Numerical investigation of aggregates size and volume fraction on hydro-mechanical properties of 3D meso-scale concrete

Al Khazraji H.[1,2], Benkemoun N.[1], Choinska M.[1], Khelidj A.[1]

[1] *Université Nantes Angers Le Mans (L'UNAM), GeM,*
Research Institute of Civil Engineering and Mechanics, CNRS UMR 6183, Nantes University, IUT Saint-Nazaire
58 rue Michel Ange, 44600 Saint-Nazaire, FRANCE
[2] *Department of Civil Engineering, University of Misan, Iraq*
hayder.al-khazraji@etu.univ-nantes.fr

RÉSUMÉ. *Dans ce papier, l'influence de la fraction volumique et de la taille des granulats sur les propriétés hydromécanique d'un béton à l'échelle mésoscopique est étudiée. Trois différentes fractions volumiques variant de 10 à 30 % sont étudiées. De plus, deux tailles de granulats sont testées 10 et 16 mm. Les résultats des simulations numériques ont montent que l'augmentation de la fraction volumique entraîne l'augmentation de l'énergie de dissipée, la contrainte de traction ainsi que de l'ouverture de fissure. Finalement, les résultats montrent aussi que l'augmentation de l'ouverture de fissure et la diminution de la fraction volumique diminuent la perméabilité au gaz.*

ABSTRACT. *In this paper, the influence of aggregates size and volume fraction on hydro-mechanical properties of meso-scale concrete is investigated. Three volume fractions of aggregates are investigated varying from 10 to 30 %. Furthermore, two aggregates sizes are examined, 10 and 16 mm. Numerical results provide some indications: increasing volume fraction leads to increase fracture energy, tensile stress and crack opening. The results show that increasing crack width and decreasing volume fraction lead to increase the gas permeability.*

MOTS-CLÉS : *Essai de fendage traction ; Modélisation méso-échelle ; Faible discontinuité ; Forte discontinuité ; Méthode des éléments finis ; Perméabilité aux gaz*

KEYWORDS: *Tensile splitting test; Meso-scale modelling; Weak discontinuity; Strong discontinuity ; Finite Element Method; Gas permeability*

1. Introduction

There are many parameters play a critical role in controlling a durability of concrete such as : aggregates size, type, volume fraction and surface area. Tasdemir et al. [TAS 96] investigated the influence of aggregates size and its type on the mechanical properties. Bisschop and van Mier [BIS 02] showed increasing aggregates size from 2 to 6 mm leads to an increase in total crack length but also in the maximum crack depth.

Grassl et al. [GRA 10] found out that permeability increases with the increasing of aggregates diameter and decreasing of the volume fraction. Picandet et al. [PIC 09] pointed out the permeability of gas and water increase with the increasing of crack opening .

The aim of this study is to investigate the effect of aggregates size and volume fraction on hydro-mechanical properties of heterogeneous material in the context of tensile splitting test. In this work, we describe a numerical method to model the hydro-mechanical coupling, a 3D computational meso-scale model is used in the framework of the Enhanced Finite Element Method which is proposed by Benkemoun et al. [BEN 10]. This method has two discontinuities : the first one is weak discontinuity which refers to continuous displacement field and discontinuous strain field (see [ORT 87]). The second discontinuity is introduced here is the displacement discontinuity (strong) to represent crack opening (discontinuous displacement field) (see [SIM 93]).

2. Numerical simulations and results

2.1. *Mesostructure and discretization of cylinder specimen*

The resulted inclusions are spherical with a mono-size for each cylinder specimen. Two groups of specimens with dimensions 110 x 50 mm diameter and thickness respectively, have been simulated. Each group of cylinder has one size of aggregate and three volume fractions of 10, 20 and 30 %. However, two aggregate sizes of 10 and 16 mm are used.The mechanical properties for each phase (cement paste, aggregate and interfaces), are summarized in Table 1 for specimen with aggregate diameters of 10 and 16 mm and volume fractions 10, 20 and 30 %.

