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Influence of Blend Ratio on The Electrical Characteristics of Vulcanized SBR/NBR Blends Compatibilized by *Cis*-polybutadiene Rubber

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BLENDS composed of styrene butadiene rubber (SBR) and acrylonitrile-butadiene rubber (NBR) have been fabricated by melt-blending technique using two-roll mill blend machine. *Cis*-polybutadiene rubber (CBR) was used as a compatibilizer for enhancing the homogeneity between blend phases. No previous reports were found to discuss improving electrical properties of vulcanized SBR/NBR blends using unfilled rubber system (*i.e.* no fillers incorporation). SEM micrographs were utilized to verify the compatibility between two rubber ingredients in various blends, owing to the use of compatibilizer. Thermal stability of blends was investigated by differential thermal analysis (DTA) and differential scanning calorimetric (DSC) to evaluate the influence of blend ratio on the compatibility of investigated samples. Results revealed that the dielectric properties of blends are dramatically influenced by altering the blend ratio. The results revealed that the SEM observations confirmed the compatibilization effect of CBR on vulcanized SBR/NBR blends. Meanwhile, thermal properties of vulcanized SBR/NBR blends were enhanced with increasing of SBR contents in blends. The complex impedance graphs showed circular arcs showing the bulk contribution to overall electrical behavior for investigated vulcanized SBR/NBR blends. During *I-V* characteristics have been presented, where a remarkably change from linear behavior to nonlinear conduction at lower temperatures was found for 0SBR/100NBR blends. These findings supported and confirmed that the compatibilization effect and the blend ratio between rubber compositions have strongly influenced on their thermal and electrical properties of vulcanized blends.

Keywords: SBR/NBR blends, CBR Compatibilizer, Thermal properties, Impedance spectroscopy, Electrical characteristics.

Introduction

Rubber blends are consisting of two or more types of polymer matrices which improve the electrical characteristics and are utilized in a wide-scale of applications *e.g.* automotive and electrical sector [1]. The blend has unique properties with high resistance to both thermal degradation and organic solvents. For investigation of the electrical properties of blends, it was suggested to illustrate their electrical properties *e.g.* permittivity and conductivity. The electrical characteristics of elastomers were found to affect by structure, crystallinity, morphology, additives, and using of compatibilizer [1,2]. Meanwhile, the electrical characteristics of elastomers are associated to

the volume fraction of rubber, polarity, type and different factors such as adhesion between two polymers matrix, processing method and potential interactions between the highest and the lowest conductive phases [3]. Accordingly, it was found that, the measurement of the electrical properties of elastomers as a function of temperature is useful method to monitor the miscibility of diverse polymers component of blend system [3], which could be tested using impedance spectroscopy. This technique was found as a useful tool that permits investigation of polymer dynamics in broad temperature and frequency ranges. It was utilized as an investigator for dielectric processes occurring in hybrid polymeric materials, the electrical relaxation phenomena and to detect the conductivity relaxation behavior. Nitrile butadiene rubber (NBR) is a polar rubber, it has a good conductivity compared to other types of rubber like SBR. Styrene butadiene rubber (SBR) is a non-polar synthetic elastomeric copolymer consisting of two monomers of styrene and butadiene. It is rather rare in literature to use CBR as a type of compatibilizer rubber for rubber-rubber phases (SBR/NBR) blend interaction. Some of rubber blends are immiscible due to polarity of rubber, occurring phase separation and poor interfacial adhesion between polar and non-polar rubber portions. The interfacial miscibility has been improved by incorporating of coupling agent for immiscible blend to obtain a chemical interacting between the two phases [4].CBR acts as a proper compatibilizer for heterogeneous blends and processing the separation phenomena of components. Recently, incorporation of CBR into the rubber blends has improved the cure characteristic and mechanical properties [5-7]. Previous and few studies have discussed in details the thermal and dielectric functions of vulcanized SBR/NBR against the effect of changing blend ratios. For example, Reffaee et al.[8] carried out attempts on electrical and mechanical properties of NBR, SBR and NBR/SBR blends without addition of carbon black. Mansour *et al*. [9] have prepared SBR/NBR and CBR/NBR blends, while dielectric properties were measured over a wide frequency range (10^2-10^6 Hz) at different temperatures. In SBR/NBR blends, the permittivity has been improved with an increase of NBR contents in blends (*i.e.* C≡N dipoles contents) [9]. Furthermore, introduction of polar contents into polyethylene blend

enhanced dielectric constant and dielectric loss of rubber blends [10].

In the present study, the influence of various blend ratios, composed of vulcanized SBR/NBR ratios compatibilized with CBR, on the surface morphology and the thermal stability of resultant vulcanized blends were investigated. For the dielectric study, the emphasis was addressed by the Maxwell–Wagner polarization to assess the influence of SBR/NBR blends interfacial adhesion. The interfacial polarization is mostly adjusted by a conduction phenomenon at elevated temperatures and low frequencies. Also, this work aims to explore the physical origin of the applied charge transport and the conduction mechanisms in SBR/NBR blend. AC conductivities of SBR/NBR blend systems are tested by altering specific parameters *e.g.* the blend ratio, frequency and temperature.

