Numerical Simulation Of Cemented RLOW For Packaging System

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ABSTRACT

The selection of immobilization waste technologies based on cementation should demonstrate that the so obtained matrices for packaging systems are reliable, durable and stable. Cementation of radioactive liquid organic wastes (RLOW) is a difficult technological task because of complex chemical composition, and relatively high activity of wastes streams to immobilize. A proper characterization of the cemented matrices is therefore felt necessary.

The aim of this study is to investigate numerically, by means of finite element (FE) modelling, the thermo-mechanical behaviour of cementitious material or RLOW simulant. The FE numerical model is adopted to benchmark several RLOW simulants composition and correlate/compare the structural properties. Ageing effects are also investigated.

Results are compared to experimental data. They indicate that the thermal conductivity monotonically decreases as the temperature increases. The compressive strength confirmed to be dependent on w/c ratio and to suffer irradiation damage; e.g. it reduces as porosity increases.

1 INTRODUCTION

Generally liquid organic wastes (LOWs) are consisting of solvent and oil wastes that are kept separate during collection. However, frequently contaminants such as small quantities of water and sludges may be present. It is generally agreed that aqueous waste with a significant organic content, including soluble organic decontamination agents, should be considered to be liquid organic waste.

The immobilization technologies of radioactive wastes is one of the main waste management activities aiming at producing durable waste form that should ensure sustainable performance over long periods of time [1]. In order to reduce the potential for migration or dispersion of radionuclides to biosphere during handling, transportation, storage and disposal, LOWs are precipitated and converted into a more stable solid waste form resistant to leaching by water.

The solidification is achieved by using a cementation process (conventional technologies and equipment are used in remote or shielded operations) in which waste, water and additives are metered from a tank into the drum at the waste loading station to produce cementitious waste forms. Detailed information on immobilization and disposal practices can be found in [3], [4] [5].

Cement by itself has limited efficiency for the solidification of organic liquid wastes, e.g. about 12 vol% of oil can be incorporated directly into cement. However, this waste loadings percentage can increase when emulsified and multiphased (oil/water/solvent) wastes are used.

The variability of waste streams results in structural elements of different compositions of the ingredients as per the strength, durability, fire resistance and non-combustibility properties [2], and performance requirements. Considering such a chemical complexity, which unavoidably affects the performance of the immobilized radioactive LOWs (RLOWs), a proper characterization is felt necessary, even if the volume of these radioactive waste is small.

In this study, the attention is put particularly on the effects caused by the fire exposure. Fire is one of the most severe environmental conditions (important design requirements to fulfil) that packaging system stowing RLOW may face during both transportation and storage.

The heterogeneous nature of concrete and high temperature exposure makes it difficult for the researchers to assess the exact extent and cause of the deterioration of the concrete structural elements. However, the knowledge of material properties of individual concrete constituents at the temperature exposed may help assess the extent of damage.

A number of studies have been conducted in the past to discover significant changes in the material properties of different types of concrete exposed to different temperatures, e.g. strength decrement trends (from [6] to [9]), effect of moisture movement [10]-[11] and contribution of aggregate types and additives on strength depreciation at elevated temperatures. However, none of these have so far studied the RLOWs. And to select an appropriate waste management strategy it is important to establish the nature of waste, use and characteristics.

The aim of this study is to provide a preliminary assessment of the thermo-mechanical behaviour of RLOW cemented material or simulant. To take into account the variability of the waste loadings into the cement matrix, numerical analyses were performed

In the following section 2 the numerical modelling is described. Results are presented and discussed in Section 3.

2 DESCRIPTION OF THE NUMERICAL MODELLING

The exposure to the elevated temperature affects the concrete mechanical and physical properties. Cemented structures could distort, and, under certain conditions, surfaces could spall due to the build-up of steam pressure: dimensional changes could also occur and affect adversely the cemented waste form.

The numerical simulations were carried out with reference to a standard RLOW cylindrical sample (Figure 1) of 100 mm diameter and 400 mm (height). The model, implemented by means of FE code MARC [12] is shown in Figure 2. It represents only the real scale cement sample: this was possible because of symmetry characterising the cylindrical shape.

