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Numerical Evaluation of Fracture in Woven Composites by Using Properties of Unidirectional Type for modelling

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ABSTRACT

The modelling of woven composite structures or components, which subject to statically loading, requires a fundamental understanding of the progressive modelling software and deterioration mechanism within the composite structure. Presented modelling techniques for the design then analysis of woven composite structures and components by using Finite Element Method (FEM) are either based on amount of critical stress on crack tip from Von Misses theory. In this paper three dimensional model of woven composite which their modelling is too complex because of their orthotropic structure, simulated by using the unidirectional (UD) and woven models. In first method the properties of unidirectional composites that have defined method for modelling have been used and in other method the 3D structure of woven composites are modelled exactly. For modelling of fracture on mode I predict of pre crack is necessary. When statically loading of specimen started, amounts of load and opening of specimen for several crack length incorporated, then diagrams of load relative crack length are plotted. Compliance theory which is the best theory for estimate critical strain energy release rate (SERR) is used for study fracture on mod I. by using values of opening displacement in Double Cantilever Beam (DCB) specimen for variable load amounts, diagram of strain energy release rate versus crack length plotted and compared with experimental data. The results shows using wove model shows better conclusion.
KEYWORDS: Woven Composites, Unidirectional Composites, Fracture, FEM, Unit cell, SERR

1. INTRODUCTION

The increased application of woven composites, particularly in the transportation industry, in the design of aircraft, helicopters, boats, cars, etc. requires a detailed understanding of the behaviour of these composite component or structure to a wide range of potential external loadings, some of which may be severe. This interest is due to their outstanding mechanical properties, impact resistance, high durability and flexibility in design capabilities and light weight [1].

Ultimately, a statically loading woven composites component may be subject to in-service loadings, and hence the residual strength, and whether any existing loads will propagate is an important parameter to consider in the design process. In particular in the aerospace industry, statically damage in laminated composite materials continues to be a major cause of concern. In such cases, layered composites suffer severely by delamination cracking because of poor interlaminar fracture resistance. On further loading, the interlaminar crack propagates and thus weakens the structure [2]. The internal damage is not easily detectable which increases the associated risks. In the majority of real applications transverse matrix cracking and delamination are intrinsically associated and constitute a typical damage mechanism of composites especially when structures are submitted to bending loads [3].

On the other handlaminated composite structures are made up of orthotropic laminae that are bonded together. Due to the lack of reinforcement in the thickness direction and, also, since interlaminar stresses exist in the boundary layer of laminates under transverse loading, the layers are likely to deboned, and delamination is one of the prevailing forms of failure in laminated composites [4]. These composites have generally good fibre dominated in-plane properties capable of meeting the design requirements for various types of structural applications. nevertheless, Z-axis (through the thickness) properties of the composites, such as delamination resistance, have often been far below the expectations due to poor performance of the matrix dominated interlaminar region [5].

Hence, in some practical applications, these materials may exhibit lower overall structural integrity in according with their presumed properties. Delamination has the potential for being the major life limiting failure process. It may even happen during processing of the laminates due to contamination or regions of high void content of manufacturing process [6].

In general, delamination corresponds to a crack-like discontinuity between the plies and it may typically extend during application of mechanical or thermal loads or both during service life of composite [7]. One of the common ways to improve the delamination resistance of reinforced polymer composites is to

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incorporate some toughening agents or thermoplastic binders into the brittle matrix resins [6, 8]. There are many ways to improve the mechanical and other properties of the various types of composites. But experience of each way is not only too hard and expensive but also need many samples that manufactured with special method for improve properties that waste enormous time.

Therefore using different methods that perform simplest way to evaluation of requirement parameters is necessary. One of these methods is using FEM. Finite Element Modelling has arisen as a useful technique for studying fracture problems from a theoretical point of view. Several methods are documented in the literature for computing the strain energy release rate (G) by means of numerical analysis procedures in fibre reinforced composite materials [9]. Among these methods, the virtual crack closure technique has been the most widely used for computing energy release rates [10]. For this reason demand to appropriate model for using in FEM is actually visible. Some analytical and theoretical models simulated via finite element method (FEM) are also used for predicting interlaminar delamination in composite structures [11].

