Introduction

Clay has been used extensively in different rubbers as filler for many years and it is of great commercial interest as it makes the products cheap. Due to its low surface activity, clay has very poor reinforcing ability as compared to carbon black or precipitated silica. Modification of the filler surface to improve adhesion has become increasingly important. Kondo, Miyazaki et al. (2008). A new method of clay surface modification by coating the clay fillers with an acrylate monomer, trimethylolpropanetriacrylate (TMPTA) followed by electron beam irradiation of the coated fillers was reported Ray and Bhowmick (2002). It has been found that compared to pristine clay, the surface treated clay fillers show better physical properties while incorporated in nitrile rubber. Precipitated silica fillers have been modified by the above technique Ray and Bhowmick (2002) and it is found to exhibit significant property improvement while added in the ethylene-octene copolymer (Ray and Bhowmick 2001). A major test of the mechanical behavior of polymers, especially those plastics below their glass transition temperature, involves the measurement of tensile strength. While it can be argued that tensile strength is not the best quantity to characterize engineering behavior, it is simple, inexpensive, and very widely reported (Karger-Kocsis and Zhang 2005). The conduction electrons are originated by impurities or from products of polymer degradation. In the recent years, there have been few attempts to study, for example, charge carrier mobility as an independent variable. Electrical conductivity is important in many rubber and plastic compounds including anti-static applications, wire and cable sheathing (Madani and Aly 2010), Koh, Park et al. (1996) and shielding against electromagnetic interference (EMI) (Madani 2010). Electrical conduction in polymers has been studied extensively during the past two decades to understand the nature of charge transport in these materials. Various mechanisms, such as Schottky emission, Poole-Frenkel emission, space-charge limited conduction, and hopping conduction, have been suggested for the charge transport. Considerable interest has been shown on the effect of doping on the transport properties of

Keywords: Nano composites, Electron beam, SBR, DC properties, Mechanical properties.
polymers (Hernán, Morales et al. 1998) (Ishida and Miller 1984, Pukanszky 1995, Petrović, Javni et al. 2000). Depending on their chemical nature and the way in which they react with the host matrix, the doping substances alter the transport properties to different degrees. Consequently, the so-called fine particle filled polymers sometimes contain a number of loosened clusters of particles and exhibit properties even worse than conventional particle/polymer systems (Herron and Thorn 1998, Von Werne and Patten 1999).

In the present work clay, surface modification by coating the clay fillers with an acrylate monomer, trimethylolpropanetriacrylate (TMPTA) followed by electron beam irradiation of the coated fillers have been synthesized. Also, mechanical variation of conduction mechanisms and thermal decomposition behavior as well as the thermo mechanical were studied curves to investigate the effect of Nano clay particles treated and untreated by trimethylopropa triacrylate monomer (TMPTA) loading on SBR matrix.

**Experimental Work**

**Materials**

All the materials under investigation are commercially available products. The styrene butadiene rubber (Grade : 1502) containing 23.5% styrene was supplied by Synthetic and Chemicals Ltd, Barielley, India. The clay powder (bentonite, BE125, mean size 100 nm, density= 2.5 gcm$^{-3}$) was obtained from Spectrum Chemicals & Laboratory Products, USA. The acrylate monomer, trimethylolpropanetriacrylate (TMPTA) (flash point >100°C, b.p.>100°C, specific gravity 1.110 kg/m$^3$) was obtained from UCB chemicals, Belgium. TMPTA was used as grafting monomer without further purification.

**Sample Preparation**

Before being mixed with the monomers, the Nanoparticles were preheated at 120°C for 5 hr to eliminate the absorption water on surface of the particles. Then 100 g of the powder fillers were mixed with 100 ml 3wt% solution of TMPTA in acetone in a glass beaker under constant stirring with a glass rod and then the solvent was removed by evaporation technique, followed by grinding of dry fillers to obtain the surface coated fine powders. The treated filler, acrylate modified, was irradiated in an electron beam accelerator (Model ICT) in the presence of air at NCRRT, Cairo, Egypt. Treated nanoparticles were irradiated at a dose of 100 kGy. The dose determined by the FWT 60-00 dosimeter that was calibrated using the CERIC/CEROUS dosimeter. The uncertainty in the delivered dose was estimated to be 1.15% (Yang, Yang et al. 1996).

