International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-5 Issue-2, December 2015

Modeling of Mechanical Behavior of Concretes with Organic Matrices

Ilhem Hawachi, Habib Sammouda

Abstract-This work is devoted to the study mechanical characteristics of polymer concrete. In order to improve the resistance of concretes in environmental attacks under mechanical pressures, the cement matrix can be replaced by an organic one. The addition of fibers allows moreover obtaining a better strength of these materials. We here simulate the mechanical behavior of this composite. These mechanical properties of composite material depend on the manufacturing processes employed in the present paper we will study the manufacturing processes by LRI resin infusion (Liquid Resin Infusion). The infusion process has been developed to be a cost-effective technique for the fabrication of large and complex composite structures, a strong coupling between resin flow and reinforcement deformation takes place in infusion processes. A model which describes the mechanical interaction between the deformations of the porous medium and the resin flow during infusion has been developed. The model developed is based on an ALE formulation of the liquid flow across the deformable porous medium

Keywords: Liquid Resin Infusion (LRI), Numerical model, Polymer concrete, Saturation

I. INTRODUCTION

In recent years, the use of composite materials in primary structural applications has been continually increasing. In the LRI process, liquid thermosetting resin is infused under pressure into a rigid mold filled with fiber performs. The Resin Infusion Processes have become popular for manufacturing structural polymer-based composites in [1]. Many innovative materials have been widely adopted for structural purposes over the last years in the rehabilitation and upgrading of existing structures in several conditions. These materials exhibit high structural performance in their use in the field of new constructions. Within the context of new materials, polymer concretes can represent an interesting design option in [2], with them being typically characterized by more than double the strength of cementations concrete, at the same time, a good chemical resistance to corrosive agents. In this work we will treated the behavior of these during of their elaboration by the resin infusion process. In the simulation of LRI processes, resin flow through dry fibers is conventionally modeled as a saturated flow through porous media, where Darcy's law is used. The determination of the exact location of the flow front is an important issue in the flow analysis.

Manuscript published on 30 December 2016.
***** Correspondence Author (s)
Ilhem Hawachi, Laboratory of Energy and Material (LabEM-LR11ES34) University of Sousse-Tunisia, ESSTHS, Rue Lamine Abbassi, 4011, Hammam Sousse, Tunisia.
Habib Sammouda, Laboratory of Energy and Material (LabEM-LR11ES34) University of Sousse-Tunisia, ESSTHS, Rue Lamine Abbassi, 4011, Hammam Sousse, Tunisia.

On the other hand, in infusion processes performs are infiltrated in the transverse direction (Figure1) by resin of the work of [3, 4], that is consolidated and cured in a single step. It is necessary to treat the behavior of deformable material when high pressure gradients are applied. In the infusion process, it is important to take into account the reinforcement deformation as well as the resin flow. Moreover, a strong coupling takes place between these two phenomena. A study about this fluid-structure interaction problem was carried out by [5]. [6] developed an analytical model for a Two dimensional analysis of a resin film infusion process, which can be used to simulate non-isothermal infiltration of a hot-melt resin into a textile preform of complex shape. [7] dealt with the modelling and simulation of resin flow, heat transfer and curing of a multilayer thermoset composite manufactured by the resin film infusion process. Recently, an analytical solution for the flow of incompressible fluids through compressible porous media and its application to vacuum infusion of composite materials was made by [8]. [9] suggested an analytical solution for one-dimensional flow in the planar direction and compaction in the thickness direction, to describe infusion of resin under vacuum in deformable fibrous porous media. [10] studied infiltration of initially dry deformable porous medium by a pressurized liquid, taking into account the influence of variations in permeability of the deformed porous medium. Infiltration of a liquid matrix through a deformable fibrous preform was also investigated in [11, 12, 13]. In this work we will study first the coupling of liquid regions, ruled by Stokes equations, with the fibrous preform regions governed by a Darcy's law, Second, the interaction phenomena due to the resin flow in the highly compressible preform is treated, too and in a second party we treated to microscopic scale the addition of short fibers in the behavior of concretes with organic matrices. A numerical analysis procedure using a finite element approach has been developed, and is presented in this paper. The model developed here and is based on an ALE formulation of the liquid flow across the deformable porous medium.

