Motion of air bubbles through fresh concrete during concreting process

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Scientific motivation:

Over the last years, the concrete technology has progressed in order to improve the quality of its use and mechanical performances. Despite the technical development known in the concrete society, the aesthetic aspect remains poorly treated in the literature. Among the aesthetic problems, there is the formation and dispersion of air bubbles (bugholes) inside the concrete during the concreting process. An important class of non-Newtonian materials (such as fresh concrete) exhibits a yield stress which must be exceeded before significant deformation occurs [1]. The results show that the concrete density and yield stress have an influence on the air bubble motion. The more the concrete density increases, the more the air bubble motion will be constrained and vice versa.

As a rule of thumb, there are 3 aesthetic disorders related to the texture of the concrete (fig1). In this present work, we focus in the bugholes in concrete (fig1,c)

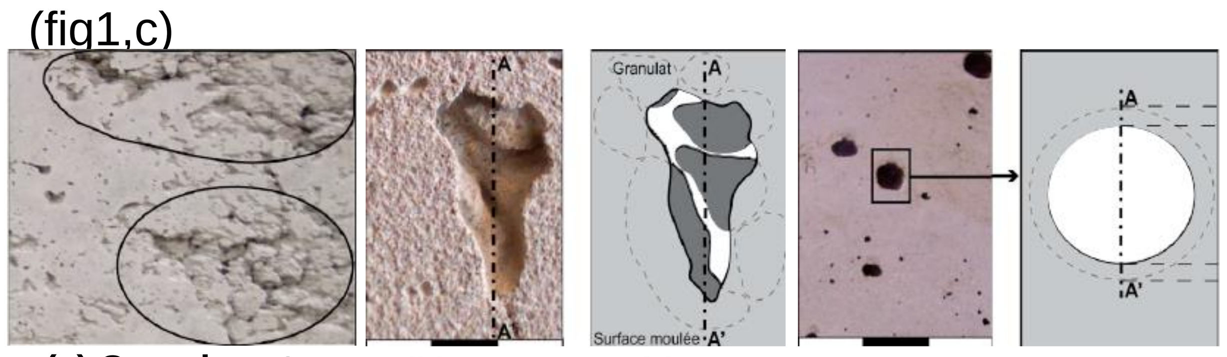

***Fig 1**. Aesthetic disorders in concrete surface.*

Analytical approach:

1. Motion of air bubbles in the viscous fluid is described by the momentum and mass conservation principles according to **Navier-Stokes equations**, with an additional force term representing the surface tension f_Γ (Eq. 1).

$$\rho_i \frac{\partial \boldsymbol{u}}{\partial t} + \rho_i \boldsymbol{u}\cdot\nabla\boldsymbol{u} - \nabla\mu_i(\nabla\boldsymbol{u} + \nabla\boldsymbol{u}^T) = \rho_i g + f_\Gamma \quad (1)$$

where: ρ (Kg/m³) is the density, u (m/s) is the fluid velocity, μ (Pa.s) is the dynamic viscosity, g (m/s²) is the gravity and t (s) is the time .

2. We considered the incompressible case (Eq. 2):

$$\nabla\cdot\boldsymbol{u} = 0 \quad (2)$$

3. The **level set method** [2] was used in order to represent the behavior of the interface between two incompressible fluids in flow. The movement of the interface was followed by the convection equation (Eq. 3):

$$\frac{\partial\phi}{\partial t} + \boldsymbol{u}\cdot\nabla\phi = 0 \quad (3)$$

where ϕ is the level set function.

4. The **reinitialization method** [2] could be applied to the conservation level set method as well. The equation governing the transport and reinitialization of ϕ is in Eqs 4 and 5:

$$\frac{\partial\phi}{\partial\tau} + \nabla\cdot\{\boldsymbol{n}(1-\phi^2)\} - \nabla\cdot(\boldsymbol{n}\boldsymbol{\varepsilon}\nabla\phi\cdot\boldsymbol{n}) = 0 \quad (4)$$

$$\boldsymbol{n} = \frac{\nabla\phi}{|\nabla\phi|} \quad (5)$$

where: τ is a pseudo-time, n is the normal of the interface and ε is the diffusion parameter to be chosen.

5. For the numerical simulation, COMSOL Multiphysics® 5,1 proposed this equation for describing transport and reinitialization:

$$\frac{\partial\phi}{\partial t} + u\cdot\nabla\phi = \gamma\nabla\cdot\left(\varepsilon\nabla\phi - \phi(1-\phi)\frac{\nabla\phi}{|\nabla\phi|}\right) \quad (6)$$

where: u (m/s) is the fluid velocity, γ (m/s) and ε (m) are reinitialization parameters.

