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Tensile examination of progressive damage and failure in porous ceramic composite materials using the XFEM

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Abstract:

Introduction/purpose: Porosity is a significant factor that causes voids to become trapped in materials during composite material fabrication. This study is dedicated to modelling fracture modes within highly stressed areas of an advanced SiC/C$_f$ component at a macroscopic scale.

Methods: The finite element method is used to analyze defects within composites, considering factors such as porosity size, shape, and tensile stress. The Monte Carlo method predicts the distribution function (F).

Results: Three pores are distributed across the width of the material, which reduces the active cross-sectional area of the material and, consequently, leads to a significant reduction in strength. Overall, resistance tends to decrease, with a more noticeable drop.

Conclusion: It is concluded how the form and the size affect the failure load, employing the Extended Finite Element Method (XFEM) to predict mode-I fracture behaviour. The porosity parameter significantly affects the durability of the structure. It is noted that the size of pores (ϕ) is a crucial component that affects the distribution function (F). The variability in this parameter substantially elevates the likelihood of plate failure and diminishes the longevity of a structure.

Keywords: composite, XFEM, tensile load, failure load, fibre reinforced, size.

Introduction

A composite material is a mixture of two or more materials that exhibit improved properties when combined. Each material retains its unique chemical, physical, and mechanical properties, as demonstrated by various studies, in contrast to metallic alloys. (Kumari et al, 2018; Venkatesan et al, 2020; Michael et al, 2021; Muthalagu et al, 2021; Kishore et al, 2021; Hatti et al, 2021; Mizerska et al, 2022)

Ceramic matrix composites (CMC) demonstrate exceptional characteristics such as superior strength, stiffness, stiffness-to-density ratios, and thermal stability at elevated temperatures (Gavalda Diaz et al, 2019; Gowayed et al, 2013; Xia et al, 2019). Ceramic composite materials are increasingly used in major industrial sectors such as aeronautics, automotive, and nuclear industries. Defects can sometimes arise within composite materials, including ceramic matrix composites, during manufacturing, regardless of the specific method employed. These imperfections may occur during the forming process because of the uneven composition of composite materials. A porosity defect is characterized by the presence of small cavities that contain gaseous matter known as pores. These pores are classified based on their size, including micro, meso, and macro-pores. There are various methods to characterize porosity; the thermal and mechanical properties of porous ceramic bodies are influenced by factors such as the size, shape, distribution, orientation, volume fraction, and interconnection of pores (Meille et al, 2012; Bartuli et al, 2009). Various models have been suggested to explain the strength of brittle materials, but the Weibull analysis is widely utilized, as demonstrated by Cui et al. (2017) and Keleş et al. (2018). An approach to calculate the pore volume and the area distribution directly from the isotherm desorption of porous substances was introduced by Barrett et al. (1951).

The approach has effectively been used for adsorbents with various maximum pore volumes. An innovative numerical simulation technique utilizing the Finite Element Analysis (FEA) is regarded as a powerful tool for enhancing the utilization of ceramics in components and members. This method can accurately assess the likelihood of fractures produced by fault distribution characteristics. Evans et al. (1979) presented data regarding microstructure distribution, including relative density, pore size, aspect ratio, and grain size. These data were used as input values and incorporated into a continuum damage model through a fracture mechanical model. The fracture mechanical model was based on a circumferential circular crack originating from an oval spherical pore. The findings indicate that the suggested Finite Element Analysis (FEA) approach is applicable for assessing the likelihood of fractures in ceramics. Zimmermann & Rödel (2004) have illustrated and given results based on a model that describes the instability of the cracks that occur with the configuration of a micro-crack positioned in the effect of concentration of the stresses of a large pore. The study conducted by Rezaee et al. (2020) established that pores exhibit a nearly spherical shape, consistent size and distribution, and strong connection. This work aimed to enhance the strength of porous alumina-zirconia ceramic composites by combining the toughening and strengthening properties of tetragonal zirconia with the positive densification impact of niobium oxide. In this study, Ying et al. (2018) examined how the amount of Al_2O_3 fibre in ceramic materials affects pore size distribution, porosity, compressive strength, and load-displacement behaviour. The materials were created using the gel-casting process. Pia et al. (2016) have introduced an intertwined fractal model that can establish a connection between the thermal characteristics of ceramic materials and their pore microstructure.

The investigation into fracture phenomena such as crack propagation and delamination in composite materials continues to evolve, aiming for a more precise modelling approach. (Luan et al, 2018; Carrère et al, 2000). The ongoing refinement of assumptions and methodologies aims to accurately predict damage, optimize computational resources, and facilitate progressive damage modelling. The finite element technique (XFEM) has been widely employed in the prediction of fracture propagation in composite materials, as demonstrated by the research conducted by Swati et al. (2019) and Benzaama et al. (2018). XFEM methodology has recently emerged as a distinctive way of tackling the simultaneous propagation of mode-I cracks and delamination in composites. This has been proved in research conducted by Hu et al. (2016), and Daggumati et al. (2020). Previous applications of this method have mainly concentrated on either simulating large-scale specimens in carbon fibre-reinforced polymer (CFRP) composites, as demonstrated in the research conducted by Stuparu et al. (2016), or simulating individual fibres in SiC/SiC composites at a microscopic level, as investigated by Daggumati et al. (2020) and Lang et al. (2018). Hence, the primary objective of the present investigation is to replicate different types of fractures occurring in the concentrated area of high stress within a non standard SiC/SiC component but on a larger scale. To accomplish this, XFEM methodology was utilized to forecast fracture behaviour in both mode-I and mode-II, using the strategy described by Sun et al. (2013).

