The Effect of Thermal Perturbation on a Polymer Material's Tensile Test via Simulation and Experimental Analysis

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***Abstract*— Polymers are made from pieces of monomer that can be connected into a long chain. Natural rubber is studied in this research. In this research, tensile testing was conducted to the rubber specimen in order to check the heat release from the specimen. A thermocouple device was used to measure the specimen's temperature during tensile testing. The data from the tensile test were used to generate the stress vs strain curve. Computer simulation study was also performed. The results show that the temperature reading from the thermocouple device has increased to prove that there was a heat release from the tensile test. The heat was detected after the specimen's fracture. The simulation test proved the same phenomena as the experimental test.**

***Index Terms*—Tensile Test; Simulation Analysis; Polymer Material; Thermal Perturbation.**

I. INTRODUCTION

The manufacturing industry has increased interest to use polymer for their product due to their low density, inherent high-temperature resistance and ease of fabrication. These characteristics also prefer that polymer composites have an expressive potential as materials in high-temperature structures. Nevertheless, there is normally a mutual concern around the durability of polymeric materials, partly because of their maintenance, replacement and useful life. These material deteriorations depend upon the duration and the intensity of interaction within the environment.

Energy saving is the primary reason for the trend of replacing metal parts by polymers. Generally, the density of metals is higher than the density of polymers. So that, in comparison with a certain amount of fuel, the cars with polymer parts can travel more distances than a standard car with mostly metal parts.

Nowadays, the most widely applied and the simplest measure to check material dependent property is by tensile testing. By stretching a material, the result of the experiment can be determined immediately. The results can be used by engineers and designers to predict materials and products for their project or application to the highest caliber. Tensile testing can be valued in many performance parameters.

Figure 1: 300kN AUTOGRAPH Shimadzu AG-IS MS series Universal Testing Machine

In our daily life, we use so many polymer materials. For example, clothes hanger that we use, are always placed under hot sunny day. We noticed that after a few years, the hanger will be easy to bend and fracture. It is often evident that the mechanical character of a solid polymer is altered greatly by changes of temperature as small as a few degrees [1].

Tensile test is important for designers and engineers to make sure that the material used in their work is suitable for their projects. Higher temperatures will respond badly as a result of a tensile test. If the result is bad, their projects will face problems.

The main objective of this present study is to study and analyze the effect of thermal perturbation on the mechanical strength of polymer material by tensile test. On the other hand, this research is conducted to study whether the heat release during the process will give any effect to the mechanical properties of the specimen. Skill in processing and analyzing the data and results from the test is required.

The work will be analyzed in simulation test of thermal and mechanical properties of polymer material via ANSYS software. The data will be collected and studied to compare the experimental and simulation part of the polymer material's tensile test.

II. METHODS

A. Experimental

a. Universal Testing Machine

The 300kN AUTOGRAPH Shimadzu AG-IS MS series Universal Testing Machine is connected to a personal computer. To control the machine and tabulate the data from the experiment, the Trapezium 2 software is associated with the machine. The machine also provides high body rigidity, loading speed and reliability in force measurement in order to perform material strength measurement. Additionally, the machine can sustain to a maximum load of 300kN. The Trapezium 2 software is used to control the Universal Testing Machine. It can also generate or plot graph during experiment. A universal testing machine equipped with a specially made electrical furnace heated by thermal rays was used for elevated temperature in tensile test, and a hydraulic actuator was used to apply a tension load to specimens [3].

b. Thermocouple Device

The test temperature in the furnace and of the specimen must be accurately controlled due to the typically strong temperature dependence of tensile ductility. For this reason, the thermometers are attached to the surface of the specimen using thermometer tips. This ensures precise temperature control and uniformity on the specimen.

c. Specimen

The test specimens used in this experiment are polymer sheet. Column specimens were cut into dog bone shape. Dog bone tensile test samples are primarily used in tensile tests. The sample has a shoulder at each end and a gauge section in between [2].