II. NUMERICAL MODEL OF THE RESIN INFUSION PROCESSES

Recently, a complete model for the study of a fluid flow through compressible porous media (Figure1) such as fibrous preforms has been proposed by [14,15,16]. This approach opens the way to the development of numerical simulations of infusion process, accounting for large variations of the preform thickness during the process.

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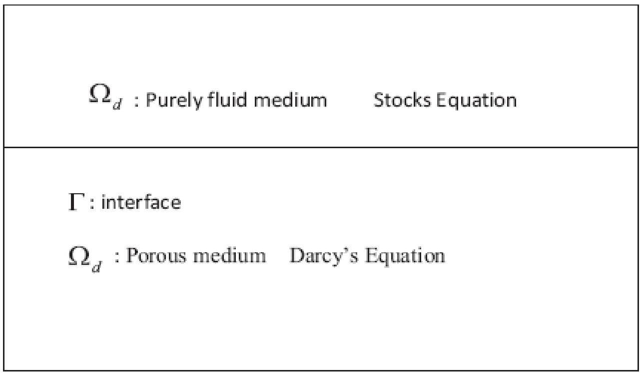

Fig. 1. Geometric model

In this section a set of governing equations modified to consider preform deformation and resin infiltration at the same time is presented. Then a numerical formulation is performed with the models for material properties (such as preform and resin). In the macroscopic model the two components (resin and preforms) are represented in 2 different areas separated by moving boundaries (see Figure 1). This model includes proper boundary conditions and continuity conditions at moving interfaces. The macroscopic modelling achieves a direct numerical coupling while offering reasonable computation costs. In the parametric study, the influence of total stress on the final part height was investigated. The infusion time was also studied for the various total stresses

- Modelling the fluid part

The Arbitrary Lagrangian Eulerian Approach (ALE) is an excellent way to study flows in deformable moving domains bay [17]. In our case an ALE formulation allows a precise flow front tracking while fluid sources can be represented. Resin infusion processes are characterized by a very low infusion velocity. In [18], the resin can be considered as a Newtonian incompressible fluid.

$$\overline{\overline{\sigma}} = 2\eta\overline{\overline{D}} - p\overline{\overline{I}} \quad (1)$$

With $\overline{\overline{\sigma}}$ the Cauchy stress tensor, $\overline{\overline{D}}$ the strain rate tensor, η the fluid dynamic viscosity, p the hydrostatic pressure in the porous medium and $\overline{\overline{I}}$ the second order identity tensor;

- The purely fluid region

A pure fluid resin area is present in the RFI process (see Fig 2). The resin flow is modeled in this zone by stocks equation

$$\eta\overline{\Delta v} - \overline{\nabla} p = 0 \quad (2)$$

$$\bar{v} = -\frac{\overline{\overline{K}}}{\eta}.\overline{\nabla} p \quad (3)$$

With *v* the resin velocity.

b. Resin flow within the preform

The resin flow through the preforms consists in analyzing the problem of a viscous fluid flowing in a compressible porous medium. Under a macroscopic approach, the Darcy's law equation can describe this resin.