Regarding the experimental point of view, double cantilever beam specimens (DCB) have been widely used to measure the mode I critical energy release rate (GIc) [12]. The computed results have been very similar and in close agreement with both the experimental results and solutions obtained from a corrected beam theory [13]

2. MATERIAL AND METHODS

Design weaved part of woven composite which have complex structure in comparison with other types of composites is hardship, because of their anisotropic structure. Present paper offers two methods for simulation of these composites:

A) Simulation of woven composites by using properties of unidirectional composites.

B) Simulation of these composite by modeling of unit cell

Then modelling of DCB samples by using of these methods, and load statically then plot diagrams of strain energy release rate on mode I versus crack length for both of samples. Finally compare results of two methods for modelling, to choice better method.

2.1. Simulation

A) **First method:** In first method the properties of unidirectional composites have used for simulation of woven composites. Unidirectional composites are a simple type of composites that a special method predicted for simulation of them and we can use ANSYS software to simulation of them. In unidirectional composites reinforcing fibres are straight in each layer which fibres directed special direction in each layer. For this reason unit cell of woven composites should be divided to 9 sections that each section made up of 10 unidirectional layers (Fig. 1).

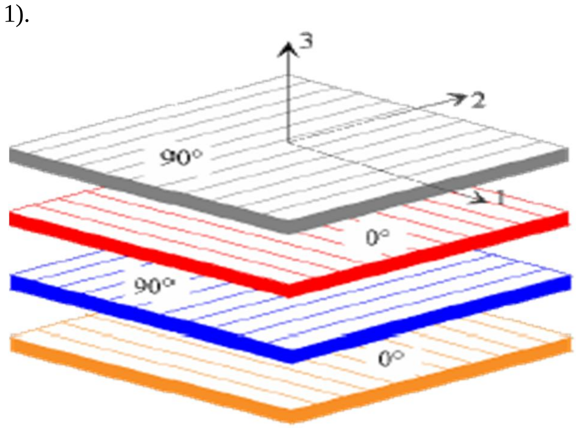

Figure 1. Layers of unidirectional composite that used for simulation of woven composites

For modelling of woven composite by this method we should avert 6 steps:

1.Modelling an unidirectional block with 12 layers which fibres in even layers are in 0 degree, and in odd layers are in 90 degree (Fig. 2).

2.Modeling a unidirectional block with 12 layers which fibers in odd layers are in 0 degree, and in even layers are in 90 degree, then fill that beside block modeled in step1(Fig 3)

3. Modeling unit cell by alternating of blocks by together only if fibers in first layer are 0˚,the first layer of inside block should reinforce transversely (Fig. 4).

4. Merge together all of these blocks to make a unit cell of woven composite.

5. To modeling of DCB sample, copy handful of this unit cell beside together and merge them (Fig. 5).

6. Meshing crack tip of DCB sample with singular elements.

Young modulus	Poisson ratio	Shear modulus
E_{XX} = 12 GPa	ν_{xy} = 0.13	G_{XY} =1.9 GPa
E_{YY} =20 GPa	ν_{yz} = 0.13	G_{YZ} =2.85 GPa
E_{ZZ} = 12 GPa	ν_{xz} = 0.13	G_{XZ} =2.85 G Pa

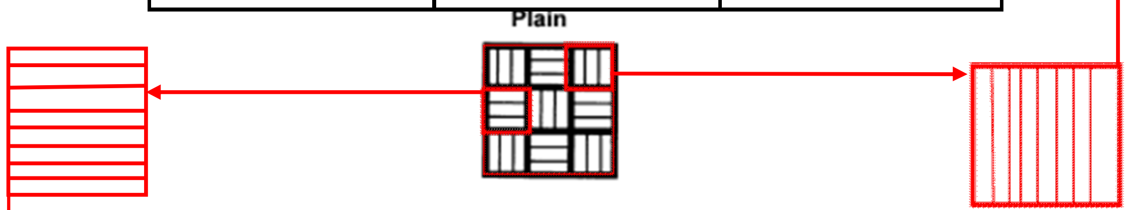

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Figure 2. Unit cell of woven composite simulated by method A and property tables of applied unidirectional composites [14].

