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Review Article

Infusion of a Polymer in a Porous Medium: Application of Cement to Concrete

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Abstract

In the present paper, an overall model for the study of a non-isothermal fluid flow across a highly compressible porous medium is proposed, in order to be included into a finite element software. This model can be applied to a wide range of activities, and as an application it is used here to repair of cement concrete by bonding a layer of a polymer.

Keywords: Cement concrete; Polymer; Infusion; Porous media; Polymer bonding

Introduction

With the aim of improving building materials, an idea is developing in the world for the search for new intelligent materials for building with mechanical and thermal characteristics that meet certain energy and technological challenges [1]. Thus, the first consideration is to improve the quality of the cementitious product by adding or replacing cement with polymers [2-4]. The study of the pathological behavior of reinforced concrete and prestressed concrete structures reveals damage to materials and structures due to design errors or aging of materials [5]. The physical properties and more specifically the mechanical behavior of concrete liable to deteriorate depending on the operating conditions of the structure as well as the climatic environment. The main causes of aging are of chemical or mechanical origin which can lead to irreversible damage in the long term [6]. In order to maintain the best and optimize their lifespan, various repair and maintenance techniques for structures have been used for many years [7,8]. The treatment of concrete can be the subject of smoothing operations by applying layers of paint or hydraulic or polymeric mortar after treatment of the degraded surface. In order to mitigate the loss of mechanical strength of these structures, it has become necessary to carry out repairs. Among these distributions, the use of bonding of composite materials [9,10]. The advantage of composite solutions lies mainly in the resistance performance of polymers, their ease of installation and formation on the structures to be repaired as well as in the specific mechanical properties which are associated. The main polymers used for the civil engineering industry are epoxy resins and polyester resins which are both thermosetting polymers [11]. In the case of the association of cementitious materials and polymers requires an introduction to the nature as well as to the respective properties of each, in our case when the support is porous, we use concepts of material transport at the within the material [12-14]. Knowing these fluid movements necessarily involves studying the microstructural characteristics of the support material Indeed, these characteristics are reflected at the macroscopic scale by transfer coefficients, such as permeability or diffusivity, which have a direct influence on the transfers of matter.

Simulation of the Infusion Process at the Mesoscopic Scale

In This part we deal with the case of infusion at the mesoscopic scale, i.e., a heterogeneous medium is considered made up of two phases, the solid phase (the aggregates) and the liquid phase (resin). We consider a flow of the fluid through a porous medium formed by the assembly of homogeneous spherical particles simulating the solid skeleton of the porous medium. Figure 1 shows the geometric configuration where an inlet pressure (p=p0=Pa) is imposed on the upper border, an outlet pressure (p=0). For the movement of the fluid at the interface of the particles, adhesion conditions are imposed. Figure 2 show the progressions of the infusion on a mesoscopic scale, the red color shows the volume fraction of the fluid 1 which in our case is the resin which penetrates into the porous medium constituted by the grains and the pores filled with air. In (Figures 3 & 4) we present respectively the Iso-values of the vertical component of the speed and the field of the speed during the infusion process. We see that the velocity field has a greater amplitude in the permeable case. In addition, we also notice that the speed is lowest at the solid-fluid interfaces, while it is highest at the pore level.

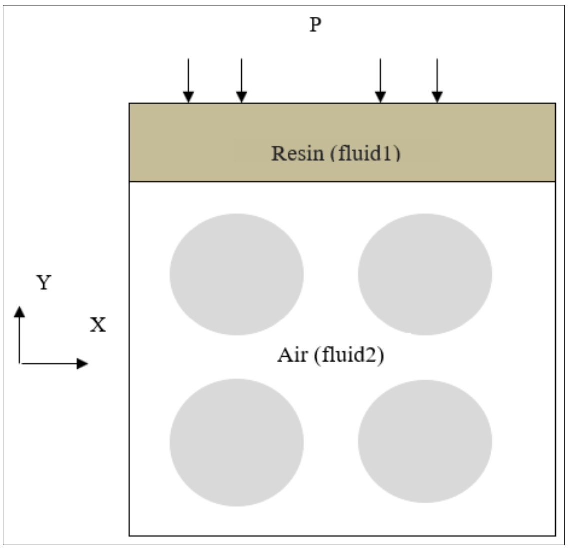

Figure 1: Geometric model and boundary condition.

