e-ISSN:2321-6212
p-ISSN:2347-2278

Research & Reviews: Journal of Material Sciences

Numerical Study of the Mechanical Behavior of Polymer Concrete

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Research Article

Received date: 01/09/2015
Accepted date: 08/01/2016
Published date: 12/01/2016

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Keywords: Polymer concrete, Simulation, Characterization.

ABSTRACT

Polymer concretes (PCs) represent a good alternative to traditional cementitious materials in the field of new construction. In fact, PCs exhibit high compressive strength and ultimate compressive strain values, as well as good chemical resistance. Within the context of these benefits, this paper presents a study on the behavior of polymer concrete using a mechanical model recently developed by the authors.

A 2D model is constructed in which aggregates are modeled by random distributed polygon. Compressive testing of the PC is firstly carried out to provide experimental benchmark for validation of the proposed numerical model a numerical simulation of the model is then performed using COMSOL software and the compressive and bending stress-strain curves are obtained.

INTRODUCTION

The PC is a new type of concrete in which the matrix is polyurethane polymer substituting the conventional cement mortar, the aggregate is crushed stone. The PC material has better toughness properties, better fatigue performance and better pavement behavior compared with traditional asphalt and cement concrete [1], which qualifies it as a potential high-performance pavement material [2]. In the optimization process of the new material, the mechanical properties at high strain rate must be addressed, especially the response subjected to dynamic compression. Uniaxial compression test is the most common method for characterizing strengths of concrete materials [3-5]. The literature indicates that, as they have greater mechanical strength than cement concrete, they can save up to 50% of competing materials for special applications. This type of concrete is used in construction, especially public or commercial buildings.

Due to their lightness and high structural performance, polymer-based materials have been widely utilized in recent years to strengthen existing construction that are subject to static and seismic loads. Their general mechanical features [6] and constructive details [7] have been investigated in previous studies.

Normally in the numerical simulations, polymer concrete was assumed to be isotropic and homogeneous. Whereas, polymer concrete materials are very complex, which make the material behavior under loading very complicated. Some macro-structure [8] and micro-structure [9] models also have been developed to analyze the mechanical behaviour of polymer concrete materials. In order to obtain the resin concrete with superior performance of the fibers can be added to the mixture. The addition of fibers, either continuous or discontinuous, with brittle matrix materials, significantly improves the fracture toughness and strength of the resulting composites [10-12].

Reis [13] studied the effect of natural fibers on the bending strength of a PC. He concluded that using natural fibers in composition of the PC increases the bending strength. Griffiths and Ball [14] determined the modulus of rupture and fracture toughness of a polyester PC using three-point flexural testing method.

Multi-scale analysis for various materials with microscopic heterogeneity has been one of the major topics in both computational mechanics and materials science. Among some computational methods for the multi-scale analysis, the homogenization method has been successfully applied to the composite materials including polymer matrix composites (PMC) [15]. This paper proposes a multi scale approach for polymer concrete. The meso-mechanical model includes the explicit description of the heterogeneous material geometry, as well as a description for interaction between the matrix-aggregate, then treated the behavior of polymer concrete in macroscopic mode. In the first part will study a meso-scale model, aggregate model generated firstly, and the rest area is ‘‘filled’’ by resin. In this model the interfaces are not included and the perfect bonding between the aggregate and the matrix is assumed, then we will deal the case of a macroscopic model.

To study the law of behavior of polymer concrete at the macroscopic scale, a typical uniaxial compression loading sequence of epoxy based mortars, i.e. aggregate (sand)/resin mixtures, and one three-point bending test have been simulated utilizing the comsol software for finite element analysis of structures, The purpose of this work was to study the distribution of stress and displacements in models assuming elastic behavior for the inclusion and elastoplastic behavior for the resin.