Energy dispersive X-ray spectroscopy (EDX) was performed on untreated, irradiated and treated fillers in a JEOL-JSM 5800 scanning microscope operating at an accelerating voltage of 30 kV and equipped with Linux X-ray analyzer. However after TMPTA modification, a noticeable decrease in the oxygen/elements ratios from 0.91 to 0.87 is observed as compared to the control sample, indicating the presence of acrylate TMPTA in it (Ray and Bhowmick 2002). In order to do a comparative study, both unmodified, and modified clay fillers were incorporated in SBR by different concentrations. The formulations of different mixes are given in Tables 1 and 2 for non-modified and modified clay respectively. SBR rubber was mixed in a Bra bender Plastic order PLE-319 at 80 rpm rotor speed for 2 min at Temperature 80°C and then the compound ingredients were then added constituents in ratios as shown in Tables (1) and (2) respectively. The total time of mixing was 10 min. After compounding, the stocks were left for 24 hr to mature. It was then cured into sheets of 2mm thick using hot press at 5 MPa pressure in an electrically heated press (type carver M-154) and heating temperature 170± 20°C for 20 min. To insure reproducibility, the samples were conditioned at 70°C for 20 days (Nasr and Madani 2005).

**TABLE 1. Composition of SBR-untreated clay Nano composites.**

<table>
<thead>
<tr>
<th>Ingredient, phr$^{(a)}$</th>
<th>blank</th>
<th>Su5</th>
<th>Su10</th>
<th>Su15</th>
<th>Su20</th>
<th>Su30</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBR</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Clay</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>DCP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sulphur</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*(a) SBR-untreated clay Nano composites.*

TABLE 2. Composition of SBR- treated clay Nano composites.

<table>
<thead>
<tr>
<th>Ingredient, phr(%)</th>
<th>Sample destination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>St5</td>
</tr>
<tr>
<td>SBR</td>
<td>100</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>5</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>2</td>
</tr>
<tr>
<td>Modified clay</td>
<td>5</td>
</tr>
<tr>
<td>DCP</td>
<td>1</td>
</tr>
<tr>
<td>Sulphur</td>
<td>2</td>
</tr>
</tbody>
</table>

**Characterization**

**Direct Current Measurements:**

The electrical measurements were carried out using a DC voltage/ current generator, along with a precision digital electrometer (Keithley 6514) to determine the current generated on application of a known voltage to filled rubber blend vulcanizes. The sample holder consists of two parallel clamps of brass electrodes, which were isolated from each other using Teflon.

**Mechanical Measurements:**

Dumbbell shaped specimens for tensile are cut from the molded slabs. Tensile strength was done according to ASTM D-412-06 the values of tensile strength, modulus, percentage elongation at break are recorded directly from the digital display at the end of each test. Tensile strength and elongation at break were estimated from stress strain curves measured by using a tension meter (carried out with the use of H10KS Hounsfield Co. UK); tension speed was 50 mm/ min. Tensile tests were carried out on dumbbell shaped specimens. Three samples per formulation were tested. By using the dimensions of samples the stress and strain were calculated.

**Results and Discussion**

**DC conduction mechanism.**

The current (I) pass through the bulk modified run modified clay /SBR composites samples as a function of applied voltage (V) is measured while we maintaining the sample at 300 K and plotted as shown in Fig. 1 and 2. We recognize that at low voltages, the current increased gradually with applied voltage and at higher voltages; the rate is slower. This behavior can be explained in terms of Schottky’s field-assisted thermoionic emission charge transport (Pillai, Narula et al. 1981, Sharma, Adinarayana et al. 1991, Tyagulskii, Tyagulskii et al. 2013), and the relation for current will be:

\[
I = \frac{A s T^2 \exp\left(\frac{\phi}{K (V / \varepsilon d)}\right)}{T}^{1/2}
\]

Where A, is the Richardson constant, s, the electrode area, \( \phi \), the metal work function, d, the thickness of the dielectric \( \varepsilon \), the permittivity, K, the Boltzmann constant, and T, is the temperature in Kelvin. If V expressed in volts and d in cm, the value of C is 4.058 For the Poole-Frenkel effects, the value of C, replaced by 2C.

