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The Effect of the Arrangement of a Reinforcement on the Mechanical Behavior of a Composite VER Composite Material

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Abstract: Composites, like any material, can degrade under the action of the loading applied to them by causing mechanical degradation of the composite parts (cracking). The study of existing damage and its behavior is of great importance. In fact, the cracking resulting from the propagation of a defect can lead to the failure of a component that would promote the total ruin of the structure. Fracture mechanics is the right tool to analyze this kind of situation based on the material's fracture characteristics which are the critical stress intensity factor (K_C) or the critical energy restitution rate (G_C) also called toughness. This degradation of the composite has been studied by many authors. The objective of our work is to analyze by the finite element method the evolution of the parameter K_I stress intensity factor of two representative elementary volumes (REV) made of the same epoxy matrix and with different reinforcing fibers (Alfa and Glass) as a function of the displacement of the two fibers (a) and (b). The numerical study showed that the position of the fibers has a significant role on the composite material as well as the alfa/epoxy REV behaves better than the glass/epoxy REV due to the good mechanical characteristics of the alfa/epoxy REV.

Keywords: Representative elementary volumes (REV), Stress intensity factor, Finite element method and Crack

Introduction

The fibers used for the reinforcement of the polymer matrix are generally continuous and discontinuous fibers, the first ones (boron, glass, Kevlar ...) of which the costs of raw materials, the methods of implementation and the low production capacities, make that these composites have higher cost prices being limited to high performance applications such as aeronautics and aerospace, the gap between the properties of these fibers as well as the unreinforced polymers is filled by the staple fibers. For a REV long time, the properties of polymers have been modified using reinforcements to optimize the mechanical properties. Polymer materials reinforced with synthetic fibers, such as aramid fibers, carbon fibers or glass fibers are widely used in various fields of application. The behaviour of such a material can be predicted by studying the effect of its individual constituents on a microscopic scale. The arrangement of fibers in the matrix plays an essential role in the development of a pattern.

Finite element micromechanical analysis, using the concepts of representative elementary volume (RVE) (Gusev,1997; Segurado, 2002) or repeated unit cell (RUC), (Li,1999; Li, 2015) can be performed to assess the

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heterogeneous stress field of composites, thereby more accurately predicting the effective properties and characterizing the microscopic yield and the behaviour to the damage compared to the analytical methods. The assumptions made for a typical micromechanical analysis can be seen in the work of Hori (1999). A square arrangement of fibers and matrices is a model commonly used to represent the micro-scale model of continuous fiber composites. Due to the symmetry and periodic arrangement of fibers, a single rectangular grating can be used to analyze material on a microscopic scale, called a Representative Volume Element (RVE).

The behaviour of plant fibers has recently been studied in the literature. Ameri (2016) used a new type of unidirectional linen / paper reinforcement. The linen-paper / epoxy composite is superior, both in specific resistance and in modulus, to any other linen / epoxy composite (without the paper layer). It also surpasses the specific stiffness of a unidirectional E-glass / epoxy composite. Baley (2002) studied the mechanical properties of flax fibers using micromechanical expressions, it was shown that the longitudinal Young's modulus is of the order of 59 GPa and that its transverse modulus is l 'order of 8 GPa. (Maligno, 2008) investigated (studied) using a three-dimensional micromechanical representative volume element (RVE) model with hexagonal packing the geometry and finite element method the effect of the residual stress due to the process of hardening on the evolution of damage in polymer-matrix composites reinforced with unidirectional fibers (UD) under longitudinal and transverse loading. The study is based on different failure criteria and a stiffness degradation technique was used for the damage analysis of RVE subjected to mechanical loading after hardening for a range of fiber volume fractions. The initiation and progression of predicted damage is clearly influenced by the presence of residual stresses.