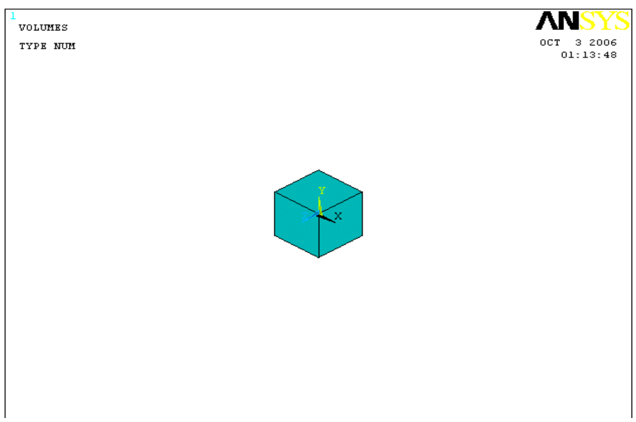


Figure 3. Unidirectional block which fibres in even layers are in 0 degree and 90 degree in odd layers

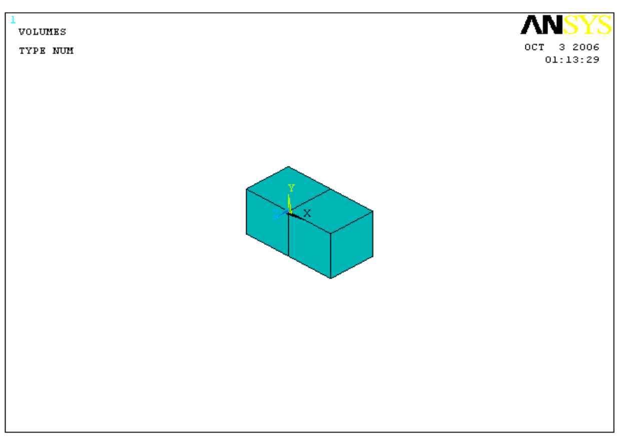


Figure 4. Two blocks with transverse fibres

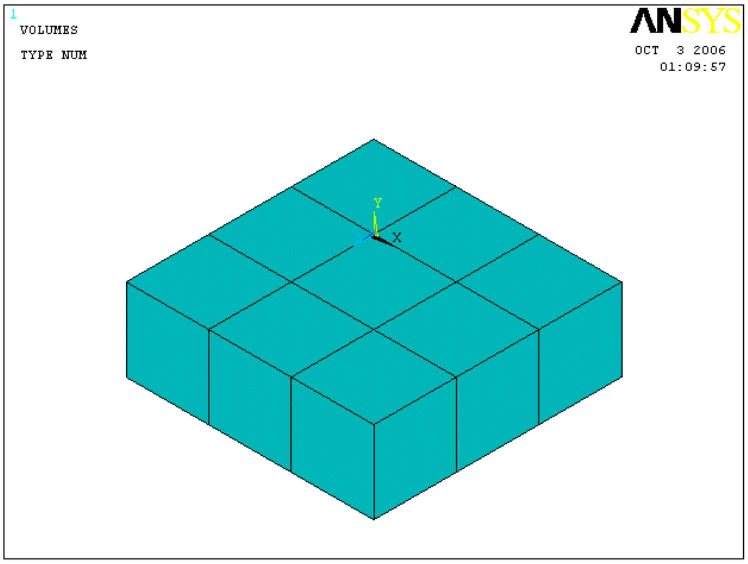


Figure 5. Unit cell of woven composite which made up of 9 unidirectional blocks

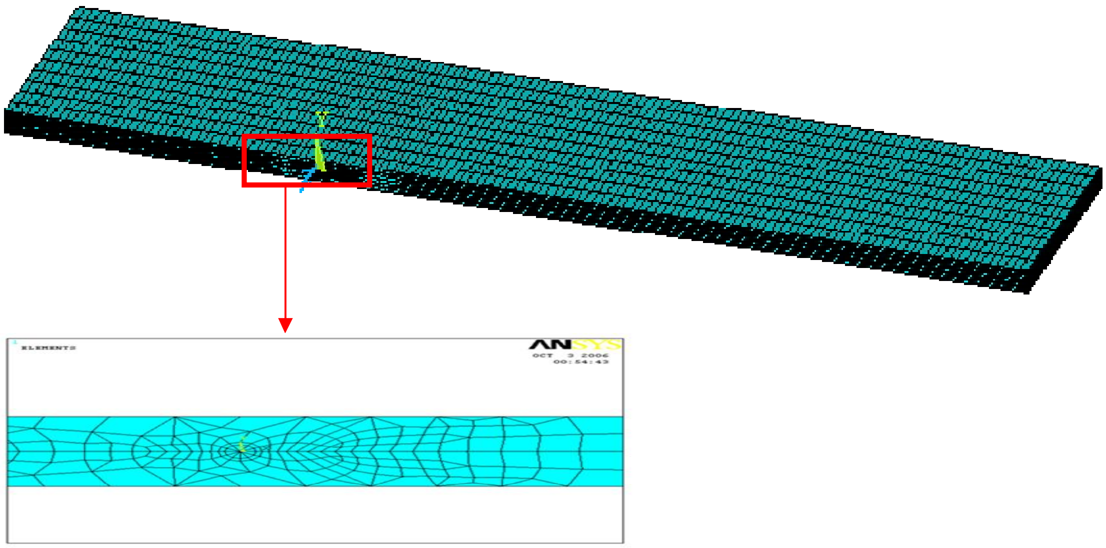


Figure 6. DCB model of woven composites, and singular meshing in crack tip

B) Second method:

In the second method for simulation of woven composites, the geometrical properties of woven textile which measured from geometry of experimental sample have been used.

For modeling by this method we should avert 8 steps:

1. For modeling cross section of warp, we try to simulate periphery of it's by usage of four arcs which they radius extract from microscopic properties of experimental sample (Fig. 6)

2. Cross section that confined to these arcs for constitute cross section of warps have been modeled (Fig. 7).

3. For modeling of warps, cross sections that are modeled in X-Y plane should be extruded in direction of Z (Fig. 8).

4. Generation of woofs which weave to warps is the most significant part of design. To do this, the key points on rout of guide line that transmitted between of warps have been defined (Fig. 9).

5. In this part of design the cross section of woof should be generated according to step one and two but in X-Z plane (Fig. 10).

6. To generation of first woof, cross section of step 5 should be extruded along the guideline which is transmitted between warps (Fig. 11).

7. In this stage, steps 4, 5, 6 have been repeated to generate second and third woofs. Now the unit cell of fibers is presented. And matrix should be added to fibers unit cell to fill out woven composite unit cell (Fig. 13).

