# Calculation of stress concentration around a hole in a hybrid composite lamina using finite element method

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**Abstract:** The hybrid composites have exceptional properties such as strength to weight and hardness ratios. These characteristics make the application of these materials in the aerospace industry. In such industries, any defects in the form of holes or cracks will increase the tension in these materials and fail, which are very dangerous. In composite materials, there are various fittings, such as a bolt and a rivet, which is 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 also assumed that the length of the sheet is infinite. The force on the lamina is tensile force which applies on matrix and fibers while the fibers in the layers are one directed. In this paper the effects of different parameters such as number of total fibers , number of broken fibers , the ratio of  LM to HM  fiber  extensional stiffness , Hole dimension ratio are considered. By using finite element method (FEM) stress concentration around the hole in a hybrid composite lamina is calculated and compared by the results obtained by analytical method [1] via written codes for finite element method.In this research unlike reference the matrix can withstand tensile stress. The results of the validation showed that compared to the reference data are close to each other, indicating the correctness of the code written for the analysis.The difference is only greater for the number of broken fibers.

**Keywords:** Hybrid composites, Lamina, Hole, Finite element method, Stress concentration

## 1.  Introduction

Increasing the use of composite materials in designing structural components with a high level of me-chanical performance has led to a better understanding and modeling of the behavior of these struc-tures. Creating holes in composites due to the stress concentration or pressure created is inevitable and hence the mechanical properties of the structure are reduced [2]. In continuous single-layer fibers, fi-bers with different volume fractions are placed in the matrix, and the mechanical properties of compo-site 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 [3].

Taghipour Birgani[4]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[1]the effect of stress concentration around the hole under the effect of plasticity on the matrix was investigated 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. Taghipour Birgani and shishesaz[5]Using the shear-lag model, with the aim of investigating the stress concentration around the hole, it was concluded that the shape and size of the hole and the stiffness ratio of the fibers with a low elasticity modulus were high to the elastic modulus and also the size of the plastic region had a significant effect on the normal and shear stresses in matrix and fibers, respectively. Rahnama[6]using modified shear-lag model, and to study the stress concentration in a hybrid composite with unidirectional fibers and symmetric (angular and toothed) cracks. The results showed that by increasing the fiber elastic modulus ratio, the maximum stress concentration coefficient in the first healthy fiber of the tip of the crack decreases. When the modulus of the field elasticity to fiber is goes to zero, the results of the present model show good agreement with the initial shear-lag model. Khechai[7]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[8]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[9] used finite element method and reported with increasing diameter-to-width ratio stress concentration factor increases.Hu and Soutis[10] 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 [11] 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 [12] 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. In this paper the effects of different parameters such as number of total fibers, number of broken fibers, the ratio of LM to HM fiber extensional stiffness, Hole dimension ratio are considered. By using finite element method (FEM) stress concentration around the hole in a hybrid composite lamina is calculated and compared by the results obtained by analytical method [1] via written codes for finite element method. The difference between the current studies with the previous work could be related to different approach for solving such problems by using finite element method and comparing the effectiveness of this method with other methods. The aims of this research include: the effect of the elasticity modulus of the fiber on the stress concentration factor around the hole, effect of hole dimensions on stress concentration factor, effect of the total number of fibers on stress concentration factor, effect of broken fibers on stress concentration factor and the effect of the number of layers on the stress concentration factor. The difference between this research and the reference research is that in the reference research, the symmetric hole stress concentration in a hybrid composite lamina subjected to matrix plasticity with using shear lag model(SLM) but in this research, finite element method(FEM) was used to calculate the stress concentration factor around the hole in a hybrid composite lamina. The studied traits in this research were: plate Length-to-width ratio, number of broken fibers, modulus of weak elasticity to strong ratio and hole dimension ratio.

