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Research article

Using finite element model in calculation of stress concentration factor around an elliptical hole in composite hybrid lamina

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Abstract

The hybrid composites have exceptional properties such as strength to weight and hardness ratios. These characteristics make their application in the aerospace industry. In composite materials, there are various fittings, such as a bolt and a rivet, which are the focus of stress concentration in the joints because the fibers are damaged. In this research in hybrid composite materials, a high elastic modulus fiber (HM) and a low elastic modulus fiber (LM) are used. It is assumed that the length of the sheet is infinite. The force on the lamina is tensile force which is applied on matrix and fibers while the fibers in the layers are in the same direction. The effects of different parameters such as number of broken fibers and the ratio of (LM) to (HM) fiber extensional stiffness are examined. By using finite element method (FEM) and investigation geometrical and crack modeling, stress concentration factor (SCF) around an elliptical hole is calculated and compared with those reported in the literature. The results indicate the correctness of the code written for the analysis.

Keywords: Finite element method (FEM); Hole; Hybrid composites; Lamina; Stress concentration factor (SCF);

1- Introduction

Increasing the use of composite materials in designing structural components with a high level of mechanical performance has led to a better understanding and modeling of the behavior of these structures. Creating holes in composites due to the stress concentration or pressure created is inevitable and hence the mechanical properties of the structure are reduced [1].In continuous single-layer fibers, fibers with different volume fractions are placed in the matrix, and the mechanical properties of composite materials depend on the volume fraction of the fibers, and on the other hand, given that the fibers are usually crisp and fragile, and the matrix is soft and elastic. The importance of stress concentration in the fibers and its calculation is more important [2]. Taghipour Birgani [2] with the aim of investigating the effect of volume fractions of fiber and matrix on stress concentration around the hole in composite materials, using the shear-lag model, it was concluded that in addition to the volume fractions of the fibers and the matrix, the length of the plastic region also had a significant effect on the concentration of stress in It has a layer. Taghipour Birgani and shishesaz [4] investigated the effect of stress concentration around the hole under the effect of plasticity on the matrix and using by shear-lag model it was concluded that the shape and size of the hole as well as the length of the plastic region have a significant effect on the concentration of stress within the layers, The size of the hole and the tensile strength ratio of the low-modulus fiber to the modulus are high. Khechai [5] examined the stress concentration and failure criteria in composite sheets with a circular hole. The method used was finite element method. The results showed that the numerical results obtained with the analytical results showed a significant correlation and the results are consistent with the reference results. Saini [3] studied the variation of stress around a circular hole in a graded bend with using finite element method. The results showed that by increasing the Young's modulus and also by moving away from the hole, the stress concentration factor is decreased. Wankar and Bayas [6] used finite element method and reported that increasing diameter-to-width ratio increases stress concentration factor. Hu and Soutis [7] studied the stress concentration factor in hybrid multi-layer composites with a circular hole and the results showed that the finite element method can be used for any conditions of loading, stretching or pressure in composite materials with a thickness of thin or thick layers. Ramesh Wari [8]. In his studies, he concluded that the presence of any hole or opening in the composites can lead to failure due to increased stress, so it is necessary to reduce the stress around the hole to achieve a safe structure. Furthermore Farsakh and Almasri [9] was focus on stress concentration around a hole in a hybrid composite material that was loaded. By using finite element method, the results showed that the hole diameter, width and length of the plate have a significant effects on the stress concentration factor.

The aims of this research include investigation of effect of broken fibers and the effect of the elasticity modulus ratio of the fibers on the stress concentration factor around an elliptical hole in a hybrid composite lamina and the difference between results obtained from this research and the reference research. In the reference research using shear lag model modified (MSLM) but in this research, finite element method (FEM) were used.