MECHANICAL CHARACTERIZATION OF THE POLYMER CONCRETE TO THE MICRO-SCALE

Numerical Modeling

The the present procedure based on the finite element method is described in this section. Here, the large aggregates are introduced into the new homogenized matrix to perform assumed virtual tests.Preparation of a concrete sample at a mesoscopic level suitable for two- and three-dimensional numerical simulations is described with the emphases on two essential steps: (i) geometry preparation and (ii) generation of finite element mesh.A numerical prediction of the non-linear behavior of concrete on a microscale is described in this section. The obtained material properties are then utilized for the finite element simulations at the microscopic level. Therefore, concrete is seen as a two-phase system, the inclusion embedded in an infinite matrix **(Figure 1)**.

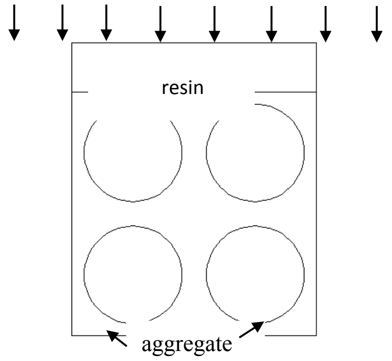

Figure 1. Geometry of model.

To evaluate the mechanical behavior of resin/aggregate mixtures, several two-dimensional simulation models of the microstructure of the resin/ aggregate mixture were developed and subsequently modeled, using the finite element method.In first part we will study the influence of inclusions of geometry on the behavior of materials. In the second part it was assumed that the aggregate phase in the model consists only of spherical particles. In the case of the model, each circular particle is positioned at the centre of a virtual square of size 1x1 mm **(Figure 1).**

Effect of the Nature of the Inclusions on the Behavior of the Resin Concrete

The objective of this research is to develop micro concrete made of a polyester resin binder using two types of inclusions, sand and gravel.

Materials Used

The materials used are sand, gravel and a binder consisting of a liquid polyester resin, 1.11g/cm^3 density, flammable, viscosity 20 dPa. The studied composite is assumed composed of a matrix, denoted by the index “r”, and inclusions denoted by the index "s". These inclusions may be aligned or randomly oriented in the matrix. In the first part we will study the case where the inclusions are gravel, the model studied is shown in **Figure 2**.The gravel is modeled by square particles included in a resin matrix .In the second part we will study the case or the inclusions have a spherical shape

Influence of Fiber Content on the Resin Concrete

The mechanical properties of the resin concrete are improved by adding fibers which reduce the brittleness of these materials **(Figure 3)**. In this section we present a simulation of the elastic behavior of a polymer concrete beam reinforced by glass fiber and biased by three-point bending. The gravel is modeled by square particle and glass fibers by cylindrical particles oriented in space randomly **(Figure 4).**

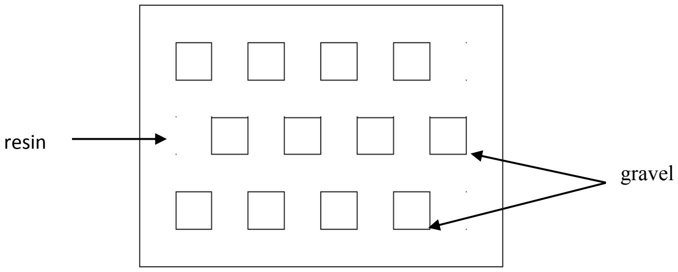

Figure 2. Geometry model at the microscopic.

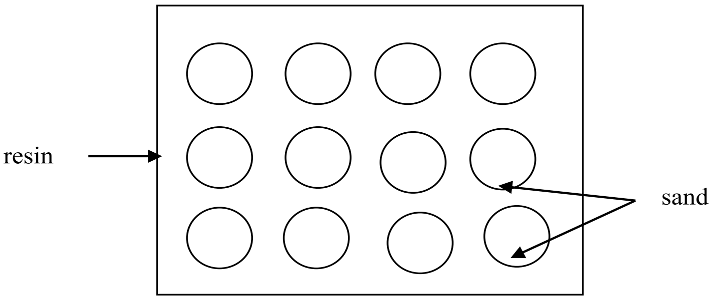

Figure 3. Geometry model at the microscopic level of the resin concrete.

