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Tensile and Bending Analysis of Simplified 3D Woven Fabric Modelled with Finite Element Analysis

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ABSTRACT

This paper presented the modeling of simplified 3D woven fabric in tensile and bending behavior. The modeling technique used to simulate woven fabric using finite element analysis and incorporated with Abaqus software. 3D means that the woven fabric features in software having three dimensions which are horizontal, vertical, and depth (x, y, and z) dimensions. The simplified 3D woven fabric model is treated with various parameters on modulus and mesh size to study realistic stress-strain and force-displacement fields. Therefore, the important detailed FEA for modeling woven fabric requires setting geometric parameters such as dimension fabric structures, loads, pressure, boundary conditions to simulate the successful assumption on the mechanical performance of the fabric. The model is first used to simulate tensile and bending under various modulus. Each simulation shows the highest modulus give the higher stress and lowest strain for tensile simulation and higher force and lowest displacement for bending simulation. In a second step, different mesh size has been added to the model with the same modulus, show the smaller mesh size gives the accurate analysis. The prediction results of tensile and bending simulation presented in strain-stress and force-displacement curve, respectively based on modulus and mesh size.

Keywords: Finite element analysis; woven fabric; tensile behavior; bending behavior

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INTRODUCTION

In a recent development, textile material became the demand application that is widely used in the fashion industry and high-performance industry such as automotive, medicine, civil engineering, construction, and electrical due to their advantages on mechanical properties [1]. The study of tensile and bending are the common method to identify mechanical properties in textile materials. One of the difficulties to investigate fabric mechanical performance is due to the complex geometry of textile materials. For example, Shehzad et al. [2] studied the tensile behavior of fabric membrane structure. The research needs to understand the concept of fabric properties in order to observe and analyze tensile performance. Alam et al. [3] investigated the relationship between fiber, yarn, and fabric on bending properties. The study claims that the bending and shear rigidity of plain-woven fabric is mostly influenced by yarn count followed by fabric sett.

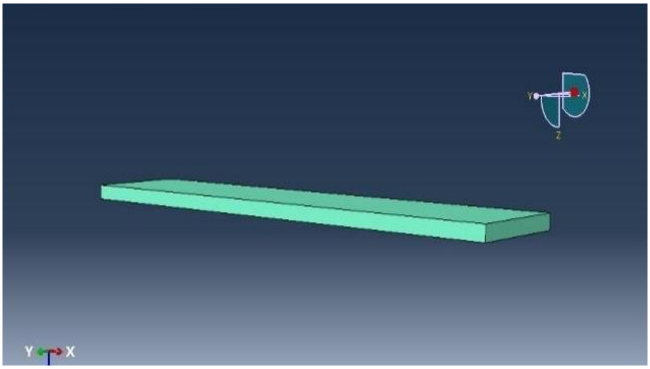
The finite element analysis (FEA) can provide the solution to this problem by successfully simulating the realistic model and analyzing various kinds of complicated textile structures [4]. The complex equation from physical testing would lead to inaccurate results of the analysis. Thus, the numerical approach of FEA has been widely used in the textile sector to overcome this issue.

Generally, numerical approaches [5] are more accurate than analytical analysis [6]. But solving process of numerical approaches can be time consuming and the user need to understand in detail CAD/CAE model and finite element methods. However, the model can be improved by generating simplified model geometry in the right way to show accurate results [6].

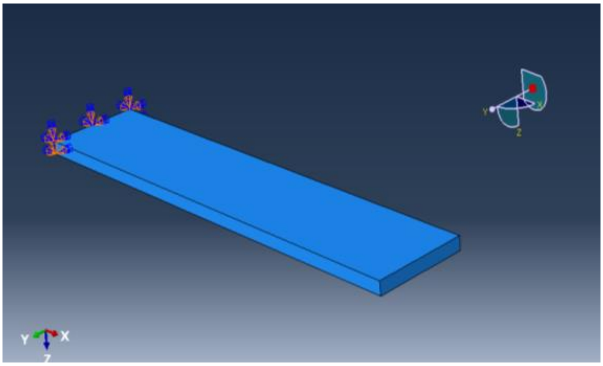
The objective of this research is to model, simulate and analyze the tensile and bending behavior of the 3D simplified woven fabric using finite element analysis. To achieve this objective, three dimensional (3D) simplified woven model was developed by using Abaqus software and FEA tools. The simulation is set up with the different values of modulus and mesh size to study the stress-strain value for tensile simulation and force-displacement for bending simulation.