Cichocki (2002) used a semi-empirical micromechanical model to estimate the anisotropy of jute fiber. Based on their simulation results, the Jute fiber-reinforced composite has a longitudinal stiffness of 39.4 GPa and a Young's transverse modulus of 5.5 GPa. Chen (2019) explored, by the finite element method with different fiber volume fractions (Vf) and RVE sizes, the mean response and isotropy of 3D representative solid elements (RVE) for elastomer composites reinforced with short fibers random (SFEC). The results found by Chen, lili et al show that the anisotropy of the RVEs decreases with the increase in the size of the RVEs and is higher for the RVEs with a higher Vf. Fiber anisotropy decreases with increasing Vf. A method of averaging the responses of each (RVE) over all loading directions greatly reduces the response variation on different RVEs, which can be used to improve the accuracy of the prediction more effectively than increasing the size of the (RVE). Bourmaud (2009) used tensile and nanoindentation tests to characterize the anisotropic behaviour of composites reinforced with hemp and sisal fibers. The tests showed that the longitudinal and transverse moduli are respectively 5, GPa and 3.9 GPa.

Our work aims to analyze by the finite element method, the evolution of the damage of a REV (Representative Elementary Volume) hybrid composite made up of the same epoxy matrix and with different reinforcing fibers (Alfa and glass), the mechanical characteristics of the materials that are presented in table 1 using the Abaqus 6.14 calculation code. Several factors were highlighted such as the length of the crack, the arrangement of the fibers in relation to the crack tip, and the distance between the two different fibers. In the first case, the first fiber placed is the Alfa fiber and the glass fiber in the second.

The objective of our work is to analyze by the finite element method the evolution of the parameter K_I stress intensity factor of two representative elementary volumes (REV) consisting of the same matrix Epoxide and with different reinforcing fibers (Alfa and Glass), whose mechanical characteristics of composite materials are shown in Table 1 (Zeddour, 2018). Our study shows the variation of the equivalent Von Mises stress of both as well as the variation of the stress intensity factor under the effect of the fiber displacement (a) (longitudinal displacement) and the fiber displacement (b) (vertical displacement). Note that the K_I factor is taken at two positions, from edge 1 and edge 2.

Geometric Model

The chosen geometrical model is a representative elementary volume of parallelogram shape of dimension 0.010*0.010*0.010 mm3 (undamaged model and damaged model), this one is subjected to an applied stress of 10 MPa along the Y-axis perpendicular to the reinforcements, the other face being fixed (see figure 1).

The fiber (a) moves along the X axis.
The fiber (b) moves along the Y axis.
We fix the fiber (a) and we move the fiber (b) and so on.

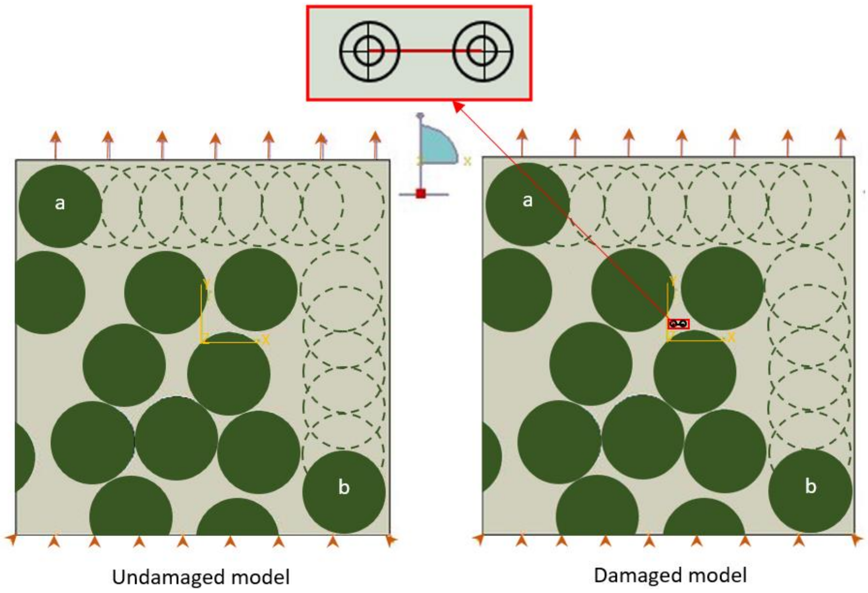


Figure 1. Geometric model and boundary conditions

Table 1. Mechanical characteristics of materials

	Density [g/m3]	Young's modulus [GPa]	Poisson's ratio
Alfa	1.4	12	0.3
Glass	2.6	27	0.3
Epoxy		5	0.33

