

The Study of Electrical Conductivity of ABS Reinforced Carbon Black Blends

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Abstract- Acrylonitrile-butadiene-styrene (ABS) is a synthetic engineering resin that is widely used worldwide in various industries. ABS is known for its physical properties and capable to become electrical conductor. Naturally, ABS exist as insulating behavior thus carbon black (CB) were introduced into ABS matrix to change its behavior from insulation to conducting behavior. Electrical conductivity of ABS reinforced carbon black blends was study. Electrical conductivity of ABS reinforced CB blends will be determined by taking the weight percent (wt%) content of carbon black at various ranging from 10 wt% to 50 wt%. Besides that, effect of temperature on electrical conductivity were also investigated. Various temperature ranging from room temperature to 100°C were used. Increasing CB content in the blends create higher conductivity. Conductive network created by conductive filler has change the ABS matrix thus increase the electrical conductivity of ABS. Introducing more CB content will produce ABS and CB blends with higher conductivity. The temperature also plays a major role in order to achieve higher conductivity. As the temperature increase the conductivity of ABS CB blends will also increase.

Keywords— Electrical conductivity; Resistivity; Conductive filler; blends; effect of temperature

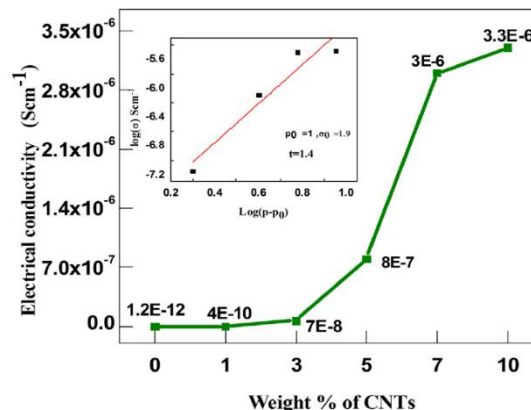
I. INTRODUCTION

Acrylonitrile-butadiene-styrene (ABS) is recognized as an engineering resin with good properties such as mechanical, electrical and thermal properties. ABS is classified as engineering plastics called thermoplastics. Generally, ABS thermoplastic is insulating in behavior. Well known for having good mechanical properties, good finish product and easy to fabricate, ABS have high demand in electrical and electronic industry. Therefore, a conductive filler is introduced into the ABS matrix to increase the electrical conductivity of ABS. Carbon black (CB) is a conductive filler used in this experiment. CB has homogenously dispersed in ABS matrix and change the morphology of ABS by publishing a new network between the matrix called conductive network. This conductive network changes the behavior of ABS from insulating behavior into conducting behavior. Advantage of introducing CB into ABS matrix is it can help to overcome the problem faced by ABS where ABS is not a conducting material but it also has a disadvantage. One of the disadvantages is when CB is introduced into ABS matrix, it slightly decreases the mechanical properties of ABS as the CB selectively dispersed in ABS.

In addition, temperature also play an important role in electrical conductivity of ABS. Any temperature above the melting point of ABS will increase the separation distances between aggregates. Increasing in temperature will increase the separation distance between aggregates thus decrease the electrical conductivity of ABS (Huang, 2002).

ABS need to have very good electrical properties as they have been widely used in electrical and electronic assemblies. ABS can act as good insulator and good conductor. Pure ABS without any additive or filler is showing insulation behaviour (Jyoti et al., 2015). Therefore, conductive filler where introduce into ABS matrix so that it can conducting an electric as well. Various study had been done by researcher from all around the world. Only small amount of conductive filler is required to show transition from insulating behaviour to conducting behaviour of ABS. According to a research done by Academy of Scientific and Innovative Research (AcSIR), CSIR-National Physical Laboratory, New Delhi India, led by Jeevan Jyoti, addition of Multiwall Carbon Nanotube (MWCNT) filler can enhance the electrical conductivity of ABS. Figure 1 illustrated result obtained on electrical conductivity of ABS reinforced with MWCNT.

Figure 1: Electrical conductivity of ABS with different weight percent of MWCNT.



Based on the result provided, it is proven that pure ABS without any conductive filler added have insulating behaviour. Increasing weight percent of conductive filler will increase the electrical conductivity of ABS. The right blending formulation is important. Adding too much conductive filler will decrease the mechanical properties of ABS as the conductive filler filled up the ABS matrix (Wang et al., 2014).