## 2. Materials and Methods

($K_t$) is the Stress concentration factor equal ($\sigma_{max}$) maximum stress to ($\sigma_{nom}$)nominal stress ratio is defined as the ratio of the calculated peak stress to the nominal stress that would exist in the member if the distribution of stress remained uniform and is obtained through the equation:

$K_t = \sigma_{max} / \sigma_{nom}$                                                                                  (1)

   Where the stress concentration factor is equals 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 cal culated by approach used by Dipen et.al [13]. 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.
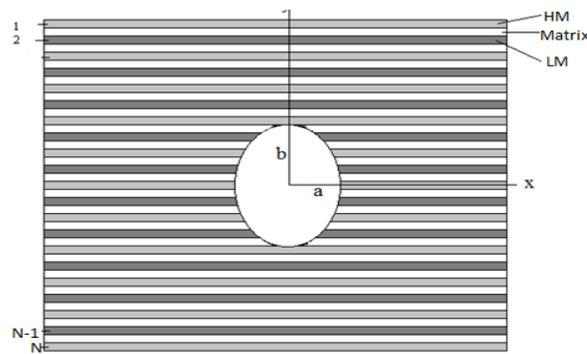


Figure 1) The hybrid plate with elliptical hole in its center under a simple tension stress.

### 2.1. 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 Figure. 2. It is worth to note that it is assumed that the width of plate increases by increasing the number of fibers.

### 2.2. Finite element method

   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 [14].
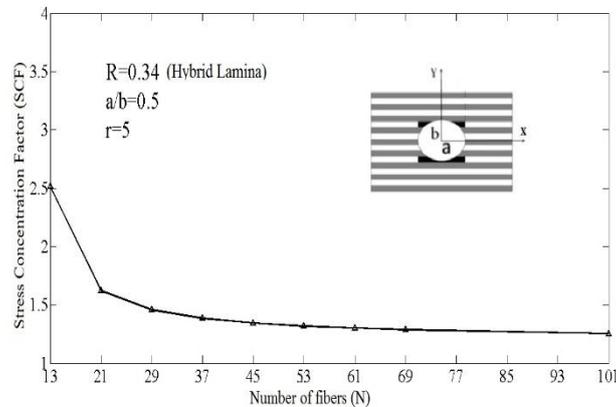


Figure 2) Stress concentration factor as function of different number of fibers (N)

## 2.3. 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 from this region. The meshed model can be seen in Figure. 3.

## 2.4. Primary analysis

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

## 2.5 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 Fig.6). 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.

## 3. Results and Discussion

### 3.1 Plate Length-to-width ratio

The length to width ratio of the parameters is effective on the stress concentration factor because of the effect of the stress contour, disturbing effects and the integer and stable stress cannot be obtained. To investigate the effect of this ratio, the maximum number of broken fibers choose 15 and a/b ratio equal to 1 considered during this study. This is considered the most critical hypothetical state in the calculations. In Figure.7, the stress concentration factor

in terms of the length to width of the plate has been investigated, which is approximately constant from the ratio of 6. The result of this ratio chooses as a criterion for next calculation.

Properties attributed to the plate for initial studies are shown in Table1.
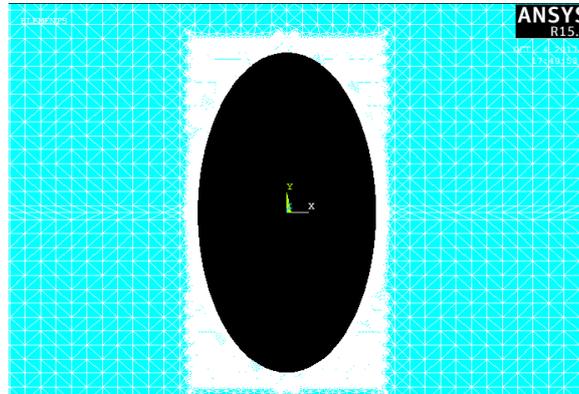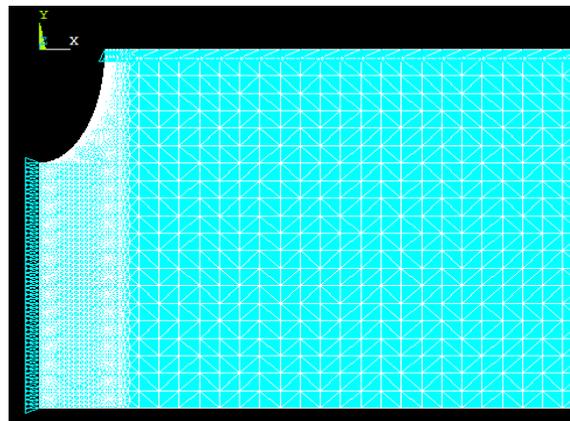


Figure 3) Meshed central part of the hybrid plate



Figure 4) A quarter-plate model

Table1) Properties of material

| Material | 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.