Mesh

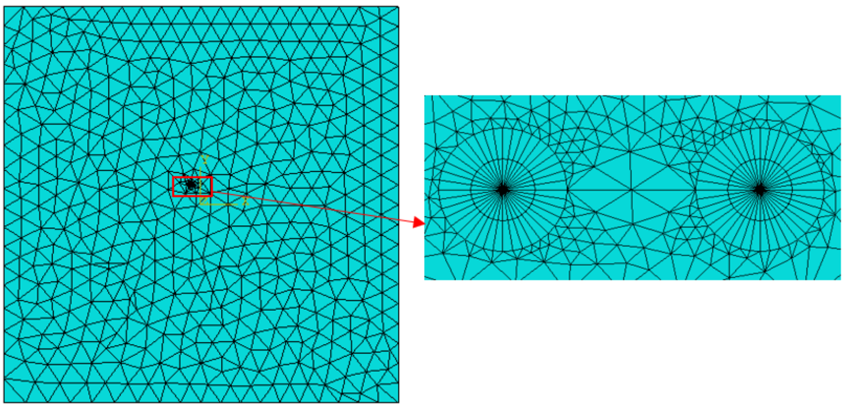


Figure 2. Model mesh

To simulate the linear behavior in tension and the influence of the longitudinal and vertical displacement of the fiber (a), (b), displacement, we used a calculation code "Abaqus" version 6.14 for the analysis of composite structures by the finite element method. This code presents a complete system, integrating not only the calculation functions themselves, but also functions of model construction (pre-processor) and processing of results (post-processor) (108).

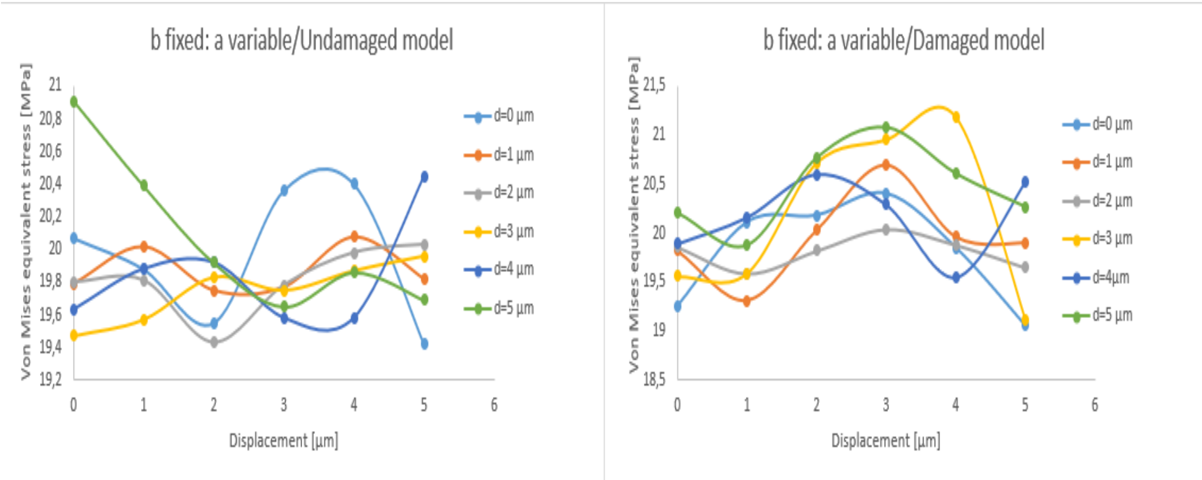
Results and Discussions

Influence of Fiber Displacement (a) and (b) on the Von Mises Equivalent Stress for the Undamaged and Damaged Models.

