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Tensile Test Simulation for Polymer Composites

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***Abstract*—Composite is a new material that consists of matrix and fiber. It can be used for many purposes such as vehicle body material, storage material, and structural material. This study had a purpose to predict the tensile strength of a composite by simulation. The composites were made from waste such as polymer. There were three variations of polymer such as PET, HDPE, and LDPE. This specimen was modeled in three dimensions. It used ASTM tensile standard (ASTM-E646). The simulation used finite element analysis. The simulation results showed that the composite with PET fibers had the highest tensile strength 471.06 MPa and the lowest tensile strength of 430.75 MPa for the composite with LDPE. The simulation result also presented the stress and strain contour in the specimen surface. It had a purpose to know the position of stress distribution and strain distribution in the specimen surface. Based on the simulation result, the high stress and high strain were in the edge position of the specimen.**

Keywords—composite, waste, PET, HDPE, LDPE, strength, stress, strain.

I. INTRODUCTION

There are many kinds of waste such as polymer. It always increases every year. Many ways are done to recycle waste such as make new products for daily human needs. There are many problems if the product is made from waste. It is about quality. The product from waste is not recommended for products that need hygiene such as a product for human consumption and product for health. One solution to reduce waste is to make new material. It can be used for building material, vehicle body, storage tank. The material must have mechanical properties to know the ability of material according to its use. Some previous tensile simulation researches were needed to be references for this study. The simulation about the behavior of plain concrete by finite element modeling. The specimen was steel fiber reinforced concrete cylinder specimen. It concluded that the finite element results relative same with experimental investigation results [1].

Ansys was used for analysis and validation of mechanical properties of various composite materials of Low-Density Polyethylene research. The result showed that Low-Density Polyethylene had more branching in structure. It had lower tensile strength and higher resilience [2].

Finite Element Analysis of metal, composite, and hybrid materials used software Ansys. It used the thermal method and ply-orientation. It concluded that the influence of thermal-based work on the body of a specimen. It was very influential towards the result of stress-strain in the specimen and ply-orientation was very influential towards the value of the stress and strain as well as the strength of these materials [3].

The research about design and analysis of carbon fiber composite mono crack arm with three conceptual models of Heavy-Duty Rack (HRV) mono crack arm had done. It concluded that mono crack arm with epoxy carbon of plain weave woven fabric was the ideal choice with a total deformation of 0.028712 mm at maximum, minimum equivalent stress of 0.00026972 MPa, and safety factor of 156.42 at minimum [4].

Other tensile simulation researches were done to predict tensile strength and contour of tensile stress [5-7]. An experimental on a specimen of tensile behavior for hybrid and non-hybrid polymer composite at elevated temperature was an experiment for discovering behavior between hybrid and non-hybrid polymer composite when the temperature of these composite was elevating. Specimens used in this experiment are carbon specimens, glass specimens, and hybrid carbon-glass specimens. The analyzing method that used in this experiment was Finite Element Analysis (FEA) for computational analysis. It resulted that the hybrid specimens had better result from other non-hybrid specimens for design because it had the least heat flow and weight loss but better damping properties at elevated temperatures [8] and other research about tensile test for polymer also had done by simulation [9].

The experiment was used for analysis Glass and Jute fiber behavior in use for composite. Reinforced experiment composite is testing experimentally and using Ansys software. Four specimens were used for testing is Pure epoxy (P.E), glass fiber reinforced epoxy composite (GFREC), Jute Reinforced Composite (JRC), and Hybrid composite. The result of the experiment test revealed that tensile strength and mechanical strength are greatly influenced the mechanical properties by fiber content. The effect of mixing jute fiber with mechanical properties of glass fiber reinforced epoxy composite in the right amount can increase the overall strength of the synthetic fiber-reinforced composite. Finite element analysis of glass fiber reinforced epoxy composite had generated detailed quantitative data about composite failure morphology [10].

Generally, composite fibers consist of carbon, fiberglass, and organic material such as coconut fiber, banana fiber. Meanwhile, this study tried to use waste as fibers such as plastic. It was called a polymer. This study wants to predict and to compare mechanical properties especially tensile strength for polymer composite. In this study, there is three various fibers from polymer. The polymers were Polyethylene terephthalate (PET), High-density polyethylene terephthalate (HDPE), and Low-density polyethylene terephthalate (LDPE). This study results are tensile strength, stress distribution, strain distribution. Based on the results, it is hoped the new material can be classified according to ability material to hold tensile force. This study was done by simulation with three dimensions modeling. For the study of composite material tensile strength, Finite element analysis (FEA) has been established as a reliable predictor and has a high degree of accuracy. This research is expected to contribute to be used as a reference in performing tensile testing simulations.