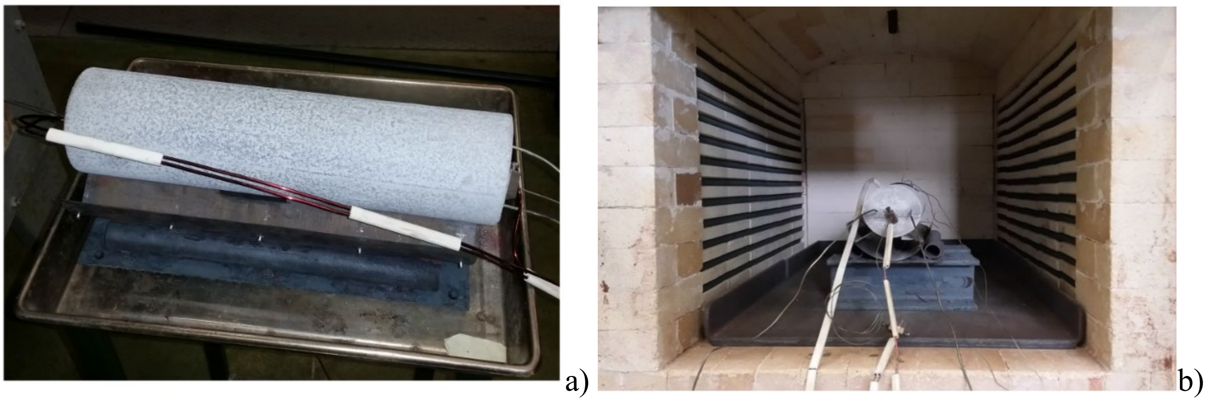

Figure 1: Overview of a cement sample with type K thermocouples and wire resistor (a). Figure (b) shows the specimen positioned into the oven before the execution of thermal tests

It is assumed to retain a waste form that is dry and monolithic with about 12 vol% and 50% of organic oil incorporated directly into the cement matrix.

The model was implemented with 3D shell element type 75 which allows for the definition of the material orientation of non-homogeneous materials by defining a coordinate system and an angle of rotation. The integration method [12] is the Newmark-Beta, whose generalized forms of integration (in u and v displacement) allows to solve the equation of dynamic of non linear transient analysis.

The material properties are entered directly into the input properties.