This study aimed to reproduce the fracture behaviour in the highly strained region of an advanced SiC/C_f component on a macroscopic scale. This inquiry utilized the Extended Finite Element Method (XFEM) to analyze a defect in a composite material. An analysis was conducted on factors like the dimensions, the configuration, and the alignment of the pores, the interplay between multiple holes and the rigidity of the matrix when subjected to tensile stress. An evaluation was conducted on the influence of the interaction among the pores on the load at which failure occurs. In addition, the extended finite element approach was used to predict the behaviour of mode-I fracture.

XFEM input parameter and materials

The cell of a unidirectional composite domain is created as a solid part of the solid section. The XFEM enrichment domain function is input as follows:

*Enrichment, name=Crack-1, type=Propagation Crack, activate= On

The solid composite section is used for the XFEM domain.

The evaluated damage is maximal at the crack opening and is calculated using the following equation (Dassault Systems, The 3D EXPERIENCE platform, 2014):

$$\left(\frac{G_I}{G_{IC}}\right) + \left(\frac{G_{II}}{G_{IIC}}\right) + \left(\frac{G_{III}}{G_{IIIC}}\right) = 1 \quad (1)$$

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The maximum principal stress measured for the composite material SiC/C_f is (178±25.7) MPa and the shear stress measured is 93 MPa (Udayakumar et al, 2014). The damage evaluation criteria also take into account the maximum traction energy (the maximum crack opening of the composite specimen has been experimentally determined to be 2.8KJ/m^2 (Udayakumar et al, 2014). The ABAQUS code included various mechanical properties and their failure parameters as damage parameters (See Table 1), in order to simulate an increase in the failure/damage level after reaching the ultime stress.

Table 1 – Mechanical properties of the constituents of the composite material used (Vijayakumar et al, 2016; Metehri et al, 2009)

Materials	SiC-matrix	Epoxy R368-1-matrix	Al 6061-matrix	Carbon-fiber
E (GPa)	410	3.05	72	230
v	0.14	0.35	0.33	0.3
Max principal stress (GPa)	3	0.08	0.12	3.2
Displacement failure damage	0.007	0.4	0.2	0.013

The XFEM technique and the Irwin hypothesis (Irwin, 1960) are used to calculate the energy release rate components, G_I, G_{II}, and G_{III}, by multiplying the nodal forces. This analysis is performed to study crack propagation in the SiC/C_f porous composite material, specifically at the crack tips of the matrix and fibres.

According to Griffith's fracture theory (Griffith, 1921), a crack will propagate when the variation in elastic energy is more significant than surface energy.

$$\sigma = \sigma_r = \sqrt{\frac{EG_{Ic}}{\pi a}} \tag{2}$$

where: E: Young modulus and
σ_r: failure stress.

This corresponds to a decrease in the system's free energy, meaning that the total energy release rate (G_T), measured at a particular location along the crack front, will reach a critical value denoted by G_C.

$$G_T = G_I + G_{II} + G_{III} \quad (3)$$

where G_I, G_{II}, and G_{III} represent the energy release rates for Mode I, II, and III, respectively.

To achieve crack propagation, it is necessary: $G_T \geq G_C$.

Table 2 – Mechanical interface properties of composites materials (Monerie, 2000)

	G_{Ic} (J/m^2)	G_{IIc} (J/m^2)	G_{IIIc} (J/m^2)
SiC/SiC	9	1	0

Finite element modeling of the problem

Residual strains are generated during the elaboration process as the temperature lowers from the elaboration temperature to the ambient temperature. The stresses frequently occur due to the difference in stiffness and thermal expansion coefficient between the reinforcing material (fibre) and the matrix.

As a result, this encourages the development and spread of fatigue micro-cracks and geometric or metallurgical flaws. Therefore, examining the escalated failure or damage in these areas and the fibres is crucial. A three-dimensional model has been created for this study.

The model consists of a ceramic matrix shaped like a parallelepiped, with two capillaries running down its central axis. Inside these capillaries, two cylindrical carbon fibres have been placed (Figure 1). The latter refers to a basic unit of a composite material that is unidirectional and has porosity.

The model dimensions are 60μm in length, 30μm in width, and 15μm in thickness. The carbon fibres are separated by 16μm and their diameter is 7μm. The porosity is situated at the core of the ceramic matrix and is represented as a pore with a diameter of 6μm. This pore serves as a reference point for comparing the dimensions of the cells in a unidirectional composite.

Figure 1 provides a diagrammatic representation of the composite material with porosity. A study was conducted to analyse the material properties and geometric characteristics. The porosity is located within the ceramic matrix at a distance of 25μm from the bottom of the structure.

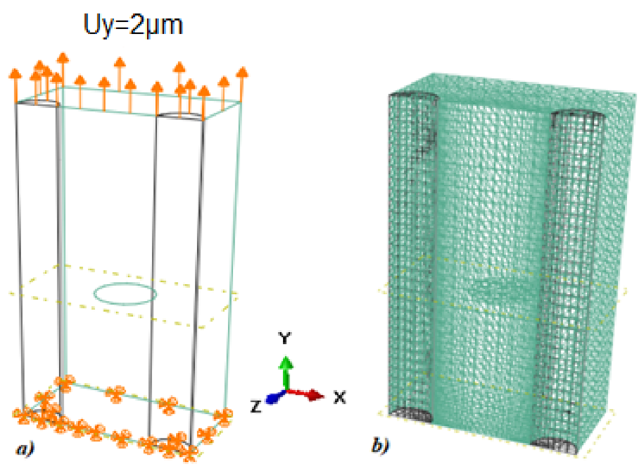

Figure 1 – The finite element model: a) Boundary conditions, b) Total meshes structure

This structure is subjected to tensile behaviour, with the fixing and loading conditions involving fixing the structure at one edge direction (U_x = U_y = U_Z = 0) and applying a traction displacement on the opposite edge (U_y=2µm). (Refer to Figure 1a).