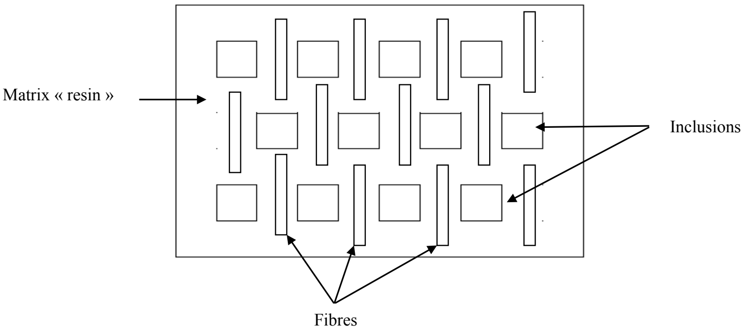

Figure 4. Geometry model at the microscopic level of the resin concrete reinforced by fibers.

Loading and Boundary Conditions

The model was subjected to a vertical edge load of 10 MPa .This value was based on the laboratory results [16] and was intended to be in the range of linear elastic response of the resin/aggregate mixture. Additionally, symmetry on the x- and y- axes was considered.

In all cases, sand material was considered isotropic, homogeneous and elastic and the elastic modulus of the aggregate (sand) Ea was varied from 1000 to 15 000 MPa.

Numerical Simulation of Composites Processing with Preform Deformation

During the liquid metal infusion, the viscous forces, and the capillary forces induce a compression stress field in the solid skeleton of the preform. The fibrous preform is then compressed during the filling phase processing, the injection phase and the compression phase are strongly coupled. In our study we will be presented a numerical model which describe the compression phase in the field of composites processing by infusion.

MECHANICAL CHARACTERIZATION OF THE POLYMER CONCRETE TO THE MACRO-SCALE

The main objective of this research work is to study the structural behavior of the polymer concrete. There has been quite extensive research done in the field of using polymers in construction materials [17]. From a mechanical (macroscopic) point of view, there are several fundamental properties to have namely, the compressive stress–strain curve, the flexural strength and the static elastic modulus, So in this part of numerical modeling of a compression test and a bending test will be studied.

Mechanical Testing Procedures

The sand used is of rather uniform particle size,The specific gravity was 2.65 g/cm^3, and the fineness modulus was 2.5. The resin content was 12% by weight, no filler was added and 88% of aggregates complete the PM formulations. To study the behavior law of concrete a uniaxial compression tests are conducted on 50 ×100 mm PC cylinders and 400 ×75 ×75 mm P C beams are used for three-point bending tests. The specifications of this standard, in terms of specimen geometry and span length, are similar **(Figure 5).**

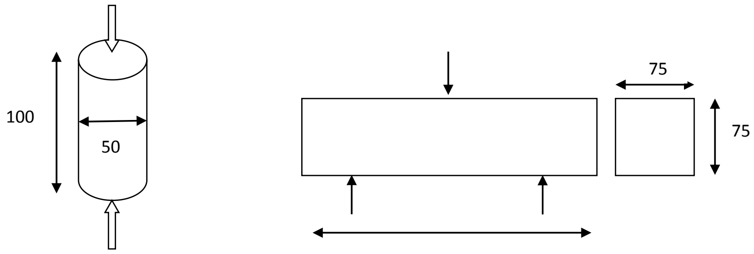

Figure 5. Dimensions of the compressive and bending models

RESULTS AND DISCUSSIONS

Mechanical Behavior of Polymer Concrete at the Microscopic Scal

The distribution of stresses and displacement are plotted for the model along a horizontal line that passes through the centers of the lower grains in each block. **Figure 6** presents the distribution of the vertical stress, S_{yy} for model for varying values of Ea. Results show that compressive loading is transferred to the sand particles, while the resin carries practically very little load. The **Figure 6** indicates that the equivalent Young's modulus increase with increase of the Young's modulus reinforcements, Also, the variation of E affect the vertical stress