Materials and Methods

Materials

SBR (SBR-1502, Sp.Gr. 0.945, styrene content 23.5%) (M_n125.6 kDa, M_w 359.5 kDa, M_z 996 kDa and polydispersity 2.86) and NBR (NBR-Perbunan™, Bayer AG., Germany) (acrylonitrile content 34%, density 0.99 g/cm³) (M_n103.1 kDa, M_w 268.9 kDa, M_z 801.4 kDa and polydispersity 2.6) were donated from Transportation and Engineering Co., (TRENCO, Alexandria, Egypt). *Cis*-1,4-polybutadiene rubber (CBR) was supplied by Bayer AG Germany. Sulfur, stearic acid and zinc oxide were used in commercial grade without purification and locally manufactured by ADWIC Co. Egypt. The preparation of six different formulations of SBR/NBR blends was carried out according to standard test method for rubber evaluation of SBR (ASTM D 3185–99). All rubber components have been supplied, weighed and mixed on a laboratory-mill at TRENCO Company (Alexandria, Egypt) with size of: outside diameter 460 mm, work length 250 mm, slow roll speed of 16 rpm and gear ratio 2. The compositions of blends for vulcanization step are listed in Table 1. Before each test, all SBR/NBR blends were vulcanized using a hot-press at 153 ± 2°C for 30 minutes by means of standard dies in accordance with (ASTM D-3191). The vulcanization process of SBR/NBR blends was carried out with blend ratios of (SBR/NBR) as (0/100, 20/80, 40/60, 60/40,80/20 and 100/0), and are shown in Table 1.

TABLE 1. Formulation of vulcanized SBR/NBR blends.

Sample Name	Blends composition SBR/NBR	Ingredients (phr[a])						
		CBR	ZnO	Stearic acid	paraffinic oil	6PPD[b]	MBTS[c]	S[c]
0/100	0SBR/100NBR	10	5	2	10	1	2	2
20/80	20SBR/80NBR	10	5	2	10	1	2	2
40/60	40SBR/60NBR	10	5	2	10	1	2	2
60/40	60SBR/40NBR	10	5	2	10	1	2	2
80/20	80SBR/20NBR	10	5	2	10	1	2	2
100/0	100SBR/0NBR	10	5	2	10	1	2	2

a) Part per hundred parts of rubber by weight, b) N-(1,3-Dimethylbutyl)-N'-phenyl-*p*-phenylenediamine and c) Mercapto-benzothiazol disulfide,

Instrumental characterizations

Scanning Electron Microscope (SEM)

The surface morphology of vulcanized SBR/NBR blends was inspected by SEM (type: JEOL, JSM-6360LA, Japan with 15 kV). The SBR/NBR blends were coated by Au using an ion sputter coater (model: 11430, USA, combined with vacuum base unit or SPi module control, model: 11425, USA).

Differential Thermal Analysis

Differential thermal analysis (DTA) (Shimadzu DTA-50, Japan) was used to evaluate the thermal stability of prepared samples. DTA analyzer was performed at a heating rate of 10°C min^{-1} under nitrogen over a temperature ranging from room temperature to 750°C. From the DTA curves, thermal degradation characteristics were calculated.

Differential scanning calorimetry (DSC)

The thermal behavior of the blends was monitored by a Mettler Toledo DSC-822 thermal analyzer. The samples were carried out from 25-750°C at 10°C/min in air atmosphere.

Impedance spectroscopy

The impedance spectroscopy depending upon frequency at different temperatures has been conducted by Keithley, LCZ 3321-meter bridge at frequencies ranging from 120 Hz-100k Hz. The relaxation frequency at each peak Z"$_{rmax}$ is given by the following equation[11]:

$$f_r = \frac{1}{2\pi\tau} \qquad (1)$$

where τ is the relaxation time.

AC Measurements

The capacitance C, electrical conductivity σ, dielectric loss and tan δ of samples are measured at different temperatures by Keithley-LCZ 3321-meter bridge at frequencies ranging from 120 Hz-100 kHz. Higher temperature was obtained by increasing the input voltage of a variance transformer connected to the wire-wound non-inductive resistance heater. The conductivity measurements were carried out up to 135°C for each SBR/NBR blend. The dielectric constant (ε) is calculated using the following equation:

$$C = \varepsilon\varepsilon_o \frac{A}{d} \qquad (2)$$

where C is the pellet capacitance(Farad), d is the sample thickness (m), ε_o is the permittivity of free space($\varepsilon_o = 8.85 \times 10^{-12} F m^{-1}$) and A is the area of electrode(m^2). The dielectric loss (ε''), which is the imaginary part of the complex permittivity, it is calculated using measured conductance values (G) from the following relation [10]

$$\varepsilon'' = \frac{d\,G}{A\,\varepsilon_o\,\omega} \qquad (3)$$

where G is the measured conductance and $\omega (= 2\pi f)$ is the angular frequency of the AC signal. The loss tangent $(\tan\delta)$ is given as follows [10]:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (4)$$

The alternating current (ac) conductivity σ_{ac}

is calculated using the following relation

$$\sigma_{ac} = 2\pi f \, \varepsilon_o \varepsilon' \tan \delta \qquad , \qquad (5)$$

where f is the frequency of the applied AC field (Hz).

Results and Discussion

Morphology of vulcanized SBR/NBR blends

SEM was utilized as a complementary tool for getting a better understanding about; to how extent the CBR can affect the compatibilization degree of an immiscible rubber blend system. Figure 1 presents SEM micrographs of the investigated vulcanized SBR/NBR blends surface with various rubber blend ratios. As shown, the introduction of the CBR compatibilizer might cause a significant enhancement in the miscibility between the blend phases (Fig. 1a-f). Accordingly, CBR content decreases the domain size to a high
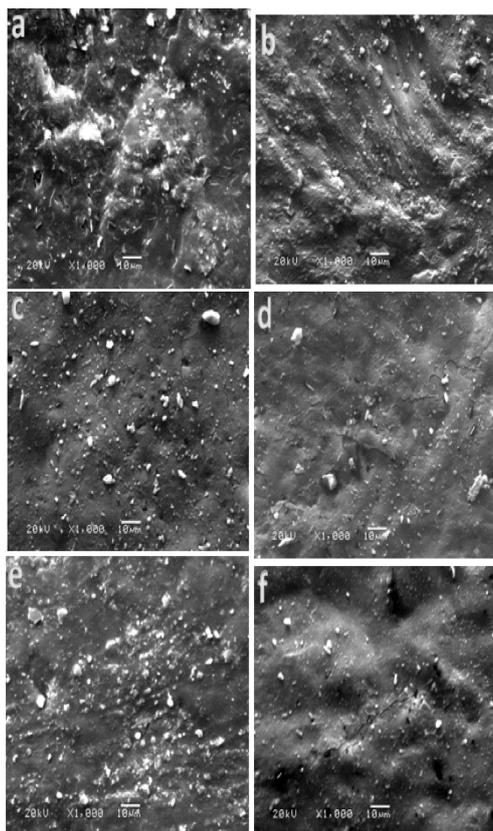
Fig. 1. SEM micrographs of vulcanized SBR/NBR blends as (0/100, 20/80, 40/60, 60/40, 80/20 and 100/0) of (a, b, c, d, e, and f), respectively.