II. Ease of Use

A. Stress

Stress is the reaction that arises in all parts of a specimen to withstand the load given. If the small number is added to reach the cross-section of the specimen, then the sum of the broad union forces that appear within the material must be the same as the outside load.

The unit of force used in the translation of stress is the unit of force divided by area. In SI units, force is measured in Newton (N) and the area is measured in units of square meters (m^2). Usually, 1 N/m^2 is known as 1 Pascal (Pa).

Mathematically the concept of Stress is written:

$$\sigma = \frac{F}{A} \qquad (1)$$

where:

σ = Stress (Nm^{-2})
F = pressure / pull (N)
A = Cross-sectional area (m^2)

B. Strain

Stretch or Pull is the quotient between increasing Length (ΔL) and initial length (L_o). Space or pull is denoted by (e) and space has no unit or dimension because the lengths of ΔL and L_o are the same.

Mathematically the concept of strain is written:

$$e = \frac{\Delta L}{L_o} \qquad (2)$$

where:

ΔL= increase in object length (m)
L_o = long at first (m)
e = strain

III. Methods

A. Specimen Geometry

The specimen used ASTM tensile standard (ASTM-E646) as a geometry standard. It can be seen in Figure 1. It had 200 mm in length, 20 mm in width, and 4 mm in thickness. Fig. 2 showed the position of specimen in tensile test machine. Based on Figure 2, the working principle of tensile test is tensile force application. The test object is clamped at both edges then a tensile force is applied in one position in an upward direction as shown and on the other edge, the condition is stationary or fixed support. The specimen condition after the tensile test can be seen in Figure 3.

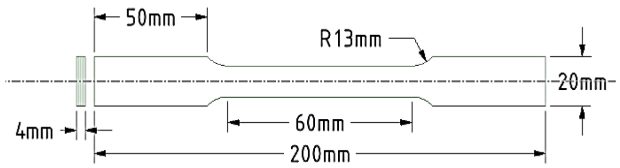


Fig. 1. Specimen geometry.

Fig. 2. Tensile test machine.

Fig. 3. Tensile test specimens.

The specimen was formed from several layers of material consisting of matrix and reinforcing fibers. The specimen condition before and after tensile test can be seen in Figure. 3. Based on Fig. 3, the specimen after tensile test had more length than before test. It was called by elongation. In tensile test procedure to know the elongation, the specimen initial length had to be measured before test then the specimen after test also measured. The elongation could be calculated based on the difference of specimen length. It is important to determine tensile strength of material.

B. *Specimen Properties*

The material properties were needed for simulation. The properties can be seen in Table I for PET, Table II for HDPE, Table III for LDPE, and Table IV for Resin.

TABLE I. PROPERTIES OF POLYETHYLENE TEREPHTHALATE (PET) FIBERS

Density	1.31 gr/cm^3
Young's Modulus	2700 MPa
Poisson's Ratio	0.4
Tensile Yield Strength	54 MPa
Tensile Ultimate Strength	55 MPa

TABLE II. PROPERTIES OF HIGH-DENSITY POLYETHYLENE TEREPHTHALATE (HDPE) FIBERS

Density	0.95 gr/cm^3
Young's Modulus	900 Mpa
Poisson's Ratio	0.46
Tensile Yield Strength	27 Mpa
Tensile Ultimate Strength	31 Mpa

TABLE III. PROPERTIES OF LOW-DENSITY POLYETHYLENE TEREPHTHALATE (LDPE) FIBERS

Density	0.91 gr/cm^3
Young's Modulus	450 MPa
Poisson's Ratio	0.32
Tensile Yield Strength	16 MPa
Tensile Ultimate Strength	32 MPa

TABLE IV. PROPERTIES OF RESINE EPOXY

Density	1,16 gr/cm^3
Young's Modulus	3780 MPa
Poisson's Ratio	0.35
Tensile Yield Strength	70 MPa
Tensile Ultimate Strength	70 MPa

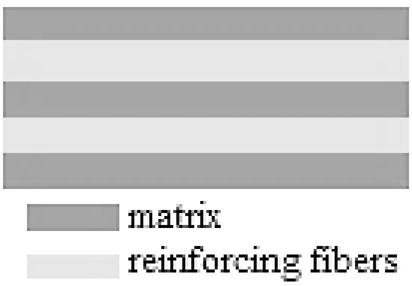


Fig. 4. Specimen layers.

