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Compressive Load Effect on Electrical Properties of Carbon Composite

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Abstract

Contrary to its name, the "lead" in pencil is predominately made up of combination of graphite and clay or polymer, hence it can be considered as carbon composite. It has been proven that the more amount of carbon, the greater Young Modulus will increase and vice versa. Some researches on electric property of carbon composite also have shown that pencil drawn can be treated as a strain gauges and chemiresistors on paper. It means that in pencil's lead, the mechanical and electrical properties are related to one another. In this study, we applied a compressive load on pencil's lead and measured the effect on its resistivity. The results show that the resistivity will decrease while the strain will increase.

Keywords: Carbon composite, Experiment, Resistance, Stress, Strain

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1. Introduction

Carbon is the fifth most abundant element in this world. It has several Allotropes, and one of them is graphene. Over the recent years, graphene has been investigated for applications in microelectronic. And due to their low specific resistivity, graphene is used for applications in interconnects as well [1]. Several graphene layers which stacked with each other are called Graphite and used in many Carbon Composites. Composite is a material that consists of two different materials, and it is made to create a material with unique properties that are lighter and stronger. In this paper, we used mechanical pencil lead as a carbon-composite which consists of graphite, polymer, and clays as matrix.

Pencil is chosen because many paper-based electronics devices, such as ultraviolet sensors, solar cells, and energy storage devices also use this item. Their potential to produce a flexible, thin, low-cost, portable, and environmental-friendly product makes paper-based electronics are more advantageous. Furthermore, the research on Pencil drawn shows that Pencil traces can be regarded as conductive thin films and mainly used as passive conductive in many devices, such as resistors, transistors, UV sensors, and many more. Pencil traces are also relatively stable against moisture, chemicals, and UV irradiation [2]. Seeing that pencil has so many utilities, we are interested to do some research related to the relation between mechanical and electronics properties for each type of carbon composite used in pencil.

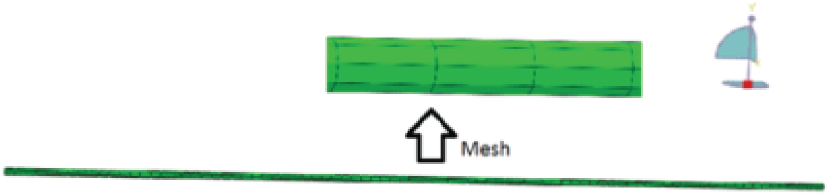

Figure 1: Dimensional geometry of simulation model.

2. Computation

Computational method that we use in this research is Finite Element Method (FEM) using Abaqus. The dimensional geometry of the simulation model is similiar to the geometry of thespecimens tested in the experiment, it is 0.5 mm for the diameter and 60 mm for the length. Tomeshing the model, we use rectangular shape with the same size all over the model. Thecomputation are performed by compressed the model along z-axis. The result will give use xplanation about strain distribution of the composite.

3. Experiment

Compress test was conducted by using 10KN Universal Testing Machine type SM-10. This evaluation gave us force value with ±0.01 accuracy and displacement with ±0.00001 accuracy. In this case, we used the B, 3B, H, and 2H pencil lead with dimension of 0.5 x 60 mm as carbon composite. Resistance of carbon composite was measured using multimeter with ±0.1 accuracy which are connected to graphite. Graphite was being used as a pad for carbon composite as long as the pencil underwent compress test (since pure graphite is harder than carbon composite, so the compression on the pad will not effect the measurement process significantly).

This experiment was carried out at room temperature and it will last until the pencil lead breaks. From this experiment, we get the Strain-Stress Curve which will make us to be able to obtain the Young Modulus of carbon composite as well. Then, to analyze the relation between mechanical and electric properties, we used Stress-Strain curve and Resistance-Strain curve. We will compare carbon composite type B with 3B, and type H with 2H; the comparison among all of them in the same curve will not be done, because we used different pencil lead product for type B and H.