(4)

Where *v* describes the Darcy's velocity, *K* the permeability tensor, p the resin pressure, η the dynamic viscosity

- Modelling the solid part

Modelling the solid part focuses on the behaviour of preforms, this can be regarded as a same solid medium, to take account of the resin - preform interaction model is adopted Terzaghi:

$$\overline{\sigma} = \overline{\sigma_{ef}} - sp_r\overline{I} \quad (5)$$

- Boundary conditions

The boundary conditions for simulating the infusion of a plate by infusion process are shown in Fig 2

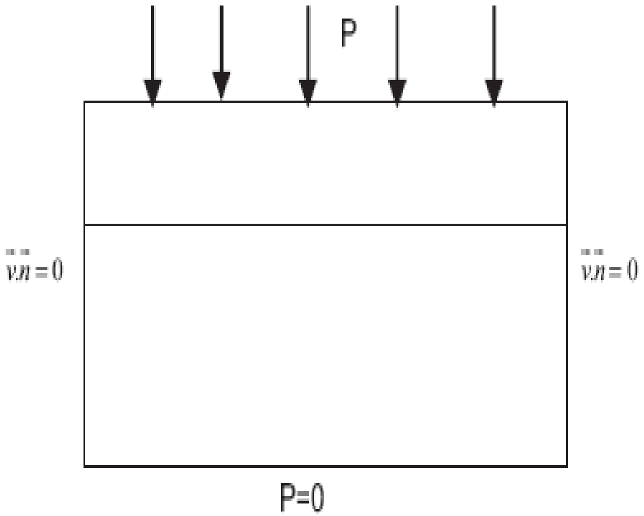

Fig. 2. Boundary conditions

III. RESULTS AND DISCUSSION

A. MODELING COUPLING STOKES-DARCY

This section is an overview of results about the coupling of Navier-Stokes and Darcy equations to model the filtration of incompressible fluids through porous media which ensure the continuity of the speeds and pressures so 'natural' through the interface. The simulation was carried out using the software COMSOL.The results of a test of transverse flow at the interface, as shown in Figure 4 show that the flow is stable

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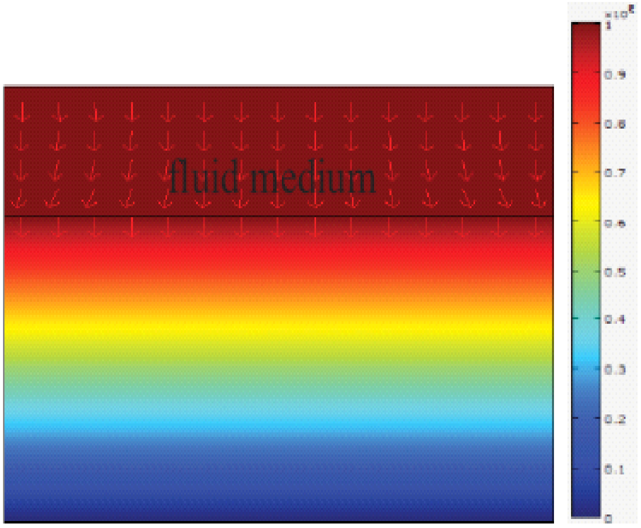

Fig. 3. Isovalues pressure

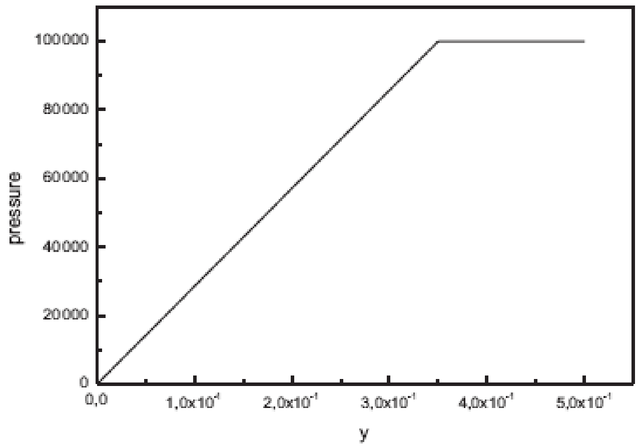

Fig. 4. Pressure profil

In this test case, we reduced the permeability of the perform. The results of the simulation of the resin front are shown in the following figures (Fig 4). We observe that the infusion height was increased into the preform with increasing permeability.