2- Materials and method

2-1 Stress concentration factor

The stress concentration factor (K_t) is defined as the ratio of maximum stress ($\sigma_{\max}$) to nominal stress (σ_{nom}) which would exist in the member if the distribution of stress is remained uniform, so

$$K_t = \frac{\sigma_{\max}}{\sigma_{nom}} \tag{1}$$

where the stress concentration factor is the ratio of the greatest stress in the region of the discontinuity to the nominal stress for the entire section. Also known as theoretical stress concentration factor. Maximum stress is maximum stress equal tensile stress on the edge of the hole and nominal stress is stress on the two ends of the complete sheet are calculated peak stress and nominal stress respectively. The nominal stress is determined through the basic equations and is defined according to the type of load that is acting on the element. In the case of an axial load that causes tension or compression, this value is calculated by approach used by Dipen et.al [10]. There are two different conditions; first one is when the last broken fiber is LM and the second case is related to the conditions that the last broken fiber is HM fiber. In the first one, HM fiber bonds the hole so the maximum stress decreases while in the second case the enduring fiber is LM so the maximum stress increases.

2-2 Properties of hybrid composite lamina

Properties of composite plate are shown in Table1.

Table 1: Properties of hybrid composite lamina

Materials	Modulus of elasticity(GPa)	Poisson ratio
Epoxy matrix	1.6	0.35
Graphite Fiber	248	0.30
Glass fiber	85	0.22

As shown in the table 1, the modulus of epoxy matrix elasticity is very low compared to the modulus of elasticity of weak and strong fibers. The modulus of fiberglass and graphite fiber elasticity is equal to 85 and 248 GPa, respectively, which results in the "R" ratio equal to 0.34.

2-3 Geometrical model

The geometric model is a completely rectangular-shaped plate that thickness is very low and of the thickness of the fiber. The plate is under a simple tension on both sides which has an elliptical hole in the center of the sheet having a large length is (a) and small length is (b).The plate is composed of 21 layers of fibers and 20 layers of matrix, so that the elementary layer of strong fibers, then the matrix layer, followed by the weak layer and the matrix of the fibers and it is assumes that the middle fiber is HM fiber as shown in Figure 1. Due to the presence of geometric and loading symmetry in the model, the symmetry lines can be used in order to reduce the time of solving. Therefore, because of the two-plane symmetry, one-fourth model can be used. Furthermore in order to consider the effects of the N, the model was solved for different number of fibers starting from 13 to 101 is considered in Fig. 2. It is worth to note that it is assumed that the width of plate increases by increasing the number of fibers.

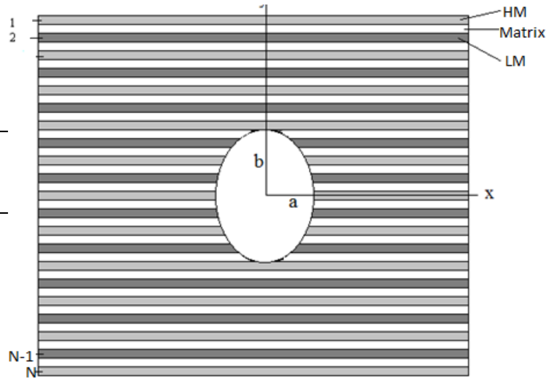

Fig. 1 The hybrid plate with elliptical hole in its center under a simple tension stress.

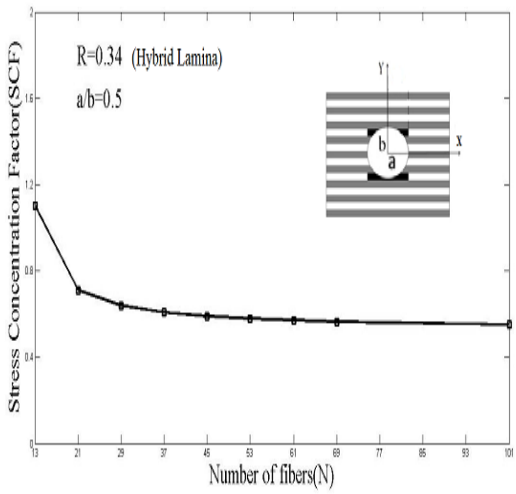

Fig. 2 Stress concentration factor as function of different number of fibers (N)

2-4 Finite Element Model

The finite element method is a numerical technique for obtaining approximate solution of wide variety of engineering problems. This approach deals with the division of given solid model into the number of simple shape of small size called elements. The quadrilateral model is essentially the same as the complete model, which has only one quarter of its two-plane symmetry, which, in computational work, raises the computational speed and reduces the computing time. Also, due to the reduction in the number of elements, it can be more accurately obtained by using more elements.