![Fig. 1. I – V Characteristic curves for untreated Clay samples at room temperature (300K).](image1)

![Fig. 2. I – V characteristic curves for treated Clay samples at room temperature (300K).](image2)
If the temperature of the sample is maintained constant (300K), then a plot of (log J) versus (E^{1/2}) gives the required information with respect to the mechanism of charge transport. The (log J) versus (E^{1/2}) plots for modified and unmodified clay/SBR Nano composites are introduced in Fig. (3) & (4).

The plots show a linear behavior with appreciable deviation from linearity at lower fields, which can be attributed to accumulation of space charge at the electrodes. The slope of these plots at higher fields yields important information regarding the nature of the conduction process, and the current-voltage temperature dependence follow the relation

\[ I \propto \exp \left( \frac{e\beta E^{1/2}}{K} \right) \]  \hspace{1cm} (2)

Where, E is the applied field and \( \beta \), a constant characteristic of the conduction mechanism.

The linear behavior of log J versus E^{1/2} plots in the present study points to an electronic-type conduction mechanism. Here, the charge carriers are released by thermal activation over a potential barrier. The physical nature of such a potential barrier can be interpreted in two ways. It can be the transition of electrons over the barrier between the cathode and the dielectric (Schottky emission). Alternatively, charge carriers can be released from traps into the dielectric (Poole-Frenkel effect) (El Tayyan and Khogali 2004).

In order to differentiate between these two, the values of \( \beta \) at different temperatures were calculated from the slopes of log j versus E^{1/2} plots.

The theoretical value of \( \beta \) can be calculated separately for either the Schottky or the Poole-Frenkel mechanisms by use of the following respective equations:

\[ \beta_R = \left( \frac{e^3}{4\pi\varepsilon_0\varepsilon} \right)^{1/2} \]

\[ \beta_{PF} = 2\beta_R \]

Where, the dielectric constant (at 103 Hz), \( \varepsilon \) for all samples are measured, \( \varepsilon = 8.85 \times 10^{-12} \text{F/m} \), and \( e = 1.6 \times 10^{-19} \text{C} \), then, The experimental as well as the theoretical values of \( \beta \) for both the Schottky and Poole-Frenkel mechanisms are calculated and tabulated. It is clear from Table 3 that all samples obey Poole-Frenkel conduction mechanism except the blank one, which is Schottky conduction mechanism.

### Table 3. Theoretical and experimental values of \( \beta \) for Schottky and Poole-Frenkel mechanism.

<table>
<thead>
<tr>
<th>( \beta_{PF} )</th>
<th>( \beta_R )</th>
<th>( \beta_{Exp} )</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.92 E-05</td>
<td>1.46E-5</td>
<td>1.38E-05</td>
<td>Blank</td>
</tr>
<tr>
<td>2.84E-05</td>
<td>1.42 E-05</td>
<td>3.75E-05</td>
<td>Untreated</td>
</tr>
<tr>
<td>3 E-05</td>
<td>1.50 E-05</td>
<td>2.78E-05</td>
<td>Su5</td>
</tr>
<tr>
<td>2.9 E-05</td>
<td>1.45 E-05</td>
<td>3.14E-05</td>
<td>Su10</td>
</tr>
<tr>
<td>2.8 E-05</td>
<td>1.40 E-05</td>
<td>2.55E-05</td>
<td>Su15</td>
</tr>
<tr>
<td>2.64E-05</td>
<td>1.32 E-05</td>
<td>3.02E-05</td>
<td>Su30</td>
</tr>
<tr>
<td>2.7 E-05</td>
<td>1.35 E-05</td>
<td>2.58E-05</td>
<td>St5</td>
</tr>
<tr>
<td>2.96 E-05</td>
<td>1.48 E-05</td>
<td>3.9E-05</td>
<td>St10</td>
</tr>
<tr>
<td>2.94 E-05</td>
<td>1.47 E-05</td>
<td>2.65E-05</td>
<td>St15</td>
</tr>
<tr>
<td>3.1 E-05</td>
<td>1.55 E-05</td>
<td>4.2 E-05</td>
<td>St20</td>
</tr>
<tr>
<td>2.66 E-05</td>
<td>1.33 E-05</td>
<td>2.97E-05</td>
<td>St30</td>
</tr>
</tbody>
</table>