This behaviour, fixed at one edge and subjected to traction displacement on the opposite edge.

The accuracy of the numerical computation is highly dependent on the mesh quality surrounding the porosity and the interface between the fibre and matrix. It is essential to have an adequate number of mesh elements in the areas between the pores and the matrix, as well as in the fibres and matrix, on which the damage properties rely. For this analysis, we used 1980 linear hexahedral elements of type C3D8R (8 Nodes Linear Brick, reduced integration) for the fibres and 35377 quadratic tetrahedral elements of type C3D10 (10 nodes Linear tetrahedron) for the matrix (refer to Table3). Figure 1b displays the finite element model, which features a dense grid in the porosity considering the concentration of stresses and the appearance of cracks.

Table 3 – Number of nodes and the element types of the mesh

Element type	Number of elements	Total number of nodes
Fibre: C3D8R Matrix: C3D10	1980 34711	54796

Results and analysis

Numerical models have been developed to evaluate the effect of the presence of porosity of different shapes and sizes in the matrix on the mechanical resistance of the composite material. In all of this work, it is considered that the stress analysis is given at a displacement equal to 1.7μm, i.e., just before the damage of ceramic composite material. The two sections A-A of this structure are taken to demonstrate the stress distribution at the porosity level, as shown in Figure 2.

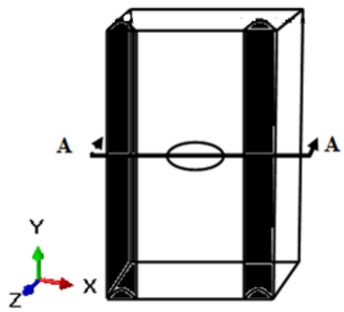

Figure 2 – Unidirectional composite cell with the sections

Tensile simulation and experimental

This study considers the SiC/C_f couple with a porosity of 4μm diameter.

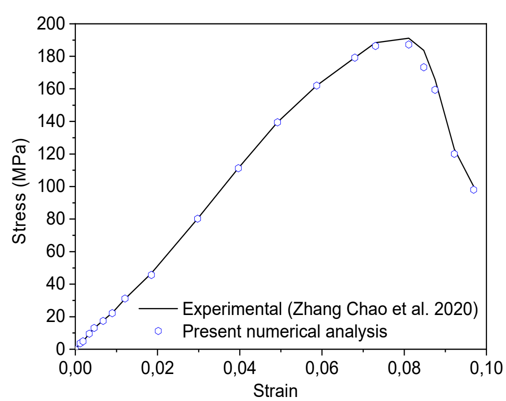

Figure 3 – Comparative analysis of the experimental and computational results for the SiC/C_f

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This section demonstrates that the software can accurately simulate the beginning and the propagation of the fibre/matrix interfacial fracture by validating the numerical approach results against experimental data. The results agreed with the experimental values (Zhang et al, 2020; Udayakumar et al, 2020). A good agreement is observed for a couple of composite materials, SiC/C$_f$, from Figure 3. These results are helpful for further studying the fracture toughness of SiC. The current results are in good agreement with the analytical solution, with a difference of around 3%.

Effect of porosity size

The influence of the porosity size (diameter) on the variation of the breaking force was considered. The force-displacement curves representing the numerical analysis results consider the average displacement and response force.

Figure 4 presents the distribution of the equivalent stresses in SiC/C$_f$ for a displacement in tension Uy of 2 μm. This result shows a concentration of equivalent stresses around the porosity and the fibre/matrix interface. Further from the porosity, the deformation and the normal stresses became weaker and weaker.

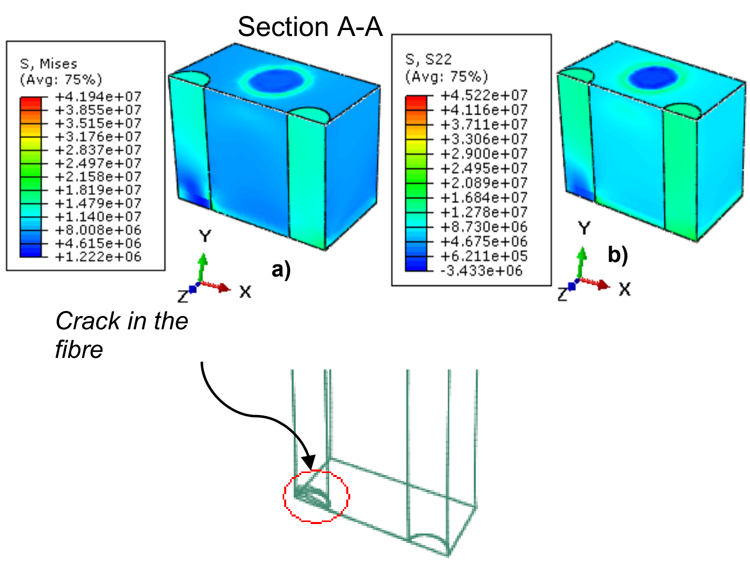

Figure 4 – vonMises and normal longitudinal stress distribution (U_y=2μm, ϕ_P =10μm)

Compared to the section A-A, one can note an interaction between the fibre-porosity and porosity-free edge; this porosity generates a low material resistance compared to the applied stress.

The level of the standard stress σ_{22} follows the direction Y, and according to the section A-A, it shows areas of high concentrations. Compressive stresses are generated at the porosity level. A high concentration of stress generates a crack in the fibre.