extent, increases the permeation property between phases in blends, and then the system exhibits similar/uniform and more homogenous surface morphology in case of the presence of two phases of blends (*i.e.* SBR and NBR, simultaneously) (Fig. 1b, 1c, 1d, and 1e).

Unlike the single ingredient's blends (Fig. 1a and 1f), the surface morphology of these blends showed a heterogeneous and rugged surface structure. As a result, it was found that, absence of

one of the phases as spherical domains dispersed in the other phase. It might indicate a possible change from the scattered morphology (Fig. 1a, 1f) to coherent and uniform surface morphology compared to Fig. 1b - 1e. This might indicate an altering from the dispersed morphology as shown in Fig. 1a, compared to co-continuous morphology structure (Fig. 1b-1e). In addition, Fig. 1b-1e showed that, the blends seem more compatible with each other and can reflect the emergence of reasonable interfacial interactions

at the contact boundaries between the phases which might be attributed to the existence of the CBR at the interface to participate in reducing the interfacial tension between phases. The morphology results entirely agree with that obtained by Essawy et al. [12], who have investigated the effect of introduction of MMT clay contents on morphology improvement of SBR/NBR blends. Similarly, George et al. [13] revealed that incorporation of NBR in various ratios into vulcanized polypropylene/NBR blend formed a continues phase resulting a co-continues morphology structure. Also, the change in NBR in blends forms dispersed to continues phases which probably results in a sharp change in electrical properties of blend system [13].

Thermal stability of vulcanized SBR/NBR blends by DTA

DTA of the vulcanized SBR/NBR blends was plotted in the temperature range 25-750°C under air atmosphere for four blended samples, and the amassed data are presented in Fig. 2. The heat absorbed at 400°C by the rubber blend is used to evaporate the processing ingredients included during the rubber synthesis. The exothermic heat in the process increased from 150°C to (*ca.*500-650°C), the temperature rising is perhaps owing to the exhaust of CO_2, CO, NO_2, and NO, *etc,* followed by the endothermic was found in a narrow temperature range of the polymer composites during blend decomposition and
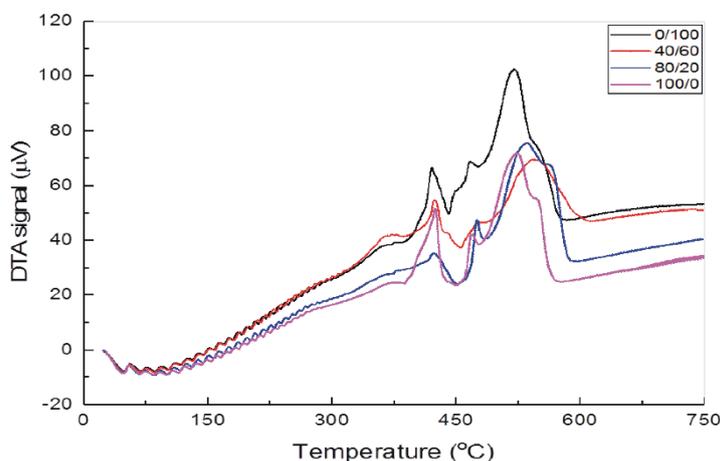
Fig. 2. DTA thermograms of vulcanized SBR/NBR blends as a function of SBR/NBR ratio in blend system.

voids formation. The endothermic heat follows capability of vulcanized SBR/NBR blends is significantly increased with increasing SBR in the blend system, which expedites the cooling rates of blend specimens, and then quenches enormous heat during the specimen's heat flow.

Thermal stability of vulcanized SBR/NBR blends by DSC

The effect of SBR/NBR ratio on thermal properties of vulcanized system was estimated by DSC measurements, where the DSC thermograms were presented in Fig. 3. Basically, vulcanized SBR/NBR blends have improved the thermal decomposition of two-phase blend system, compared to SBR or NBR single ingredient blend. This thermal behaviour reveals that the rubber

blends are highly reluctance to moisture absorption due to incorporation of bulky structure onto the rubber chains. It was probably attributed to such strong electro-negative groups (acrylonitrile group in NBR) that resulted in relatively high interaction and high heat resistance in elastomers. Therefore, NBR has endured high thermal stability compared to SBR because NBR possesses higher butadiene content than SBR. As shown, the temperature ranged from ambient to 750°C. This temperature range is unlikely to glass transitions of SBR and NBR, showing a smooth curve in this thermal area. In addition, no exothermic crystallization process is detected. However, comparison between the four investigated blends clearly reveal that an exothermic change in heat flow for
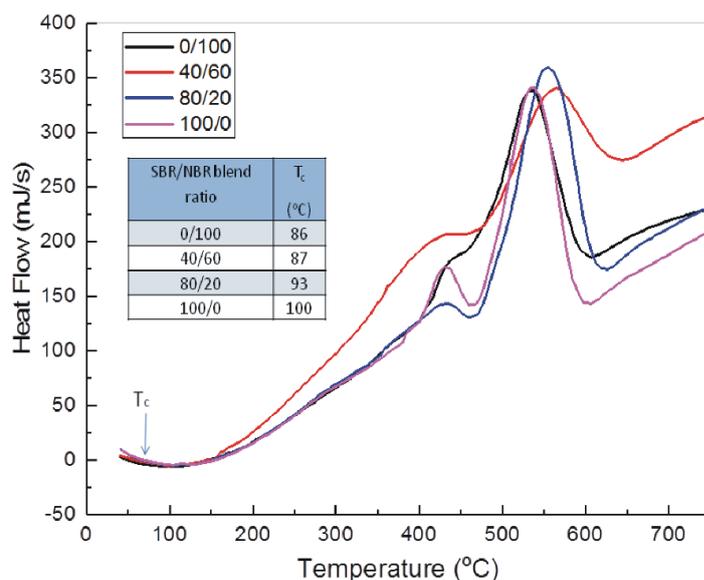
Fig. 3. DSC thermograms of vulcanized SBR/NBR blends as a function of SBR/NBR ratio in blend system.

