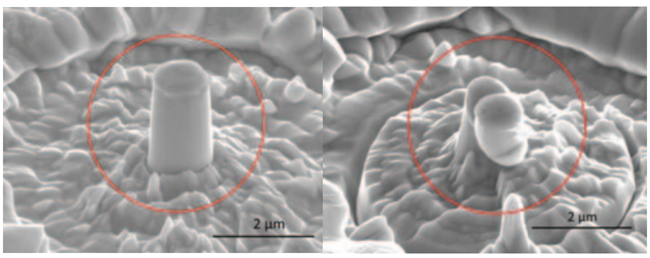

Fig. 5 Two different deformation mechanisms in compression testing of steel nanopillars

- Define criteria for low temperature application for steel and weldments (design temperatures down to -60°C);
- Develop specifications for qualification testing of materials to be applied down to -60°C;
- Develop requirements for polymer coatings to be used down to -60°C, and under large temperature variations; and
- Develop basis for application of light weight structures using composites and hybrid solutions.

The project was conducted by defining five different work packages:

- Steel fabrication and mechanical characterisation;
- Strength and toughness criteria for safe materials utilisation;
- Polymers and polymer coatings;
- New concepts and materials solutions; and
- Project guidelines for qualification requirements.

1 ISO 19902, 2007: Petroleum and natural gas industries – Fixed Offshore Structures; International Standards Organisation, 2007.

2 ISO 19906, 2010: Petroleum and natural gas industries – Arctic offshore structures; International Standards Organisation, 2010.

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