Applied Mechanics and Corrosion

November2011

Arctic Materials (Petromaks KMB project)

25% of the world's undiscovered oil and natural gas are believed to be located in the northern area. The exploration of these remote areas **will require better materials than available today** due to the harsh climate conditions (see challenges below).

The overall objective is to establish **criteria and solutions for safe and cost-effective** application of materials for hydrocarbon exploration and production in arctic regions.

Challenges

- Low design temperatures (down to -60°C)
- Large temperature variations
- Large deformations
- Long transport distances require light weight structures

The project addresses different materials: Steels, polymers and coatings, and composites/light weight solutions

Examples of results

Toughness of welded steels
The experimental work has focused on properties testing at very low temperatures, i.e., down to -60°C. Normally, most base metals may have satisfactory toughness. However, welding may cause substantial deterioration of cleavage fracture resistance. The risk of brittle fracture has been addressed fracture mechanics specimens with different mode of loading and crack depths in order to cover a wide range of local stress and strain conditions in the material. An example of results is shown in Fig.1, revealing a large scatter in fracture toughness at -60°C.

For HAZ structures, weld thermal simulation has been used to obtain local material fracture properties. From Fig.2 it can be observed that at -60°C weld thermal simulation yields similar fracture toughness as that found close to the fusion line in real HAZ microstructures.

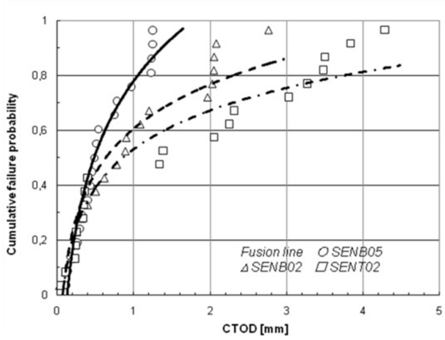

Figure 1. Large scatter in fusion line fracture toughness of 420 MPa steel.

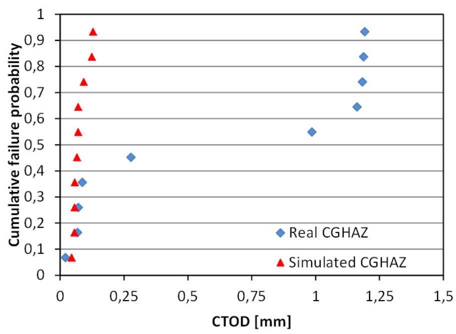

Figure 2. Fracture toughness; weld metal specimens.

Mechanisms studies of cleavage fracture in steel
The underlying mechanisms controlling initiation and propagation of brittle (cleavage) fracture in steels have been investigated using different approaches. Traditional SEM investigations have been applied to fracture surfaces in order to try to identify initiation sites of cleavage fracture.

More novel techniques like EBSD (also in-situ) has been applied for characterization of distribution of grain boundary angles and to show the temperature dependence of deformation driven phase transformation from austenite to martensite. Acoustic emission measurements have been used to classify microstructures with regards to whether fracture is dominantly nucleation or propagation controlled, and also to establish quantitative relations between AE signals and the size of arrested microcracks.

Modelling of cleavage fracture

Modelling work has covered the use of FE modelling to evaluate applicability of micromechanical cleavage models. Crystal plasticity has been applied for investigations of the influence of discrete grain orientation on the local stress field in front of cracks. Novel techniques like the quasicontinuum methods and molecular dynamics have been investigated to explore the relation between behaviour at the atomistic level and fracture behaviour in iron. Finally, FE modelling of welding is carried out, including heat flow, phase transformations, and residual stresses, the latter becoming important when robustness against brittle fracture is questioned.

Polymers and coatings

Thermally insulated pipelines undergo large deformations during spooling operations. It is important to have a small scale test in order to asses the stress/strain that the thermal insulation will be subjected to during spooling at low temperatures. Both experiments and modelling indicate that a combination of 3- and 4-point bending of thermal insulation samples is promising techniques for small scale testing (Fig. 3).

