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Дослідження впливу неоднорідних пустот на кінцеву міцність інженерних пористих матеріалів

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Investigating the effect of Non-uniform voids on the final strength of engineered porous materials

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Одним із способів ідентифікації пористих матеріалів є використання багатовимірного аналізу, і відносини, доступні в даний час для багатовимірного аналізу, обмежені середніми значеннями напруги і деформації. Ці співвідношення мають велику похибку при розрахунку міцності матеріалів на розрив. Слід зазначити, що в багатовимірного методах кількості нормальних середніх значень зазвичай використовуються для розрахунку макрофізіческіх властивостей, в той час як такі величини, як руйнування і втома, не можуть бути пояснені такими величинами. Оскільки величина напруги в різних частинах пористих матеріалів не однакова, в цьому дослідженні використовуються статистика і ймовірність, щоб краще зрозуміти напругу. Для цього спочатку досліджується гістограма напруг пористих матеріалів. За отриманою гистограмме для неї була розрахована функція щільності ймовірності. Нарешті, досліджується вплив однорідності розташування та розміру порожнини на функцію щільності ймовірності пористих матеріалів.

Ключові слова: пористий матеріал, неоднорідні порожнечі, багатовимірного аналіз

One way to identify porous materials is to use multi-scale analysis, and the relationships currently available for multi-scale analysis are limited to mean stress and strain values. These relationships have a great error in calculating the fracture strength of materials. It should be noted that in multi-scale methods, quantities of normal mean values are usually used to calculate macro properties, while concepts such as fracture and fatigue cannot be explained by such quantities. Since the amount of stress in different portions of porous materials is not the same, this study uses statistics and probability to better understand the stress. For this purpose, the stress histogram of the porous materials is firstly investigated. According to the obtained histogram, the probability density function was calculated for it. Finally, the effect of location uniformity and cavity size on the probability density function of porous materials is investigated.

Key Words: porous material, Non-uniform voids, multi-scale analysis

Статтю представив д.ф.-м.н., проф. Жук Я.О.

1. Introduction

Porous materials, as they are called, are solids that have cavities in their structure. They have a fuzzy structure that is a solid phase and a liquid or gas phase that is abundant in nature. These materials are lightweight, flexible and resistant to hair cracking, which is why Nowadays, with the development of technology, porous structure materials have been manufactured for use in various industries. It is widely used in beams, plates and shells. Materials such as aluminum, steel, plastic, copper, etc are composed of only one phase and are isotropic, so their mechanical properties include: Young's modulus (E), shear modulus (G) and Poisson's coefficient (ν) are independent of orientation and are identical in all respects but the porous materials are composites composed of two phases so they are anisotropic and their properties vary in different directions and their properties must be analyzed in different directions. There are some common theoretical methods for calculating the equivalent mechanical properties of porous material, one of the methods of hemogenization is the Mori-

Tanaka micromechanical method.

In 1987, Chensong Dong investigated the effects of cavities inside fiber-reinforced composites on the mechanical properties of the composite, with the aim of presenting an applied method for predicting the effects of existing cavities on the mechanical properties of the composite. In this study, representative volume element(RVE) of fiber /epoxy composites with different volumes of cavities were considered and the strength modulus was calculated by using finite element method (FEM). The results show that the cavities significantly affect the effective properties of the matrix including the transverse properties. Also, for cavities with greater volume than the critical volume, the transverse strength decreases and the strength decreases with increasing volume percent of reinforcement are reduced. In other words, holes have less influence on longitudinal properties. [1]

Also in 2011, S. Gong, Z. Li, and Y.Y. Zhao developed the Mori Tanaka model for elastic moduli of finite-size porous materials; the developed Mori Tanaka model takes into account the effect of pore size, number of pits, and sample size. This model shows that the elastic modulus of the porous materials decreases with increasing porosity, increasing number of holes and also with increasing hole size. [2]

As we know, stress causes fatigue, fracture, etc. Also, the strength of porous material is also determined by stress and in many studies the mean stress value has been used to investigate failure and in this research the aim finding the parameter is better than the average stress for the failure study. Also, the Mori Tanaka micromechanical method is chosen to calculate the equivalent mechanical properties to the porous material and on the other hand the equivalent mechanical properties to the selected porous material are calculated by writing a script in ABAQUS and the results will be compared. Since the stress in the porous materials is not constant and has many variations, we will use statistics and probability to better understand the stress. First, the stress histogram will be obtained by considering the size and location of the holes in different modes for the porous material. Then, according to the obtained histograms for each case, the probability density function will be found for the obtained results. Finally, the effect of the uneven location and size of the holes on the stress probability density function of the porous materials will also be investigated.