blends (0/100, 40/60,80/20 and 100/0) and are observed around 86,87,93 and100ºC, respectively. It was attributed to the change in the single rubber content (SBR and NBR percentages) in the blends, where crystallinity of blend was increased with increasing of SBR ratio in rubber system.

Impedance spectroscopy

Impedance spectroscopy has been performed with a frequency ~120Hz - 100 kHz. Figure 4 displays the impedance plots of rubber blend system. Inspection in Fig. 4 reveals that, the conductivity increased up to a specific temperature, and it was then decreased owing to the accumulations of ions at higher temperatures. However, peak shifted from 313 to 403 K, the peak height was also reduced towards a higher frequency referring to an increase in conductivity was noticed with increasing the temperature. The peak has shifted toward higher frequency with the conductivity increasing, and hence decreased the resistance in blends [14]. Higher values of f_r with the increase of temperature were clearly observed and showed that the mobility of charge carriers increased with increasing temperature. As a result, the higher mobility of charge carriers in polymer chains was responsible for the conduction mechanism. Figure 5 illustrates dependence of relaxation time of charge carriers

on 1000/T of blends at various temperature and values of activation energies could be calculated in the next section.

AC Electrical conductivity of vulcanized SBR/ NBR blends

The AC electrical conductivity of SBR/NBR blends was measured at frequencies range120 Hz-100 kHz. It was observed that, the AC electrical conductivity increases by increasing the frequency at room temperature (Fig. 6). Moreover, the obtained results were in a good agreement with the work of Sau et al.[1] who found the value of resistivity increases by decreasing NBR content of NBR/EPDM blends. The universal power law can be written as follows:

$$, \tag{6}$$

where the pre-exponent factors A and the frequency exponent *s* are functions of temperature (T). The slope $\sigma_{ac} = A\omega^s$ of the presentation shown in Fig. 6 results in the exponent *s*, where $0 < s < 1$ and this is related to the conduction mechanisms. Many theoretical models were suggested for the AC conduction in amorphous semiconductors *e.g.* classical hopping and quantum mechanical tunneling of charge carriers through the potential barrier separating two energetically appropriate centers in a random distribution [15].
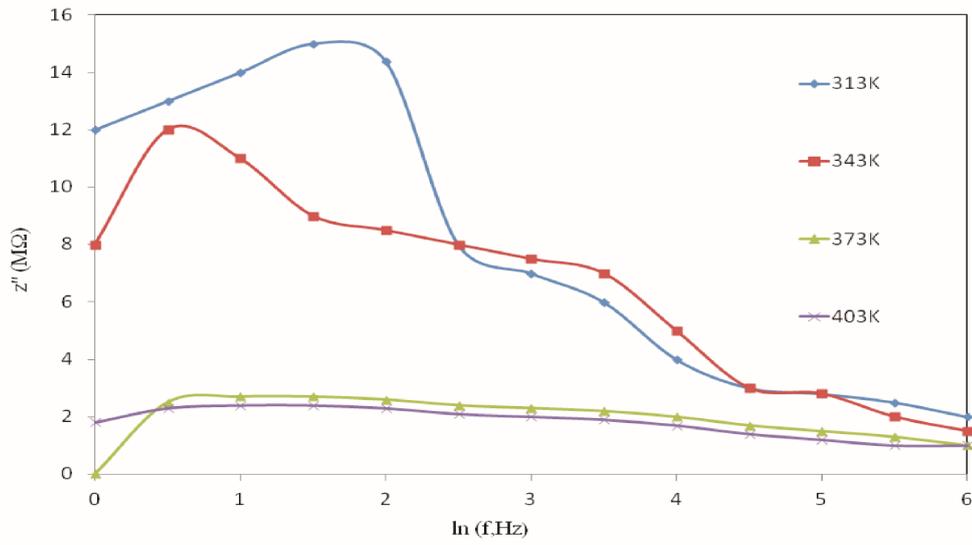
Fig. 4. Dependence of Z›› on frequency for the blends within different temperature ranges.
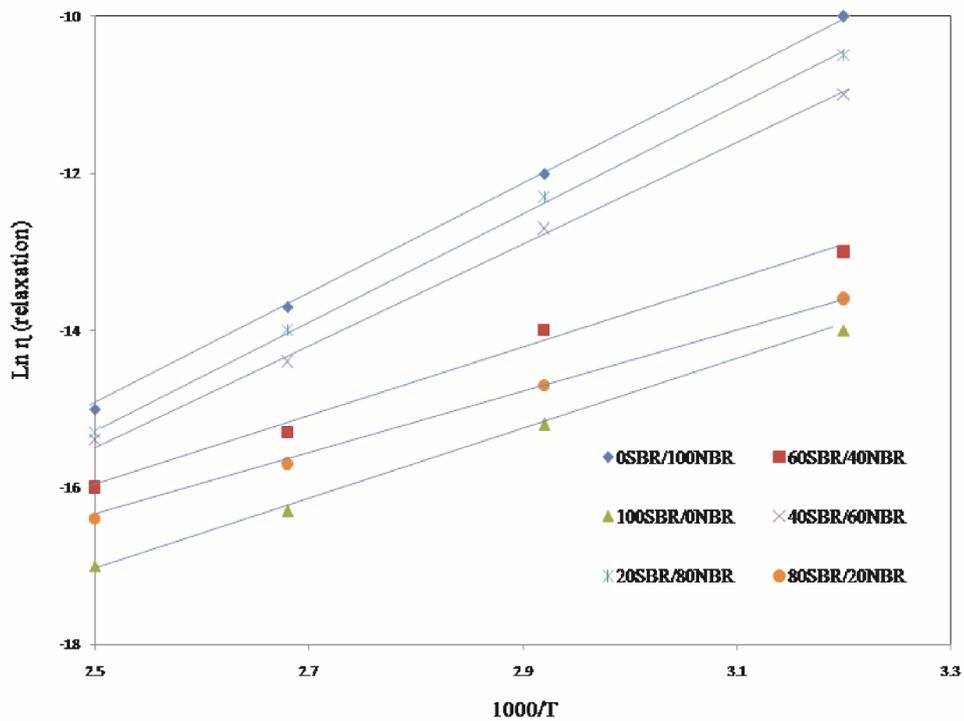