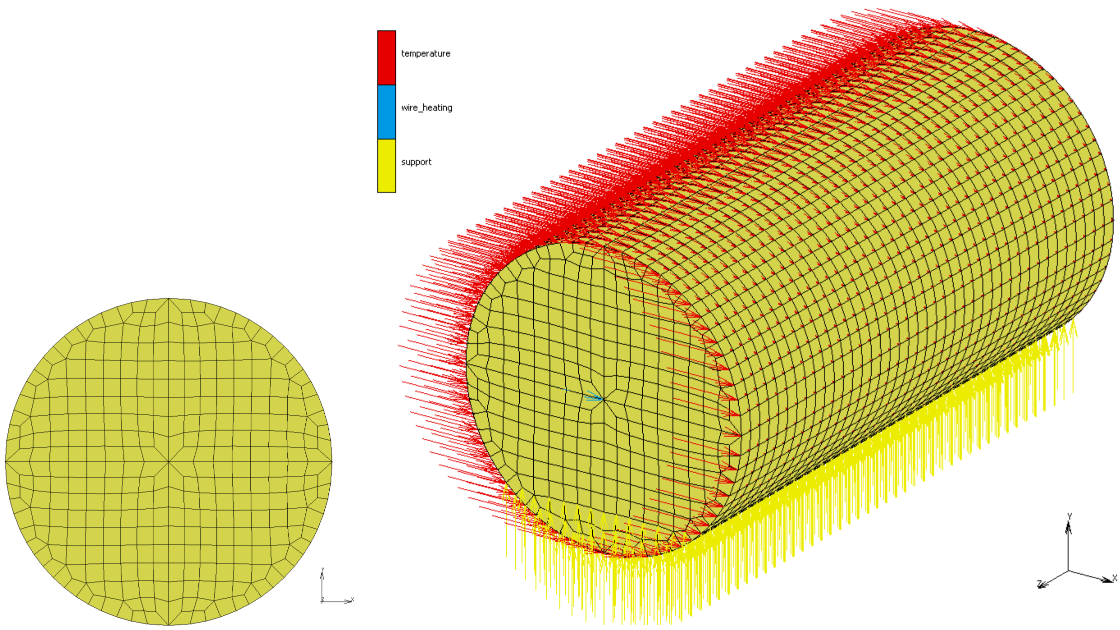

Figure 2: Numerical model of RLOW cemented material. The legend provides information on the boundary conditions: the red arrows indicate the temperature, the light blue ones represent the wire heating condition, and the yellow arrows indicate the structural constraints, respectively

In this investigation, for simplicity reason, the fire temperature (initial condition) has been considered uniformly distributed on the outer surface nodes. The shape of yield surface for multi-axial stress is specified through Von Mises yield criterion. The evolution of the yield surface with continued deformation is specified by inputting isotropic hardening rules. Piecewise linear strain rate method was adopted as well as the update Lagrangian procedure. The values of material properties entered for thermo-mechanical coupled analysis purposes were thermal conductivity, specific heat, mass density. All these values except the mass density were assumed temperature dependent. This is an important aspect to consider because de-hydration phenomena may degrade the cemented matrix for temperature higher than 400°C. The density was varied in order to consider a different percentage (12 vol% and 50% respectively as previously indicated) of oil retained within the waste cemented matrix. To the aim of this preliminary study, the mixture of substances was assumed quite uniform, therefore an equivalent value of density was inputted to the model.

The performed simulations considered also both the reduced strength and reduced modulus of elasticity possibly caused by the increased amount LOW: the reduction rate assumed, as first attempt, was of the same order of the retained waste stream.

The values of the thermal conductivity (Figure 3) inputted to the FE model have been determined experimentally by performing hot wire tests [9] (heating up homogeneously samples, like that showed in Figure 1 in an electric oven). They were calculated adopting the Fourier law of heat conduction in plane geometry:

$$k = \frac{\emptyset}{2\pi R^2 \mathrm{L}\Delta T} \left(\mathrm{X}_{ext}^2 - \mathrm{X}_{int}^2\right) \quad (1)$$

where: k [W/m °C] is the thermal conductivity. Ø [W] is the power generated by Joule effect within the wire and L [m] is the cylinder length. ΔT [°C] is the difference of temperature measured by the thermocouples, X_{ext} and X_{int} [m] are the radial distances of thermocouples from the axis and R [m] is the radius of cylindrical sample.

Figure 4 shows the Young modulus (Ec) trend versus temperature. This was used for simulating the most remarkable Ec reduction (more conservative approach) occurring at the elevated temperature. The experimental relationship obtained by Kodur [13] was adopted for the tensile strength behaviour. It indicates that at 600°C the concrete strength reduces of about 50%.

Three different numerical simulations were finally run:

- Sim 1: simulant of RLOW with nominal material properties, no oil and only temperature dependent properties;
- Sim 2: simulant of RLOW with 12% oil, reduced strength and Young modulus, and temperature dependent properties;
- Sim 3: simulant of RLOW with 50% oil, reduced strength and Young modulus, and temperature dependent properties.

Coupled thermal/structural type of analysis was performed such that the two physics passes are performed one after the other. The total time period associated with the loadcase was 1800 seconds (equivalent to fire duration)