4. Results and Discussions

The computational result of system on Fig 3(a) and (b) shows that the Force act on the composite is uneven. Greatest displacement happen in the upper part (part which force was given) and the smallest displacement happen in the down part. This caused the speciment to bent. The type of pencil H and B represent the “Hardness” and “Blackness”. The hardness of pencil is obtained from the clay. So, the higher number

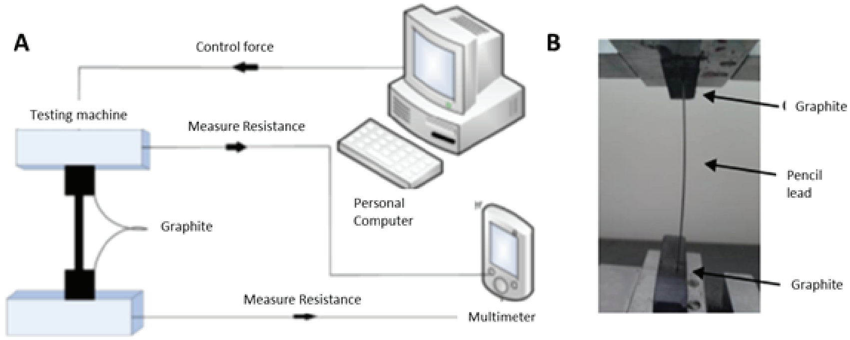

Figure 2: (a) Diagram of experiment and (b) Pencil lead under compression.

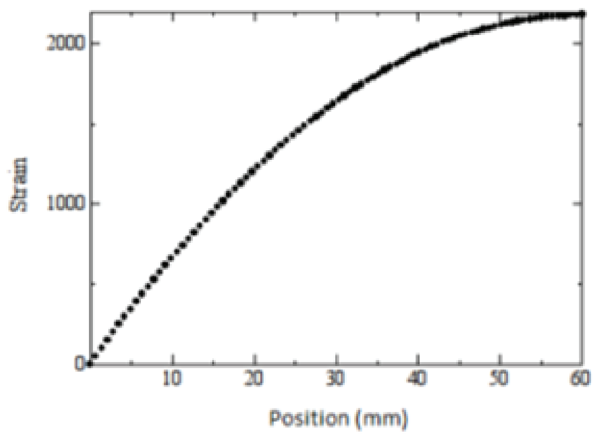

Figure 3: Strain distribution on compressed carbon obtained from computational result.

of H type contains more clay. Meanwhile the Blackness of pencil are obtained from the graphite. Graphite will give soft texture to the pencil traces. The higher number of B type contains more graphite [3]. In the Fig 4(a) we can see that pencil with type H is stronger than B and also have higher value of resistance because it contain less graphite. Pencil lead with H type also have more ductile properties than B, because it contains morepolymer as a binder.

Fig 4(A) and Fig 4(B) show the that Stress-Strain curve has both linear and non-linear graph. This linear graph is called elastic region while the non-linear graph is called plastic region. Elastic deformation occurs in the elastic region; it happens when the interatomic bonds are stretched, but they have the capability to go back to their original nearest neighbors (each carbon in Graphite is covalently bonded to three other carbon atoms). On the other hand, permanent deformation occurs in plastic region. Permanent deformation takes place when some atoms move away from their original nearest neighbors, and it cause some of the interatomic bonds to break up. This permanenet deformation can cause a fracture or even damage on the material.

In addition, Fig 4(A) and Fig 4(B) also show that the composite materials consists of ductile and britlle mixture. It can be seen from the elastic region, that the composite is not broken immediately after the ultimate point, but it breaks after encounter some elongation in plastic region and then break at ultimate rupture strain. The key of this