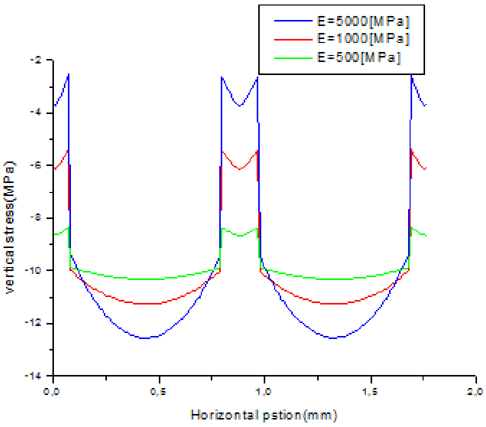

Figure 6. Distribution of vertical stress and varying aggregate properties.

Figure 7 shows the movement of particles under the effect of the applied stress. The results of **Figures 8 and 9** show that compressive loading is transferred to the sand particles; the displacement of the particles follows the direction of infusion can be clearly explained from **Figures 10 and 11.**

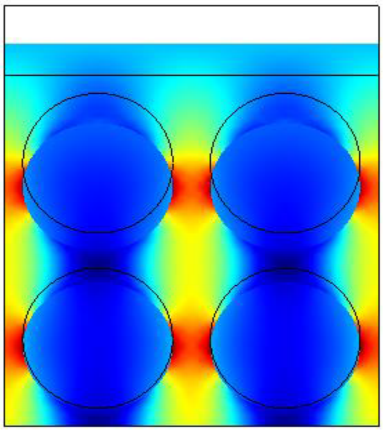

Figure 7. Shows the movement of particles under the effect of the applied stress.

The comparison of the deformation of inclusions for both types gravel and sand are noted from **Figures 12 and 13.**It states that the deformation of the sand is less important than gravel.

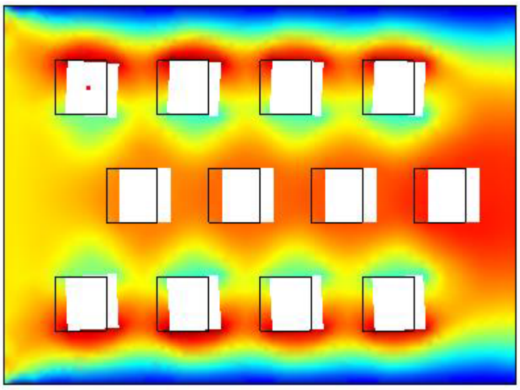

Figure 8. Iso value speed of resin.

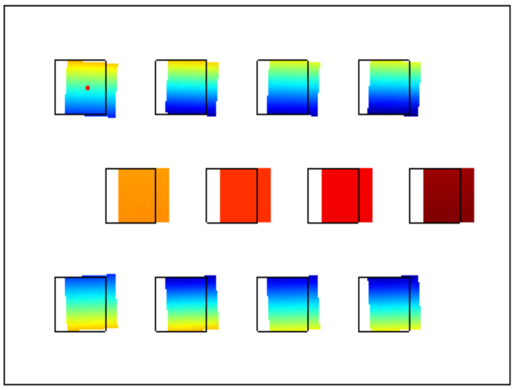

Figure 9. Particle Displacement.