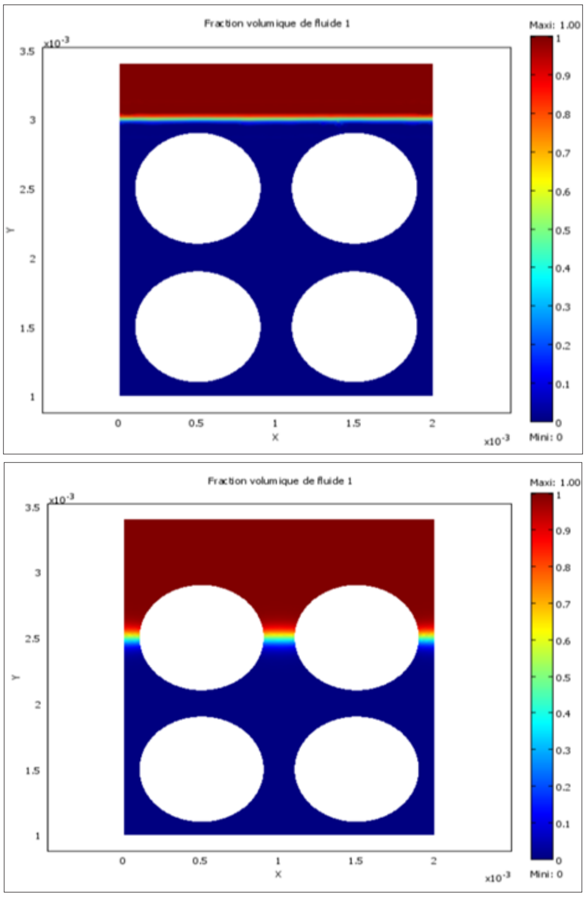

Figure 2: Monitoring of resin infusion at the mesoscopic scale.

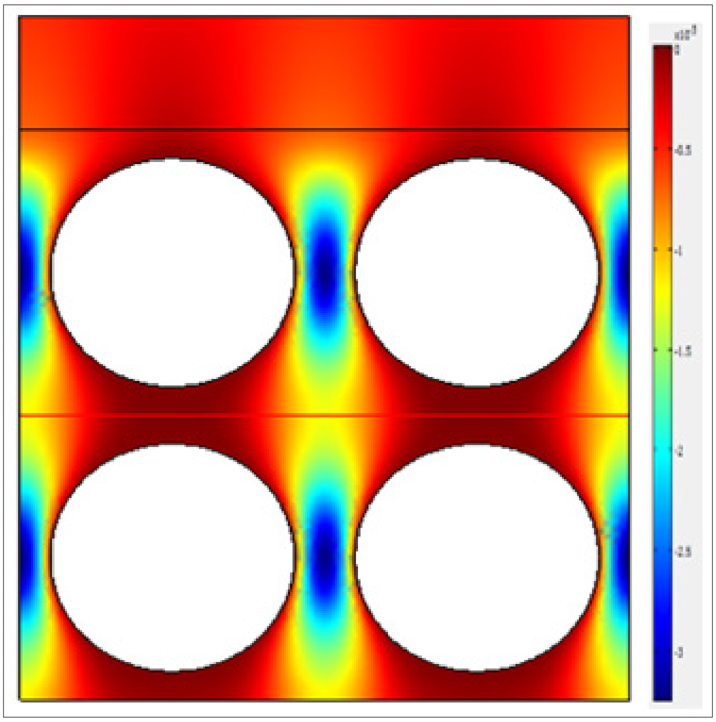

Figure 3: Iso-value of velocity (vy).