Fig. 3. Log (J) versus E^{1/2} for (SMEB) samples
Mechanical properties

Polymer Nano composites represent a new alternative to conventionally filled polymers due to their filler size and dispersion. Nano composites exhibit markedly improved properties compared to the pure polymers or their traditional composites (El-Nashar, Mansour et al. 2006). These includes increased modulus and strength (Lagashetty and Venkataraman 2005). The improvement of the mechanical properties of the material have been related to the very small size of the reinforcing clay platelets on one hand, and their large aspect ratio on the other (Van Es 2001).

The relation of the stress-strain is shown in Fig. 5 and 6 for untreated and treated clay, respectively, where with introducing the organic modifier is to increase the interfacial interaction with the polymer chains. So, all the compositions showed a tensile strength higher than the pristine rubber. And by increasing the filler loading, the tensile strength of the prepared composites increases too.

When there is a considerable strength rise of clay-g-TMPTA/ SBR composites at a clay content = 10 phr, and by increasing the treated filler we found that the strength is decrease. Here the optimum value is attained at 10 phr of filler loading. By the use of treated filler, one can achieve best mechanical properties by the incorporation of small amount of filler. Moreover, the treated clay basal SBR samples are more improve with respect to untreated one. It well known that the interface adhesion markedly influences the mechanical behavior of particulate filled polymer composites. The degree of reinforcement depends on the extent of polymer-filler interactions. The extent of polymer-filler interactions is estimated from swelling experiments using a plot of \( V_{r0}/V_r \) versus the C/ (1-C) plot according to the Kraus equation (Kraus 1963, Kraus 1965).

\[
\frac{V_{r0}}{V_r} = 1 - \frac{m}{1 - c}
\]  

(3)

Where \( V_{r0} \) is the volume fraction of rubber in the filled vulcanized and is given by (Chattaraj, Kalidaha et al. 1996):

\[
V_r = \frac{(D - F)p_r \rho_s^{-1}}{(D - F)p_r \rho_s^{-1} + \rho_s \rho_r}
\]  

(4)

Where T is the weight of the test specimen, F is the weight fraction of the insoluble components in the specimen, D is the deswollen weight of the test specimen, \( \rho_s \) is the weight fraction of the insoluble solvent (corrected for swelling increment), \( \rho_r \) is the density of SBR, and \( \rho_s \) is the density of the solvent. \( V_{r0} \) is the volume fraction of rubber in the gum vulcanized, C is the volume fraction of filler in the vulcanization, and m is the polymer-filler interaction parameter obtained from the slope of the \( V_{r0}/V_r \) versus C/ (1-C) plot. The slop should be positive for reinforcing filler having good polymer-filler interaction and negative for nonreinforcing filler with very weak polymer-filler interaction.

It was observed from Fig. 7 that polymer-filler interaction for treated samples is higher than for untreated samples.

Fig. 4. Log (J) versus E1/2 for unmodified samples.

Fig. 5. Stress–strain curves for untreated samples at 300K.
The elongation at break for treated and untreated clay filled composites increases with an increase in the loading of filler up to 10 phr and then followed by a decrease up to 15%. This reduction is more pronounced for untreated clay loaded samples and is due to stiffening of the matrix by the clay particles or filler. In fact, with further increases in filler loading the molecular mobility decreases due to formation of physical bonds between filler particles and polymer chains that stiffen the matrix up to 15 phr. This results in a drop in elongation at break for both treated and untreated clay samples beyond 10 phr clay. However, a higher elongation at break is observed for SBR loaded with 10 phr of treated clay. This is mainly because of the greater chain mobility of these samples than that of untreated clay loaded SBR samples.

Increasing the clay loading beyond 15 phr, leads to an increase of the elongation at break for both treated and untreated clay particles.

Table 4. Elongation at break versus clay loading for untreated and treated samples.