The coagulation of particle to form networks that change insulating behaviour of a composite into conducting behaviour depends on the balance interactions between filler-filler and filler-polymer. The conducting behaviour will only occur when there is interaction between CB and ABS matrix. This interaction will form a network called conductive network. Point where polymer composite makes a transition from insulation behaviour to conducting behaviour at a critical concentration is called percolation threshold. Based on this study, the critical concentration is referring to weight percent of CB added in ABS matrix. The critical concentration is highly dependent on interfacial energy between the filler and the polymer composite (Brigandi et al., 2014).

Positive temperature coefficient (PTC) and negative temperature coefficient (NTC) impacts are hugely affect the electrical conductivity of a composite that happen close or more the dissolving purpose of the polymer network in semi-crystalline mixes with CB over the permeation limit. PTC shows decreasing in conductivity as the composite goes through its melting point, and is because of fast demolishing in thickness after melting, which causes an expansion in the separating between CB particles. Electron can flow across the polymer barrier and having a high electrical conductivity when the separation distances between aggregates is less than some critical distance (Huang, 2002). The NTC can gradually increase the conductivity as the mix is additionally heated over its melting point, and is because of complex impacts of temperature on conductivity of the materials in the composite (Brigandi et al., 2014). Therefore, the temperature should be control under its melting point so that the electrical conductivity can be determined

II. METHODOLOGY

A. Materials and Apparatus

i. Materials

Acrylonitrile-Butadiene-Styrene (ABS) and Carbon Black (CB) were used as the raw material. ABS and CB were blends together by taking CB content as the manipulated variable. ABS will be blends together with five different CB weight percent ranging from 10% to 50% with 10 % percent interval.

ii. Apparatus

Hot air oven were used to remove moisture content in ABS and CB. After the drying process, the materials will be blend by using internal mixer. Haake Rheomix 600 by thermofisher were used as an instrument to blend ABS with CB. Composite polymer produced after the mixing process then will be heat press by using heat press machine. Heat press were used to mold ABS reinforced CB blends into a disc shape. Disc shape sample then were tested by using Electrochemical Impedance Spectroscopy (EIS). HIOKI 3532-50 LCR HiTESTER EIS were used to investigate the electrical conductivity of ABS reinforced CB blends and the effect of temperature towards electrical conductivity.

B. Method

i. Preparation of Composite

Prior to mixing, ABS were pre-dried for 3 hours in a hot air oven at 80°C to remove moisture content. CB resins need 3 hours drying time with temperature of 65°C before compounding with ABS. The ABS/CB composites were prepared using Haake Rheomixer. First, ABS were added into the mixer with temperature 210°C. The mixer screw speed is 5 rpm 20 kg/hour and the time for mixing is 3 minutes. After 3 minutes, CB was put in the mixer at 210°C with screw speed 100rpm and mixing time is 10 minutes. CB was added with 10 wt% ratio. After 10 minutes, the CB was inserted by varying wt% of CB from 10-50wt%. Each mixing process was let for 10 minutes. The volume of internal mixer is 69 cm³. Therefore, the maximum amount of composite added into mixer can be calculated by using following formula.

$$\text{volume of mixer} \times \text{density of polymer} \times \text{percent of composite mixer}$$

$$69\text{cm}^3 \times 1.06 \frac{\text{g}}{\text{cm}^3} \times 70\% = 51.2\text{g}$$

Based on the maximum number calculated above, weight of ABS and CB blends can be calculated. Table 1 shows the blending formulation for ABS and CB blends.

The composites were then compression moulded using a hot press at 220°C with 150 kg/m² pressure. The duration for the heat press as follows; pre-heat time 6 minutes, compress 8 minutes and cooling time 6 minutes.

Molded sheets then were cut using a cutter to obtain specimen for electrical conductivity testing. Use disc shaped cutter (ASTM B 193-87) for electrical conductivity testing to cut the sample. 5 units of disc shape sample needed for electrical conductivity testing. Each disc shape sample will have different amount of wt% CB added into ABS polymer.

ii. Conductivity Test

For conductivity testing, the standard test strategy for deciding the resistivity of electrical conduit materials is ASTM B 193-87. Conductivity is computed from the deliberate obstruction and measurements of the sample. The precision and accommodation with which obstruction can be estimated relies upon the real opposition of the example. Electrochemical Impedance Spectroscopy (EIS) were used to measure the conductivity of ABS reinforced CB blends.