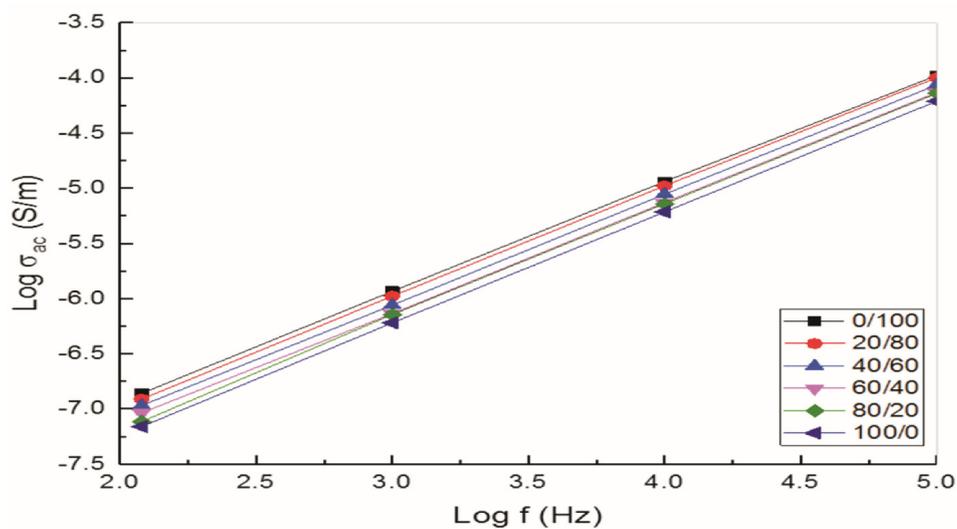Fig. 5. Relaxation time versus 1000/T of all investigated rubber vulcanized blend sample.

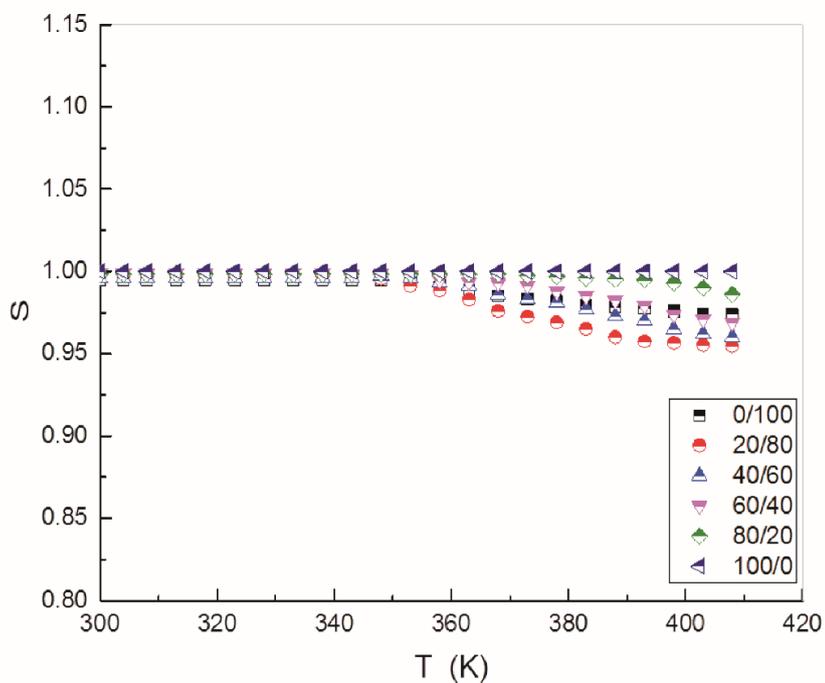**Fig. 6. AC electrical conductivity of SBR/NBR blends versus frequency at room temperature, (300K).**

Fig. 7. Dependence of s exponent on temperature of vulcanized SBR/NBR blends.

In electron tunneling model, S is independent of T. With the small polaron tunneling, S was found to increase as T increases. The variation of S with T was shown in Fig. 7.