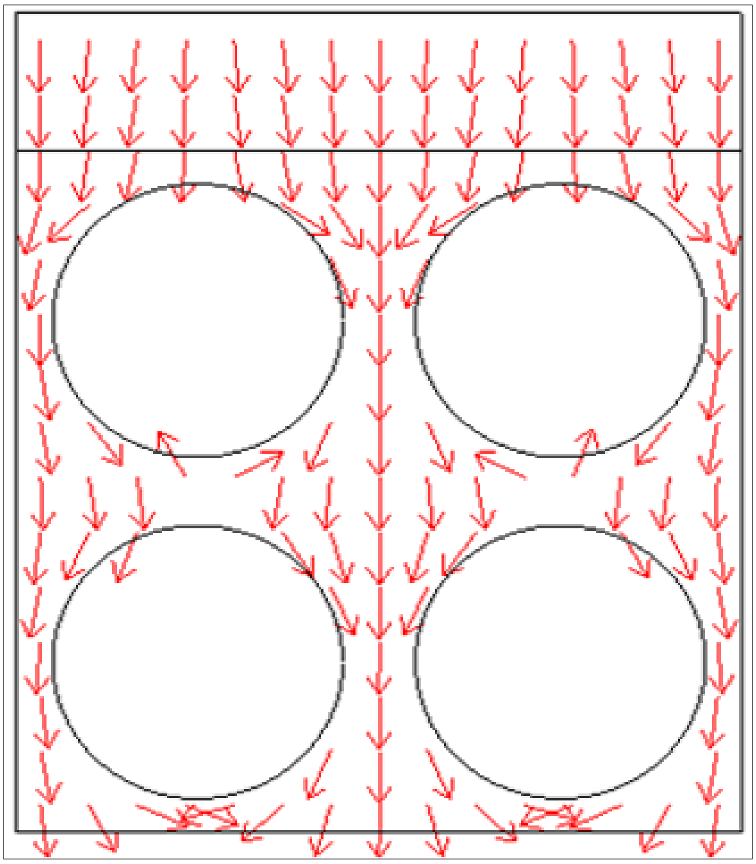

Figure 4: Resin velocity field.

In order to identify the effect of the characteristic parameters of the resin, namely the viscosity, we present in (Figure 5) the variation of the speed (vy) We notice an intrinsic heterogeneity of the speeds inside the pores: the speed is maximum in the middle of the pore and minimum along the walls In addition, the oscillations of the profile of the field of the speed of the fluid are due to the resistance of the matrix solid to mechanical stresses. Likewise, we see the influence of the viscosity of the resin on the flow rate. Note that the lower the viscosity, the greater the flow.

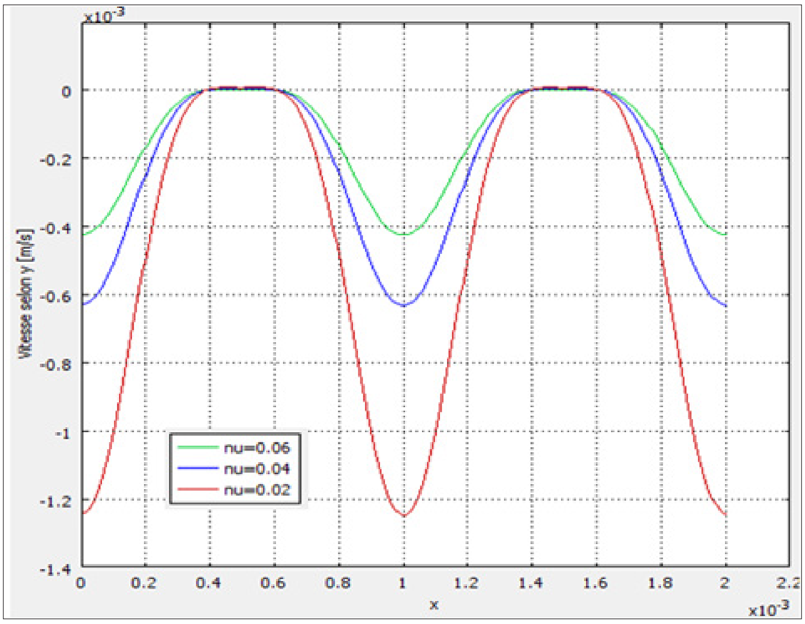

Figure 5: Variation of the speed for different values of the viscosity of the resin.

Application of Cement to Concrete

Modeling

The problem is complex since it is based on the compatibility of several materials with each other. The behavior of each of them is much studied, however the study of inter-facial behavior is relatively recent [15,16]. So, in this part we will study the coupling between the resin and the concrete of the cement since the resin deposited on the concrete gradually penetrates into the pores to form a so-called transition or interphase zone [17]. The aim of this study is to be able to estimate the influence of the various parameters during the infusion process created during the deposition of an epoxy resin on cement concrete. The digital tool developed will make it possible to analyze the sensitivity of the various parameters in order to envisage an optimization of the resin penetration.