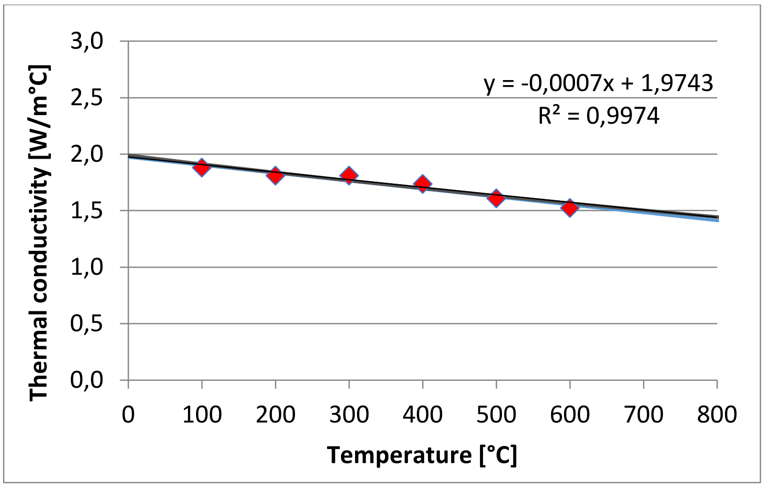

Figure 3: Behaviour of the thermal conductivity [15]

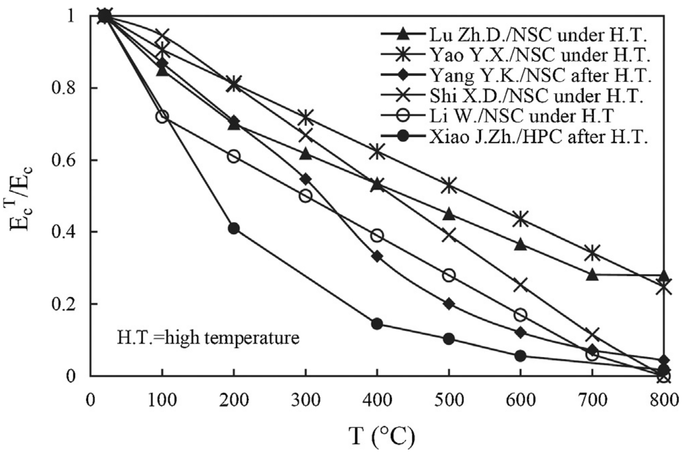

Figure 4: Variation of the Young modulus for a normal weighted concrete vs. temperature [13][14]

2.1 FE analysis results

In what follows we describe the results obtained from the performed numerical analyses.

The numerical simulations shows that the RLOW matrix behaviour is dependent on the matrix elasticity. The stiffer the matrix, the lower its deformation capacity of the material. The liquid waste may reduce the density and the cohesion of the cemented LOW. The increased porosity seems beneficial in relieving stress concentrations at crack tips. But a durable concrete should have low permeability. Concrete density is inversely proportional to its porosity: the entry of “elements” into the pore structure is responsible for durability problems.

Figure 5 and Figure 6 show the Von Mises stress distribution and the overall nodal displacement obtained for the cemented LOW with higher oil content.