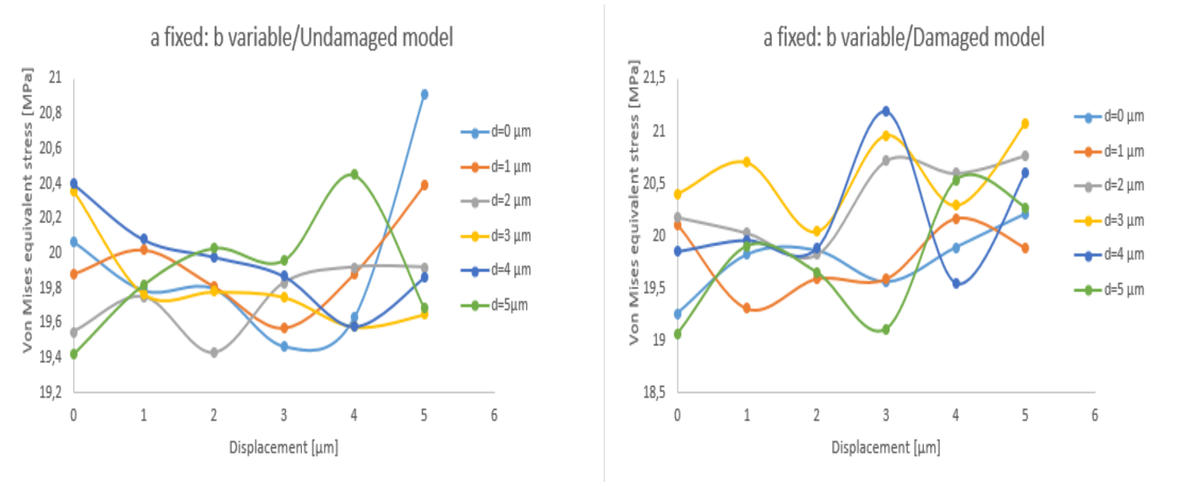
To see the effect of the position of the fibers relative to each other on the equivalent Von Mises stress and on the stress intensity factor, we took a random arrangement of the fibers in our representative elementary volume (REV) so as to have one fiber (a) moving along the X-axis and another (b) moving along the Y-axis. This work is performed on an undamaged and a damaged REV using the finite element method.

Case of the REV Alfa/Epoxy

Figure 3 shows the variation of the equivalent Von Mises stress as a function of fiber displacement for the damaged (n) and undamaged (m) models and for both cases of fiber displacement (a=fixed; b=variable and b=fixed; a=variable). It is found that the displacement of the fiber (a) and the fiber (b) relative has a significant influence on the equivalent Von Mises stress. The curves are not symmetrical, this is probably due to the random arrangement of the reinforcements in our VER.



m) Model without cracks



n) Model with crack

Figure 3. Variation of Von Mises equivalent stress as a function of fiber displacement for both damaged and undamaged models and for both cases of fiber displacements (fixed a; variable b and fixed b; variable a)

Comparison between Fiber a=Fixed; b=Variable and b=Fixed; a=Variable.

Figure 4 shows the variation of the equivalent Von Mises stress as a function of fiber displacement for the undamaged model and for each fiber displacement case (a fixed; b variable and b fixed; a variable). Note that the fiber displacement curve (a fixed; b variable) does not resemble the fiber displacement curve (b fixed; a variable) and this is likely due to the non-symmetrical arrangement of reinforcements in our REV.