2. Statistical Analysis of Stress in Porous Materials:

The purpose of this study is to mechanically analyze the porous material with the help of statistics and probability. Also, considering the non-uniformity of the pores as a random size of the pores and random location of the pores, the effect of probable stress distribution on the final strength of the porous material is also will be reviewed.

An aluminum cube of specified dimensions containing a number of spherical holes with random radii will be considered, with holes randomly scattered in the cube, The cube is modeled as a three-dimensional representative volume element (RVE) in Abacus and undergoes a specified static loading, As mentioned, the aim is to investigate the location and size of pores on the possible stress distribution of porous materials. Therefore, three modes will generally be considered such that once the rate of change of the pore radius (size change) is zero, the location of the hole changes with the specified rate of change, once the rate of change of the pore location is zero and there are only radius variations of the holes, finally the rate of change of location and radius are both equal to zero.

In the first case the rate of change of location (rate p) will be zero and only for the rate of change of radius (rate r) that are: 0.05, 0.1, 0.15, 0.2, 0.25 and 0.3 the stress for each of the elements, Young's modulus (E), the density (ro), which shows the porosity are calculated from the following equation by writing the script in ABAQUS[3]:

$$S_i = S_i * v_i / V_t \qquad (1)$$

The Young's modulus value will be calculated from the following equation:

$$E = S_t / 0.02 \qquad (2)$$

S_t is the total stress of the sample and 0.02 is the strain value.

The porosity of the porous material is calculated from the following equation:

$$r_o = \left(1 - \frac{V_{t_1}}{V_t}\right) * 100 \qquad (3)$$

V_t represents the total volume of the sample and V_{t_1} represents the volume of the bulk material.

Also the stress values for each element are extracted as a separate file.

For example, for rate r=0.1 representative volume element (RVE) would be as follows:

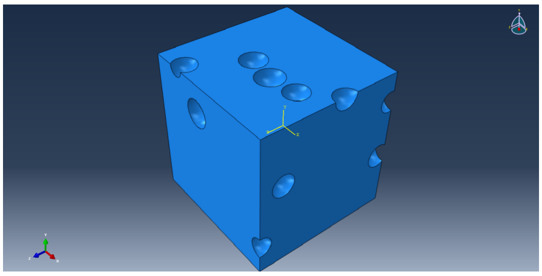

Fig. 1. Representative volume element (RVE) for rate r=0.1

And the the Young's modulus (E), density (ro) calculated from Equations 2 and 3 for rate r=0.1 are equal to the following:

E=64135882146

r_0=4.5026923

After extracting the stress values, it is observed that the stress is not a constant value for each element and has different values, so for the analysis of the stress results obtained from equation (1) for rate r=0.1 the histogram will be plotted as follows:

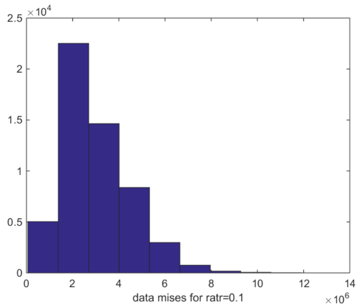

Fig. 2. Stress histogram for rate r=0.1

In the latter case, the radius changes will be considered zero, and only for the rate of location changes that are: 0.025, 0.05, 0.075 and 0.1, stress for the elements, the Young's modulus (E), density (ro) are also derived from Eq. (1), Eq. (2) and Eq. (3).