Table 1. *Mechanical Properties of Materials.*

Cement paste	Aggregate	Interfaces
E_{mor}= 35 GPa	E_{agg}= 100 GPa	-
σ_u= 3 MPa	-	σ_u= 3 MPa
G_u= 80 J/m^2	-	G_u= 80 J/m^2

2.2. *Constitutive maximum crack opening*

In this section, we focus on the effect of aggregates size and volume fraction on the maximum crack opening. The numerical results of simulations are shown in Figure 1, there is a significant and effective relation between the volume fraction and the maximum crack opening. In the other word, the increase in volume fraction leads to an increase in the maximum crack opening. To interpret this ascending correlation, it could be selected to due to the increase of surface area around the aggregate particles leading to more weak debonding areas in the split elements. In addition, when a volume fraction of 30 % is used, it causes reduced spacing between the aggregate particles taking into account that the aggregate size is constant.

The numerical results show a reverse effect of the aggregate size on the maximum crack opening. The increase of aggregate diameter decreases the maximum crack opening with taking into account that the volume fraction of aggregate is constant. The maximum crack opening is calculated at the peak tensile stress.

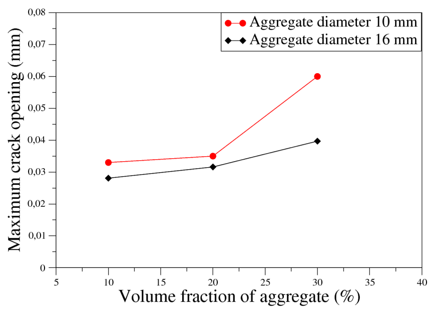

Figure 1 – Effect of aggregates size and volume fraction on maximum crack opening.

2.3. *Volume fraction-ultimate tensile stress relationship*

The influence of volume fraction on the ultimate tensile stress is studied using three volume fraction percentages 10, 20 and 30 % with aggregate sizes 10 and 16 mm. The numerical simulations results show in Figure 2, the ultimate tensile stress increases with the increasing of aggregates volume fraction. Also we note that this increase depends on the aggregates size. We can explain this behavior due to the higher modulus elasticity for aggregate particles. These particles strengthen the cement paste. Increasing the volume from 10 % to 30 % resulted in 38 % increase in splitting tensile stress for aggregates size 10 mm and 22 % for the aggregates size 16 mm, in addition the bonding strength between the aggregate particles and cement paste depends on the aggregates size.

2.4. *Influence of volume fraction and aggregate size on fracture energy*

The simulation results for the influence of volume fraction and aggregates size on the fracture energy we plotted in Figure 3. Specimens having a larger aggregate size and a higher volume fraction show higher fracture energy. The increase in aggregates size and volume fraction leads to increase in the fracture energy.

Our results are in agreement with some authors, Petersson [PET 80] pointed out that increasing the volume fraction leads to increase fracture energy. The influence of aggregate size on the fracture energy has already been discussed by Elices et al. [ELI 08]. They carried out that the bonding force between the aggregate and cement paste influence on the fracture energy, significantly.

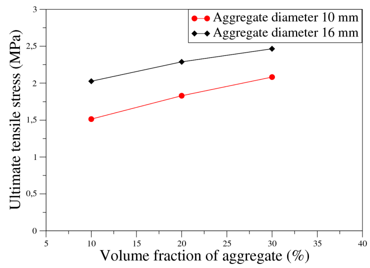

Figure 2 – Effect of aggregates size and volume fraction on ultimate tensile stress.

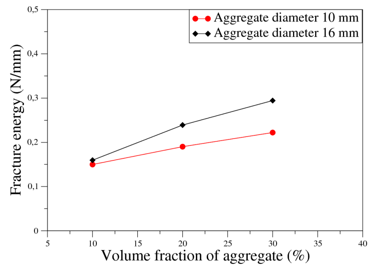

Figure 3 – Effect of aggregates size and volume fraction on fracture energy.