The variation of the failure load as a function of the displacement for different sizes of the porosity is shown in Figure 5. It is noted that the breaking force is in an order of value of ~ 13KN, decreased proportionally with the increase of the pores to reach a minimum value for a large porosity size, which shows that the strength of the material becomes low. On the other hand, if the porosity size is minimal, it can be observed that the SiC/C_f couple is more rigid, which means that the damage will appear sooner.

The existence of porosity in the composite material enables the identification of the crack's starting point, which is challenging to determine due to its dependence on factors such as the elastic displacement of the constituent materials and the characteristics of the fibre/matrix interface and porosity/matrix.

In other words, referring to the material response to the applied displacement, the increase in the porosity volume generates the most considerable drop in the material resistance; the maximum breaking force appears sooner than in the case of a material without porosity.

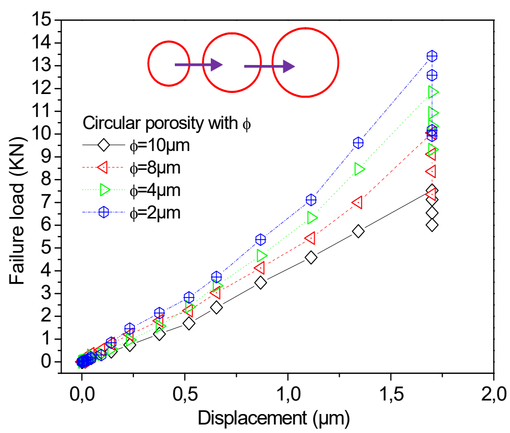

Figure 5 – XFEM stress-displacement curve for different porosity sizes

Cubic shape

In this part of the work, the effect of the geometric shape (characterized by different porosity lengths in a composite material) on the damage force was analyzed.

In the presence of a cubic-shaped porosity, the value of the von Mises stresses increases more considerably than in the case of the presence of circular and elliptical-shaped porosity. This is mainly due to four wedges, areas of high-stress concentration.

The high concentration of stresses at the porosity level lightens the stresses compared to the rest of the structure. It is noted that compressive stresses are present at the porosity level. Therefore, the crack is initiated in the two fibres. The results of this analysis are shown in Figure 6.

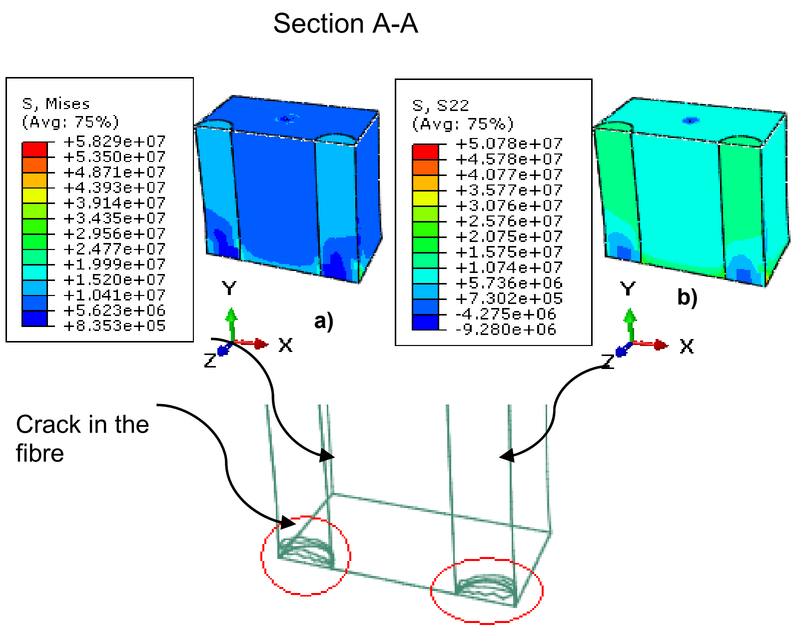

Figure 6 – vonMises stresses distribution for the cubic porosity (U_y= 2μm, l_P=4μm)

Comparing these curves (Figure7), the changes in the ultimate failure load are almost the same, but with an increase in the level in all cases; a higher level is observed in the case of cubic shapes with lengths equal to 2 μm. When subjected to tensile stress, the crack propagation rate is significantly reduced as it nears the interface between the fibre and the matrix. However, it then quickly expands within the fibre. This behaviour becomes more pronounced as the stresses increase for all the examples tested (lengths ranging from 2 to 6μm). In these circumstances, the failure load is relatively modest compared to spherical porosity.

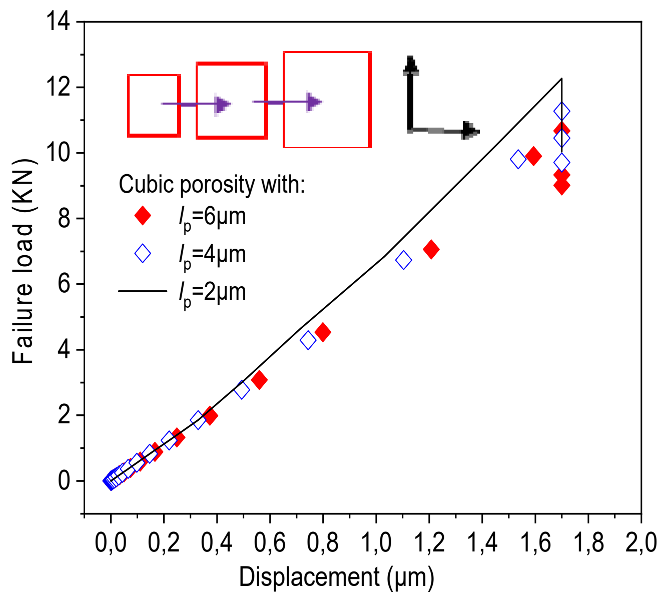

Figure 7 – XFEM load-displacement curve related to the cubic porosity

Comparative analysis

These models were developed to evaluate the influence of the organization of the porous structure on the effective mechanical resistance. They have closed porosities. In the first case, closed-pore composites are connected in the same direction (direction x), and in the second case, they have a composite with closed pores that is only distributed.