8. For making unit cell of fibres and matrix; matrix should be added to unit cell of fibres (Fig. 14).

9. For make of samples with several layers and dimensions unit cells should be copied and merged in contact surfaces.

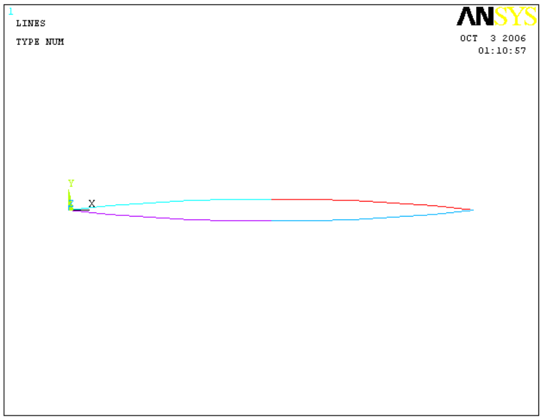


Figure 7. Periphery of yarn that is made up of four

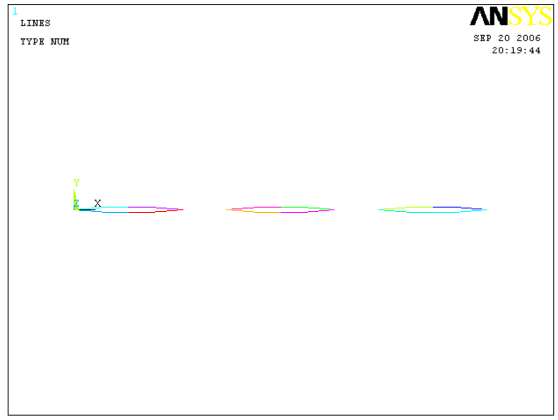


Figure 8. Cross section of three warps

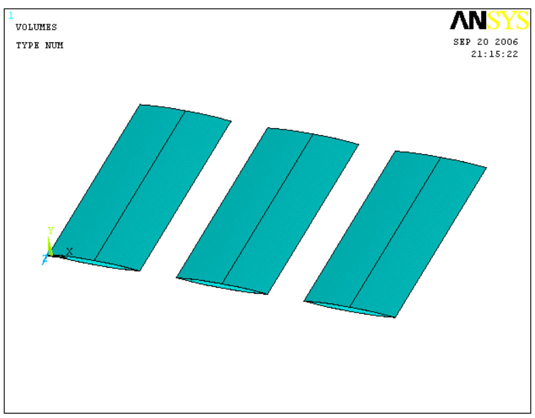


Figure 9.
Modelling of warps that constructed base of unit cell

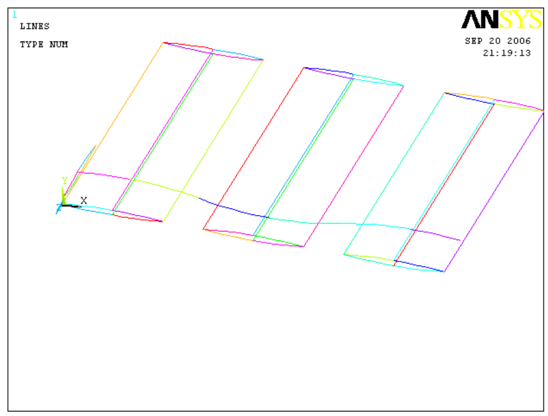


Figure 10.
Guide line of woof that transmitted between warps

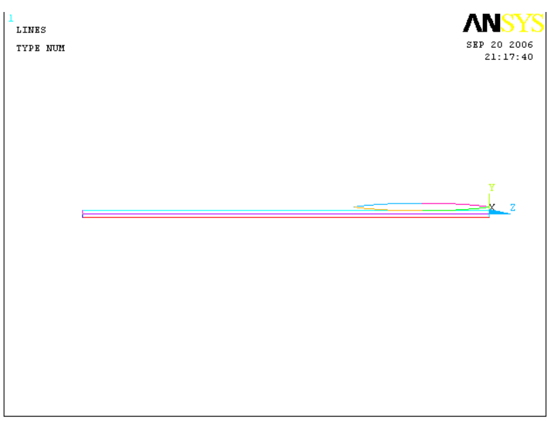


Figure 11. Cross section of woof

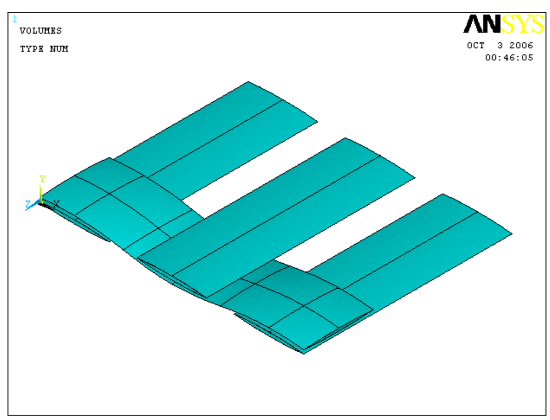


Figure 12. First woof that transmitted between warps

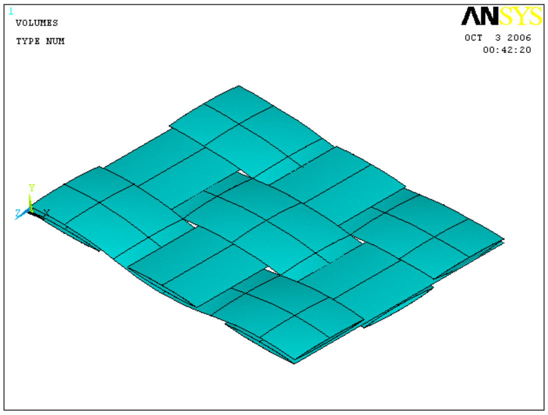


Figure 13. Modelling the fibres of unit cell

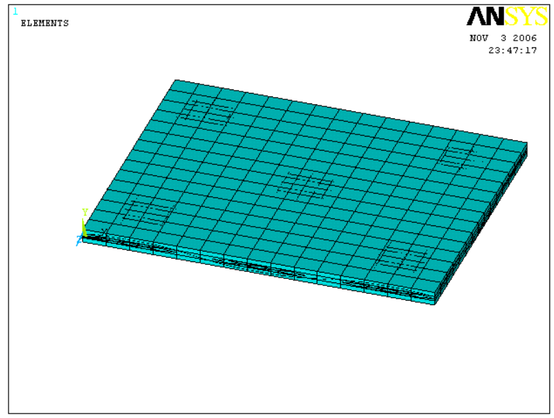
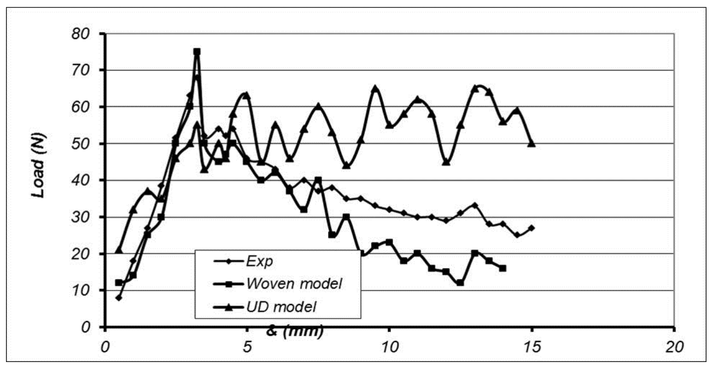


Figure 14. Unit cell of fibres with matrix

3. RESULTS AND DISCUSSION

Now variable loads can be applied statically to DCB sample and can be estimated the critical load (F_c) for variable opening of sample (δ_c). Then diagram of critical load (Fcr) that in this force crack starts to grow is plotted versus critical opening of sample (δ_c) for both of samples which are modelled in previous section and compare these results with experimental data afforded from [15].

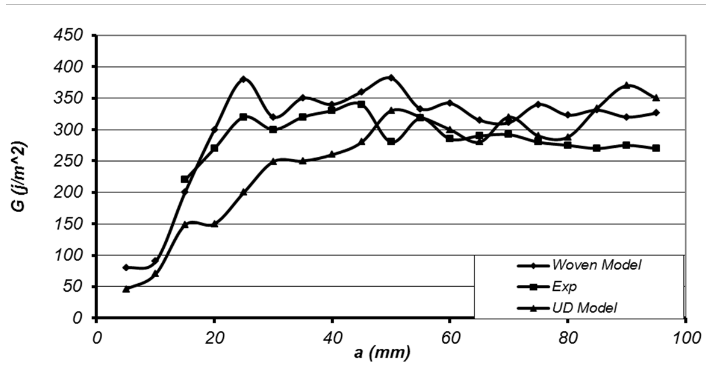
Figure 15. Diagrams of load-displacement and comparison of numerical data with experimental data for two types of models



The numerical analysis of a DCB specimen has been carried out using the displacement control method in order to format stable delamination growth. Therefore, by checking the displacement of the two ends of the cantilevers, the load is applied to the specimen until it reaches the critical amount of force that is related to the material strength.