### 3.2 Validation

Compared to the Taghipour Birgani et.al [1] 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 Figure.8 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.
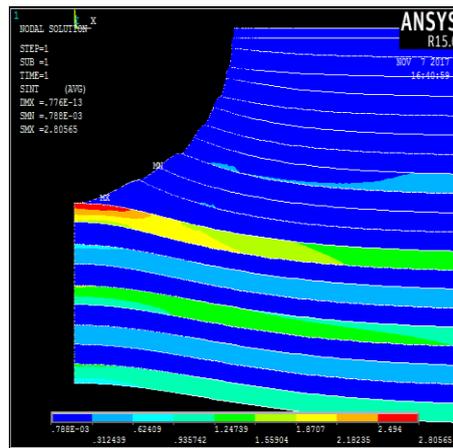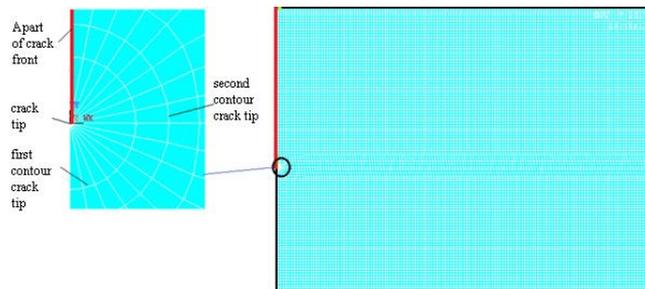
Figure 5) Maximum stress on the plate

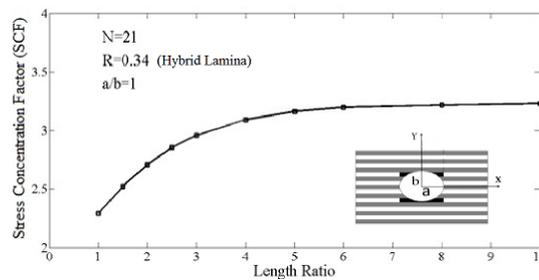Figure 6) Meshing part of the part and crack tip magnification

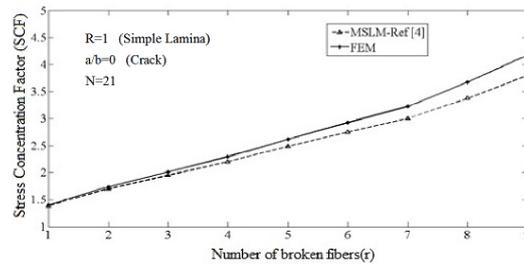Figure 7) Stress concentration factor as a function of plate length to width ratio

Figure 8) The stress concentration factor comparison FEM and MSLM method
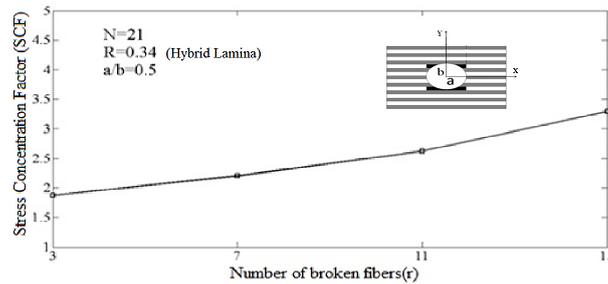


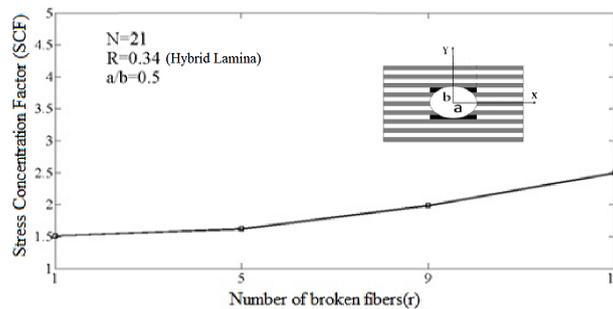Figure 9) Stress Concentration factor based on the number of broken fibers (HM fibers)