<table>
<thead>
<tr>
<th>Clay content (phr)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>259.2</td>
</tr>
<tr>
<td>5</td>
<td>252.2</td>
</tr>
<tr>
<td>10</td>
<td>267.6</td>
</tr>
<tr>
<td>15</td>
<td>44.5</td>
</tr>
<tr>
<td>20</td>
<td>151.05</td>
</tr>
<tr>
<td>30</td>
<td>231.7</td>
</tr>
<tr>
<td>Treated clay</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>209.25</td>
</tr>
<tr>
<td>5</td>
<td>336.8</td>
</tr>
<tr>
<td>10</td>
<td>143.9</td>
</tr>
<tr>
<td>15</td>
<td>237.6</td>
</tr>
<tr>
<td>20</td>
<td>249.6</td>
</tr>
</tbody>
</table>

Crosslink density determination.

The crosslink densities of the treated and untreated clay loaded SBR samples were determined from the elastic moduli of the samples according to the rubber elasticity theory modified by Nielsen (Landel and Nielsen 1993).

\[ \nu = \frac{E}{3R} \]  

(5)

Where \( \nu \) represents the crosslink density, \( R \) is the gas constant, \( T \) is the temperature in Kelvin (300k), and \( E \) is the elastic moduli obtained from the stress-strain curves (as shown in Fig. 4 for both groups).

The strong impact of the presence of the clay on the initial modulus of the materials, as evaluated by the slope at the origin of the nominal stress-strain curves, can be observed in Fig. (8). The initial modulus increases from 0.5 Mpa to 8.8, 8 Mpa with increasing the filler volume fraction from 0 to 20 phr for both of treated and untreated clay respectively. However, the increment of the modulus with the clay contents appears strongly non-linear, suggesting two different regimes, at low and high montmorillonite content, respectively.

The calculated values for the crosslink densities are tabulated in Table 5. It was found that \( \nu \) increases with both treated and untreated clay contents and treated samples have higher increasing rate of \( \nu \) values than untreated one.

The kinetic theory predicts a directly proportionality relationship between the stress at break \( \sigma_b \) and \( \nu \), the crosslink density, on the other hand, the strain at break, \( \varepsilon_b \), should increases as the crosslink density decreases (Fedors and Landel 1975).
To elucidate the tensile behavior of the test samples, the HT model is tested by using non-Gaussian chain statistics. The HT model in conjunction with non-Gaussian chain statistics for rubber elasticity provides for a limited extension of the chain and leads to an equation predicted elsewhere (Haward 1999). In this equation $L^{-1}$ represents the inverse Langevin function.

Where $L^{-1}(x) = (\coth x - \frac{1}{x})$

Where $L^{-1}$ is the inverse Langevin function. However, according to Cohen (Cohen 1991), the inverse Langevin function may be accurately approximated by a pade equation and checked by Cohen (Cohen 1991, Haward 2000), to bring for us an equation simpler for nominal stress $f$ and more easily to be calculated.

$$f = Y_0 + \frac{C}{3} \left[ \frac{3 - \left( \frac{\lambda^2}{n} \right)}{1 - \left( \frac{\lambda^2}{n} \right)} \right] - \frac{3}{\lambda n}$$

(6)

Where $\lambda$ is the extension ratio and $n$ is the number of flexible units between crosslinks, and in this article $Y_0$ is the yield stress and may be separately measured or treated as a disposable constant, generally, the two values are much the same. Furthermore, it can readily be seen that when $n$ is large the equation approximates to Gaussian form where the second term becomes $C \lambda^{-2}$. It should be noted that when uniform extension takes place, as assumed here, nominal stress can be converted into true stress using the constant volume assumption so that true stress is $f \lambda$. In order to support the validity of the HT model, the stress-strain curves for samples loaded with different concentration of modified and unmodified clay has been fitted by equation (6) which reflects the good fitting between both theoretical and experimental values, and we found that the fitting parameter, $n$, increases with unmodified clay contents meanwhile; it has a maximum value with modified clay at 10 phras indicated in Table 6.

So the number of flexible chain per unit crosslinks is higher for samples loaded with unmodified clay, reflects the good reinforcement gained by modified clay than unmodified one.