2.5. *Numerical simulations of crack-induced permeability in concrete*

In this work, crack-induced permeability in concrete is modeled to examine the interaction between crack opening and permeability. We also investigate the influence of aggregates size, volume fraction and crack opening on gas permeability. The results show that the permeability decreases when the aggregates size and volume fraction increase, while the permeability increases significantly with crack opening. Six numerical simulations were performed to investigate one single controlled crack.

Figures 4-8 show that the gas permeability increases rapidly when crack opening is larger than 5 μm. These results are agreement with several studies. Wang et al. [WAN 97] investigated the water permeability increasing with the increasing of crack width. Rastiello et al. [RAS 14] offered a relationship between the permeability of fluid with the crack width for the saturation concrete specimens based on the Brazilian splitting test. Choinska et al. [CHO 07] presented the permeability of concrete as a function of diffuse microcracking with the level of damage from 0 to 15 % before the peak load, and as a function of the macrocracking created after the peak load.

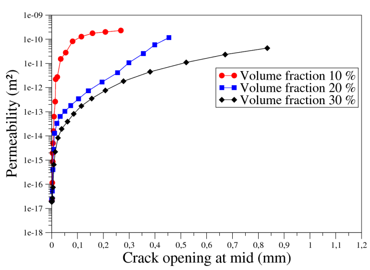

Figure 4 – Effect of crack opening and volume fraction on permeability with aggregates size equal to 10 mm.

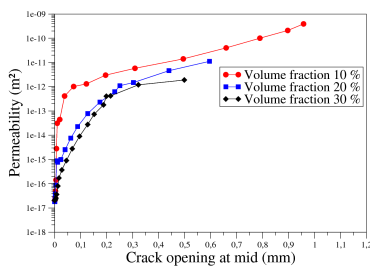

Figure 5 – Effect of crack opening and volume fraction on permeability with aggregates size equal to 16 mm.

3. Conclusions

From the numerical results we can conclude that the mechanical behavior is influenced by the aggregates size and volume fraction. In this study, showed crack opening increased with volume fraction, while it decreased with aggregates size. The results indicate that both, ultimate tensile stress and fracture energy increase with aggregates size and volume fraction. Gas permeability increases with crack opening while it decreases with aggregates size and volume fraction.

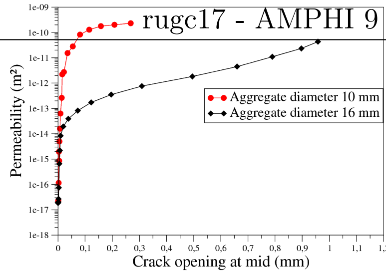

Figure 6 – Effect of crack opening and aggregates size on permeability with volume fraction equal to 10 %.

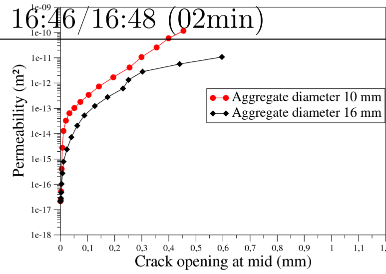

Figure 7 – Effect of crack opening and aggregates size on permeability with volume fraction equal to 20 %.

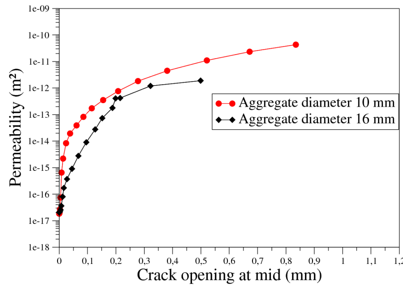

Figure 8 – Effect of crack opening and aggregates size on permeability with volume fraction equal to 30 %.

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