The equations of the problem

This part of the study aims to model the transport of resin in cement concrete

Hypotheses: For reasons of simplification, we have considered that the resin is immiscible and that it does not interact with water or with cement. Remember also that the resins studied do not contain solvents. Thus, in order to simplify the model, we will first focus on the convective movement of the phases present, without taking into account the heterogeneities of the composition of the phases. Sand is often the porous medium chosen to represent concrete, because it is a simple granular porous medium in the sense that it is easily characterized, and often already characterized and studied in the literature. In addition, it is a medium relatively inert, homogeneous and free of organic matter. Concrete, which in reality is rarely composed of only sand, can, of course, contain gravel, but these aspects will not be dealt with in the context of our study in order to be close to the building.

We will digitally study the transfers through a concrete specimen of the cement. The geometry is shown where the mesh is visible. In our case the concrete was considered as an equivalent homogeneous medium. We have solved, under Comsol Multiphysics, the coupled transport and Darcy equations in the porous medium, with the boundary conditions and presented in the following Figure: In this model (Figure 6), a vertical section of porous media extends over 20cm in the x direction and 6cm in the y direction. The properties of the material are homogeneous and isotropic.

a. There is no flow on the edges of the geometry

b. Resin concentrations exist at the upper limit (along y=6cm)

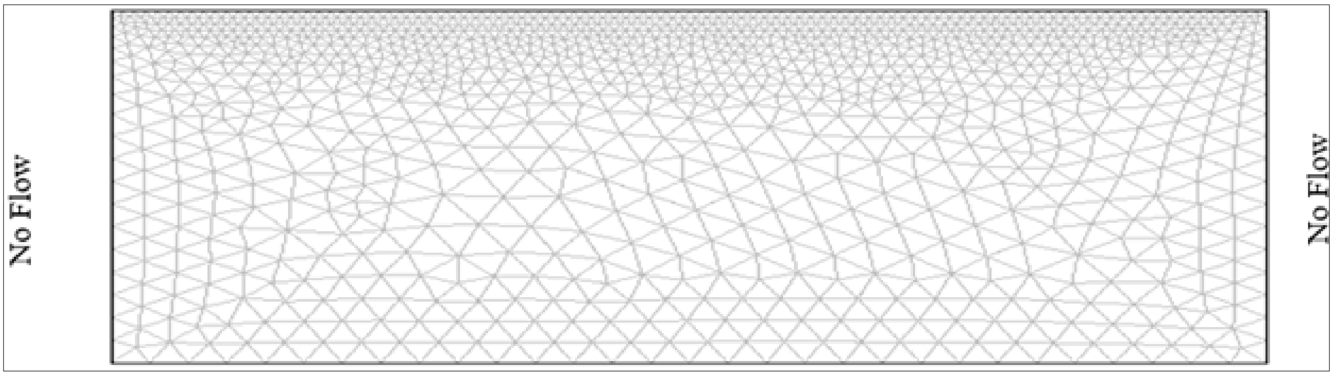

Figure 6: Geometric model and boundary condition.

To describe the fluid flow in this problem end will use Darcy's law with an additional term to make the coupling between the flow and the resin concentration in the concrete:

$$\rho S \frac{\partial p}{\partial t} + \theta \frac{\partial p}{\partial c}\frac{\partial c}{\partial t} + \nabla \left[\rho \frac{k}{\eta} \left(\nabla p + \rho g D \right) \right] = 0 \quad (1)$$

Where p the pressure, c the concentration, ρ is the density (kg/m^3); S is the storage coefficient, tests the time (s), k is equal to the permeability, η is the viscosity, g is the gravity and D is the vertical coordinate, y (m).

Boundary condition: The boundary conditions associated with this equation for a single solution, a reference pressure was specified. In this case, we have chosen a point. Then, with Darcy's Law enforcement mode, you express all of these conditions as:

$$n \cdot \left(\frac{k}{\eta} \left(\nabla p + \rho g D \right) \right) = 0 \partial\Omega \quad \text{(Quoted) (2)}$$

$p=0$ $\partial^2\Omega$ (Point) (3)

$p(x,y,0)=\rho gD$ $t=0$ (4)

The governance equation for this problem is given by the Solute Transport equation

$$\theta_s \frac{\partial c}{\partial t} + + \nabla \cdot \left[-\theta_s D_d \nabla c + uc \right] = 0 \quad (5)$$

Where D_d is the diffusion coefficient θ_s is the volume fraction of fluid; C is the dissolved concentration, u is Darcy's speed.