**TABLE 6. Fitting parameter ($n$) for all samples.**

<table>
<thead>
<tr>
<th>Clay (phr)</th>
<th>Unmodified</th>
<th>Modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$5 \times 10^6$</td>
<td>$5 \times 10^6$</td>
</tr>
<tr>
<td>10</td>
<td>$5 \times 10^7$</td>
<td>$6 \times 10^6$</td>
</tr>
<tr>
<td>15</td>
<td>$4 \times 10^7$</td>
<td>$9 \times 10^5$</td>
</tr>
<tr>
<td>20</td>
<td>$6 \times 10^7$</td>
<td>$4 \times 10^6$</td>
</tr>
</tbody>
</table>

**Conclusion**

Clay/SBR Nano composite were prepared using internal mixture of modified and unmodified clay filler. The charge carriers are released by thermal activation over a potential barrier. The physical nature of such a potential barrier can be interpreted in two ways, It can be the transition of electrons over the barrier between the cathode and the dielectric (Schottky emission) or charge carriers can be released from traps into the dielectric (Poole-Frenkel effect) and to differentiate between these two, the theoretical and experimental values of $\beta$ were calculated separately for both the Schottky and the Poole-Frenkel mechanisms. It was clear that all samples obey Pool-Frenckel conduction mechanism except the blank one, which followed Schottky conduction mechanism.
With increasing the filler loading, the tensile strength of the prepared composites increases up to 15 phr. The optimum value of the tensile strength for the prepared clay is attained at 10 phr of filler loading. Moreover, the mechanical properties of the treated clay basal SBR samples showed more improvement compared to unmodified one. Elongation at break increases slightly with clay loading up to 10 phr and then abrupt decrease is detected at 15 phr clay loading (for modified and unmodified samples). In addition, the fitting parameter, n, increases with unmodified clay contents meanwhile; it has a maximum value with modified clay at 10 phr.

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(Received 2/4/2017; accepted 30/7/2017)
المحمل بحبيبات SBR المتواجدة الصغر من الميكا المشععه وتوصيل الكهربائي والمواصفات الميكانيكية لمتراكبات مطاط المعادن.

محمد محمد مدني، أحمد شوقي البيومي ومحمد مصطفى السيد عطا 
المركز القومي لبحوث وتكنولوجيا الاشعاع - هيئة الطاقة الذرية - مصر.

تستخدم متراكبات البوليمرات المحملة بالمعادن، أشباه الموصلات، أسود الكربون، أنواع الطمي النانومترية المختلفة كمواد لها تطبيقات صناعية متعددة أو يتم تحضيرها بغرض التطور في خواص البوليمرات.

وتظهر متراكبات البوليمرات عند تحملها بالطمي النانومتري تخضع ملحوظ في خواصها بالمقارنة بمتراكبات أخرى. لذا تم التحقيق وتجهيز مواد جديدة لها خواص مطلوبة و محددة يجب أن توفر في المادة الخواص التي تحتاج لها والقيام بدراسة.

ومن خلال منحنى الاجهاد-الانفعال للعينات وجد أن القوة الإجهاد للعينات المحملة بالطمي النانومتري أزدادت بنسب كبيرة بالمقارنة مع العينة الغير محملة بالطمي كما أنها تزداد بزيادة نسبة الطمي بهذه العينات.

ووجد أن الاستقطاب عند الكسر للعينات المحملة بالطمي النانومتري (المعالج والغير معالج) تزداد بزيادة نسبة الطمي حتى 10% ثم تنقص عند نسبة 15%.

كما وجد أن الكثافة الوصليه تزداد للعينات المحملة بالطمي كما أنها أكبر في حاله العينات المعالجة.

وتوضح السلوك التوترى للعينات وحث تطبيق حيوي للبيانات العملية HT وتمت الاستعانة بنموذج ونظريه.

تم قياس التيار المار بين عينات البوليمر المتواجدة مع الطمي النانومتري كاذا وفرج الجهد عند درجة حرارة 300 كلفن. ووجد أن ذلك سلوكا خطيأ لمنحني التيار-الجهد للعينات مع وجود التحول عن السلوك الخطي عند الجهود المنخفضة وذلك بسبب وجود الشحنات الفراغيه عند إقطاب الدائر المستخدم في القبلي.

مع العينات تظهر سلوكا متفقا مع موصليه Poole-Frenckle . Schottky تظهر سلوكا متفقا مع موصليه