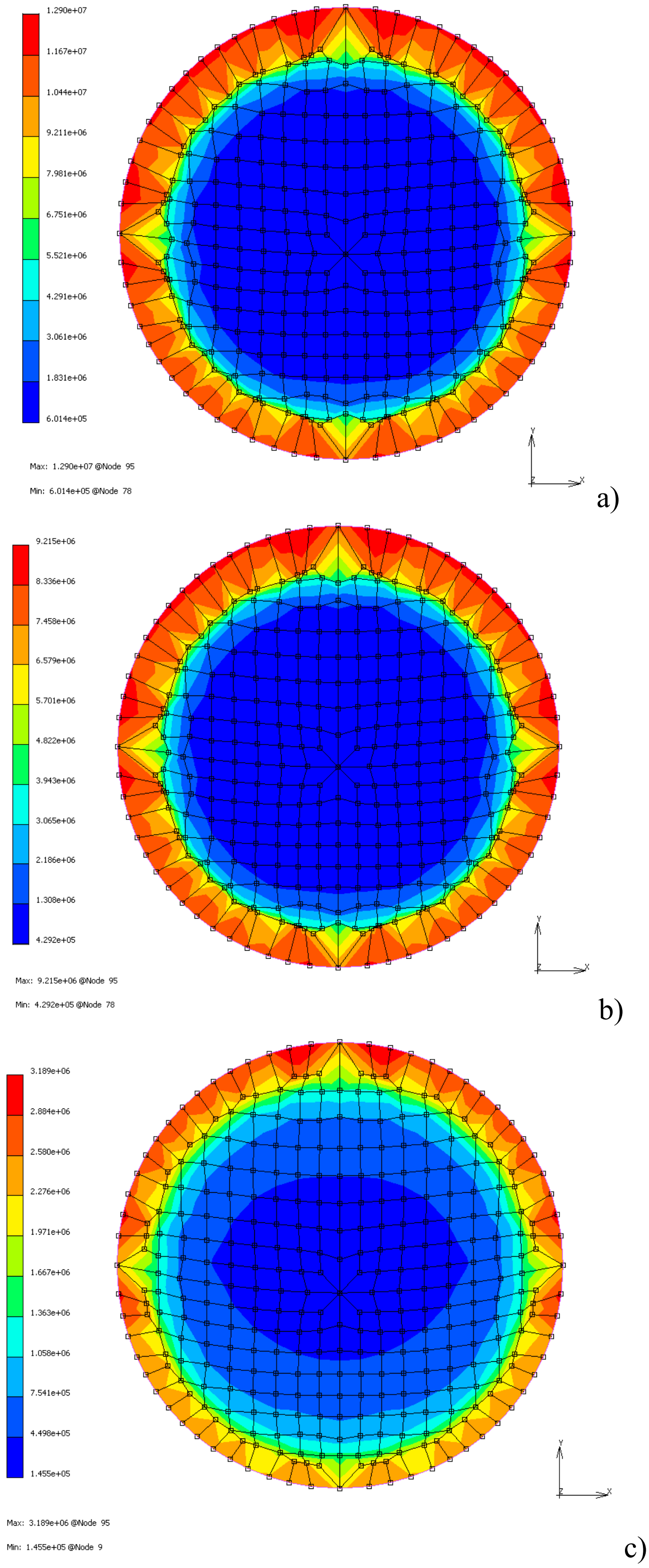

Figure 5: Von Mises stress [Pa] for Sim 1(a), Sim 2 (b) and Sim 3 (c)

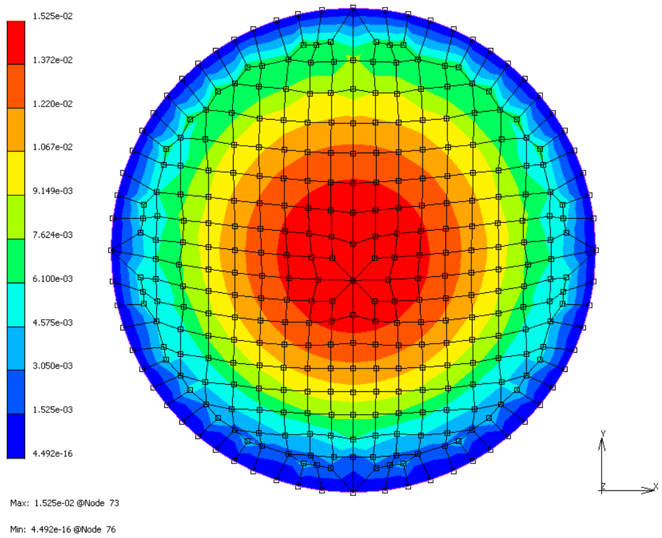

Figure 6: Overall displacement [m] for Sim 3

Numerical results showed that the content of liquid waste stream yields degradation of durability and structural performances: in Sim 3 case the overall displacement was about 15 mm, while the material in Sim 1 conditions highlighted the better resistance.

3 SUMMARY

This preliminary study investigated three different RLOW conditions. The results show:

- stiffer the matrix, the lower the ROLW deformation capacity.
- Increasing the amount of liquid waste reduces the density and the cohesion of the cemented waste form.
- Concrete porosity is responsible for durability problems. The displacement in the Sim 3 case (50% oil retained within the matrix) was about 1.5 mm although the Von Mises stress did not exceed the allowable limit value.

Further numerical and experimental investigation shall be carried out in order to obtain a more accurate characterization of the RLOW performance. Mechanical compression and thermal test on several RLOW are going to be carried out in order to relate both the strength and durability to the RLOW composition.

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