For delamination growth, the critical loads corresponding to the Von Misses stress of 35 MPa, founded iterating variation of displacement for the various crack lengths, have been carried out. Thus the critical load (Fcrt) and critical displacement (δcrt) corresponding the crack length have been obtained. Then, by increasing the crack length, the same operation has been repeated. Hence, for different values of crack lengths, the curve of load versus displacement has been drawn for UD and woven models Fig. 16).

Figure 16. Curves of strain energy release rate relative crack length for UD and woven models



According to Fig. 16), which has been plotted for UD and woven model, while the woven model present good results simply for the crack length between 40mm - 80mm, for the crack length before 40mm values of G_{Icrt} that are above experimental results and for crack length after 80mm these values drop out. Evaluation of the obtained results shows that there is a difference of 60% between the experimental and numerical results. From the above evaluation, it can be seen that UD model is not convenient to use. Therefore, woven model for the solution of this problem must be used in spite of the difficulties.

3. CONCLUSION

The structure of a woven composites that are an orthotropic materials, are modelled by using two different methods. Firstly, unidirectional blocks are used. In this method 9 blocks that each block made up from 10 unidirectional layers which are modelled with [0,90] fibre orientations. Then mentioned blocks merged together to create a continues model. In the second method that is too complicated modelling method with the mention to ability of ANSYS program in modelling of complex geometry, the structure of these types of composites is modelled too exactly by using of simple geometric shapes as an arcs and splines. In both models, singular elements are used for meshing of crack tip. SERR and compliance theory are used to evaluation of crack growth in DCB model that made using the mentioned methods. The results of UD and woven modelling compared with experimental results. The result of this study shows the modelling of woven composites by using woven model gives better results to UD models.

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The authors declare that they have no any conflicts of interest in the research.

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