For every wt% ranging from 10 – 50 wt%, there are 5 units of sample. The thickness and diameter for every disc shape (The sample was labeled 1 – 5) was measured. The frequency of the EIS was set range from 50 to 5000000 Hertz. The sample was placed on sample holder. UiTM software had been used to conduct conductivity test by calculating the resistance. The details of the sample have been filled up (Operator name, materials of the sample, test number and frequency of the EIS machine).

From the result obtain, graph can be plotted by using Microsoft excel. Graph obtain will show the series resistance of the sample. Thickness and area of the sample were calculated before the test were run. By having thickness, area and resistance, electrical conductivity can be calculated by following formula.

$$\text{conductivity} = \frac{\text{thickness}}{\text{resistance} \times \text{area}}$$

$$\sigma = \frac{t}{Rs \times A}$$

iii. Effect of temperature on conductivity test

Same method as ii were applied in order to investigate the electrical conductivity of ABS reinforced CB blends. However, the temperature was set ranging from room temperature to 100°C in order to determine effect of temperature on electrical conductivity. The temperature was varying by increasing 10°C each time till 100°C. The sample was placed on sample holder. UiTM software had been used to conduct conductivity test by calculating the resistance. The details of the sample have been filled up (Operator name, materials of the sample, test number and frequency of the EIS machine).

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III. RESULTS AND DISCUSSION

Electrical Conductivity of ABS Reinforced Carbon Black Blends

CB weight percent (wt%)	Resistance (Rs)(kΩ)	Conductivity (σ)(S.cm ⁻¹)
10 wt%	5.275	7.0146x10 ⁻⁹
20 wt%	5.2956	1.1293x10 ⁻⁸
30 wt%	5.7405	1.3104x10 ⁻⁷
40 wt%	7.0321	2.1842x10 ⁻⁷
50 wt%	7.2276	2.2346x10 ⁻⁷

Table 2 shows electrical conductivity of ABS reinforced CB blends

Based on table 2, its clearly shows that increasing in conductive filler content will increase the conductivity of ABS. At 10%, 20%, 30%, 40% and 50% of CB blends, the conductivity of ABS polymer is 7.0146x10⁻⁹, 1.1293x10⁻⁸, 1.3104x10⁻⁷, 2.1842x10⁻⁷, and 2.2346x10⁻⁷ respectively. Figure 2 clearly shows how CB weight percent content effect the electrical conductivity of ABS polymer. Transition from insulating behavior to conducting behavior is also known as percolation threshold. From figure 2, percolation threshold for ABS reinforced CB blends can be seen at 20%. Below than

20%, it can be said that the composite polymer is still in insulating behavior while at 40% CB content, this composite polymer starts to act as conductor. In between 20% to 40%, the composite polymer is in semi-conducting zone where transition of behavior from insulation behavior to conducting behavior took place. In previous study by Wang in 2014, he claimed that addition of conductive filler into polymer can increased the conductivity of the polymer. Figure 1 sows result obtained by Wang where ABS polymer was blends with multi-wall carbon nanotubes (MWCNTs). From his study, the percolation threshold can be detected at 3% of MWCNTs content. As MWCNTs is more conductive compare to CB, the transition of insulating behavior to conducting behavior occurred earlier. Therefore, Wang study can be used as reference to study the effect of conductive filler content in electrical conductivity.

The data that can be obtained from EIS is in resistivity. Resistivity is inversely proportional to conductivity. Therefore, from the resistivity data obtained, the conductivity of the ABS and CB blends can be calculated.