2-5 Meshing

Two-dimensional PLANE 182 element is used for modeling in ANSYS software, which is suitable for two-dimensional analysis. Stress concentration is caused by the presence of a hole and the maximum tension occurs around the hole because of this the smaller elements are employed around the hole to have more accurate results for this region. The meshed model can be seen in Fig. 3.

Since the plate has a geometric symmetry as well as a two-plane force, a quarter-dimensional model can be used to increase the speed of computing.

As shown in Fig. 4, the left side of the model is a quarter in line 'x' and above this model in line with 'y' it is closed because of symmetry. For primary analysis of the plate under tension, the result of the stress concentration factor is obtained by considering the number of broken fibers 11 and dimensional ratio of 0.5 for the hole.

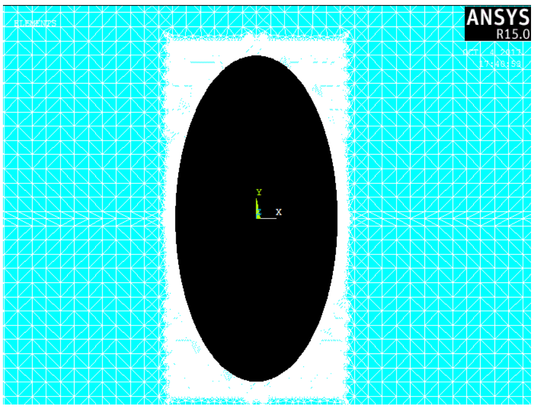

Fig. 3 Meshed central part of the hybrid plate.

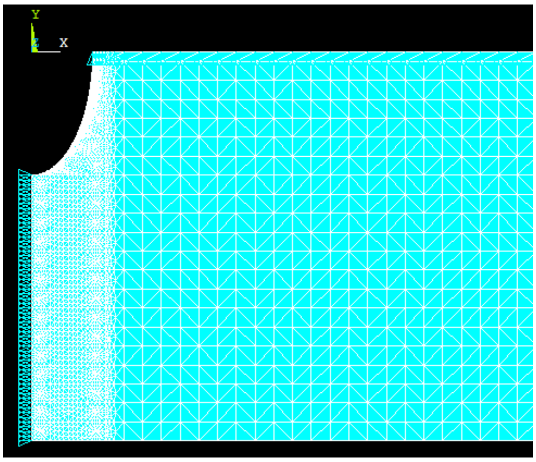

Fig. 4 A quarter-plate model

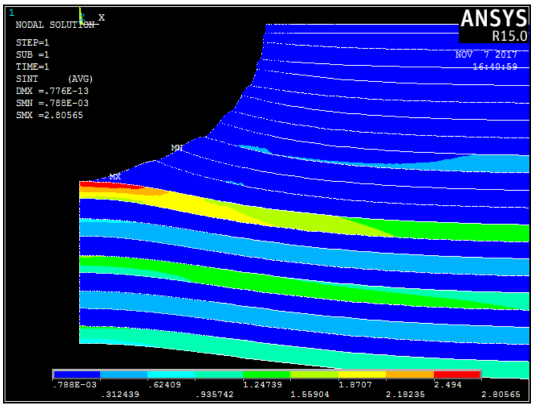

Fig. 5 Maximum stress on the plate

The maximum stress on the plate was reported while the applied pressure is 1 MPa. In the finite element model shown in Figure 5, the maximum stress is 2.8 MPa, indicating a stress concentration factor of 2.8.