From Fig. 7, it is observed that, in case of 0/100, 20/80, 40/60 and 60/40 blends, the exponent S increases with increasing the temperature, until it reaches to a value of 1 and then decreases by further increase in temperature while for 80/20, S decreases with increasing temperature and finally for 100/0, S is constant with temperature. The small polaron hopping conduction mechanism

is mostly at low temperature and followed by a correlated barrier hopping conduction mechanism for high temperature values was described (K). The decrease in the values of S has been interpreted by the correlated barrier hopping (CBH) model [16-18]. The temperature dependence of σ_{ac} for SBR/NBR blends at different frequencies is shown in Fig. 8. From these data, it is evident that σ_{ac} is dependent on the temperature and could been hanced by increasing the frequency. This indicates that, the charge carriers can be moved by hopping through the defect sites along the polymer chain. The temperature dependence of AC conductivity at constant frequency can be
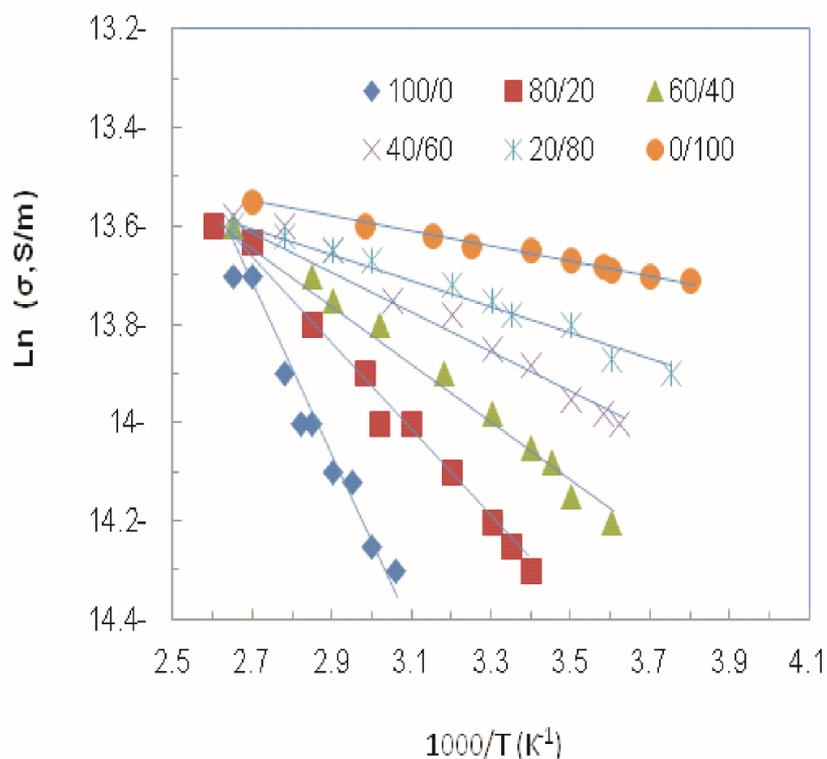

Fig. 8. Dependence of   on temperature of vulcanized SBR/NBR blends at 100 kHz.

TABLE 2. Activation energy versus blend composition ratio of vulcanized SBR/NBR blend at 100 kHz.

Blend composition	0/100	20/80	40/60	60/40	80/20	100/0
Activation energy (eV)	1.0	1.60	1.70	1.85	1.93	1.80

expressed as f

$$\sigma_{ac} = \sigma_o e^{\left(-\frac{Eac}{kT}\right)} \quad , \quad (7)$$

where σ_o is a constant, E_{ac} is the activation energy and k is the Boltzmann constant.

The values of E_{ac} versus blend compositions are listed in Table 2. It is clear that, E_{ac} decreases by increasing the NBR content. This observation is confirmed by the fact that the applied field facilitates the redistribution and regrouping of conductive particles, which resulting the lower activation energies for the conduction process.

Current-voltage characteristics
The current-voltage relation for 0SBR/ 100NBR has been investigated over the whole temperature range. Figure 9 shows the I-V characteristics of vulcanized SBR/NBR (0/100) at different temperature. It is so clear that diode-like characteristics are observed for all data. Where, all data are well fitted by the following equations:

$$I = G_0 V e^{\left(\frac{V}{V_0}\right)}$$

$$G = \frac{I}{V} \qquad (8)$$

$$(9)$$

where G is the conductance and G_0 is the low field conductance. Equation (8) can be represented as foll

$$\ln \frac{I}{V} = \ln G_0 + \frac{1}{V_0} V \qquad . \quad (10)$$

Equation (10) can be employed and plotted in Fig. 10, where the fitting parameters could be listed and simplified in Table 3. From the data in Table 3, it is clear that G_0 shows a strong increase with temperature in investigated sample activated behavior, while V_0 shows only a relatively decrease with temperature.

Dielectric measurements of vulcanized SBR/NBR Blends
Figure 11 shows the change of dielectric constant (ε') and the dielectric loss(ε'') for SBR/ NBR blends as a function of the frequency. It is clear that ε' values were increased by increasing NBR content. The reduction of ε' values might be attributed to increasing of polarity in blend because of the increase of C≡N dipoles in blend system. This result was confirmed also by the

work of George et al.[20] on PP/NBR blends. Using equation (1) the relative dielectric constant ε_r has been det------d---y the given equation:

$$\varepsilon_r = \frac{Cd}{\varepsilon_o A} \qquad (11)$$

where C is the measured capacitance and was obtained at frequency ranges from 120 Hz to 100 kHz using equation (9). It can be noticed also from Fig. 11, that ε'' decreases by increasing SBR content. This decrease could be attributed to a decrease in the polarity due to the incorporation of SBR with NBR which is a non-polar rubber and leads to a decrease in the orientation polarization. This result may be due to the fact that the values of dielectric loss and dielectric constant for the blend with incorporating carbon black (filled) are much higher than that of pure blend [21]. When the frequency is increased at blends, the dipoles will no longer be able to rotate in a sufficient way. As a result, their oscillations begin to lag those of the field. With further increase in the frequency, the dipole is completely unable to follow the field and the orientation polarization is stopped. Furthermore, ε' (ω) decreases at higher frequencies approaching a constant value, due to the interfacial or space charge polarization only [22](Fig. 11).

Figure 12 shows the variation of ε' and ε'' with the temperature. It is well known that dipolar groups are bound in the solid structures are structural elements of the solid lattice and the rigidity of the lattice hinders the orientation of the dipoles [22]. At higher values of temperature, the dipoles acquire energy which allows them to reorient. Accordingly, the increase in dielectric properties is achieved (*i.e.* at low frequency) by increasing the temperature, which is consistent with the present results.

