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Finite Element Modelling of microscale and macroscale on deformation of composite material

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ABSTRACT – Performance prediction is an important aspect in confirming the correct design specification of composite materials. Finite Element Modelling (FEM) approach enables to calculate stress and strain components of a structure for more realistic strength predictions. In this study numerical simulation is perform using FEM method to simulate composite materials through tensile test at micro and macro level. The geometric for tensile test were according to ASTM D3039 for GFRP and CFRP. Micromodelling of composites were simulated based on theory of Representative Volume Element (RVE). It is found that RVE able to predict deformation and mechanical properties extraction of composite in unidirectional.

1. FINITE ELEMENT MODELLING OF COMPOSITE

The finite-element method (FEM) has been found to be la powerful numerical tool for the analysis of composite structures under static loading [1-3]. In this study, different types of elements for composite have been used namely plane strain, plane stress, 3D Conventional Shell and 3D Continuum Shell. There are many ways in studying the effect of different element used for composite material simulation in accounting for through thickness shear deformation, normal stress and width influence.

2. METHODOLOGY

2.1 Composite solid elements in FEM

The use of composite solids is limited to three-dimensional brick elements that have only displacement degrees of freedom. Composite solid elements are primarily intended for modelling convenience.[2] They usually do not provide a more accurate solution than composite shell elements. The thickness, the number of section points required for numerical integration through each layer and the material name and orientation associated with each layer are specified as part of the composite solid section definition. The solid (or continuum) elements in Abaqus can be used for linear analysis and for complex nonlinear analyses involving contact, plasticity, and large deformations.

2.2 Creating conventional shell composite layups

Conventional shell composite layups are composed of plies made of different materials in different orientations. A layup can contain a different number of plies in different regions. Shell elements perform somewhat better than solid elements in modelling the transverse shear stress through the thickness. Since the transverse shear stresses in thick shell elements are calculated by Abaqus on the basis of linear elasticity theory, such stresses are often better estimated by thick shell elements than by solid elements.[6]

2.3 Stacked or layered continuum shells

The continuum shell model is a fully three-dimensional geometrical study of stress and displacement elements in composite which the thickness is defined as nodal geometry. The results in this method are more accurate and it can be used for all thickness.[6]

2.4 Material properties of the GFRP and CFRP Macroscale

The GFRP layups is builds up with 10 plies and stack with 0 degree fiber orientation. The CFRP layups is builds up with 2 plies and stack with 0 degree fiber orientation. The material properties of the GFRP and CFRP are listed in **Table 1**.

Table 1 Material properties of the GFRP and CFRP.

Property/ Material	**GFRP**	**CFRP**
Young's Modulus (GPa)	E_1= 37.6 E_2= 10.3	E_1= 120 E_2= 7.614
Poisson's Ratio	0.3	0.31
Shear Modulus (GPa)	5.85	4.8

2.5 Micromechanical modelling

Micromechanical of materials is the analysis on the level of individual constituents that represent the whole material of composite material or might as well defined as heterogeneous materials which is defined as non-uniform and composed of diverse parts that occupy the same volume [4].For heterogeneous material, it display a statistical arrangement of the constituent where it shows an orthotropic material symmetry which the behaviour depends on the shape and orientation of the inclusions, instead of deterministic arrangement of the constituents such as homogeneous material. Thus, the concept of representative volume element (RVE) is used as the method of micromechanics where such task known as homogenization applied. In this study, the micromechanical modelling of RVE represents the unidirectional composite material [5].Besides that micromechanical representation on macrolevel is limited to corresponding volume fraction and fiber orientation which is 60 percent and 0 degree in longitudinal direction. Figure 1 shows the RVE modelling under longitudinal tensile loading with boundary condition involved. The size of RVE were modelled as accordance to real size in microscale and represents volume fraction of 60 percent which similar with real size. Meshing type used is swept mesh for matrix and fiber solid region with hexahedral 3D shape. This is based on other scholars' previous works. [4,5]

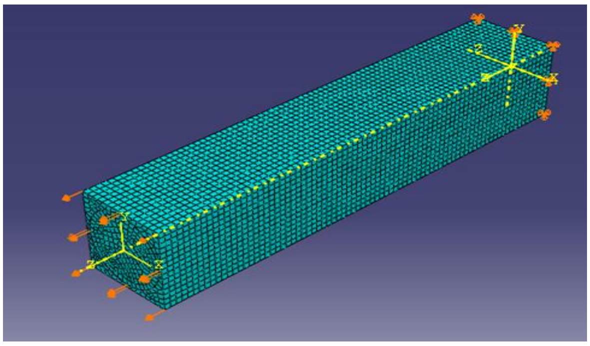

Figure 1 Unit cell of RVE for longitudinal tension.