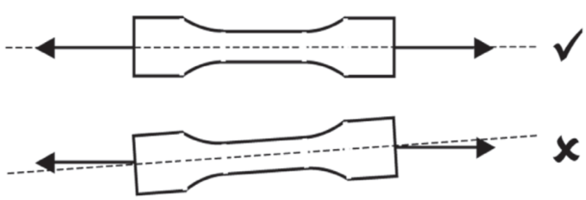

Figure 2: ASTM D412 dog bone shape use for the dimension of specimen [4] (ADMET, 2010)

B. Experimental Procedure

a. Tensile Test

Tensile testing is also known as tension testing [5]. The gap between the upper jaw and lower jaw of the Universal Testing Machine were adjusted. Cross head speed of the universal testing machine was set to a defined value. The sample was clipped tightly in between the jaws. The test was started. The upper jaw proceeds to move upwards at the defined rate. When failure occurred, the results and stress-strain graph are automatically plotted. Return button of the machine was pressed to allow the upper jaw to return to its original position. Properties that are directly measured via tensile test are ultimate tensile strength, maximum elongation and reduction in area [6].

b. Temperature Measurement during Tensile Testing

The test apparatuses were set up for temperature measurement test. The thermocouple wire must be attached to the specimen. The set points have been set on a center line where maximum heat concentration will be released. The purpose of defining these points was to set a reference point where temperature readings were taken.

After that, the experiment was started. The temperature reading was at room temperature initially, and the change of the temperature reading was recorded during the experiment.

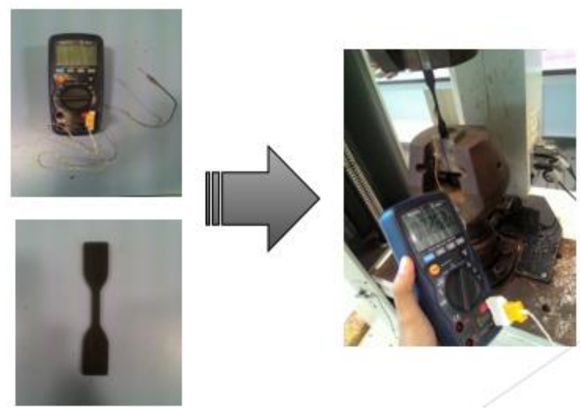

Figure 3: Preparation to conduct the experimental

C. Simulation

The design of the model applied the rubber and thermoplastic Elastomers ASTM D412 dog bone standards. The material applied to the model is rubber.

The data of the experiment was used for the simulation. The applied simulations were static structural and transient thermal.

a. Solidworks

The SolidWorks software was used to model the sample. The drawing applied the dimension of the rubber and thermoplastic Elastomers ASTM D412 dog bone standards. For the experimental specimen, 3 mm thickness was used.

b. Ansys

The ANSYS software was used to do finite-element analysis of the sample. It can perform thermal and strength analysis. Static structural testing was performed. In this test, the designed specimen from Solidwork was imported and transferred to ANSYS. Then, the material (rubber) was applied to the specimen. After that, the value of the force of the fixed support was set. The stress value, deformation, and strain were obtained after the simulation.

The transient thermal was used for another simulation. It applied the same step as the static structural testing. The value for the initial temperature and the heat convection were set to find the result of the final temperature.

III. Results and Discussion

A. Experimental

For the first experiment, Figure 4 shows that from the strain value 0.03 until 0.53, there is the elastic region. After that, the curve from 0.53 to 0.68 is the offset yield strength. At this point, the curve begun to bend over. So, it can be called as maximum stress. The shape of the specimen changed obviously at this point. Lastly, the stress value dropped drastically downward due to the fracture of the rubber specimen. The Figure 5 shows that at the initial point, the value of the thermocouple was 26.6ºC and the final value, which is after the fracture of rubber specimen was 26.7ºC. There were just 0.1ºC of temperature increases.

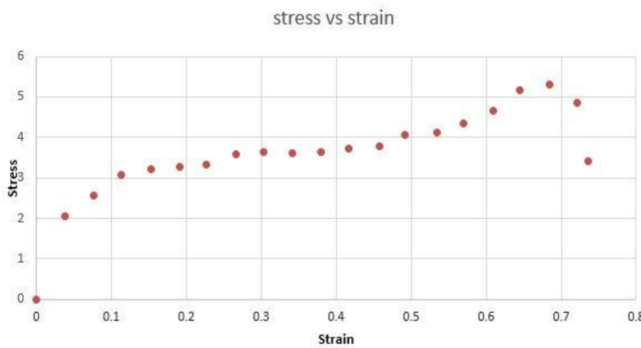

Figure 4: Experiment 1: Stress vs Strain graph

Figure 5: The temperature reading for Experiment 1

For the second experiment, Figure 6 shows that from the strain value 0.03 until 0.64, there is the elastic region. After that, the curve from 0.64 to 0.79 is the offset yield strength. At this point, the curve begun to bend over. So, it can be called as maximum stress. The shape of the specimen changed obviously at this point. Lastly, the stress value dropped drastically downward due to the fracture of the rubber specimen. The Figure 7 shows that at the initial point, the value of thermocouple was 27.2ºC and the final value, which is after the fracture of rubber specimen was 27.3ºC. There were just 0.1 º C temperature increases.

