Field Joint Coatings for Deep Sea Pipelines

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Heerema Marine Contractors

Heerema Marine Contractors (HMC) is contracted to install pipelines in the sea. The metallic pipes, generally of carbon steel, need not only to be protected against corrosion, but also to be insulated to maintain the temperature of the pipe contents and assure the flow. Therefore a multilayer polymer coating is applied.

Although the individual pipe sections (12 m) are coated with a factory-applied coating along their full length, the coating is cut back at the ends before welding them together during a J-lay or reel-lay installation. After welding, a field joint coating is applied over the welded area. Ensuring optimal application conditions for the coating during an offshore installation is far from straightforward.

Pipe sections
Welded together

Surface cleaning
Grit blasting

FBE application
Corrosive protection

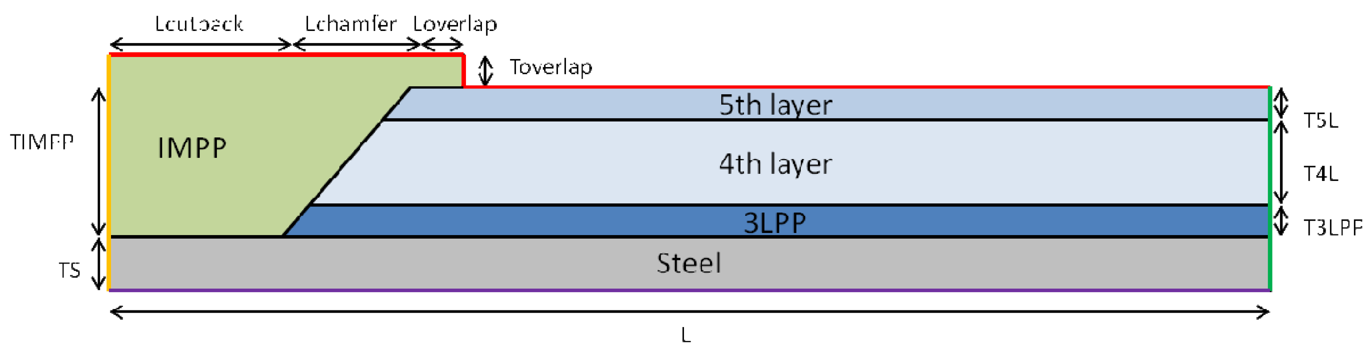
Injection moulding
Thermal insulation

Field joint
Needs cooling

Objectives

In order to optimise the application process of the field joint coating, deep insight into the cure and crystallisation kinetics, together with a good comprehension of the heat transfer in the field joint is required. Experimental data on the raw materials, acquired by thermal analysis, will be used to determine the crystallisation[1] and cure[2] kinetics model, which will consequently be implemented in the computational finite element model.

Cross section model with dimensions (mm) and boundary conditions: symmetric, outflow, convective cooling h_1, convective cooling h_2



L	1200.00	TS	15.70
Lcutback	313.00	TIMPP	52.59
Lchamfer	91.10	T3LPP	9.19
Loverlap	50.00	T4L	39.40
		T5L	4.00

In the first part of this research project, the cooling process of a field joint coating is simulated, computing the temperature and crystallinity profiles, throughout the coating, as a function of time using the cure and crystallisation kinetics model obtained from experimental data.

1. J.D. Hoffman, R.L. Miller, *Polymer* **1997**, *38*, 3151-3212
2. G. Van Assche, A. Van Hemelrijck, H. Rahier, B. Van Mele, *Thermochim. Acta* **1995**, *268*, 121-142

Computational Methods

All computations are performed in COMSOL Multiphysics. The crystallisation kinetics model was incorporated as a set of ODEs,[3] all of form

$$e_a \frac{\partial^2 u}{\partial t^2} + d_a \frac{\partial u}{\partial t} = f$$

Where u is the dependent variable, d_a the damping coefficient, e_a the mass coefficient and f the source term. Since our model only has first order time derivatives, all mass coefficients e_a are always zero. Furthermore, all equations are written so that the damping coefficient d_a equals 1.

ODE parameters for the crystallisation kinetics model

Dependent variable u	Source term f
N	$-N\left(q(T)+\frac{1}{1-\alpha}\frac{d\alpha}{dt}\right)+(1-\alpha)\frac{dN_0(T)}{dT}\frac{dT}{dt}$
N_{at}	$\frac{q(T)N}{1-\alpha}$
α	$4\pi(1-\alpha)G\left(F^2 N_{at}-2FP+Q\right)$
F	$G(T)$
P	$\frac{FNq(T)}{1-\alpha}$
Q	$\frac{F^2 Nq(T)}{1-\alpha}$

In order to obtain stable and low time-consuming computations, preferably the PARDISO solver was used, together with the BDF timestepping method.