2-6 Crack modeling

In the case which the ratio of a/b is equal to 0 it means there is crack on the plate. To investigate the stress concentration factor due to crack, the singular elements should be used. In theory, in the case of linear elastic fracture mechanics, stress at the tip of the crack will go to infinity. To do this; singular elements should be used which transmits the middle node of the element to a quarter of the tip of the crack (see Figure6). In order to model crack, it is only necessary to enter the number of broken fibers in the written APDL (Ansys

Parametric Design Language) code, which indicates the length of the crack.

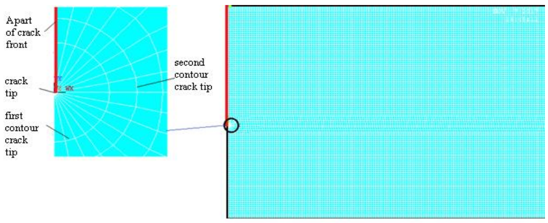

Fig. 6 Maximum stress on the plate

3- Results and discussion
3-1 Validation

Compared to Taghipour Birgani et.al reference [4] the correctness of the results obtained by the code was reviewed. To compare the results, we use the ratio of weak elasticity to strength to equal one, which in practice means uniformity of the fiber of the fiber.

As shown in Fig.7 the stress concentration factor compared for FEM and MSLM method. The responses are close to each other, indicating the correctness of the code written for the analysis, and the difference is only greater for the number of broken fibers.

3-2 Number of broken fibers

The number of broken fibers has a significant effect on stress concentration factor, as the number of broken fibers is increases, the local stress near the hole increases. For the correctness of this claim, taking into account the hole size ratio of 0.5, the stress concentration factor for different number of broken fibers 3, 7, 11, and 15 is described as the failure of the last layer is the strong fibers (HM) Fig. 8 as well as for the number broken fibers 1, 5, 9, and 13.

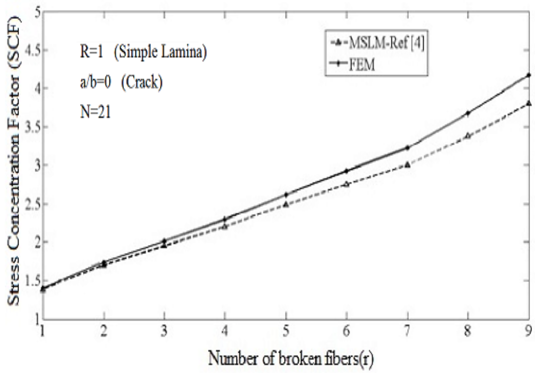

Fig. 7 The stress concentration factor comparison FEM and MSLM method

Fig. 9 is described as the failure of the last layer is the weak fibers (LM). As shown in Figs. 8 and 9, the trend of increasing in the stress concentration factor is accomplished by increasing the number of broken fibers. There is a difference in the range of variations in the case of Figs. 8 and 9. As it is known, the stress concentration factor in a position where the hole is surrounded by weak fibers is less than the case which surrounded by strong fibers (HM). This is why the strain closest to the hole has the highest rate. The resulting stress is obtained by multiplying the elastic modulus in the strain.

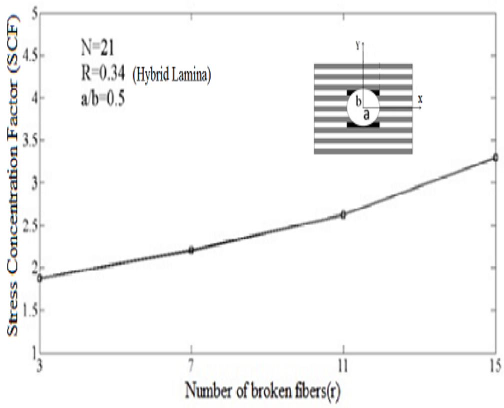

Fig. 8 Stress concentration factor based on the number of broken fibers (HM fibers)