METHODOLOGY

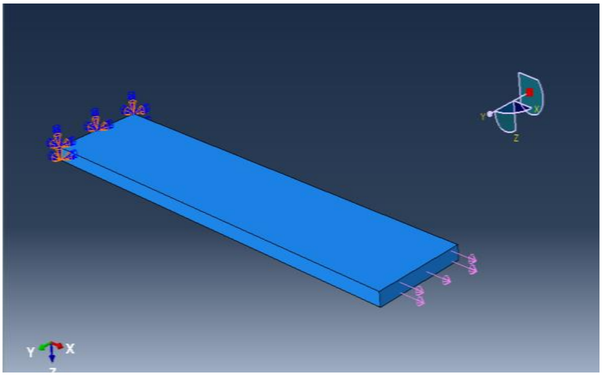
In this paper, the study of the mechanical behavior of simplified 3D woven fabric is demonstrated in finite element analysis (FEA). The coordination of woven fabric was set up in 3-dimensions to the x-direction, y-direction, and z-direction as shown in Figure 1. Woven fabric is produced by interlacing two sets of yarns, which are warp and weft yarns. Warp yarn runs in a lengthwise direction and needs to be prepared earlier in the weaving preparation process. Weft yarn is introduced in the weaving process and runs in a perpendicular direction to warp, which is often regarded as a width direction. Yarn interlacing in woven fabric depended upon weave structures and yarn linear density. For example, plain weave is the most interlaced extensive structure as yarns will have to move above and below its counterpart yarns. Additionally, with thicker yarn more thickness and space will be generated each time the yarn has to bend during the interlacing process. These have created complexities in establishing woven fabric models for finite element analysis (FEA) in terms of geometries and computation time. For this reason, the woven fabric model has been simplified as a rectangular 3D plate shape for FEA analysis.



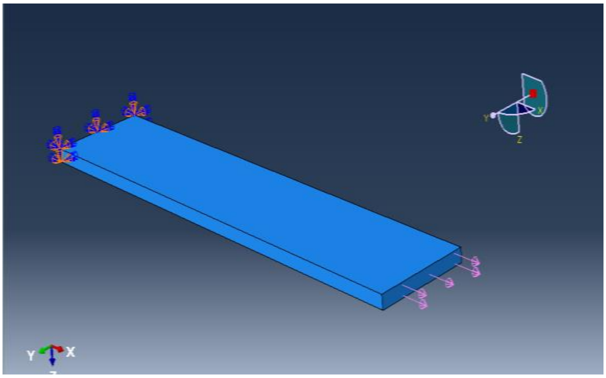
(a) The woven plate with material properties



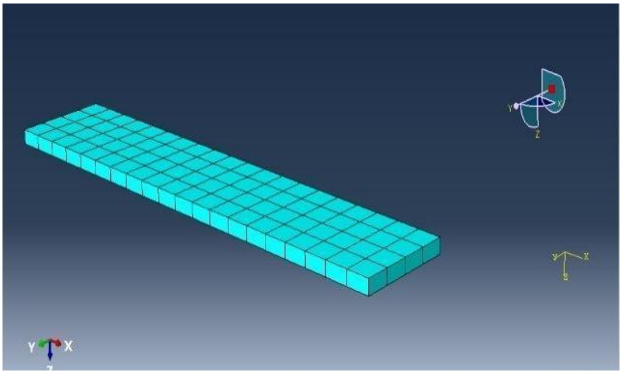
(b) Boundary condition on woven plate



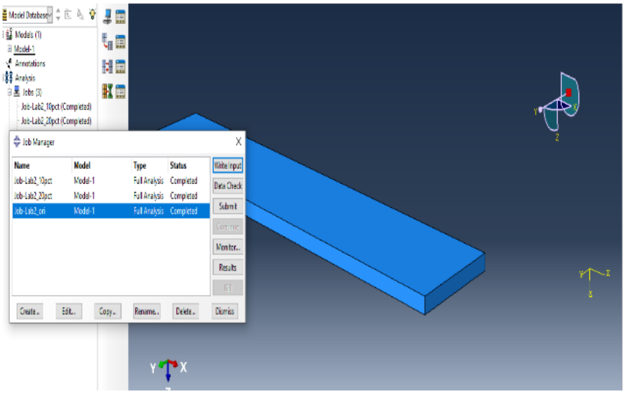
(c) The load on woven plate for tensile simulation