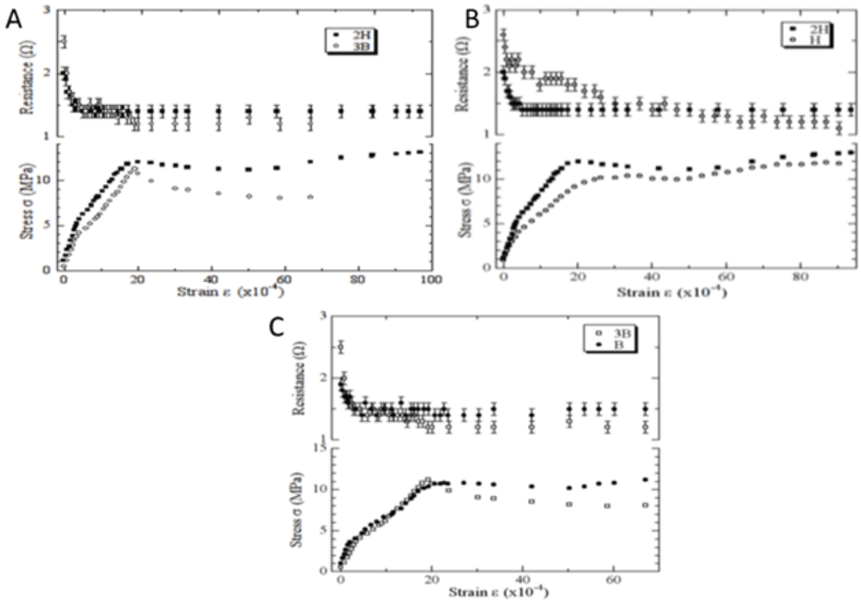

Figure 4: Mechanical Properties of (a) type 2H &3B, (b)H &2H and (c) B & 3B.

phenomenon is the composition of pencil lead. Graphite and clay are indeed considered as brittle materials, but the pencil lead we used has polymer as a binder (polymer is included in ductile material). So, the ductile found in the properties are caused by the polymer.

Other than that, Fig 4(A) shows that 2H has higher stress and resistance than H. It is found in the reference [3], that 2H has more clay and less graphite. Composite that have less graphite will have bigger resistance because graphite is conductive material. In this results, we got the resistance value of 1.4Ω for the 2H and 1.1Ω for H. On the contrary, Clay give hardness to pencil lead; in this experiment, we use pencil lead which contains polymer. Polymer is known as the elastic material. In this investigation, 2H that contains more mixture of clay and polymer has higher stress (around 13.1 MPa) than H (around 11.77 MPa). Meanwhile, B type which has higher number contains of more graphite. It can be seen from Fig 4(B) that 3B has lower resistance and stress than B (resistance of B is 1.5Ω and 3B is 1.2Ω). The Stress-Strain curve for the B type shows that B has higher Stress (around 11.52 MPa) than 3B (aroung 8.1 MPa) in Ultimate rupture strain. The result of this study represents that harder composite has more ultimate rupture strain. If we arranged it in descending order, it would be 2H, H, B, then 3B.

Now, we are going to compare the Ultimate point of each type. H type has Ultimate point in 9.17 MPa while 2H is in 11.77 MPa. We can see that hardest composite will have higher ultimate point for the H type. As explained before, 2H has less graphite, so it must be stronger than H. And about the B type, B has ultimate point in 10.70 MPa while 3B is in 11.21 MPa.

Fig 4(A) and Fig 4(B) illustrate that the electrical properties run into three phases. First is the sharp fall of resistance, second is slowly down of resistance, and the last is stable resistance. Similar to them, the mechanical properties also experience three stages. First is sharp linear graph, second is also linear graph with lower slope, and the last is graph that tends to be more stable. We can see that elastic region obeys the resistance equation, where resistance is proportional to the length and density while inverse with the area of material. When the composite encounter the compress test, the length of material is shorter, therefore the resistance will also down. Meanwhile, in plastic region, the resistance equation is not applicable because some atom has encounter permanent deformation that makes small change in the density and length of material.

Through Fig 4(A) and Fig 4(B), we can investigate the strain between ultimate point in Stress-Strain curve and Resistance-Strain Curve of each type. The results shows that all the type reach their ultimate point of resistivity first and then ltimate point of stress. For the H type, the strain differences between that two ultimate point is 18.29 for H and 14.95 for 2H. Meanwhile, for the B type, the strain differences is 19.95 for B and 17.73 for 3B. We can see that there is an inverse result between H and B type. In H type, the Harderst pencil has a closest differences between two ultimate point. It may happen because 2H have biggest resistance, so it would reach the ultimate point of resistance in longer strain than H. So, that's why, for the same strain of ultimate point of stress, 2H will have little strain differences. Meanwhile, for the B that has more resistivity than 3B, it ecounter more strain differences but not too specific. Further investigation of the lead composition needed to explain this phenomenon.

5. Conclusion

The force distribution on carbon composite is uneven, therefore the displacement are different in every point and the result shows that composite will be bent. Computational result shows that the highest displacement is happen in the upper part (part which force was given directly) .Carbon composite with the mixture of polymer and clay as a binder has ductile and brittle properties. Composite with more graphite has lower resistance and lower stress. The resistance equation just applied in elastic region. In plastic region, the resistance equation is not applied and the resistance tends to be more stable. In H type, the strain differences between two ultimate point is more specific than B type.

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