Computational methods:

Case 1: The interaction between one air bubble and viscous fluid is considered,

Case 2: A set of air bubbles with a uniform space distribution.

Case 3: A set of air bubbles with random distribution.

***Table 1**. Materials properties*

	Yield stress (Pa)	Density (Kg/m³) ρ	Viscosity (Pa.s) μ
Air	0	1,293	$1{,}94 \times 10^{-5}$
Water	0	1000	$1{,}01 \times 10^{-3}$
Cement Paste	10-100 [2]	1220-1900 [3]	0,01-1 [5]
Mortar	80-400 [2]	1620-1699 [4]	1-3 [5]
Concrete	500-1000 [2]	1700-2400	50-100 [5]

Geometry: We used a cylindrical container of 1 cm in diameter and 2 cm in height, with 5% volume of bubbles having a surface tension of 0.049 N/m [6]. The calculation was launched on ESTP cloud (16 CPU and 128 G of RAM).

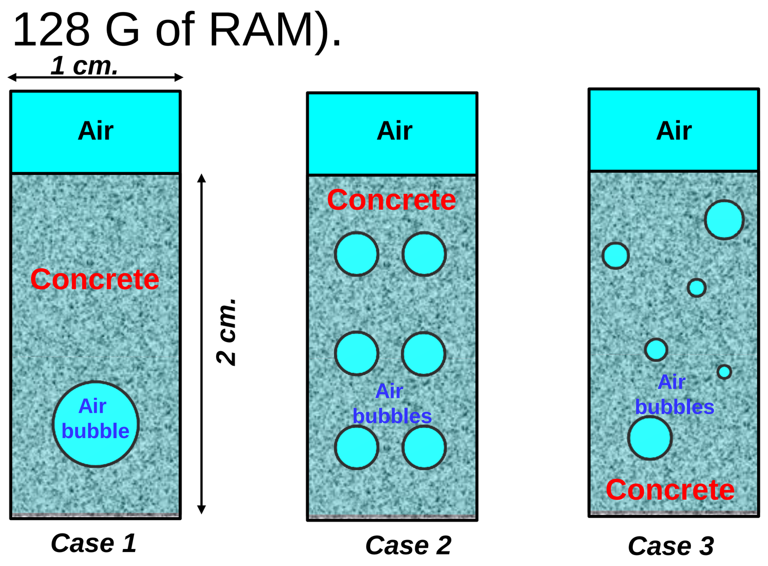

***Fig. 2**. The geometry for rising bubbles of two-flow simulation*

Results: Case 1. Case 2. Case 3.