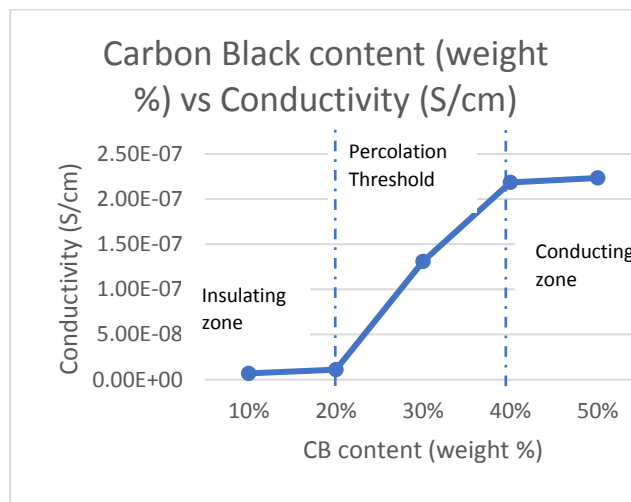


Figure 2 A bar chart represent CB weight percent against Conductivity

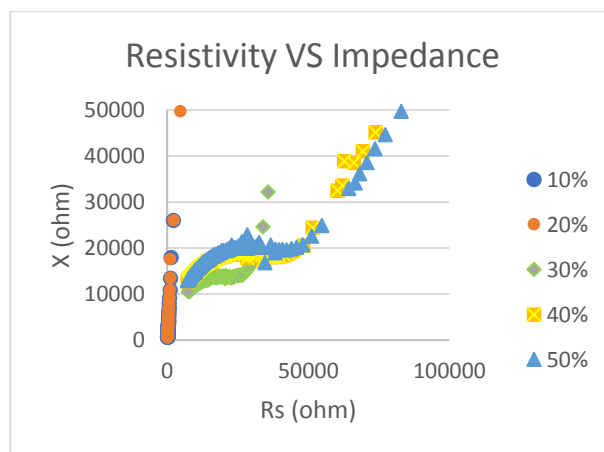


Figure 3 A Plot Show resistivity against impedance at different blending ratio.

From table 2, when the resistivity decrease, conductivity will increase. This can be proved by data obtained from EIS. Figure 3 shows graph resistivity against impedance. From the graph, it can be said that at 10% and 20%, the ABS and CB blends are still in insulating behavior. In order for the composite polymer to change from insulating to conducting behavior, the graph should show some plateau. At 10 % and 20%, there is no plateau can be seen but it can be seen from 30% to 50% of CB content added into ABS polymer matrix. From the graph plotted, it is proved that increase in CB content will decrease the resistivity. At 10% and 20% the impedance increased as the frequency increase and there is no sign that the graph will plateau. So, at 10% and 20% the composite polymer is still in insulating behavior. Differ for 30% to 50% CB content. At 30%, the graph already shows some plateau and as the frequency increase. At this state, the composite polymer starting to change from insulating to conducting behavior. This phenomenon also known as percolation threshold. Percolation threshold can be define as point where polymer composite makes a transition from insulation behaviour to conducting behaviour at a critical concentration (Brigandi et al., 2014). At this state, CB have dispersed uniformly in ABS matrix. The CB has create a conductive network between the ABS matrix thus allow ABS to conduct electricity (Wang et al., 2015). CB composites dispersed in ABS have change the structure of ABS matrix as conductive network were produced resulting from addition of CB into ABS matrix(Wang et al., 2014). Clear plateau can be seen as the frequency is lower. Extrapolation need to be done in order to obtained the conductivity of the polymer composite as the experiment where run starting at frequency 50 MHz.

Figure 4 clearly shows the effect of CB content in conductivity of ABS. As the CB content increase, the conductivity of ABS also increased. At lower frequency and lower CB content, the composite polymer is still in insulating behaviour as the graph shows no sign of plateau yet. At the same lower frequency, range from 1 to 3 MHz, higher CB content already start to plateau and change from insulating behaviour to conducting behaviour. According to Jyoti, 2015, during percolation threshold, this composite polymer is still in semi- conducting range but once it reaches its critical concentration, the polymer is in conducting range. Therefore, at 10% and 20% of CB content dispersed in ABS matrix, it is still in semi-conducting range while for 30% to 50% of CB content, the polymer is in conducting range. In conclusion, increasing in CB content will increase the conductivity of ABS reinforced with CB and change natural behaviour of ABS polymer from insulating to conducting behaviour by changing the ABS matrix and producing conductive network between it.

Effect of temperature on Electrical Conductivity of ABS Reinforced Carbon Black Blends

According to previous research, the electrical conductivity will increase as the temperature increase. As the temperature increase, the conductivity will occur at lower frequency. Figure 5 (a) and (b) shows how temperature will affect the electrical conductivity of ABS reinforced CB blends at different weight percent of CB.