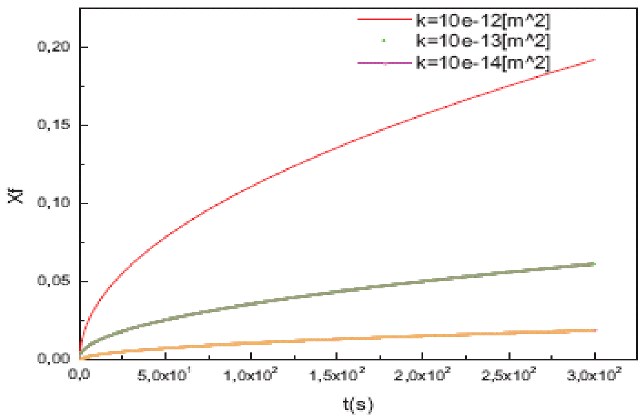

Fig. 5. Height of resin infusion for different permeability

From these results, it can be seen that the permeability is a key factor for use in the numerical model.

B. BEHAVIOR OF PERFORM

We present in this section the deformation of preform, these are deformed under the action of the mechanical pressure applied and the pressure of the resin within the pores. The Fig 6 presents the distribution of the tensile strains of the preform. The red area in Fig 6 signifies the location of the maximum tensile stresses that lead to the formation of the flexural crack.

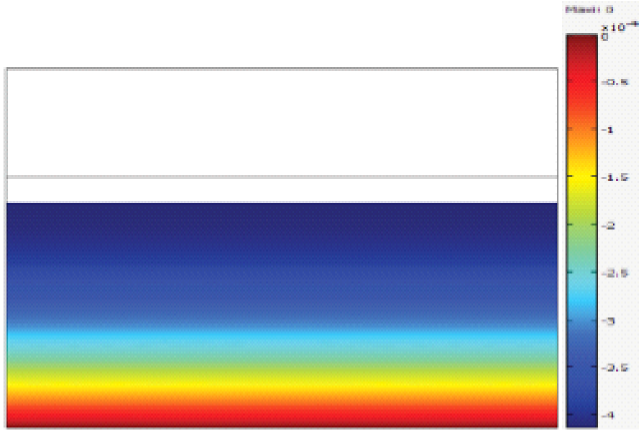

Fig. 6. Isovalues displacement

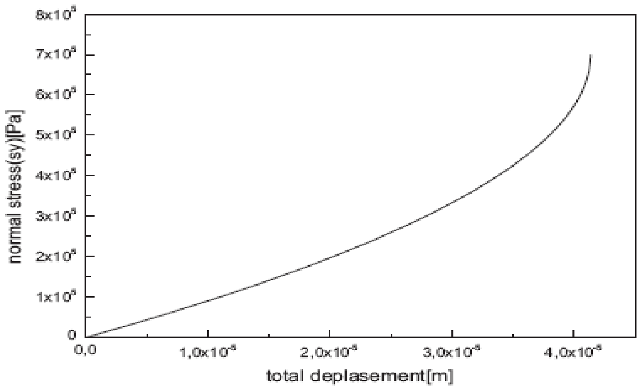

Fig. 7. Displacement of perform

As a result, the preform is deformed uniformly in the thickness direction. On the other hand, the principal resin flow and preform deformation occur in the same direction (i.e. the thickness of product), in the infusion process.

The compression results show that the preform has a nonlinear reversible behavior (Fig 7). In most of related works, the preforme is supposed to be uniformly deformed in the direction of applied stress and the fibre volume fraction remains uniform in this direction while it is variable in the principal flow direction.

C. Variation of the saturation during the infusion process

Saturation is the parameter that determines the efficiency of displacement of the fluid in the porous medium considered. We noticed (Fig 8and 9) that the saturation of the fluid phases and the hydraulic conductivity of the medium greatly affects the efficiency of the infusion. In general we have seen that the permeability of the porous network is a parameter it is important to control a function of the saturation of the medium.