This paper proposes an ideological model that considers the probability of multiple porosities and the influence of the interaction with the surrounding existing porosity, suggesting that mono-porosity is insufficient.

Figure 8 represents the equivalent stresses of von Mises along the y direction of the three cylindrical connected unidirectional pores with Φ_p =6μm (See Figure 8a), the three cubic pores with the length l_p=6μm connected unidirectionally (Figure 8b). The last one is one of the three randomly dispersed pores with Φ_p =6µm (Figure 8c).

Section A-A

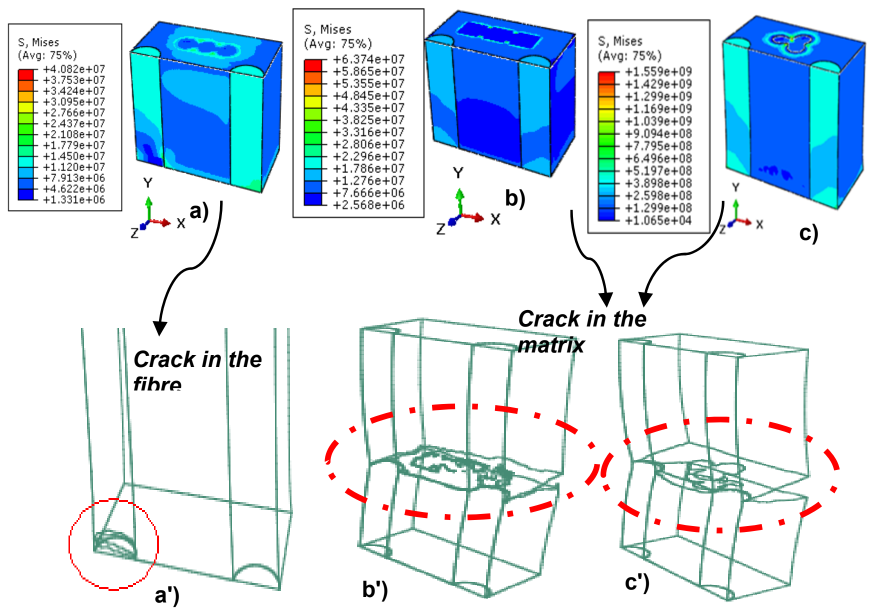

Figure 8 – vonMises stresses distribution with closed pores connected to the cylindrical cubic organization and the triangle organization (ϕ_p=6µm)

Some three-dimensional models of composite materials with closed pores, possibly connected, were studied to evaluate the ultimate failure damage on the mechanical resistance at a displacement Uy=2µm—the pores of cylindrical, cubic, and triangle shapes.

In the presence of three porosities of a circular shape arranged linearly along the width, the value of the von Mises stress is very high only if the arrangement is according to the case of Figure 8a.

However, the cubic and triangular shapes of the porosity are always the most dangerous for the material (Figures 8b, 8c), especially if there will be more porosity arranged along the width. The stress concentration is at the acute point of the porosity with a high concentration between porosities. At the same time, in the case of the triangular and cubic shapes, we notice a high stress concentration between the porosities and another

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stress concentration between the porosity and the free edge of the material.

Figures 8b and 8c show the fracture microstructure of the composite material after the tensile test where the cracks propagated and deflected along the edge of the fibres in the matrix under the applied displacement, and the existence of the fibres effectively blocked the further expansion of the cracks, as well as broken fibres at the same time.

The tensile response of the material following the presence of three porosities according to different arrangements clearly shows a considerable drop in the curve of the force-displacement variation, especially in the case of the cubic shape of the porosity.

Figure 9 shows the variation of the damage force for three defect shapes, i.e., cylindrical, cubic, and triangular, with the organization of the porous structure (ordered and randomly). Comparing these porosity shapes, the change in the curve of the ultimate failure load is observed, though a higher level is observed in the case of a triangular shape.

The structure of the composite material has the propagation crack in the fibres in the case of the circular shape, but in the case of triangular and cubic pores, we observed very clearly that the crack has been initiated in the matrix and propagated to the other side; the composite material is not very strong. More porosity can trigger the rupture of the composite material too early and for low applied stress.

Suppose there is the presence of three porosities arranged along the width of the material. In that case, this minimizes the active section of the material and, therefore, a considerable drop in its resistance. Higher, linked pore densities tend to result in a more notable decrease in overall resistance.