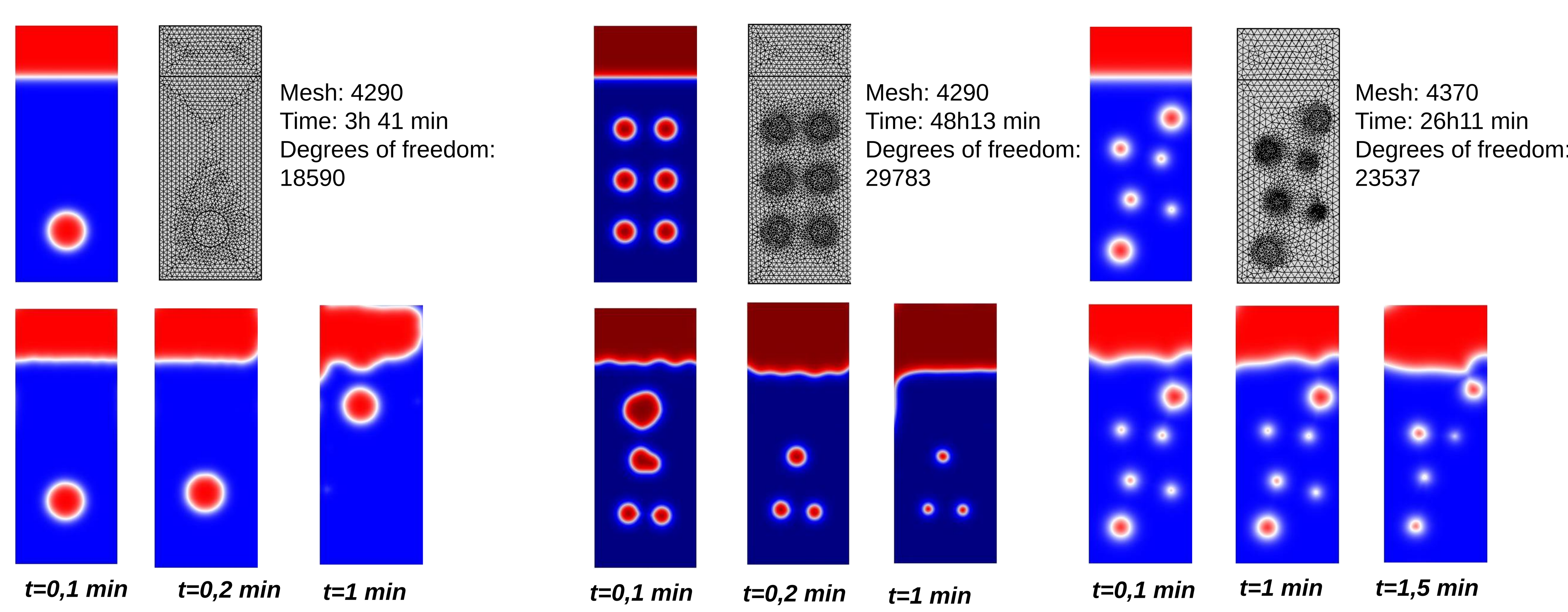

***Fig. 3**. Snapshots showing the rising bubbles with 1 and 6 bubbles*

***Table 2** . Speed of an air bubble through different materials at a given point.*

Fluid	Rising velocity COMSOL (m/s)	Terminal velocity Stokes (m/s)
Water	0,78	7,0409
Cement Paste	0,0179	0,0134
Mortar	0,013	0,0039
Concrete	0,0029	0,0003

The rising velocity was measured in a boundary point of the bubble and was compared with an analytical approach (Stokes law) in Table 2.

In case 2, the ascent behavior is:

1. Close to the surface, the air bubbles tend to merge one to another and rise.
2. In the middle deep, the air bubbles also tend to merge but they stay immobile in the fluid, and the size of the bubble is reduced.
3. In the bottom, the bubbles do not interact nor rise, and the size of the bubbles is reduced too.
4. After simulation the fluid surface stays smooth.

For case 3, the bubbles are in random positions and have different sizes inside the liquid.

1. The bubbles near the surface reach the top of the container and the other bubbles remain static regardless their volume.
2. After simulation, we can explain the formation of a rough surface and the presence of bubbles on the surface (bugholes) (Fig 1c).

Conclusions and perspectives :

Case 1. According to the results, we find a correlation between the COMSOL Multiphysics® models and the analytical approach (table 2).

Case 2. If no bubble escapes from the container, the fluid surface can be smooth.

Case 3. We notice that the bubbles that are close to the surface can generate rough and porous surfaces (Bugholes).

This simulation was performed considering the concrete as an homogeneous fluid forming a biphasic fluid (concrete-air bubbles), which is far from reality. The concrete is a very complex material composed of aggregates, sand, cement paste, water, air, etc. Our goal is to make a multiphase simulation with the presence of its principal materials.

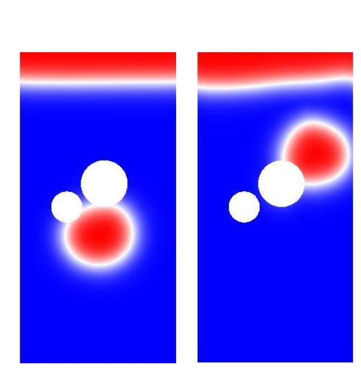

***Fig. 4**. Rising bubbles in multiphase simulation*

References:

1. J. Blackery, Creeping motion of a sphere in tubes filled with a Bingham plastic material, J. Non-Newtonian Fluids Mechanics,70,59-77.(1997)
2. D. Kennedy, level set methods for two-phase flows with FEM, Uppsala Universitet, pp5-13 (2014)
3. Hover, KC, Air Content And Density Of Hardened Concrete , pp 304 (2006).
4. Ian H Murray, Mortar coverage assessment, Building research establishment Ltd. (2006)
5. P.F.G. Banfill, Rheology of fresh cement and concrete, Rheology Reviews,pp 61-130 (2006)
6. Qi Yang, stability of air bubbles in fresh concrete, Chalmer university of technology, pp 6 (2012).

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