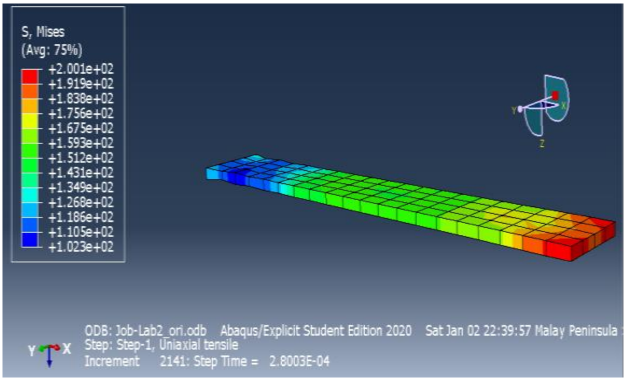
(d) The load on woven plate for bending simulation



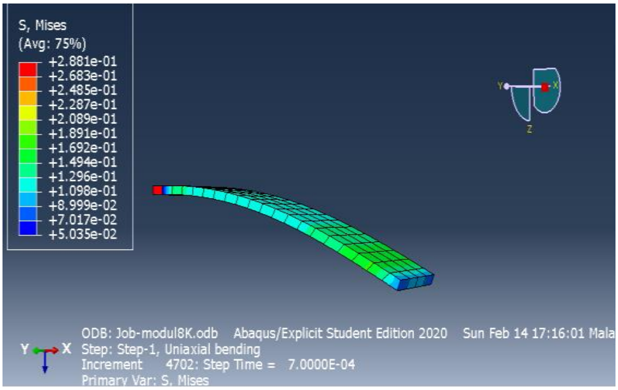
(e) Mesh process of woven plate



(f) Job process on woven plate



(g) Tensile simulation on woven plate



(h) Bending simulation on woven plate

Figure 1: Simulation of woven plate with finite element process

Tensile and bending simulations of 3D woven fabric models were illustrated in Figure 1 by using finite element analysis. FEA has an ability to simplify the complex geometry of woven fabric structures to the simplified 3D woven fabric model. Figure 1(a) shows the model dimension was 20 mm in length, 4 mm in width, and 0.5 mm in thickness. Fabric properties were enforced to the model plate and the details of the model is listed in Table 1.

Table 1: Fabric model construction particulars

Density	Material Property			
	Elastic		Plastic	
	Young Modulus(MPa)	Poison Ratio	Yield Stress	Plastic Strain
$1.41x10^{-9}$	10861	0.3	0.1	0
			200	0.1
			350	0.2
			420	0.3

The boundary condition was applied on the edge side of the plate as demonstrated in Figure 1(b). Boundary condition in FEA is necessary to constrain the model. The type of constraint was 'encastre' which gives the model plate constraint in the all x, y and z directions. Figure 1(c) shows a load of tensile simulation is set up in x-direction with an appropriate magnitude of 200 N, producing an outward force on a fabric model. Figure 1(d) presents the bending woven plate was applied with a load of 0.1 N on the partition part, producing force acting towards the woven plate. Figure 1(e) illustrates the next process which is mesh. In the meshing process, the model was broken up (discretize) into small elements. Each element was connected with the nodes to help in accurate calculation and results in analysis. The job was performed calculation in 'abaqus solver' as shown in Figure 1(f). The last process of FEA is the visualization process also known as post-processing. The visualization of tensile and bending simulation was demonstrated in Figure 1(g) and Figure 1(h), respectively. In this section, the simulation of woven fabric and computed results were displayed in the software.