Boundary condition

Along the upper side of the test piece, we have deposited a layer of resin where we have assumed a concentration equal to 1 on this side. The two vertical edges have no flow, on the lower edge we have a zero concentration. The initial concentration is zero. The following equations represent these conditions:

$$n \cdot \left[-\theta_s D_d \nabla c + uc \right] = 0 \quad \partial\Omega \text{ (vertical side)}$$

$c=1$ $\partial\Omega$ (upper side)

$c=0$ $\partial\Omega$ (lower side)

$c(x,y,0)=0$ to $t=0$

Resin layer ($c=1$, $p=P_{atm}$)

$c=0$, $p=0$

The parameters of the simulations are: $\rho=1590 kg/m^3$, $k=810^{-11} m^2$, $D_d=610^{-6} m^2s^{-1}$, $\theta=0.4$.

Result and Discussion

The following figure (Figure 7) presents the isovalues of the penetration of the resin on the surface of the cement concrete, we notice that the results of the simulation of the penetration of the resin in the cement concrete are similar to the study of [17] which considers the repairing a concrete surface with a polymer will gradually penetrate the pores to form a so-called transition or interphase zone. In (Figures 8 & 9) we present the profiles of the concentration of the resin within the substrate as a function of the viscosity which presents an essential parameter governing the capillary flow inside the porosities of the concrete. Indeed, a low viscosity and a high surface energy make it possible to increase the capillary flow of resins in the cavities and to avoid the formation of air pockets, so the resin can penetrate into the open pores of the concrete, and the depth will be greater. Thus, the following two Figures (Figure 10) show that the transition zone created by the penetration of resin within the porous network of the cement concrete, is greater in the case where the porosity of the concrete is higher. These results can be explained by the direct link that exists between the intrinsic permeability of the material and the porosity of the network. In fact, permeability expresses the ease with which the fluid moves through the material, so the more porous the material, the more the fluid penetrates into the material.

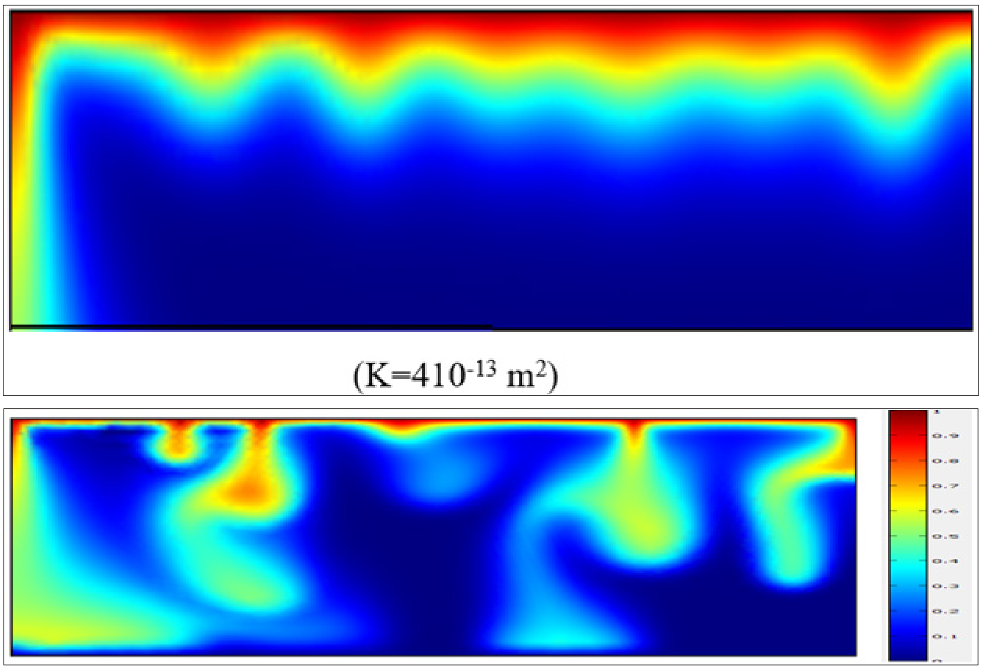

Figure 7: Isovalue of the variation in resin concentration.