In this simulation, the composite was made from five layers. The layering model fiber and resin for modeling is showed in Fig. 4. There are five layers, the matrix is in the first, third, and fifth layers. The reinforce fibers were PET, HDPE, and LDPE. It was in the second and fourth layers.

C. *Meshing*

The mesh geometry used hexahedron structured mesh consists of 11440 nodes and 5150 elements. It is showed in Figure 5.

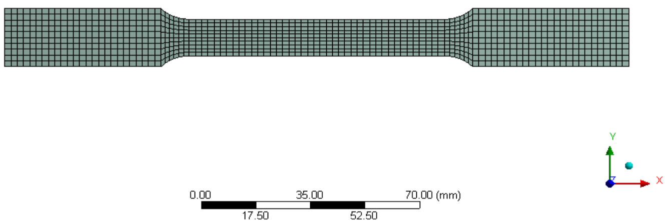


Fig. 5. Meshing.

D. *Parameter Setting*

The specimen was located in plane x-y, which was extruded along the z-direction. The simulation set up in this paper used the finite element analysis to estimate tensile strength of composite material. This simulation used node displacement method to represent tensile force that had been explained based on tensile test procedure. Fig. 6 shows selecting setting and specimen direction. The nodes at section A of the specimen set as fixed support nodes and nodes at section B set as displacement nodes which move to the x-positive direction. The contact surface between the solid body was arranged as a bonded contact region. The time step was 0.0001 seconds.

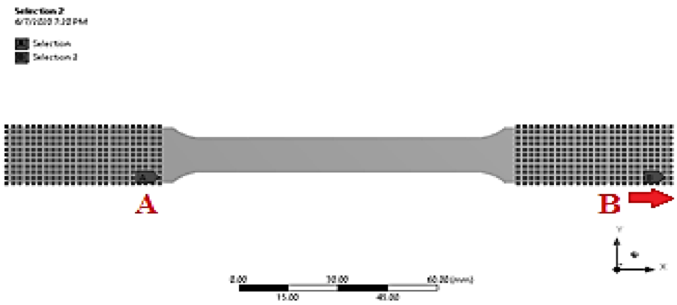


Fig. 6. Selection setting.

IV. RESULTS AND DISCUSSION

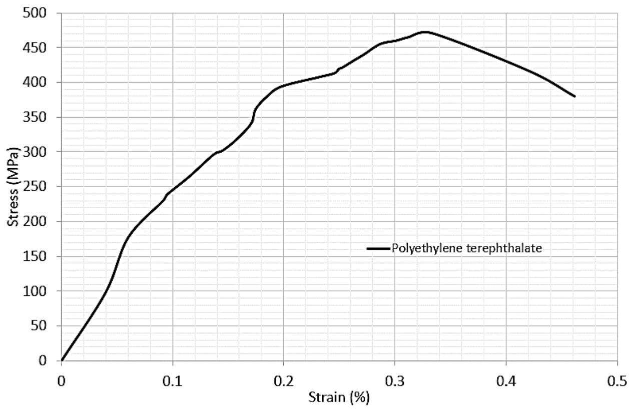
A. *Stress and Strain Graph*

This section will discuss the tensile test graph. It can be seen in Figure 7. Based on the figure, the composite tensile strength can be known for three composites. Figure 7(a) shows a tensile graph for epoxy resin composite reinforced polyethylene terephthalate (PET). It shows elastic deformation occurred up to the point of stress value around 379.48 MPa and strain value 0,184 %. The composite material underwent plastic deformation until it reached a maximum stress value of 471.06 MPa and maximum strain value at 0.461 %.