Table 2 shows the model simulations were carried out from initial value of Young's modulus and has been reduced to 10 % and 20 %, respectively. The different modulus to allow comparison of stress-strain in tensile test and force-displacement in bending test. Table 3 shows the mesh size used for tensile analysis with 10861 MPa has been repeated with different seed sizes of 1.32 and 1.00, which were reduced to 20 % and 40 %, respectively.

Table 2: Young's modulus for tensile and bending simulation

Value	Young's modulus (MPa)
Initial	10861
Less than 10 %	9775
Less than 20 %	8689

Table 3: Mesh size for tensile simulation

Value	Seeding factor
Initial	1.65
Less than 20 %	1.32
Less than 40 %	1.00

The tensile and bending behavior of woven fabrics were performed using finite element analysis. Both simulations were set up with boundary condition to constraint the fabric and an appropriate load was applied to give force on a material. Finite element (FE) model was able to simulate the tensile test similar to the experimental testing where the fabric was pulled to its breaking point to measure the strength and elongation properties of textile material. Then, the analysis of tensile behavior was implemented with different mesh sizes based on a number of elements and nodes in FEA to have a comparison of the suitable mesh size for the analysis. The simulation results of stress-strain in the tensile were plotted in the graph to allow comparison between those parameters as shown in Figure 2 and Figure 3. The stress and strain relation comes from Hooke's law. Hooke's law can be defined as equation below:

$$\sigma = E\varepsilon \tag{1}$$

where σ is the stress (MPa), E is the Young's modulus (N/m²) and ε is the strain (m/m).

The strain value is calculated as follow:

$$\varepsilon = \frac{\Delta L}{L} \tag{2}$$

where ε is the strain, ΔL is the change in length (m) and L is the original length (m).

The next analysis was bending simulation in 3D woven fabric model. Bending simulation also successfully simulates physical stiffness testing where the fabric was bent under its own weight and then the bending length was measured. The result was displayed in force-displacement relationship as shown in Figure 4. Compared to tensile, the value of stress is not suitable used for bending properties. This is because force is external force and stress is generated from the force applied to a material. Therefore, the force value in bending was obtained from stress value by using the calculation as follow:

$$F = \sigma \times A \tag{3}$$

where F is the force per unit area (N), σ is the stress (MPa) and A is cross-sectional area (m^2).

RESULTS AND DISCUSSION

The test simulation was modeled in Abaqus software with FEA tools. Three simulations were prepared for each analysis. The young modulus and mesh sizes were varied as shown in Figure 2, Figure 3, and Figure 4.

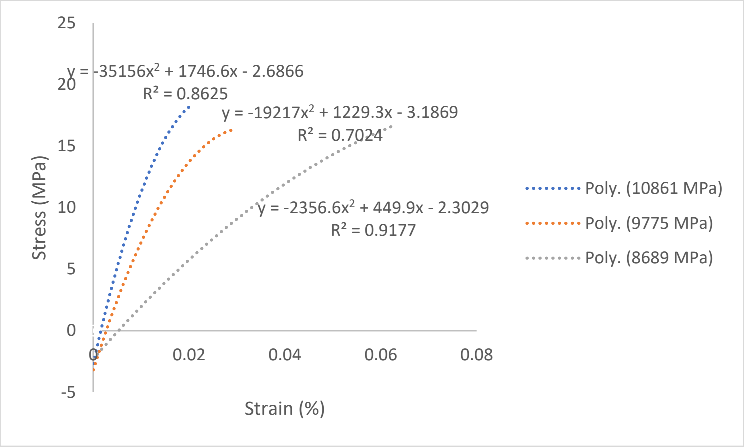


Figure 2: Strain-stress curve by the fiber modulus

Young's modulus is defined as the ability of the tensile stiffness of a material under tension. It can be used to measure the relationship between stress and strain. The investigation between stress and strain for different fiber modulus were plotted as shown in Figure 2. The model plate with a modulus of 10861 MPa was used as a standard sample for the simulation. The fiber modulus of 9775 MPa and 8689 MPa was reduced to 10 % and 20 %, respectively by referring to Table 1. From Figure 2, the variation in results of strain and stress were based on different modulus. In this case, the highest value of young modulus was obtained with the highest stress and lowest strain.