Furthermore, to avoid mathematically correct but physically unrealistic data for the relative crystallinity α (*i.e.* $\alpha \in [0,1]$), and the amount of nuclei N (*i.e.* $N > 0$), both parameters were limited using transformation functions:

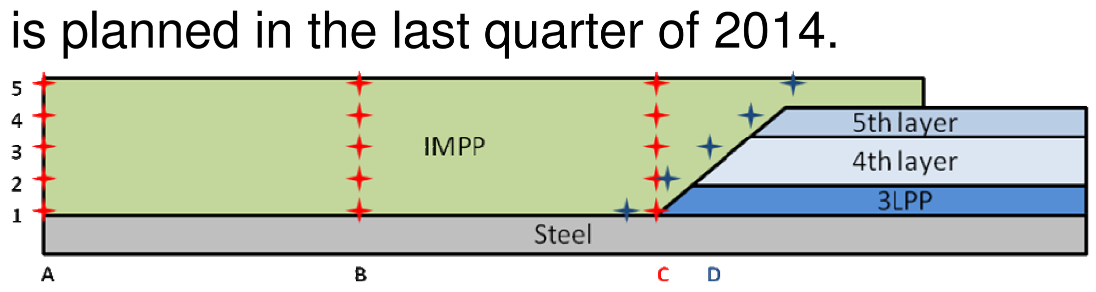
$$\alpha = \frac{erf(b)}{2} + \frac{1}{2} \qquad N = e^{\log N}$$

3. J.M. Haudin, J.M. Chenot, *Intern. Polym. Process* **2004**, *19*, 267-274 & 275-286

Results

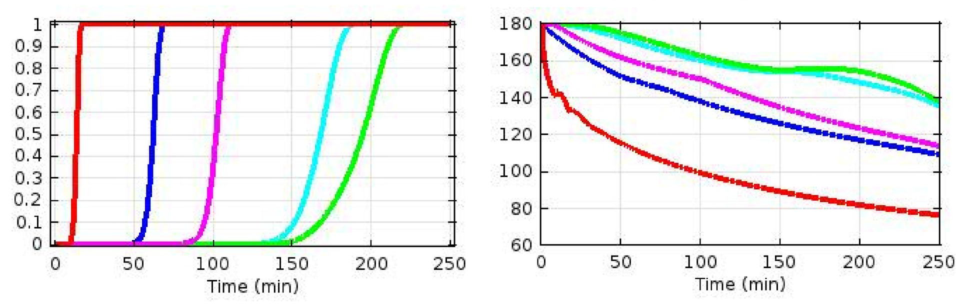
Temperature and relative crystallinity profiles were computed for different geometries (*e.g.* with and without a mould, representing an immediate removal/opening of the mould after the injection and a complete cooling in the mould), different pretreatments (preheating of steel pipe and factory applied coating) and different start and boundary conditions (*e.g.* temperature of melt, mould and air).

Points of interest were selected in the model with the perspective to be compared with industrial test results. This validation step, a confrontation of the computational results with the experimental results on the industrial scale, is planned in the last quarter of 2014.

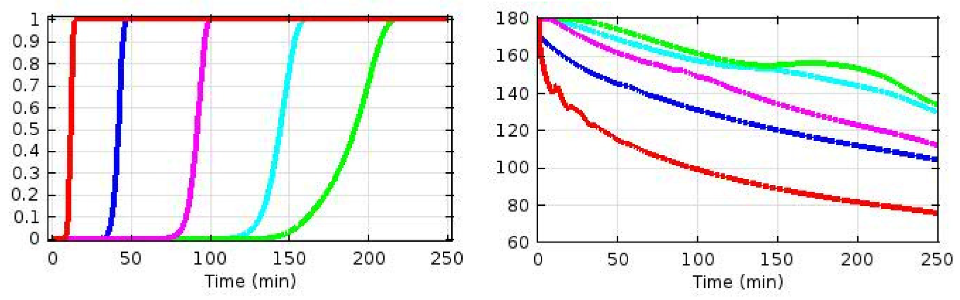


Locations of computed temperatures and crystallinities in the field joint coating.