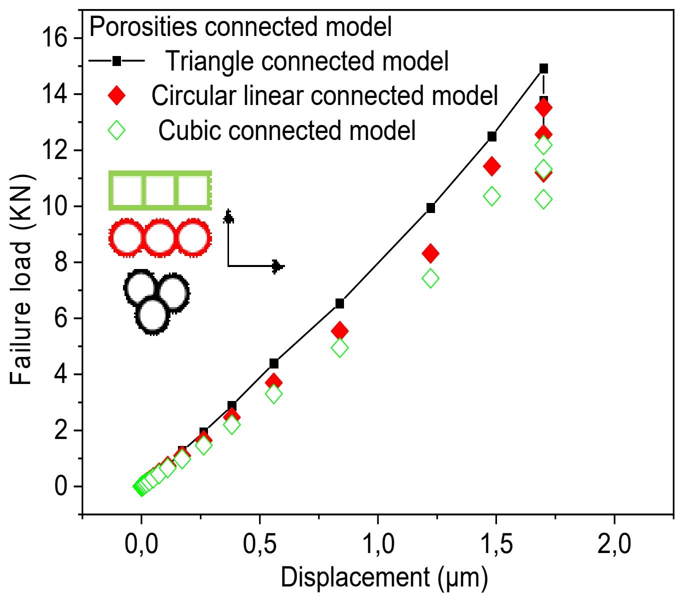

Figure 9 – XFEM load-displacement curve related to the porosity organization (circular, cubic, and triangle)

Effect of the matrix type

In this section, the impact of the matrix on the natural behaviour is examined, taking into account the severity of the tensile loading and the size of circular porosity (ϕ=10µm). The matrix chosen for this study is Epoxy R368-1 and Al alloy with a carbon fiber; tensile loading is applied for comparative analysis.

For Figure 10, the most intense longitudinal stresses are observed in the pores of the SiC/C_f and Epoxy/C_f couples, which reduce the rigidity of the composite material structure and its resistance to the damage to chemical bonds. As it loses its strength. Epoxy/C_f has a long breaking path and a corresponding curve segment. The shape of this segment depends on the matrix type and the nature of the interface. The most damage-resistant couple is Al/C_f. Conversely, the Al/C_f combination with relatively slow damage responds to loading for this behaviour.

As a result, porosity significantly impacts how composites fracture when external displacement is applied. It modifies the location and evolution of damage and results in a notable reduction in the tensile strength of the composites. In summary, porosity-induced longitudinal stresses need to be considered in both the design and the analysis of composites since they can significantly impact the damage behaviour of materials.

1- Appearance of a crack which first drops in stress at point (1).

2- Propagation of this break (from point (1) to point (2)).

3- Stabilization of the damage (no propagation), which causes an increase in stress with a resistance lower than the initial resistance. This step is between points (2) and (3).

4- Appearance of new cracks that cause the total ruin of the composite material and the relaxation of longitudinal stresses in the case of Epoxy/C_f.

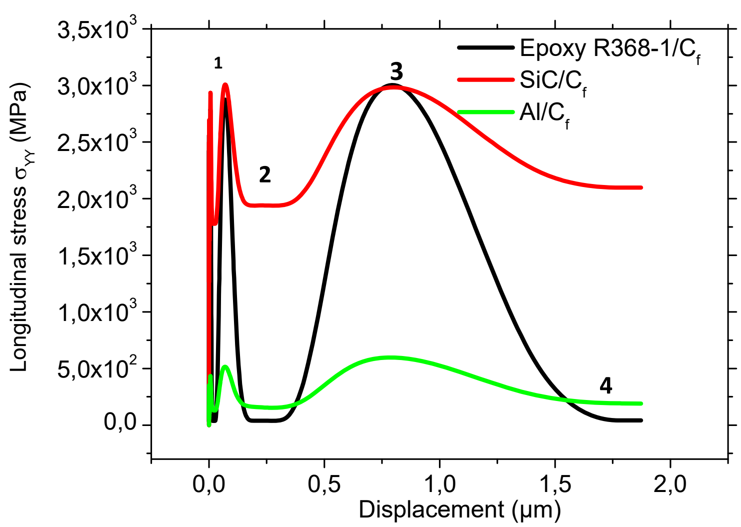

Figure 10 – XFEM Stress-displacement curve as a function of the matrix nature and the tensile load intensity

Figure 11 displays the PHILSM profile of the ceramic unidirectional composites containing a single circular pore with a diameter of 8µm.

It also shows the location of the signed distance function, which is utilized to represent the surface of the fracture.

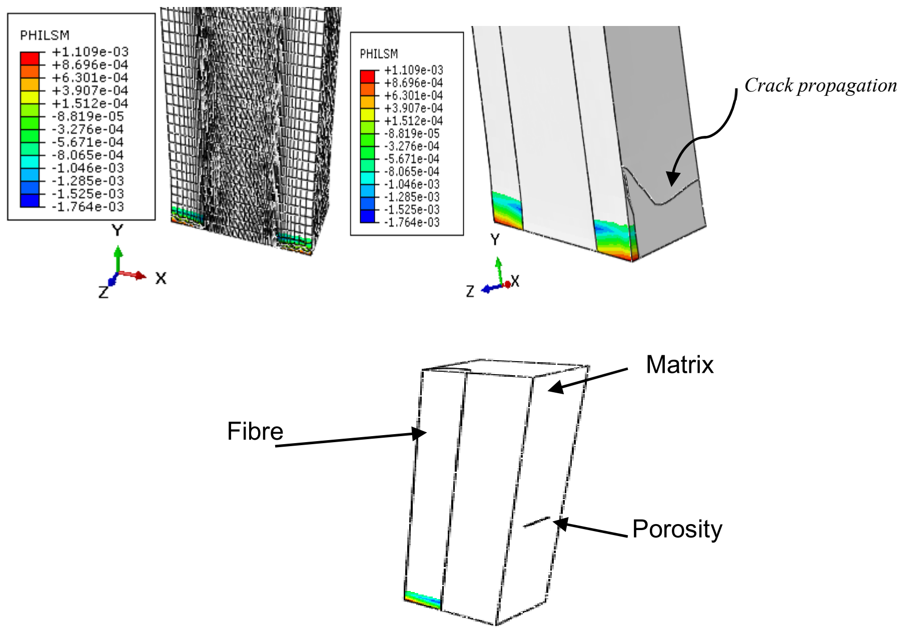

Figure 11 – Contours of PHILSM of the XFEM technique (1 circular pore ϕ=8μm)

Probabilistic Fracture Mechanic Analysis

Monte Carlo methods find extensive application in diverse scientific and mathematical domains, including physics, chemistry, biology, and engineering (Mechab et al, 2016). Monte Carlo methods are frequently employed through computer simulations to yield approximate answers for situations that are otherwise difficult or too intricate to evaluate mathematically.