Based on strain-stress curve in Figure 2, the maximum height of the stress curve indicates the fabric with high modulus is more rigid and stiffer, resulting in small deformation on fabric and larger force to produce a given deformation [8]. For the lowest modulus show, the strain value is the higher than highest modulus due to the flexibility of a fabric to stretch more when material is pushed [9].

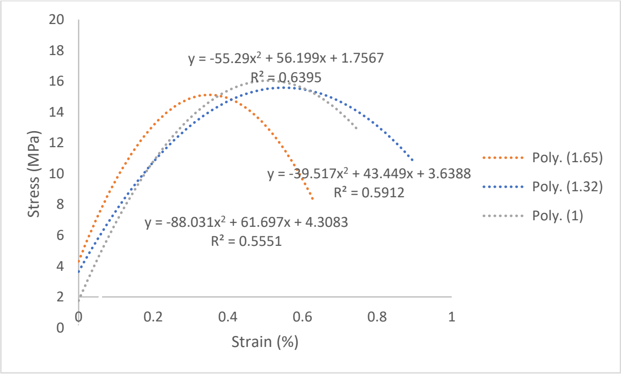


Figure 3: Strain-stress curve by the mesh size

In this analysis, the model plates were performed with the same modulus value but different mesh sizes by referring to Table 2. Figure 3 clearly shows the stress-strain value for different mesh sizes. For comparison, a mesh size of 1.65 was used as the standard sample. The decreasing mesh size for 1.32 and 1.00 was reduced by 20 % and 40 %, respectively from the original mesh size. It shows the model with the smallest mesh size gives the highest value of R-squared, where the data mostly fall on the regression line compared to a model with a bigger mesh size [10]. According to the theory of finite element analysis, the smaller mesh size will increase the number of elements and nodes, resulting in higher accuracy of results in analysis. Therefore, the mesh size in finite element analysis has a greater effect on the result's accuracy.

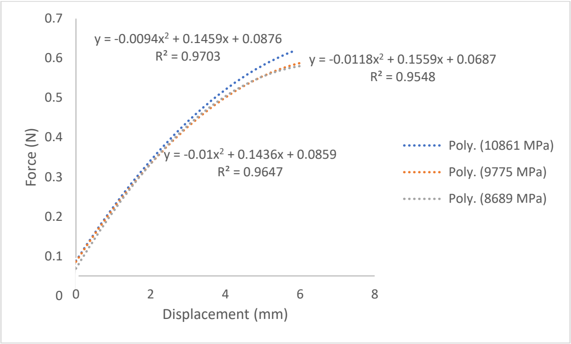


Figure 4: Force-displacement curve by the bending modulus

Figure 4 presents the bending behavior of the model simulation in force-displacement relations. In this analysis, the bending performance of woven fabrics were evaluated with 10861 MPa, 9775 MPa and, 8689 MPa based on Table 2. The value of force in bending simulation is calculated by equation 3. Based on equation 3, woven fabric with larger stress needs a stronger force to bend the fabric. It shows 10861 MPa with the highest modulus required larger force and the lowest displacement compared to another model. Therefore, the higher modulus results in higher stress at the same time larger force required in bending performance.

CONCLUSION

The finite element method is capable of providing a clear simulation of woven fabric for tensile and bending performance. The process is successfully achieved when the appropriate parameter and information related to textile for the analysis is given to the software system. Both results on stress-strain of tensile properties and force-displacement of bending are influenced by the change on modulus. Young modulus increment has resulted in higher stress to deform a material and lower strain value. FEA can minimize error on mechanical analysis by increasing the number of nodes and elements in a model. Additionally, the right selection of boundary conditions and load resulting in accurate mechanical analysis of the woven fabric. It is proved that FEA has an ability to study the mechanical behavior of various types of textile structures.

ACKNOWLEDGEMENT

The finite element analysis (FEA) software used in the work is Dassault Simulia Abaqus 2000's student version and available for students upon request. The software allows students to model realistic simulation and study various designs up to 1000 nodes. Abaqus student software is available for students to download at https://edu.3ds.com/en/software/abaqus-student-edition.

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