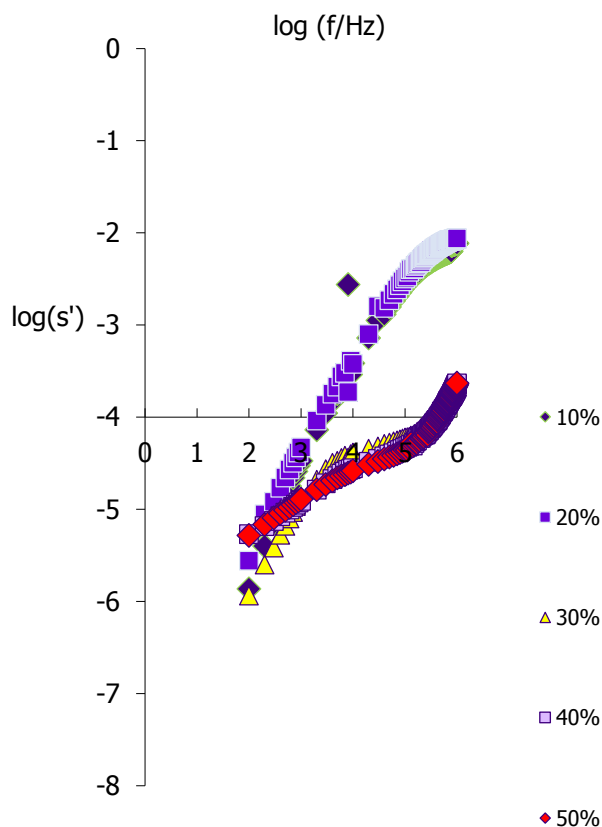


Figure 4 A Plot Shows frequency against conductivity

From figure 5 (a), at 10% of CB content, the composite polymer is still not change from insulating behavior to conducting behavior but it's clearly shows that the composite polymer starting to change its behavior. At room temperature, the polymer is far from conducting an electricity but as the temperature increase the composite starting to conduct some electricity. This can be shown when polymer is introduced to 100°C, the log conductivity graph is start to plateau. In addition, when extrapolation of at 20°C were done, the conductivity will be in range -7 to -8 while at 100°C, the conductivity already can be found as early as in range -5 to -6. It is clearly showing that as the temperature increase the conductivity also increase. Again, as the experiment were done starting from 50 MHz, extrapolation need to be done in order to obtain the conductivity of the polymer. Same goes to figure 5 (b), as the temperature increase, the conductivity of the polymer is also increase.