3. RESULTS AND DISCUSSION

Predicting deformation using RVE for GFRP and CFRP shows consistent value of mechanical properties of macroscale unidirectional with volume fraction 60% under static loading. The young modulus were obtained by using relation of Eq 1.

$$E_{11} = \frac{\sigma_{11}}{\varepsilon_{11}} = \frac{F_1/A}{\varepsilon_{11}} \qquad (1)$$

Where $_{11}$ notation apply to longitudinal similar with tensile loading direction. Figure 2 shows contour of von misses stress experienced by RVE under tensile loading. Meanwhile Figure 3 and Figure 4 depict stress against strain plot under similar direction of tensile shown by RVE after tensile loading. Gradient computed for CFRP is 115329MPa and 36086MPa for GFRP of the plot represents young modulus of macroscale GFRP and CFRP which match very closely as 120GPa for CFRP and 30-45 GPa for GFRP respectively.

4. CONCLUSION

RVE models have been developed and simulated to study the homogenization of FRP at macroscale using commercial finite element software Abaqus. Method of RVE based on specific volume fraction proved successful in predicting mechanical properties of young modulus E1 and poisson ratio. Further work could include the shear as well as compressive properties of composite. The result also limited to unidirectional cases. Macroscale FEM on composite offer arrays potential of research work, from simple comparison of static loading deformation with analytical to predicting the strength and failure of composite during static loading. The feature of commercial software Abaqus have been explored and proven able to simulate real scenario and experimental with any composite layup and any orientation.

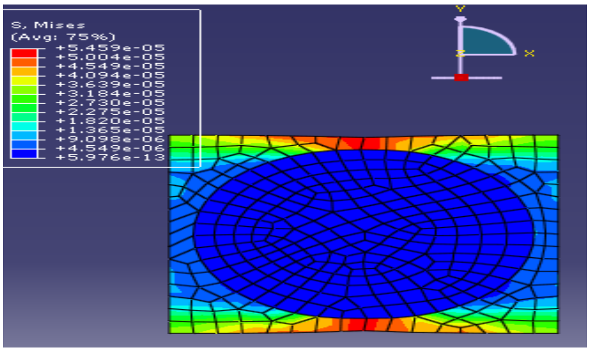

Figure 2 Stress, Von Misess Contour after longitudinal tensile loading of RVE GFRP.

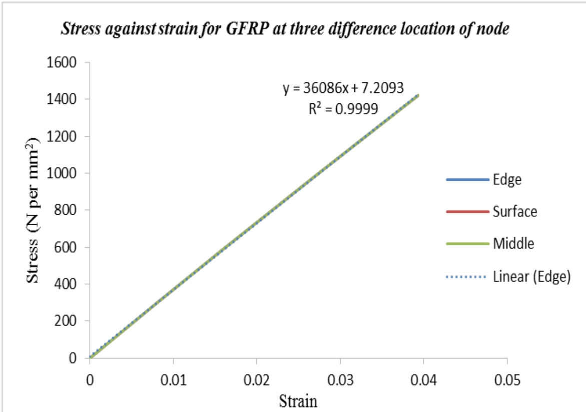

Figure 3 Stress against strain plot for GFRP model of RVE at 60 percent volume fraction.

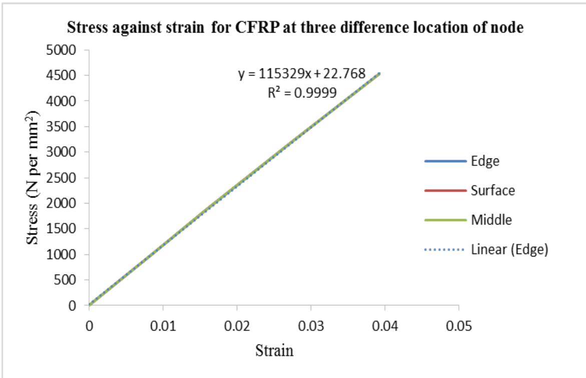

Figure 4 Stress against strain plot for CFRP model of RVE at 60 percent volume fraction.

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