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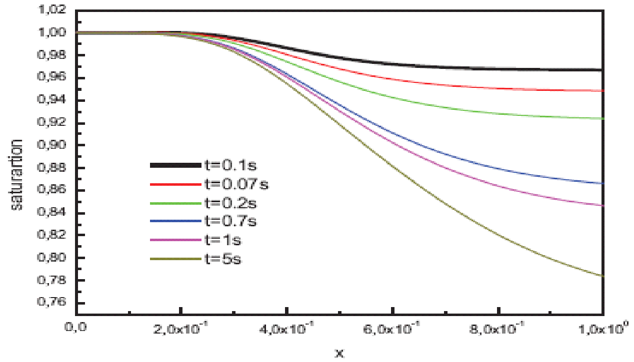

Fig. 8. Profile of distribution of the resin based on time

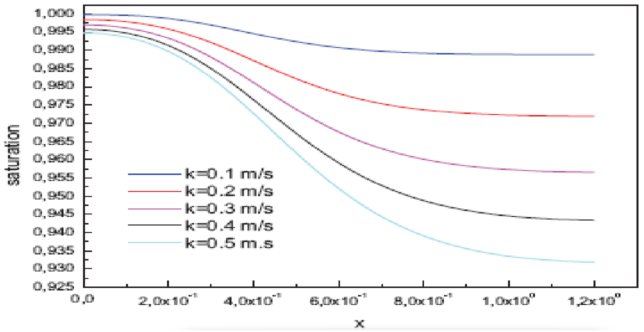

Fig. 9. Profile of distribution of the resin based hydraulic conductivity

As shown in Fig 10, the saturation increases with time up to the complete infusion of the part (1) for the higher load pressure (p = 1 and 0.5 (ms), while it remains at a lower value of 0.91 and 0.92 respectively for the lower load pressure p = 0.1 to 0.2 (ms). Thereafter, the infusion procedure runs fast depending on the total stress applied.

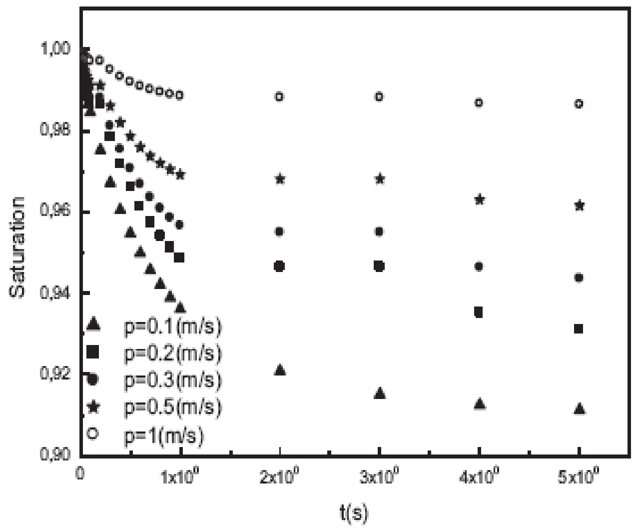

Fig. 10. Evolution of the saturation or different load pressure

IV. CONCLUSION

A numerical modeling in infusion process has been carried out. It was based on a modeling resulting from the process physics and on reinforcement behavior laws. Considering preform deformation, a numerical analysis governing by the finite element method was performed. Here we introduced according to the methods of homogenization, simulation of elastic behavior of composites used in civil engineering applications. We consider that our numerical model is deal with the problem of interaction between resin flow and the deformations of the porous performs during the resin infusion and behavior of polymer concrete. In our work we used Comsol software in order to follow the non-linear mechanical response of the solid material and to observe velocity and pressure fields during the flow we also show the importance of parameters on the efficiencies of the infusion (permeability, Infusion time, applied stress). This model can be applied to a wide range of activities from composite manufacturing processes to all industrial processes involving infiltration in deformable porous materials. In future works a microscopic study on the behavior of concrete polymer will be presented

ACKNOWLEDGEMENT

The authors would like to thank the reviewers of this paper for their constructive comments during the submission process.

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