Conclusion

The addition of CBR as a compatibilizer to vulcanized SBR/NBR blends greatly enhanced their compatibility and improved physical and dielectric properties of rubber composite system. SEM images and thermal studies verified the compatibilization process between two phases of blends, where it was achieved when CBR is incorporated significantly. Using the permittivity measurement as a powerful tool for investigating the efficiency of the tested compatibilizer agrees with physical and SEM investigations. The increase in dielectric constant/permittivity and

dielectric loss with increasing NBR content in vulcanized SBR/NBR blend was attributed to the increase of C≡N dipoles of NBR contents in composite system. The dielectric characterization showed that low value of the dielectric constant was detected at higher frequencies. It can be seen from the impedance spectroscopy measurements that the synthesized blends are conductive, and the conductivity increases with increasing the temperature and the activation energy values were calculated in AC conductivity measurements

section. Meanwhile, the AC electrical conductivity was noticed to increase with an increase of the temperature and frequency. The results revealed that the ac electrical conductivity varied almost linearly with the applied frequency with a high range and increased with diverse temperatures. I-V characteristics show a diode like characteristics are observed and the conduction could be thermally activated. The shape of SBR/NBR blends assisted thermal activation. This result is applicable more widely for the conduction
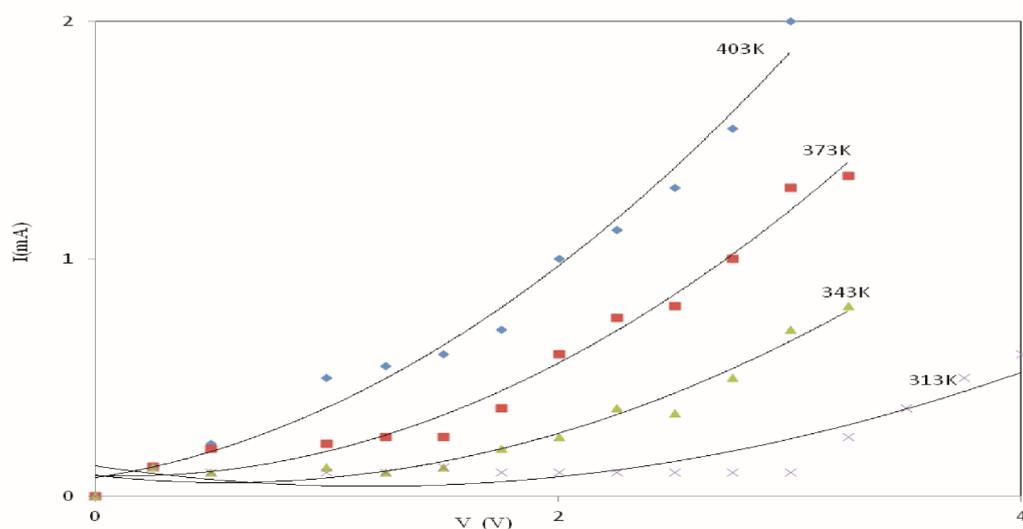

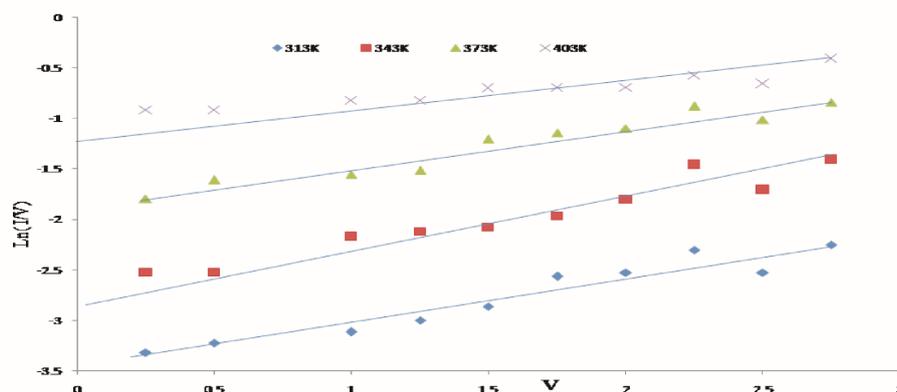**Fig. 9. Current-voltage characteristics at different temperatures for vulcanized 0SBR/100NBR blend sample.**

Fig. 10 Ln (I/V) versus V at different temperature for vulcanized 0SBR/100NBR blend sample.

TABLE 3. Fitting parameters for I-V Characteristics relation of 0SBR/100NBR blend at different region of temperatures.