Equipment has been developed in the project for testing ice adhesion on coated surfaces. Clear differences between different coating systems could be observed, and the ice adhesion was found to increase with decreasing temperature.

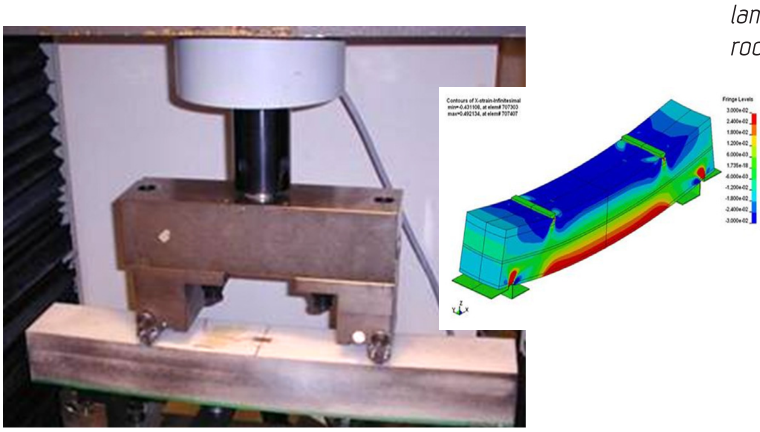

Fig.3. 4-point bending of pipeline insulation (left), and modelling of strain levels during 4-point bending (right).

Composites

Results from testing of typical offshore and marine laminates and commercial composite products used in the oil industry show that composite materials have good mechanical properties at temperatures down to -60°C. Properties in tension, compression and shear are comparable or better than room temperature values. Low temperature impact testing of composite laminates, filament wound pipes and pultruded foam core building panels show little effect of low temperature (down to -60°C) on impact damage.

A test set-up and procedure have been developed for low temperature fatigue testing of composite laminates and adhesively bonded joints. Initial fatigue testing of composite laminates indicates that the fatigue strength at 107 cycles at -30°C is comparable or better than room temperature values, Fig.4. The slope of the S/N curve is however steeper at low temperature and further investigation is needed. A first version of a numerical model has been developed to predict failure in adhesively bonded composite joints, including the effect of temperature. The main focus is on the mathematical description of the material model and the quality of material input parameters to the model.

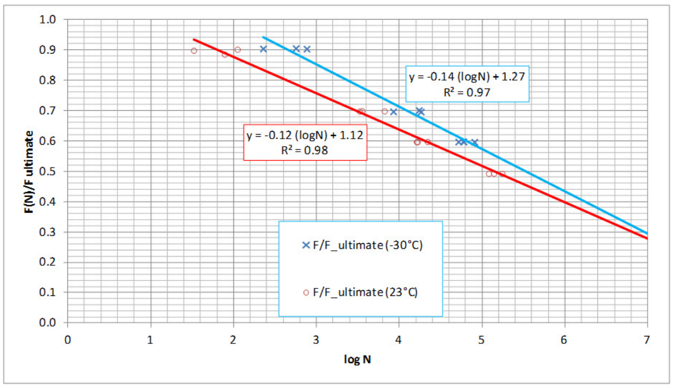

Figure 4. Results from low temperature fatigue testing of epoxy laminate with quadriaxial glass fibre reinforcement. Red curve – room temperature, blue curve – -30°C

Partners

The following partners are involved: Statoil, ENI, Total, Scana Steel Stavanger, Aker Solutions, Bredero Shaw, Miras, Trelleborg, Nippon Steel Corporation, JFE Steel, Brück Forgings, Technip, GE Oil & Gas, DNV, NTNU and SINTEF (project management).

The project is sponsored by the Research Council of Norway. The total budget is 65 million NOK for a period of 5 years (2008-2012).

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