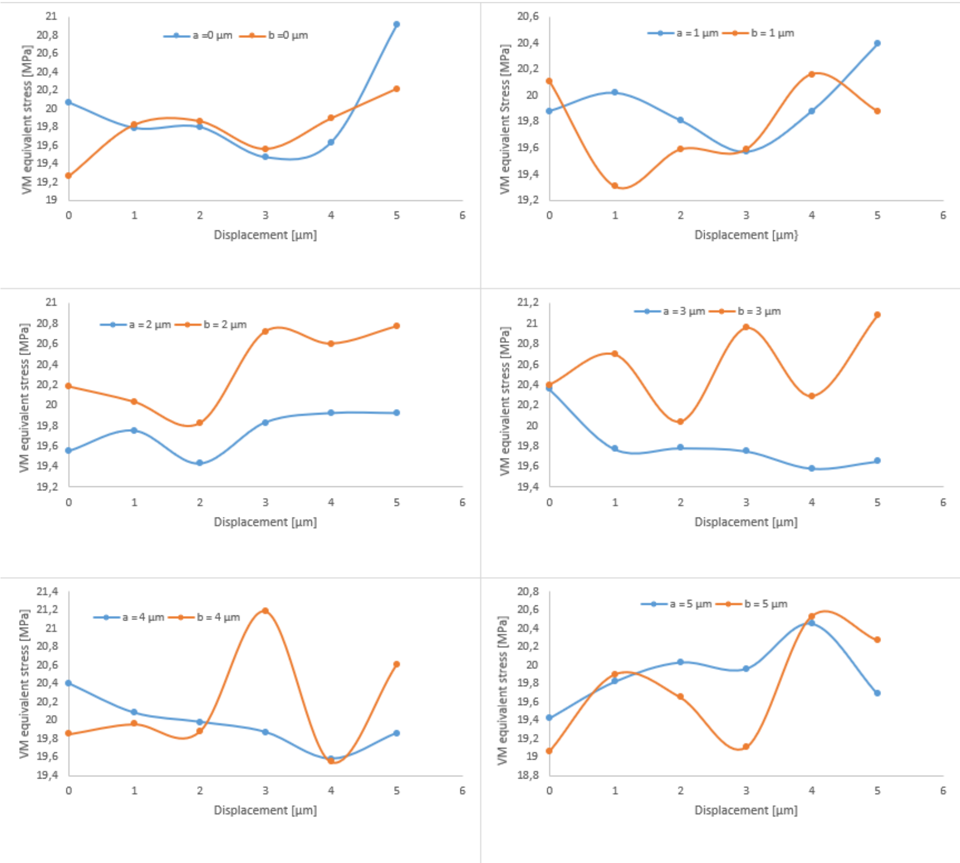


Figure 4. Variation of Von Mises equivalent stress as a function of fiber displacement for the undamaged model and for each case of fiber displacements (fixed a; variable b and fixed b; variable a)

Influence of the Width of Representative Elementary Volume on Stress Intensity Factors

Figure 5 shows the variation of the stress intensity factors K_I, K_{II} and K_{III} as a function of the width of the representative alpha/epoxy elemental volume (REV). It can be seen that the opening of composite VER occurs in pure I-mode. The stress intensity factor K_I is much higher than the other two opening modes which are negligible.