For this case also when rate p = 0.1 the representative volume element (RVE) will be as follows:

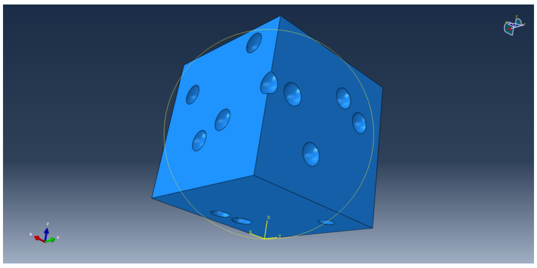

Fig. 3. Stress histogram for rate p=0.1

And the the Young's modulus (E), density (ro) for rate p=0.1 are equal to the following:

E=66745521411

ro=2.42786808

Since the stress value for rate p=0.1 is also not a constant value, the stress histogram will be plotted as follows:

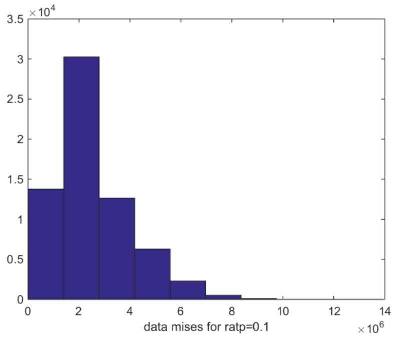

Fig. 4. Stress histogram for rate p=0.1

Also in the third case, the rate of change of location and radius both will be equal to zero in fact the distribution of the holes is uniform and the stress for the elements, the Young's modulus (E) and density (ro) will be calculated from Eq. (1), Eq. (2) and Eq. (3).

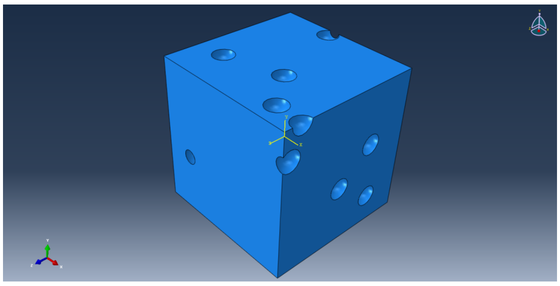

Fig. 5. representative volume element (RVE) for rate p=0 and rate r=0

For the uniform distribution of radius and location, the Young's modulus (E) and the density (ρ) are equal to the following values: E=66721371286 and $\rho = 2.46542693$.

For a uniform distribution of radius and location (rate $r=0$ and rate $p=0$), the stress histogram will be as follows:

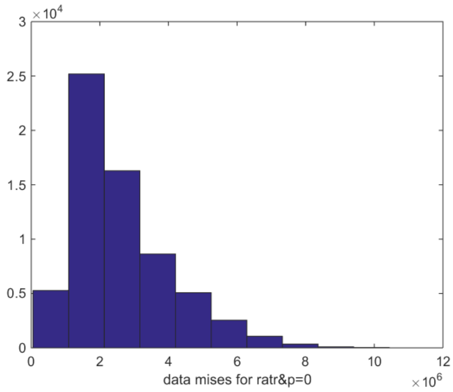

Fig. 6. Stress histogram for rate $p=0$ and rate $r=0$.

5. Conclusion

The obtained histograms show that the Gaussian distribution is not a good distribution and the Weibull distribution is a good distribution for analyzing the results, as we know the parameters of the Weibull distribution are b Θ and x_0, where $x_0=0$, so only the values of Θ (Size parameter) and b (shape parameter) will be numerically obtained for each of the three modes considered.

Weibull distribution parameters for the even distribution of holes are also calculated as follows:

rate p result		
Rate p	Teta	b
0.025	3.00E+06	1.96957
0.05	2.97E+06	1.96665
0.075	2.96E+06	1.98249
0.1	3.02E+06	1.98347

Tab. 1. Weibull distribution parameters for rate *p*

$$\Theta = 3.02E + 06,$$

$$b = 1.98347.$$

The results show that when rate r=0, the parameters of the Weibull distribution, b and Θ for the different cavity shift rates are as follows, as can be seen, there are not many changes for the parameters b and Θ.

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