A probabilistic technique has been created to estimate different response statistics and the reliability of a structure.The uncertainties are associated with the estimation of load and the attributes of the geometry and materials. These parameters are depicted as stochastic variables, distinguished by their distribution type and parameters. To ensure safety, it is necessary to manage the uncertainties in the system design. For this instance, the five random variables represent the uncertainties related to the plate geometry (thickness and height), Young modulus, and crack length.

Probabilistic results

The histogram of the (F) obtained from the Monte Carlo run is shown in Figure 12. The probability density function (pdf) uses theory models to fit the histogram. Three distribution laws are being examined: Gaussian and polynomial (8th order). Based on the information presented in Figure 12, it is evident that all three distributions provide a reasonably accurate approximation of the variable (F). The polynomial function provides a higher mean value compared to the Gaussian function. Based on the data presented in Figure 12 and Table 4, it can be inferred that the Gaussian distribution offers a reasonably precise approximation of the probability density function (F) and a dependable calculation of the mean.

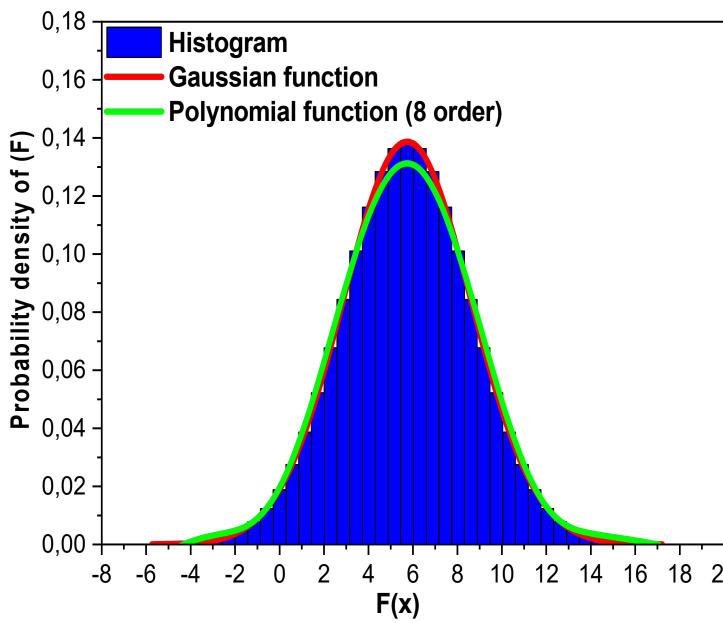

Figure 12 – Histogram and the density function of (F)

Table 4 – Mean (F) and the fitting error for probabilistic distributions

Probability density functions	Average (F)	Fitting error
Gaussian	0.1388	0
Polynomial	0.13236	0.00221

Figure 13 displays the probability density of (F) for various crack (a) lengths. It is observed that when the diameter (ϕ) of porosities is large, the probability density of (F) also increases significantly. The margin experiences a significant increase when faced with uncertainties surrounding the diameter (ϕ), resulting in a higher probability of failure. Ultimately, the failure probabilities are contingent upon the value of the diameter of porosities (ϕ).

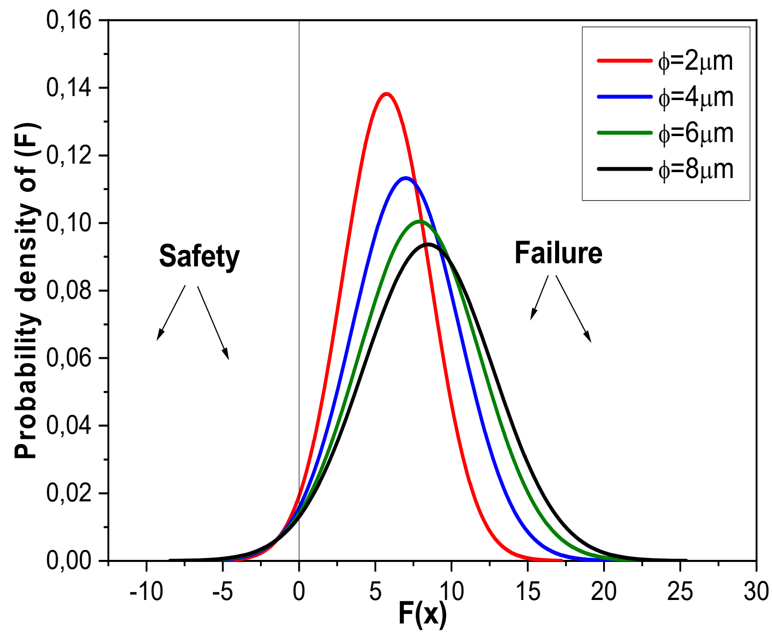

Figure 13 – Probability density of (F) for different diameter (ϕ) values

Conclusion

A finite element model using a single cell of a unidirectional composite (MCC) based on the progressive failure analysis was effectively utilized to examine the impact of geometrical characteristics (such as size and shape of the porosity) and the density of porosities (specifically the connected porosities) under a uniform uniaxial tensile load. This analysis aimed to estimate the mechanical resistance accurately. Furthermore, examining the interaction effects between porosity and the ultimate damage force was of interest. The primary findings can be inferred as the culmination of this investigation:

The XFEM has proven to be highly effective in accurately predicting fracture behaviour during crack propagation, leading to the failure of unidirectional ceramic composite materials—nevertheless, the existence of pores in ceramics results in decreased mechanical strength.