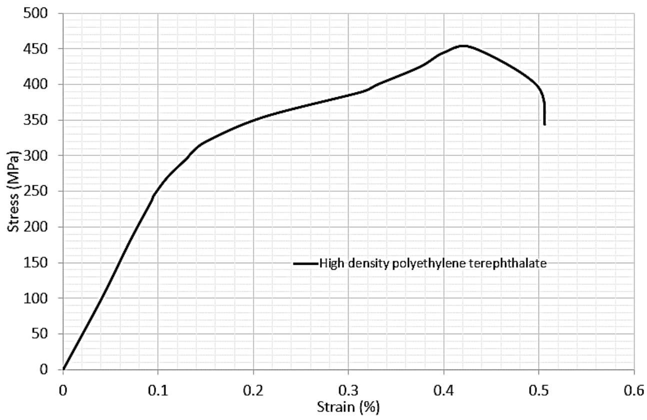
Figure 7(b) shows a tensile graph for epoxy resin composite reinforced high-density polyethylene terephthalate (HDPE). It shows elastic deformation occurred up to the point of stress value around 322.15 MPa and strain value 0.156 %. The composite material underwent plastic deformation until it reached a maximum stress value of 452.1 MPa and maximum strain value at 0.506 %.

Figure 7(c) shows a tensile graph for epoxy resin composite reinforced low-density polyethylene terephthalate (LDPE). It shows elastic deformation occurred up to the point of stress value around 389.76 MPa and strain value 0.243 %. The composite material underwent plastic deformation until it reached a maximum stress value of 430.75 MPa and maximum strain value at 0.796%.

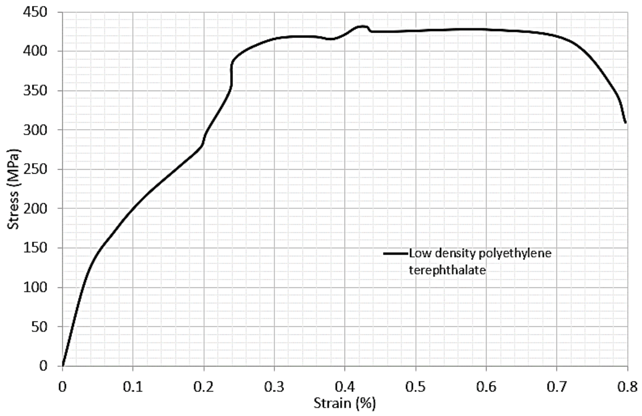
Based on the explanation of three tensile graphs, it could be concluded that composite material that had the greatest tensile strength was PET composite with a maximum stress value of 471.06 MPa and a maximum strain value of 0.461 %. The composite material which had the lowest tensile strength was LDPE composite with a maximum stress value of 430.75 MPa and a maximum strain value of 0.796%.



(a)



(b)