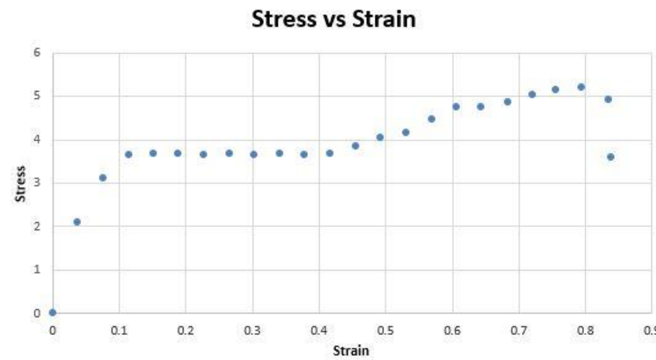

Figure 6: Experiment 2: Stress vs Strain graph

Figure 7: The temperature reading for Experiment 2

For the third experiment, Figure 8 shows that from the strain value 0.03 until 0.495, there is the elastic region. After that, the curve from 0.495 to 0.646 is the offset yield strength. At this point, the curve has begun to bend over. So, it can be called as maximum stress. The shape of the specimen changed obviously at this point. Then, the stress value from 0.646 until 0.684 shows that the stress was maintained first before the value dropped drastically downward due to the fracture of the rubber specimen. The Figure 9 shows that at the initial point, the value of the thermocouple was 27.0ºC and the final value, which is after the fracture of rubber specimen was 27.1ºC. There were just 0.1 º C temperature increases.

The differences of the data value can obviously be observed between these three experiments. However, the pattern of the three graphs is same. From these three experiments, all of them showed that the temperature increased 0.1ºC. There was not too much heat released from the rubber specimen because it is just a small specimen.

The data value may be different due to the little damage of the specimen or the surrounding environment. Both can affect the experiment.

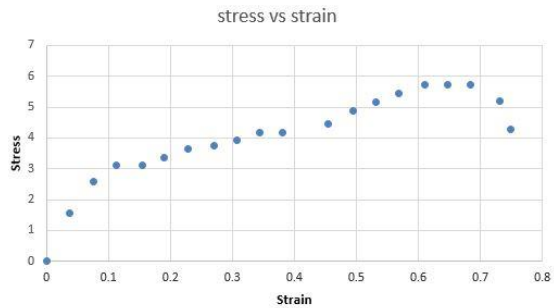

Figure 8: Experiment 3: Stress vs Strain graph

Figure 9: The temperature reading for experiment 3

B. Simulation

Results were obtained from the simulation test. For example, the stress, strain, deformation and also the thermal effect test were simulated. The meshing for this simulation test was 0. 5mm.

a. Stress

Figure 10 and Figure 11 show the simulation of the stress test. The figure shows clearly that the maximum stress was 6.4955 MPa. Maximum stress occurred at the edge of the specimen, between the larger and smaller part of the specimen.

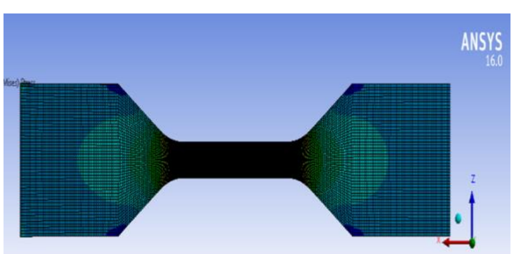

Figure 10: Result for stress simulation

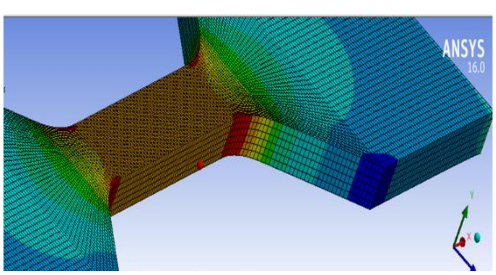

Figure 11: Side view of the model in stress simulation

b. Strain

Figure 12 and Figure 13 show the simulation of the strain test. The figure shows clearly that the maximum strain was 1.2991. Maximum strain occurred at the edge between the bigger and smaller part of the specimen.