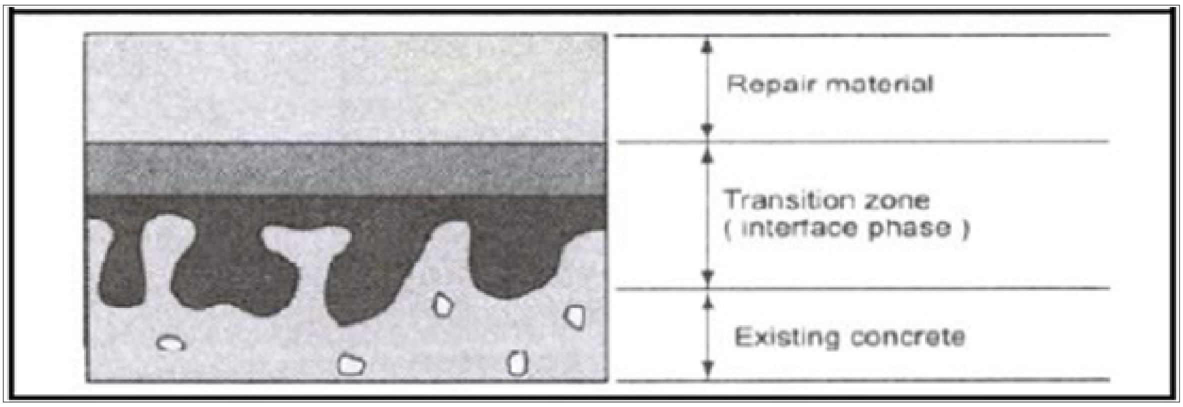

Figure 8: Model of repaired surface [17].

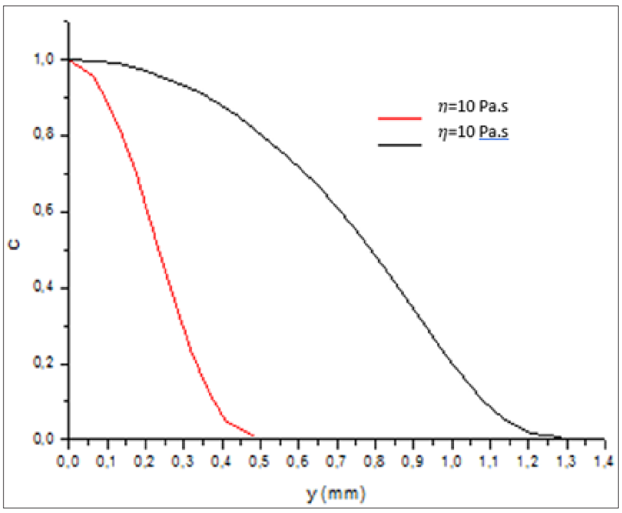

Figure 9: Variation of the resin concentration along the depth of the cement concrete for different resin viscosity value.