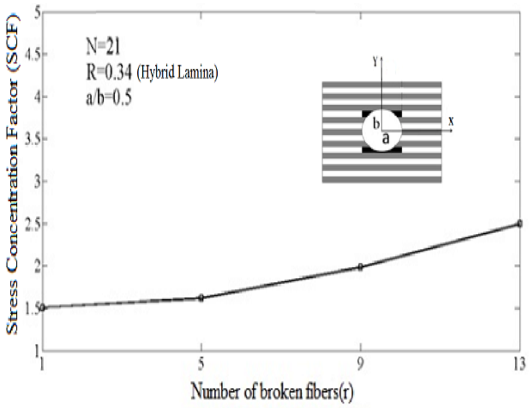

Fig. 9 Stress concentration factor based on the number of broken fibers (LM fibers)

Since, in Fig. 9, the hole is surrounded by fibers with weak (LM) elasticity modulus, the maximum stress has occurred in the same first layer but in Figure 8, since the layer with higher elasticity modulus is more spaced than the hole, the strain rate is reduced, resulting in a lower maximum stress so lower stress concentration factor exist.

3-3 Modulus of elasticity (LM) to (HM) fibers ratio

The ratio of (LM) to (HM) fibers, which is represented by R, is also one of the parameters that can be effective in the stress concentration factor. In the primitive mode, for two conditions, R was equal to 0.34 and 1, which the results are shown in Fig. 10.

The results show that when two different materials were used, the stress concentration factor is greater than when both materials are similar which indicates a reduction in the stress concentration factor due to an increase in the R value. For a closer examination of the effect of the value of R with regard to the three modes of broken fibers, 3, 7 and 11, the stress concentration factor in terms of R value was investigated (see Fig.11).

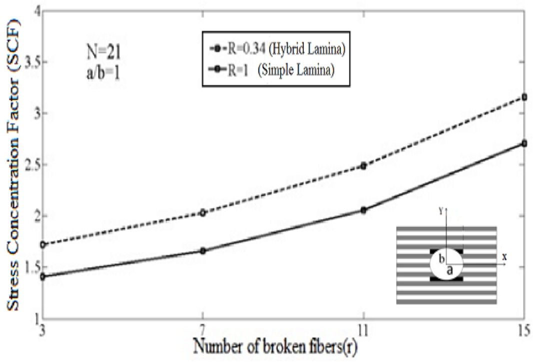

Fig. 10 Stress concentration factor in terms of modulus of weak elasticity to strong ratio

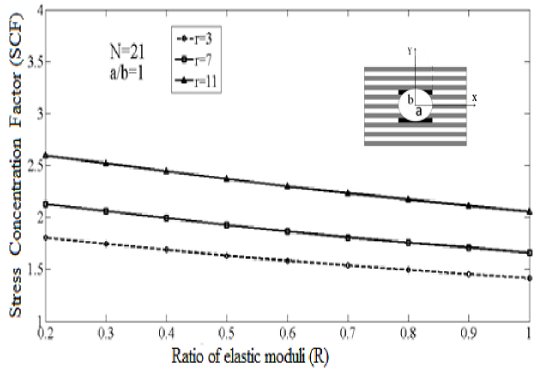

Fig. 11 Stress concentration factor as a function of "R" values

4- Conclusion

According to the results, application of finite element method and using of ANSYS software provides a very suitable way of determining stresses induced in most cases, especially in study of hybrid composites lamina. Since the plate has a geometric symmetry, it can be used to increase the computational speed of a quadratic model. As the number of broken fibers increases, the plate's resistance to the stresses is reduced. When the hole is surrounded by weak fibers, the stress concentration factor is less than the case which is surrounded by strong fibers. When using two different materials, the stress concentration factor is greater than the time when both materials are the same. The results of validation showed a similarity between the results obtained via analytical and numerical solutions. It can be concluded that in the case of more difficult problems as well as more complex types of material or complicated geometries which could be hard to use analytical solutions we can use this approach by modeling and using FEM software to overcome the engineering problem.

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