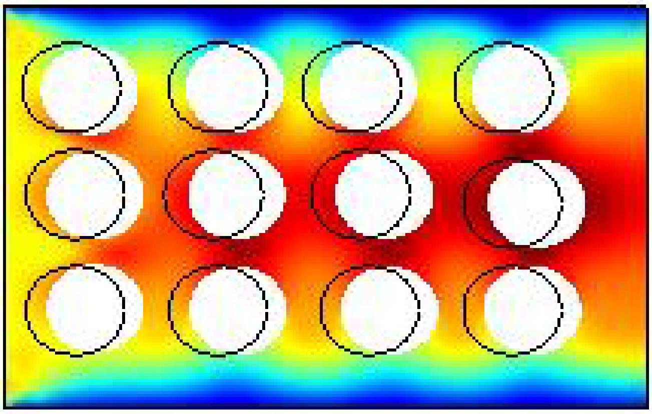

Figure 10. Isovalue speed of resin.

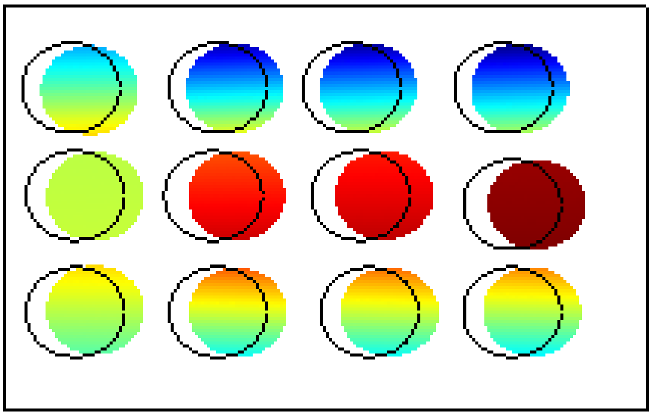

Figure 11. Particle displacement.

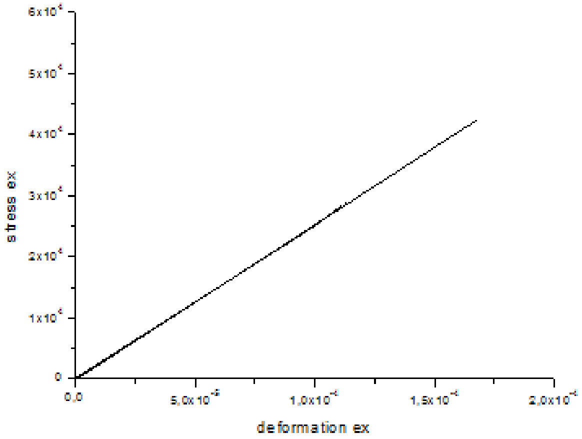

Figure 12. Curve stress-deformation of gravel.

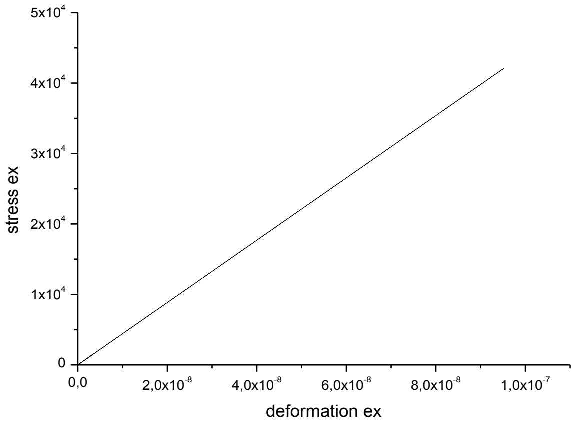

Figure 13. Curve stress-deformation of sand.

From **Figures 14 and 15** it is important to notice that the movement of the particles is more important in the absence of fibers which shows the importance of strengthening of building materials by fibers which provides better resistance to stress.