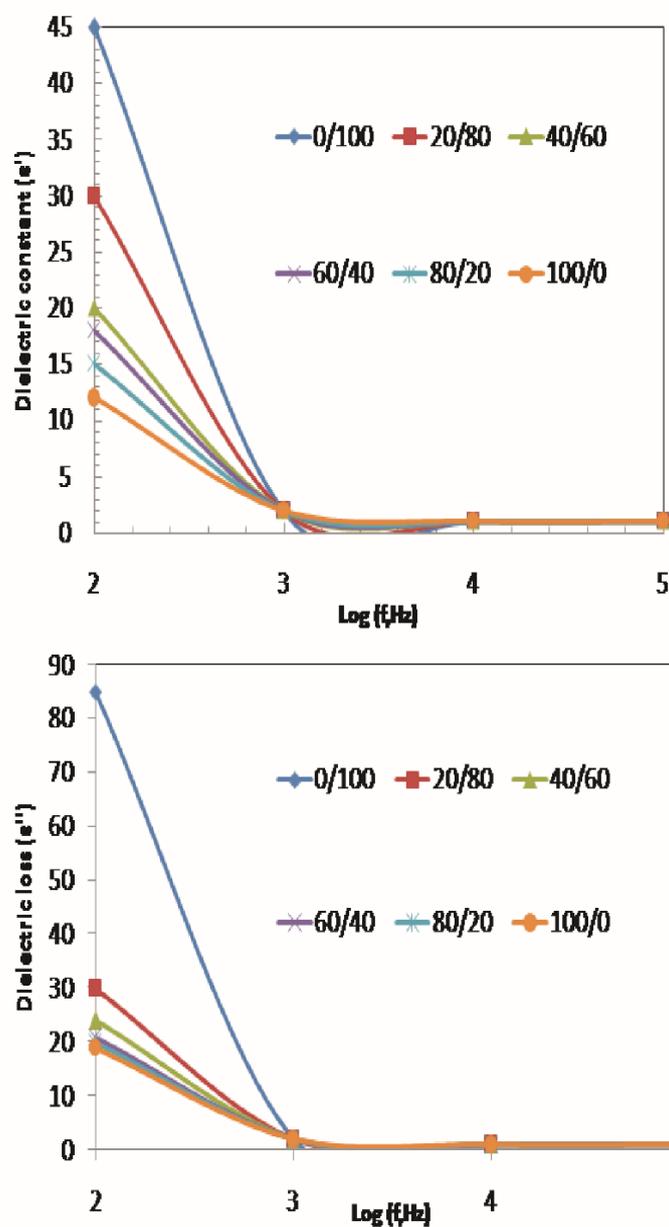| T (K)	G_0	V_0
313	1.12	3.333
343	2.01	2.5
373	4.26	2
403	9.49	2

Fig. 11. The frequency dependence of the dielectric properties for dielectric constant/permittivity, and dielectric loss of for vulcanized SBR/NBR blends at 300K.
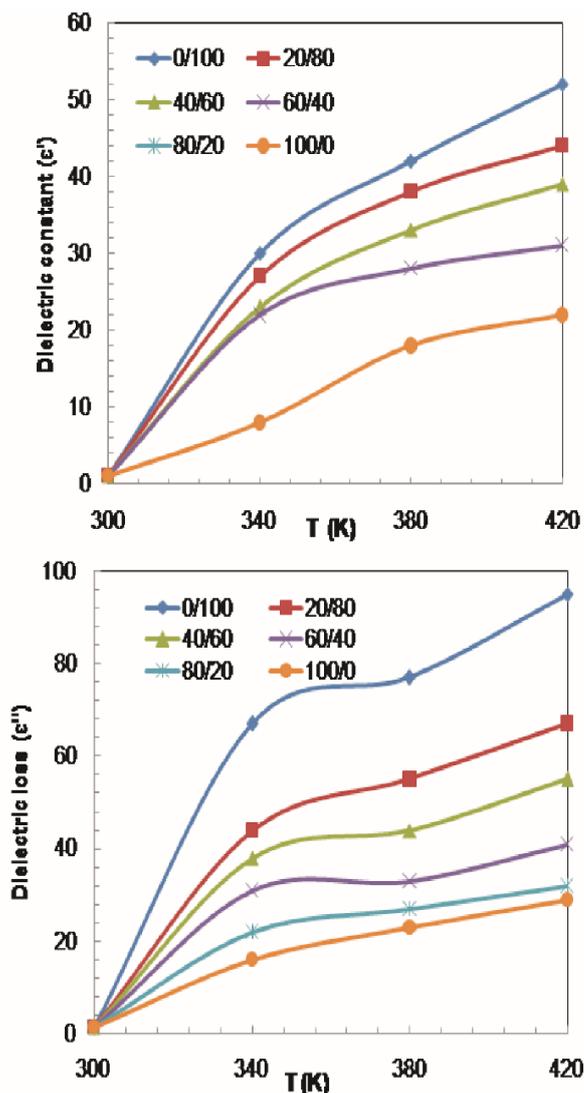
Fig. 12. The temperature dependence of the dielectric properties (dielectric constant/permittivity and dielectric loss) of vulcanized SBR/NBR blends at 100 kHz.

involving thermal activation. We can conclude from these contributions that CBR is able to create a well dispersed bi-continuous phase, and it exhibits good physical properties that close to those obtained for compatible blends having one glass transition.

Competing Interests

The authors declare that they have no competing interests.

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تأثير نسبة البليند علي الخواص الكهربية لخليط المطاط المفلكن من الاستيرين بيوتاديين والنيتريل والمعادل كيميائيا بمطاط البيوتاديين

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في هذا البحث تم تصنيع بعض توليفات من مطاط الاستيرين-بيوتاديين مع الاكريلونيتريل وذلك بتقنية الانصهار واستخدام طاحونة مزدوجة الدرفلة، ولقد استخدم مطاط البيوتاديين كمعادل قطبية لتحسين عملية الاندماج والخلط. ومن المعروف أنه لا توجد كثير من الدراسات السابقة التي تتعلق بعملية تحسين الخواص الكهربيه دون استخدام فيلر (مواد مالئة). واتضح من البحث أن الخواص المورفولوجية والتي تم استنباطها باستخدام جهاز الماسح الاكتروني التي اثبتت نتائجه تأثيرا واضحا لمطاط البيوتاديين علي البليند. هذا ولقد تحسنت الخواص الحرارية للبليند بزيادة نسبة مطاط الاستيرين بيوتاديين كما أتضح ذلك من المنحنيات المعاوقة الكهربية والتي أكدت علي وجود بعض الاقواس الدائرية والدالة علي المساهمه الفعاله من كافة تركيزات البليندات في السلوك الكهربي لتلك العينات واثبتت خصائص فرق الجهد - التيار الكهربي وجود سلوك غير خطي لتلك العينات والمتعلقة بعملية التوصيل وذلك في درجات الحرارة المنخفضة، واخيرا أكدت جميع القياسات الحرارية والكهربيه تأثير وجود معادل القطبية وايضا نسبة البليند بين تركيزات المطاط المختلفة وبالأخص الخواص الكهربية والحرارية لتلك العينات المفلكنة.