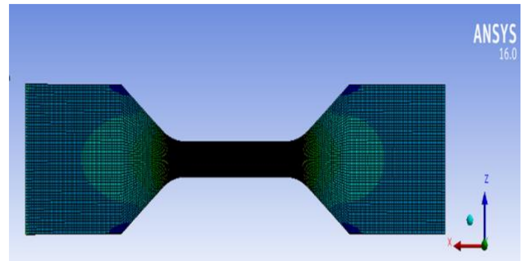

Figure 12: Result for strain simulation

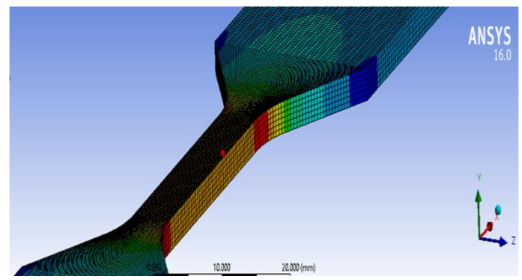

Figure 13: The side of result of strain simulation

c. Thermal

Figure 14 shows the initial temperature of the specimen before the test, which was 22ºC. Figure 15 shows the result of the thermal simulation. By comparing it to Figure 14, a part of the specimen has released some heat. Only a small amount of heat was released. Most heat releases were concentrated at the middle part of the model.

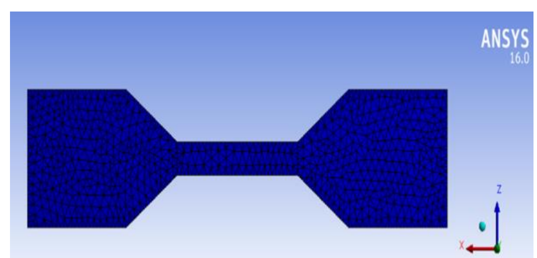

Figure 14: Initial temperature of the model

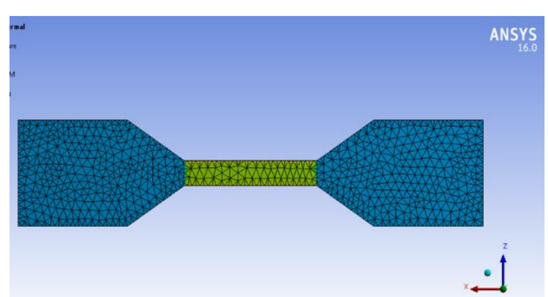

Figure 15: The result for thermal simulation

C. Comparison between experimental and simulation results

Experiment 3 shows the highest stress among the three experiments which is 5.7 MPa while for the highest strain was the experiment 2 which is 0.838. While for the simulation, the maximum stress was 6.4955 MPa, and the maximum strain was 1.2991. There was a big difference between experiment and simulation results. This occurred due to the rubber specimen and the surrounding environment. The lifetime of the product is also unknown. So, the properties of the rubber may have decreased. Besides, the cutting method to obtain the specimen's shape can also affect the results.

In experimental test, the results show that the temperature increases of all experiments was 0.1ºC, while in the simulation test, the temperature increases was 0.145ºC. There was just a small difference between these two values.

IV. CONCLUSION

The results of the experimental and simulation test were analyzed. The result shows that the experimental test gives smaller stress and strain compared to the simulation test. Before conducting the experiment, many aspects need to be counted in. The quality of the specimen must be checked first to make sure that the properties of the specimen was in good condition. Furthermore, the heat distributions during the tensile test are discussed and compare for both experimental and simulation test. There was just a small difference. The surrounding environment such as temperature, may affect thermocouple reading. As a result of this experiment, it is proven that thermal perturbation affects a polymer material's tensile test. However, some improvements can be taken for future research. The recommendations and suggestions for improvements are listed as follows;

1. During the tensile test, a plastic cover should be provided to the specimen. This is to avoid the surrounding environment affect the result. The component's wiring needs to be simplified.
2. Friction between the thermocouple sensor and the specimen may occur. To overcome this problem, another apparatus need to be used. For example, a thermal camera can be used.

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