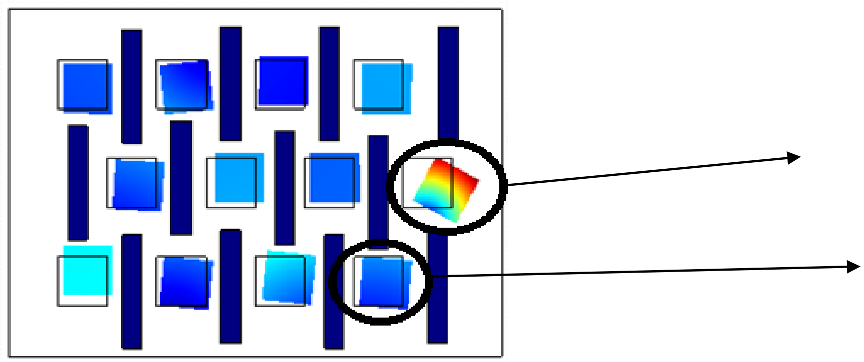

Figure 14. Particle displacement.

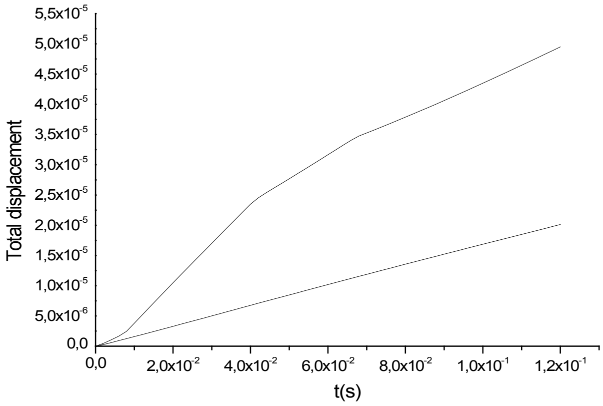

Figure 15. Displacement during time.

Mechanical Behavior of Polymer Concrete at the Microscopic Scal

Bending Tests

The PC responses in compressive and flexural tests are illustrated on the **Figures 16 and 17**, respectively. It appears that behaviour in compression is nonlinear. This is nonlinearity is more due to the damage of the loaded PC than to the viscous character of the polymer

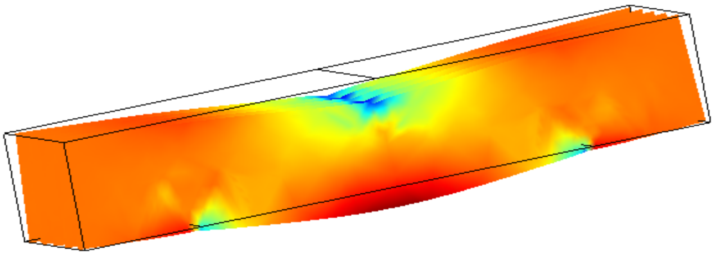

Figure 16. Screenshot of the stress distribution (3D).

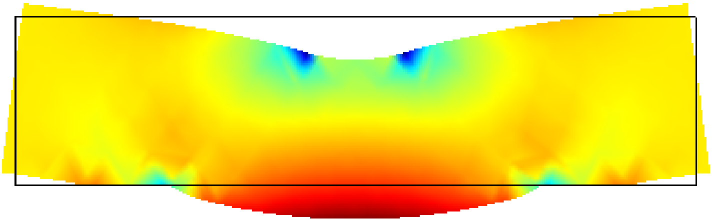

Figure 17. Screenshot of the stress distribution (2D).

Figure 16 present the distribution of the flexion strains of the polymer concrete. The red area in **Figure 17** signifies the location of the maximum stresses that lead to the formation of the flexural crack. This is in accordance to the observed behavior of the beam during the experimental results [18,19]. The stress-displacement curves vary linearly which involves the viscoelastic character of the polymer and after maximum applied load, it decreases by a soft slope to rupture **(Figure 18).**

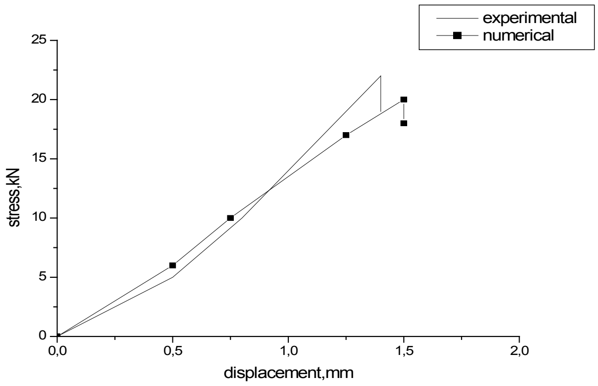

Figure 18. Bending Behaviour.