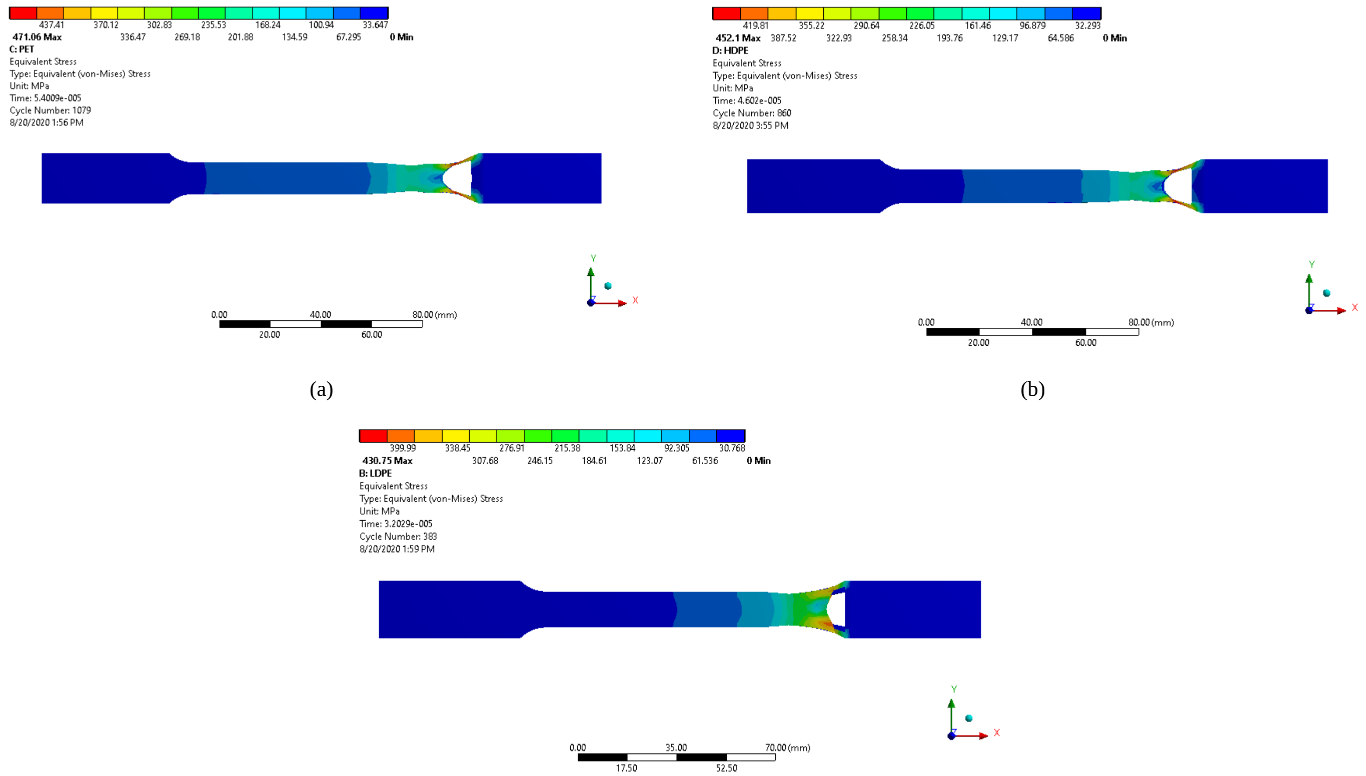


(c)

Fig. 7. Stress-Strain graph for various epoxy resin composite reinforcing fibers. (a) polyethylene terephthalate (PET), (b) high-density polyethylene terephthalate (HDPE), (c) low-density polyethylene terephthalate (LDPE).

B. Stress Contour

Figure 8 shows stress contours for various reinforcing materials. The stress contours or stress distributions were plotted at maximum stress. The color difference shows the difference in the value of the stress that occurred in the specimen. The greatest stress concentration was found at the base of the reduction section that was pulled to the x-positive direction. It is due to the change in the shape of the geometry from the reduction section to the grip section which causes accumulated pressure. Fig. 8 also shows the influence of varying composite reinforcing materials on maximum stress value. Based on the figures, the maximum stress value obtained in each reinforcement material showed different values.



(a) (b) (c)

Fig. 8. Stress contour of composite specimen for various reinforcing materials (a) polyethylene terephthalate (PET), (b) high-density polyethylene terephthalate (HDPE), (c) low-density polyethylene terephthalate (LDPE).

Figure 8(a) shows stress distribution for epoxy resin composite reinforced polyethylene terephthalate (PET) fibers. The stress concentration position was in the right edge position. It was in the moving area or point B in Figure 6. It was marked in yellow color. The phenomenon was same as experimental result if the displacement was given continuously, the material would be broken as in Figure 2. It usually happened due to the composite material was brittle. It also happened in Figure 8(b) for stress distribution in the epoxy resin composite reinforced high-density polyethylene terephthalate (HDPE) fibers surface and Figure 8(c) for stress distribution in the epoxy resin composite reinforced low-density polyethylene terephthalate (LDPE) fibers.

C. Strain Contour

Figure 9 shows the contours of strain for various reinforcing materials. The strain contours or strain distributions were plotted at the maximum strain. The color difference shows the difference in the value of the stress that occurs in the specimen. The maximum strain occurs when the composite materials were broken, the fracture in the specimens were located at the location with the highest stress concentration.

Figure 9(a) shows strain distribution for epoxy resin composite reinforced polyethylene terephthalate (PET). The strain concentration position was in edge position. It was signed by a yellow color. The phenomenon was the same as the experimental result in Figure 2 after the material was broken. It usually happened due to the composite material was brittle. It also happened in Figure 9(c) for strain distribution in the epoxy resin composite reinforced low-density polyethylene terephthalate (LDPE) fibers. But in Figure 9(b), strain distribution was different for epoxy resin composite reinforced high-density polyethylene terephthalate (HDPE) surface. It was because the composite had high elastic deformation. It would be occurred around 270 MPa as in Figure 7(b).