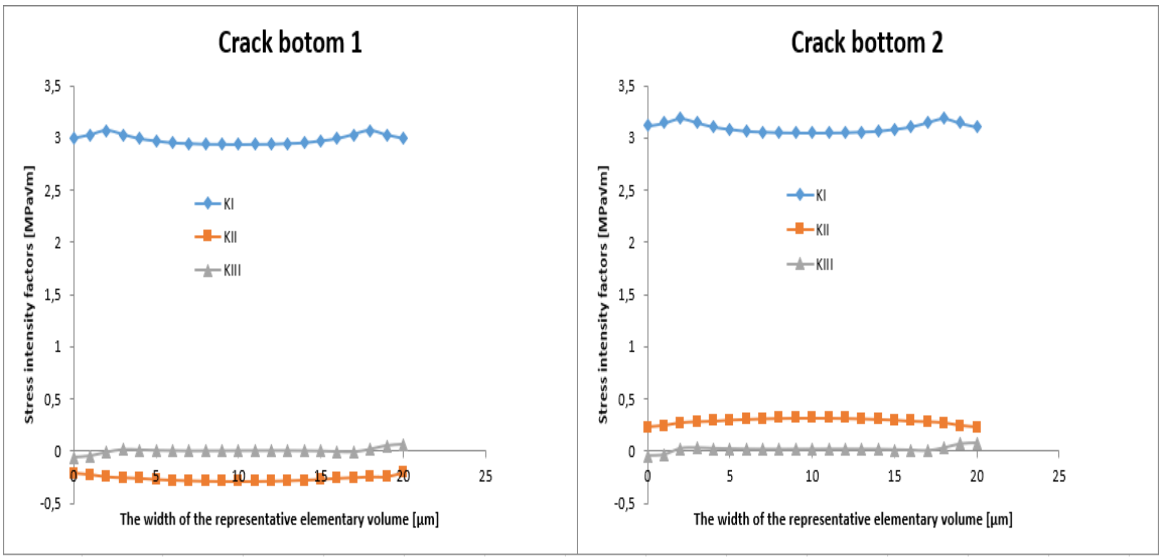


Figure 5. Variation of the stress intensity factors K_I, K_{II} and K_{III} as a function of the width of the representative elementary volume alfa/epoxy for the two crack bottoms and for d_a=0µm and d_b=0 µm

Influence of Fiber Displacement (a) and (b) on the Stress Intensity Factor for the REV alfa/epoxy

Figure 6 shows the variation of the stress intensity factor K_I as a function of the width of the alfa/epoxy REV and for the different fiber positions (a) and (b). The graphs in Figure 7 are determined for the positions of fiber (a) dep. (0) and dep. (5) and for the two crack bottoms respectively. It can be seen that whatever the position of fibers (a) and (b) of the REV alfa/epoxy composite the FIC K_I curve presents a symmetry with respect to the middle of the REV width and consequently the analysis is the same as that of the REV glass/epoxy. It is noted that the arrangement of the fibers relative to each other has a significant influence on the K_I factor.

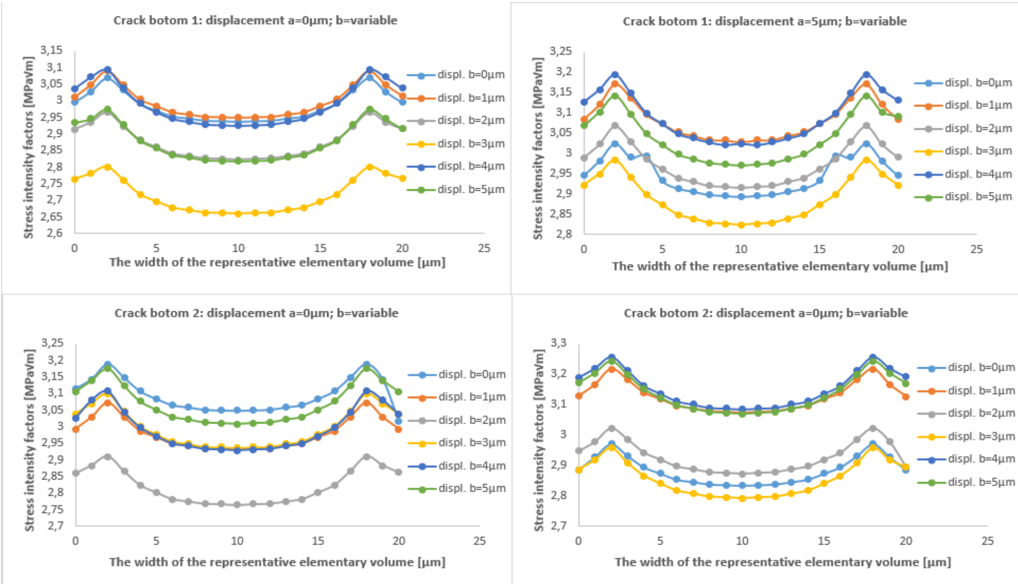


Figure 6. Variation of the stress intensity factors K_I, as a function of the width of the representative elementary volume alfa/epoxy for the two crack bottoms and for d_a=0µm and d_b=variable and d_a=5µm and d_b=variable