Compression Tests

This shows that there will be an initial inelastic deformation; however, the behavior is elastically. In this case, the fatigue is essentially elastic **(Figure 19).**

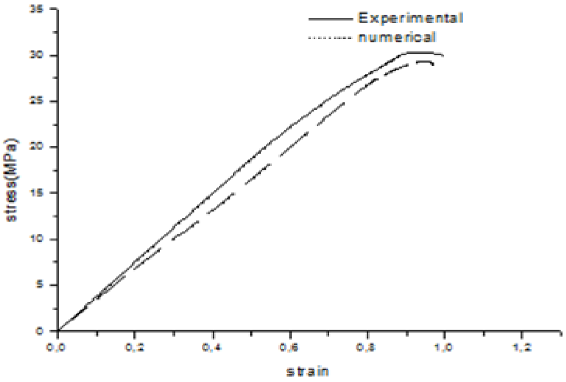

Figure 19. Compression Behaviour.

Behavior of Polymer Concrete Reinforced

A three points bending test is applied to a concrete polymer reinforced with steel bares, the numerical simulations highlight a high stress migration toward the reinforcement bars due to the effect of viscous flow in polymer concrete. Numerical calculations are devoted to a 2D composite beam model with a fiber-reinforced microstructure perfectly bonded to the matrix **(Figure 20).**The proposed problem is discretized by means of two-dimensional finite elements in the plane strain framework.

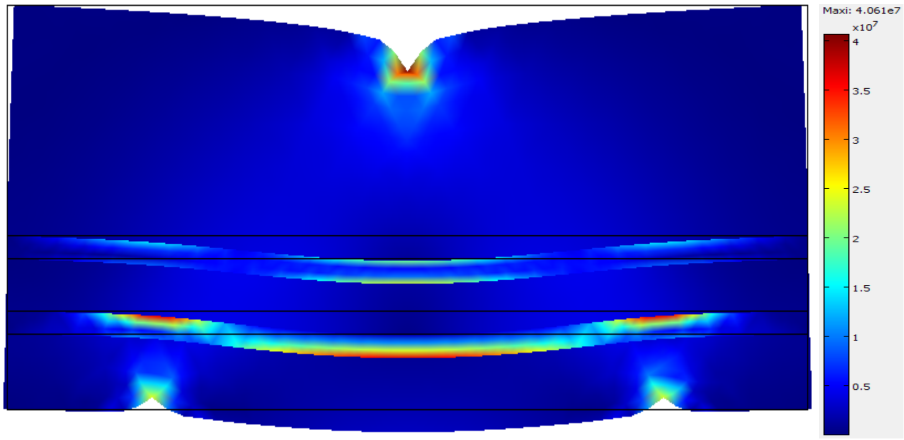

Figure 20. Isovalue of stress

CONCLUISON

In this article it was established a numerical study describing the behavior of polymer concrete to the micro and macro scale and then to study the case of internally reinforced concrete by carbon fiber and externally by conventional steel reinforcement, and strains in different materials. Two two-dimensional model types were prepared and numerically modeled in order to allow for different configurations of aggregate mixtures, the calculated stress and displacement distributions obtained for the different models are compared. Results indicate that the prominent failure mechanism is plastic deformation of the resin, especially in areas where voids are present (partial filling of voids with resin).The numerical simulations highlight relevant stress migration from the polymer concrete toward the reinforcement bars.

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