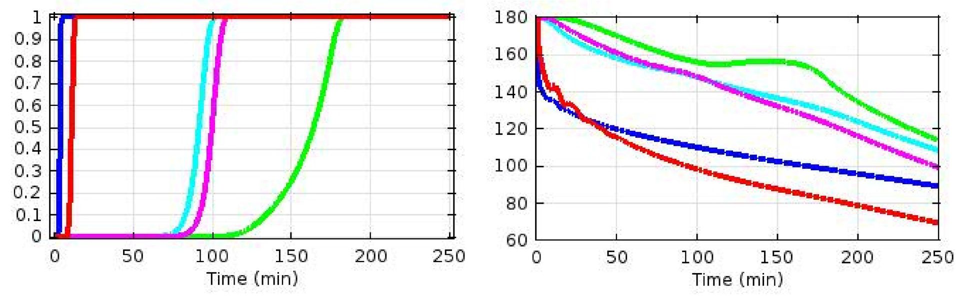
A1-2-3-4-5: Centre of the FJC



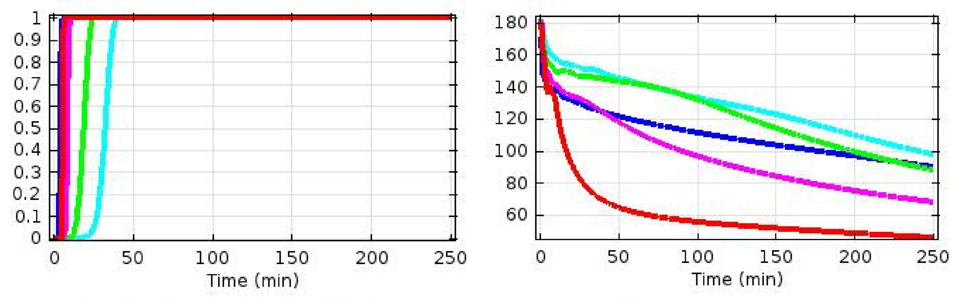
B1-2-3-4-5: Centre of the cutback



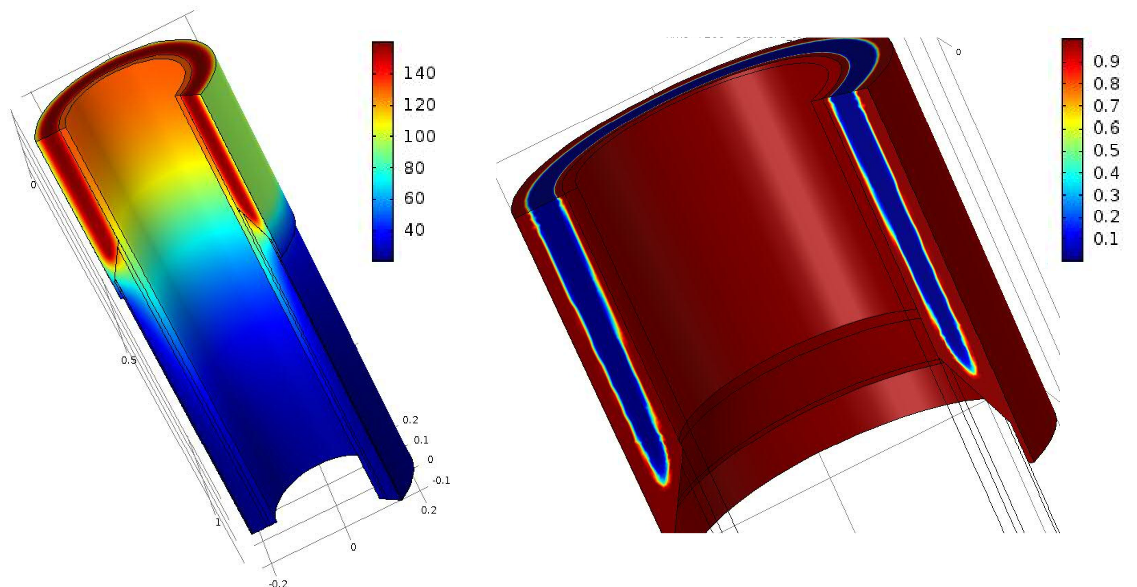
C1-2-3-4-5: Cutback



D1-2-3-4-5: Parallel to the chamfer



Relative crystallinity   Temperature



Temperature (left) and relative crystallinity (right) profile of the FJC after 120 min.

Perspectives

In the last quarter of 2014, the computed temperature and crystallinity profiles will be compared to industrial test results.

Shrinkage during cooling and crystallisation will be implemented in the model, using experimental (lab-scale) results in order to predict and to evaluate internal and interfacial stresses.

Filling of the mould will eventually be implemented.

Vrije Universiteit Brussel   FYSC   TU Delft

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Materials innovation institute

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