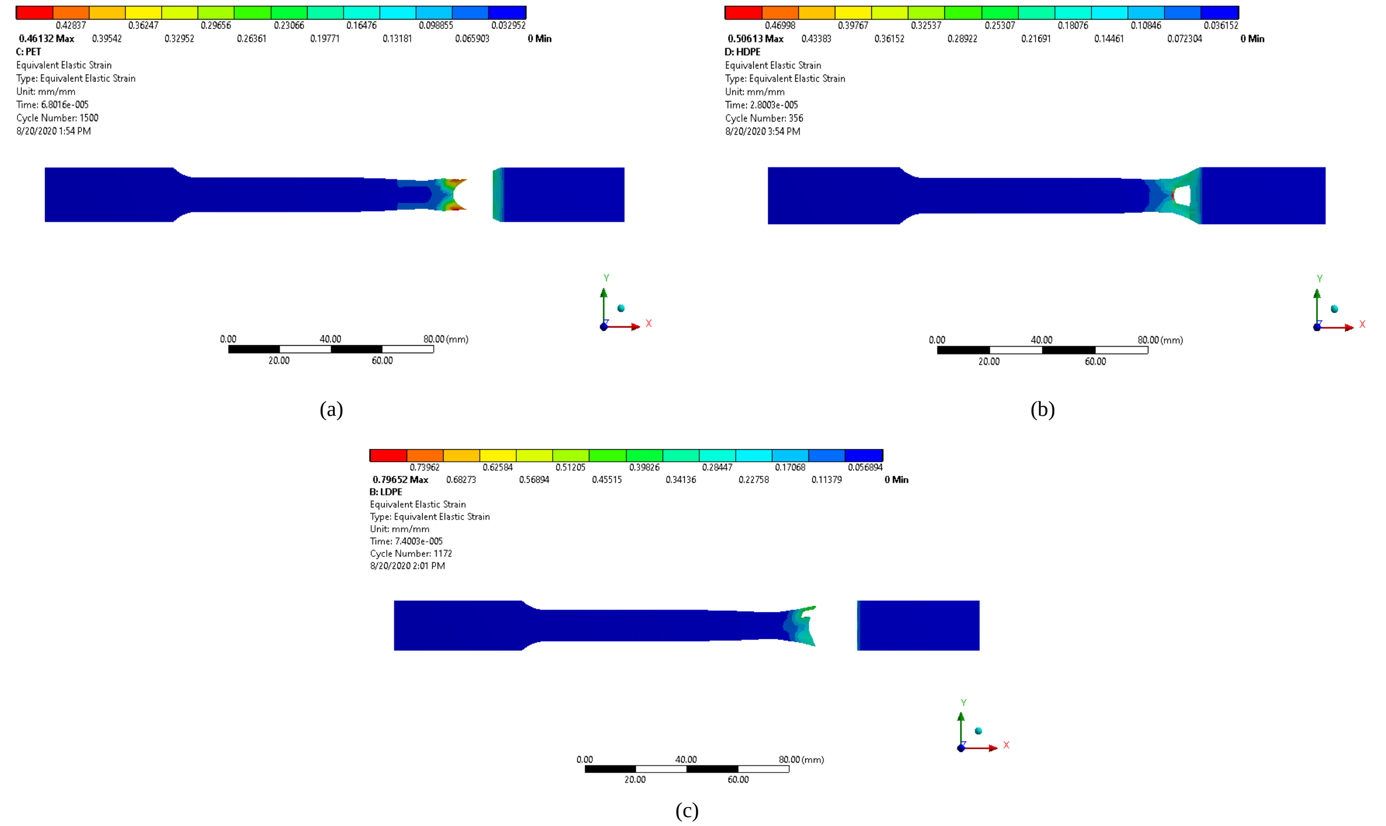


Fig. 9. Strain contour of composite specimen for various reinforcing materials (a) polyethylene terephthalate (PET), (b) high-density polyethylene terephthalate (HDPE), (c) low-density polyethylene terephthalate (LDPE).

The simulation setting can be used as recommendation for a tensile test simulation method especially setting cracking position in edge position. It due to the crack position usually happened in actual condition or experiment for composite material. The result also near to material properties in real condition.

V. Conclusion

The composite with PET fibers had the highest tensile strength 471.06 MPa and the lowest tensile strength 430.75 MPa for the composite with low-density polyethylene terephthalate (LDPE) fibers. The simulation result also presented the stress and strain contour in the specimen surface. It had purpose to know the position of stress distribution and strain distribution in the specimen surface. Based on the simulation result, the high stress and high strain were in the edge position of specimen.

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