Figure 10) Stress concentration factor based on the number of broken fibers (LM fibers)

## 3.3. 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 (Figure. 9) as well as for the number Broken fibers 1, 5, 9, and 13 (Figure. 10) are described as the failure of the last layer is the weak fibers.As shown in Figures. 9 and 10, 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 Figures. 9 and 10. 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. 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. Since, in Figure. 10, the hole is surrounded by fibers with high elasticity modulus, the maximum stress has occurred in the same first layer but in Figure. 9, 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.
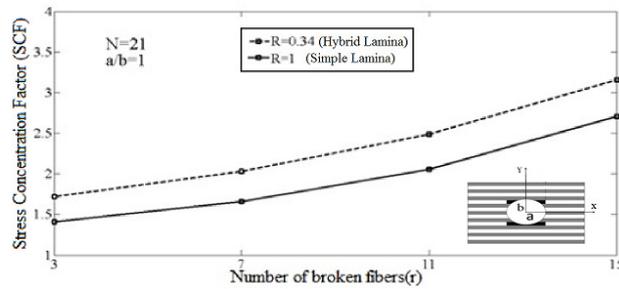
Figure 11) Stress concentration factor in terms of modulus of weak elasticity to strong ratio
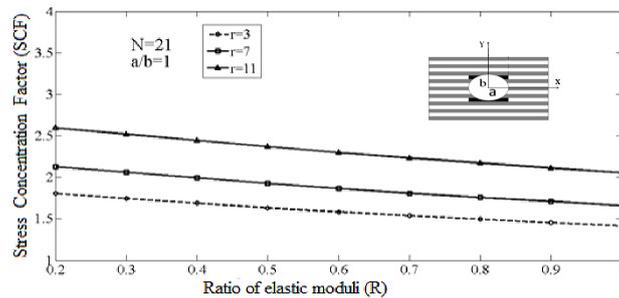


Figure 12) Stress concentration factor as a function of "R" values

## 3.4. Modulus of weak elasticity to strong ratio

The ratio of weak to strong elasticity, 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 Figure.11.

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 Figure.12). The variation of the Stress concentration factor in terms of the ratio R shown in the Figure. 12 that confirms its decrease with increasing R ratio.

## 3.5. Hole dimension ratio

The dimensions of the elliptical hole are one of the factors that can be effective in the stress concentration factor. The four aspect ratios are investigated, which are: zero (crack), 0.25, 0.5 and 1. The results are shown in Figure.13
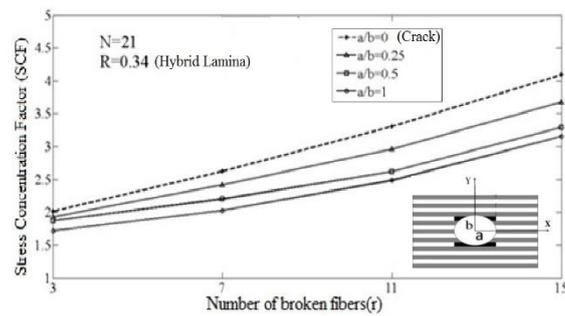
Figure 13) Stress concentration factor in terms of hole ratio

As shown in Figure. 13 by decreasing the proportion of the hole dimension, the stress concentration factor is more intense, which results in increasing the sharpness of the geometry of the hole.

## 4. Conclusions

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. Since the plate has a geometric symmetry, it can be used to increase the computational speed of a quadratic model. The length to width ratio of the parameters is effective on the stress concentration factor. 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. As the ratio of the hole dimensions is lower, the stress concentration factor is more intense. 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.

### Nomenclature

| | |
|---|---|
| $\sigma_{max}$ | Maximum stress |
| $\sigma_{nom}$ | Nominal stress |
| $K_t$ | Stress concentration factor |
| N | Number of layers |
| r | Number of broken fibers |
| R | Modulus of weak elasticity to strong ratio |

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