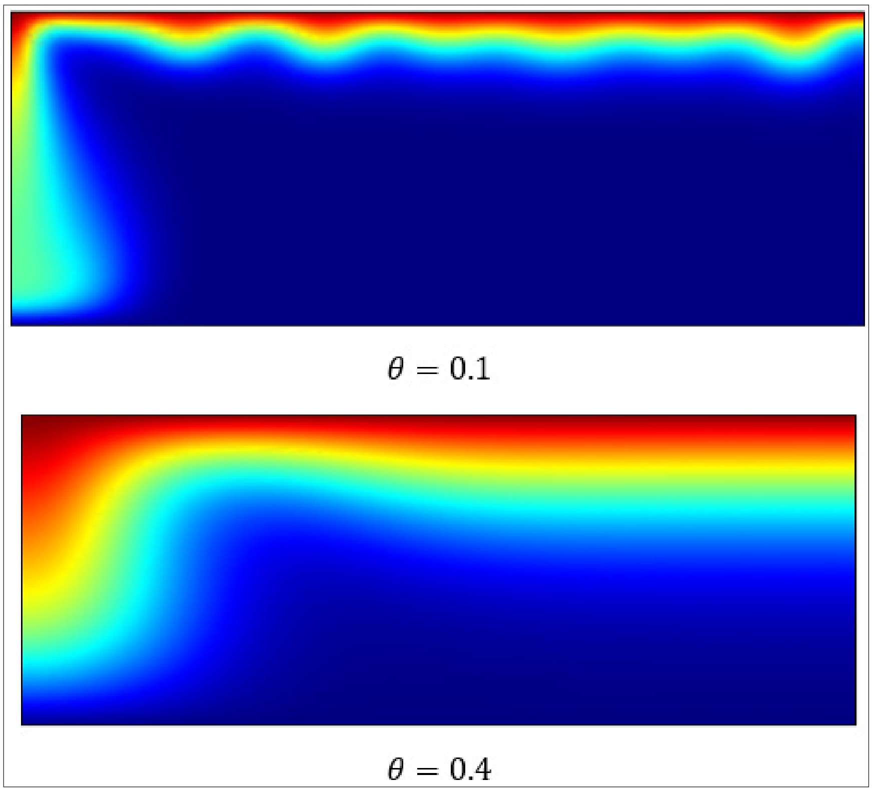

Figure 10: Observation of transition zone on cement concrete of variable porosity.

So, we can conclude that the open porosity of concrete is an essential parameter since it governs the absorption of the surface by the resin. Figure 11 below shows the variation in the concentration of resin penetrated into the cement concrete for different value of the permeability, it is noted that the lower the permeability, the less the resin penetrates in depth. Which is logical since the speed of movement of the fluid is proportional to the permeability of the network.

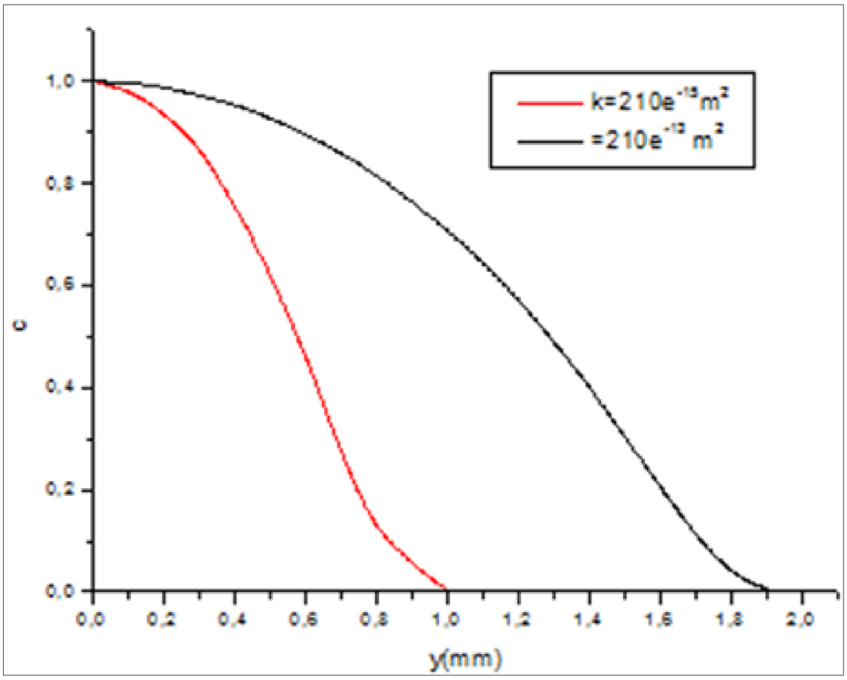

Figure 11: Variation of resin concentration in cement concrete as a function of permeability.

Conclusion

The study was carried out with the aim of ensuring the durability of the bonding of composite materials to repair aging civil engineering works. This is why we proposed a developed digital model that will make it possible to analyze the sensitivity of the various parameters highlighted in order to consider an optimization of the infusion at the mesoscopic scale, i.e., we will consider a heterogeneous medium composed of two phases the solid phase (aggregates) and the liquid phase (resin). The model developed initially just takes into account the convective flows of resin in the porous medium. In the second part and as an application of our numerical model we presented the phenomenon of transport in porous medium, this part of the study aims to model the transport of resin in porous medium. It also made it possible to observe that the distance traveled by the resin varies according to various parameters. These results allow concluding that the permeability of the porous network is a parameter that plays an extremely important role for the flow of resin within the cementitious material.

Another parameter having an influence on the depth of the transition zone has been highlighted. This is the porosity rate of the substrate. Indeed, it has been shown that an increase in porosity leads to the transport of the resin to a greater depth. Another parameter having an influence on the depth of the transition zone has been highlighted. This is the porosity of the substrate. Indeed, it has been shown that an increase in porosity leads to the transport of the resin to a greater depth.

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