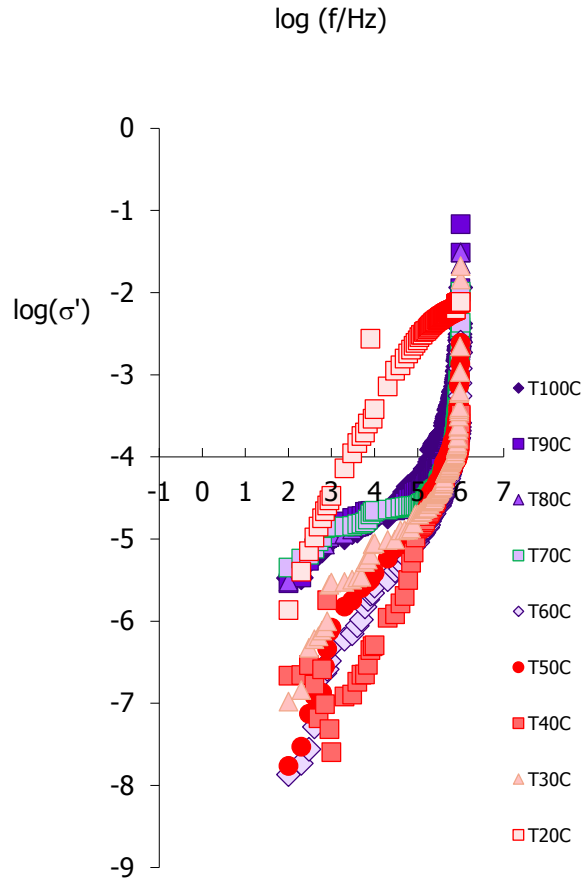


Figure 5(a) shows frequency against conductivity at 10% CB content

As comparison being made between these two figures, it clearly shows that as the CB content increase, the conductivity seems to be more organize. This is because at higher CB content, the conductivity is already occurred at earlier temperature or room temperature. From figure 2, it shown that 30% CB content at room temperature, the conductivity is already occurred while at 10% and 20% the conductivity still not archive. Thus, the graph seems more organize and conductivity can be detected at the same frequency. Therefore, by increasing the temperature, the conductivity will be much higher as compare to room temperature. By referring to figure 5(b), the conductivity of polymer seems looks alike but actually at 100°C, the conductivity is slightly higher as compare to other temperature. The conductivity can be detected as early as range from -4 to -5. When temperature was introduced to the polymer, the polymer particle starts to vibrate and absorb energy. The vibration results in shortening the distance between the particle. Therefore, it will decrease the barrier and electron can move easily across the particle. As the electron can easily pass the barrier, the conductivity of the polymer will increase as lower energy are required for the electron to pass through the barrier (Huang, 2002). However, as the polymer reach its melting point, the conductivity of the polymer will start to decrease. As the temperature exceed its melting point, the composite starts to melt. Therefore, it is important to make sure that the operating temperature are not exceed the melting point of the polymer.

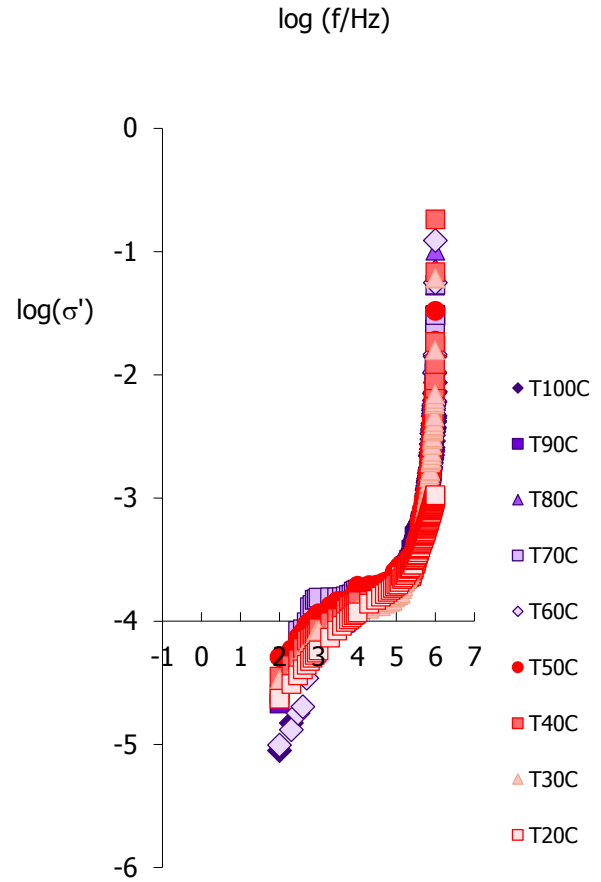


Figure 5(b) shows frequency against conductivity at 50% CB content

Increasing the temperature, force the composite to absorb energy. High in energy makes the particle to start vibrate and move randomly and rapidly resulting in particle collide with each other. As too much energy absorbed by the particle, the particle starts to break down into smaller particle. Resulting from this process, the particle starts to displace from each other. The separation between aggregates has increase the polymer barrier thus decreasing the electrical conductivity of the polymer (Wang et al., 2014). Therefore, the temperature should be controlled under its melting point to avoid from decreasing in its conductivity.

IV. CONCLUSION

As conclusion, CB is a good conductive filler that can change ABS insulating behavior into conducting behavior. CB content in ABS polymer will affect the electrical conductivity of ABS reinforced CB blends. Increasing the CB content will increase the electrical conductivity of ABS reinforced CB blends as shown in table 2 and figure 2 and figure 3. Besides that, the temperature also one of the factors that can be consider as increasing in temperature also will increase the electrical conductivity of ABS reinforced CB blends. However, the temperature should be monitor under its melting point to avoid from decreasing in conductivity. In future research, the frequency also needs to be considered as at lower frequency, it

will show clear result on how the conductivity start to plateau. Thus, more accurate results on conductivity can be obtained.

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