- The more significant equivalent stresses are concentrated near the interface between the matrix and the pore while they are positioned at the interface between the fibre and the matrix.
- The size of the pores influences the extent of damage. It has been noted that the intensity of this phenomenon increases in direct proportion to the diameter of the porosity.
- The contact between the matrix and the pore and the interface between the fibre and the matrix strongly influences the propagation of cracks. These interfaces are areas where normal and tangential stresses are concentrated.
- Triangle and cubic porosities in composite materials exhibited fracture propagation primarily and deflected along the edge of the fibres in the matrix, and the existence of the fibres effectively blocked the further expansion of the cracks.
- The material Al/C_f porous enhances the structural stiffness and damage resistance of composite materials.
- The Monte Carlo method forecasts the probability distribution function of (F). It is vital to recognize that the size of the pores (ϕ) has a significant role in determining the distribution function of (F). The variability in this parameter substantially impacts the likelihood of plate failure and the structure's longevity.

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Examen de tracción de daño progresivo y falla en material cerámico poroso compuesto utilizando el XFEM

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CAMPO: mecánica
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La porosidad es un factor significativo que hace que los huecos queden atrapados en los materiales durante la fabricación de materiales compuestos. Este estudio está dedicado a modelar los modos de fractura dentro de áreas altamente estresadas de un componente avanzado de SiC/Cf a escala macroscópica.

Métodos: El método de elementos finitos es utilizado para analizar los defectos dentro de los materiales compuestos, considerando factores como el tamaño de la porosidad, la forma y la tensión de tracción. El método de Monte Carlo predice la función de distribución (F).

Resultados: Tres poros se distribuyen a lo ancho del material, lo que reduce el área transversal activa del material y, en consecuencia, conduce a una reducción significativa de la resistencia. En general, la resistencia tiende a disminuir, con una caída más notoria.

Conclusión: Se concluye cómo la forma y el tamaño afectan la carga de falla, empleando el Método de Elementos Finitos Extendido (XFEM) para predecir el comportamiento de fractura en modo- I. El parámetro de porosidad afecta significativamente la durabilidad de la estructura. Se observa que el tamaño de los poros (ϕ) es un componente crucial que afecta la función de distribución (F). La variabilidad de este parámetro eleva sustancialmente la probabilidad de falla de la placa y disminuye la longevidad de una estructura.

Palabras claves: composite, XFEM, carga de tracción, carga de falla, reforzado con fibra, tamaño.

Исследование растяжений при прогрессирующих деформациях и разрушении пористых керамических композиционных материалов с применением метода конечных элементов (МКЭ)

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РУБРИКА ГРНТИ: 30.19.00 Механика деформируемого твердого тела
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Пористость является важным фактором, который приводит к образованию пустот в материалах при изготовлении композиционных материалов. Данное исследование посвящено моделированию видов разрушения в высоконапряженных областях усовершенствованного компонента из SiC/Cf в макроскопическом масштабе.

Методы: Метод конечных элементов используется для анализа дефектов в композитных материалах с учетом таких факторов, как размер пористости, форма и растягивающее напряжение. Метод Монте-Карло прогнозирует функцию распределения (F).

Результаты: По ширине материала были распределены три поры, благодаря чему уменьшается активная площадь поперечного сечения материала, что приводит к значительному снижению прочности. В целом сопротивление имеет тенденцию к значительному снижению.

Выводы: С целью прогнозирования поведения разрушения в первом режиме с помощью расширенного метода конечных элементов (МКЭ) был сделан вывод о том, как форма и размер влияют на разрушающую нагрузку. Параметры пористости существенно влияют на долгосрочность структуры. Следует отметить, что размер пор (θ) является важнейшим компонентом, влияющим на функцию распределения (F). Изменчивость этого параметра существенно повышает вероятность разрушения пластины и снижает долгосрочность структуры.

Ключевые слова: композит, МКЭ, растягивающая нагрузка, разрушающая нагрузка, армирующее волокно, размер.

Испитивање затезања прогресивног оштећења и лома у порозним керамичким композитним материјалима помоћу проширеног метода коначних елемената (XFEM)

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ОБЛАСТ: механика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Порозност је значајан фактор који проузрокује задржавање шупљина у материјалима током производње композитних материјала. Ова студија се бави моделирањем типова лома унутар високонапрегнуте области напредне SiC/C_f компоненте на макроскопској скали.

Методе: Методом коначних елемената анализирају се дефекти унутар композита, уз разматрање фактора попут величине и облика порозности, као и затезног напона. Методом Монте Карло предвиђа се функција дистрибуције (F).

Резултати: Три поре су распоређене свом ширином материјала што смањује активну област попречног пресека материјала и, последично, води до знатног смањивања чврстоће. Укупна отпорност показује тенденцију ка смањивању, уз приметан пад.

Закључак: Изводи се закључак да облик и величина утичу на оптерећење лома уз коришћење проширене методе коначних елемената (XFEM) за предвиђање понашања лома у моду 1. Параметар порозности знатно утиче на трајност структуре. Уочава се да је величина пора (ϕ) кључна компонента која утиче на функцију дистрибуције (F). Варијабилност овог параметра знатно повећава вероватноћу лома плоче и смањује животни век структуре.

Кључне речи: композит, XFEM, затезно оптерећење, оптерећење лома, ојачање влакнима, величина.

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