Influence of the Mechanical Properties of the Composite VER on the K_I Parameter

Figure 7 show the variation of SIF K_I of the two composite materials alfa/epoxy and glass/epoxy for the different fiber displacements (a) and (b) and for the two edges of the crack. It can be seen that the alfa/epoxy composite material has higher SIF K_I values than the glass/epoxy composite material. It is noted that the alfa fiber performs better than the glass fiber and this is due to the good mechanical properties.

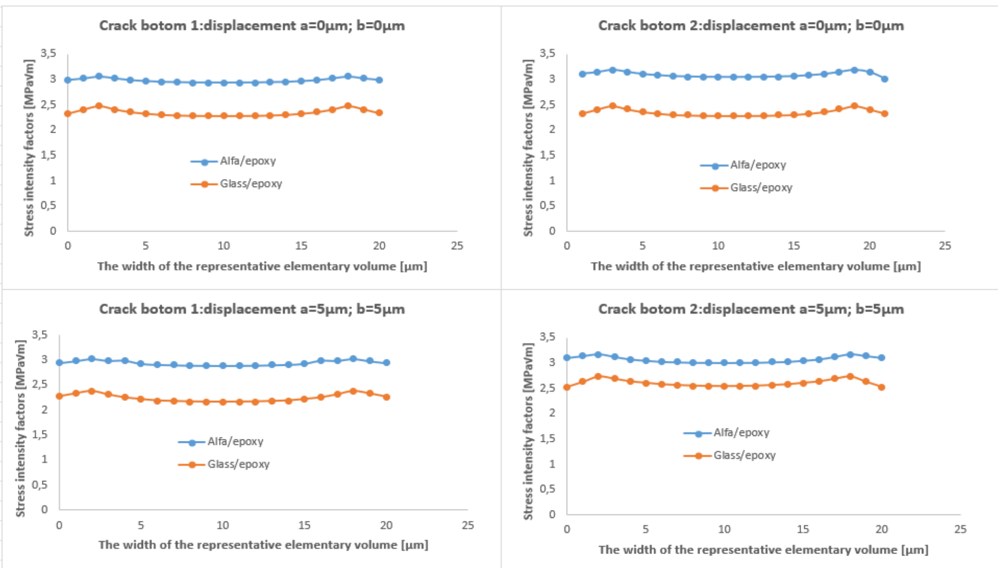


Figure 7. Variation of the stress intensity factor KI as a function of the width of the representative elementary volume alfa/epoxy and glass/epoxy for the two crack tips and for da=0µm and db=0µm and da=5µm and db=5µm.

Conclusion

From this numerical analysis using the finite element method, we can draw the following conclusions:

- The displacement of the fiber (a) and the fiber (b) relative has a significant influence on the equivalent Von Mises stress. The curves are not symmetrical, this is probably due to the random arrangement of the reinforcements in our VER.
- The fiber displacement curve (a fixed; b variable) does not resemble the fiber displacement curve (b fixed; a variable) and this is probably due to the non-symmetrical arrangement of reinforcements in our REV.
- The crack opening of the damaged composite REV occurs in pure mode I and the other two opening modes which are negligible.
- Regardless of the position of the fibers (a) and (b) of the REV alfa/epoxy composite the FIC K_I curve shows symmetry with respect to the middle of the REV width and therefore the analysis is the same as that of the REV glass/epoxy. It should be noted that the arrangement of the fibers relative to each other has a significant influence on the K_I factor.
- The alfa/epoxy composite VER performs better than glass/epoxy composite VER, this is due to its good mechanical properties following the results found numerically.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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