

Novel Peroxide-Vulcanized NBR-PAni.DBSA Blends, Part 2: Effects of Conductive Filler Particles Alignment

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ABSTRACT: Dicumyl peroxide (DCP) vulcanized poly(*n*-butadiene-*co*-acrylonitrile)-polyaniline dodecylbenzenesulfonate [NBR-PAni.DBSA] blends were successfully prepared by using the practical thermomechanical mixing method. The effect of alignment of PAni.DBSA particles on the mechanical and electrical properties of vulcanized blends was studied (by passing the blends through a two roll-mills). All vulcanized blends strained parallel to the flow direction when passed through the two roll-mills had their electrical conductivities enhanced with increasing strain in tension. Good historical memory in term of the electrical conductivities during three cycles of straining (with 300 times of strain loading and unloading motion

for each cycle) was observed for all vulcanized blends (99% retention of original value before straining). These vulcanized blends also showed better mechanical properties (i.e., higher tensile strength and tear strength) than the ones strained perpendicularly to the flow direction. With the ideal mechanical properties and reversible electrical behavior, this type of blend can potentially emerge as a new class of flexible smart material. © 2011 Wiley Periodicals, Inc. *J Appl Polym Sci* 124: 729–739, 2012

Key words: conductive rubber blends; polyaniline; mechanical properties; electrical properties; particle alignment

INTRODUCTION

It is well known that the physical properties of an elastomer could be altered by simply introduce particulate filler into its matrix. Changes of static and dynamic moduli,¹ strength,² and electrical conductivity^{3,4} can be usually observed for a filled elastomer. Fillers, for example, carbon black and PAni.DBSA (used throughout this work), which increase the strength of the elastomeric host significantly are the reinforcing fillers.⁵

As a rule of thumb, the electrical conductivity of a compound will be increased as the proportion of its conductive filler is increased.^{4,6–8} There is a volume fraction of conductive filler (PAni.DBSA as in this work), known as the percolation threshold,^{4,6–9} at which it can be assumed that a continuous interconnecting conductive filler network is created in the compound. Above this volume fraction, the electrical resistivity is relatively low and below this threshold, the compound behaves exactly like an insulator. In the region of the percolation threshold, it has been suggested^{3,10} that changes to the relative locations and the orientation of the conductive filler particles under the application of a strain result in changes of the electrical resistivity.

Yamaguchi et al.¹¹ reported that the electric resistance increased permanently after several cycles of

strain applied for the carbon-black filled-natural rubber and the carbon black-filled synthetic rubber test specimens. According to Sau et al.,¹² blends of ethylene-propylene-diene rubber, nitrile rubber, and silicone rubber respectively with carbon black as conductive filler, the conductivities were decreased by increasing the degree of compression. All these observations were attributed to the destruction of conductive carbon black networks.

Intrinsically conductive polymers (e.g., polyaniline) and their “buckytubes” that lead to the formation of microtubules instead of spheres^{13,14} may help to overcome the above-mentioned problems. By stretching the intrinsic electrically conductive polymer alone, an increase of the polymer’s conductivity along the orientation axis could be observed.^{15–18}

The aim of this work was to learn the effect of alignment of the conductive filler (PAni.DBSA) particles on the mechanical and electrical properties of the DCP-vulcanized NBR-PAni.DBSA blends. This could be achieved by passing the DCP containing-NBR-PAni.DBSA blends through a warm two roll-mills and marking the flow direction (either parallel or perpendicular to the mill). Mechanism of alignment of the PAni.DBSA particles within the NBR host matrix will be discussed later in the experimental part. Four major scopes of this study were including infrared (FTIR) spectroscopy, morphological study by optical microscope, and determination of the electrical conductivity and some basic mechanical properties of both raw materials and blends. It was decided to produce the

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NBR-PAni.DBSA blends by using a temperature-controllable internal mixer (Brabender Plasticorder, PL 2000E). It was also hoped to obtain a new type of high strength, elastomeric material with reversible electrical behavior that could be categorized as flexible smart material (responded to certain straining level).

EXPERIMENTAL

Chemicals and raw materials

Aniline monomer (99 wt %, Sigma-Aldrich), ammonium persulfate [APS] (98 wt %, Sigma-Aldrich), 36.5–38 wt % HCl solution (GPR), anhydrous ferric chloride [FeCl₃] (98 wt %, Sigma-Aldrich), 33 wt % ammonia solution (GPR), 70 wt % DBSA solution in 2-propanol (GPR, Sigma-Aldrich), chloroform (GPR), and methanol (GPR). PAni.DBSA with 42% protonation level was prepared by procedures described in the author's previous work.⁴ Commercial grade NBR [Krynac[®] 50.75 (Bayer)] was used. By ¹H NMR analysis of solutions in THF-d₈, the actual ACN content for this NBR was identified as 48.2 ± 1.0 wt %. Dicumyl peroxide (DCP; Peroximon DC40 supplied by Elf Atochem with 40 wt % of DCP, 55 wt % of calcium carbonate, and 5 wt % of silica gel) was used as the vulcanizing agent.

Preparation of NBR-PAni.DBSA blends and addition of peroxide

An internal mixer (Brabender Plasticorder, PL 2000E) was first used to prepare the nonvulcanized NBR-PAni.DBSA blend master batches with different compositions of NBR wt % : PAni.DBSA wt % (i.e., 99 : 1, 97.5 : 2.5, 95 : 5, 90 : 10, 80 : 20, 70 : 30, 60 : 40, and 50 : 50). NBR with 48.2 wt % of acrylonitrile content showed the best compatibility with the PAni.DBSA,⁴ and it was also the only grade of NBR used throughout this work. An internal mixer with fill factor of 0.75 (free total volume, 320 mL) was chosen to perform the mixing. The starting temperature of each mixing was 140°C and the mixer rotor speed was set at 100 r.p.m. Table I summarizes the procedures of each mixing.

Procedures of mixing for NBR-PAni.DBSA blend master batch by using an internal mixer

DCP of 2.5 p.h.r (density = 1030 kg m⁻³) was added manually to each of the NBR-PAni.DBSA blend master batches (with different proportions of both components) on a prewarmed 50°C two roll-mills with gap distance adjusted to 3 mm. Each master batch was removed from the two-roll mill in sheet form after about 3 minutes of mixing. The highest safe processing temperature of DCP is about 130°C.¹⁹

Preparation of peroxide-vulcanized test pieces

The DCP-containing NBR-PAni.DBSA blend sheet as prepared by the two-roll mill was analyzed. The

TABLE I
Procedures of Mixing for NBR-PAni.DBSA Blend Master Batch by Using an Internal Mixer

Stage of mixing	Timing
1. Addition of raw NBR	Zeroth minute
2. Addition of PAni.DBSA	First minute
3. Sweeping	Second minute
4. Dumping	Tenth minute
(Total time= 10 minutes)	

flow direction of passage through the mill was marked on each sheet to study the effect of particles orientation or alignment on its mechanical properties. Appropriate amounts of each blend were cut from the sheet and fed into a 2 mm thick rectangle (130 × 100 mm²) mold. The mold together with the blend was sent for hot pressing (with a Bradley & Turton hot press) and curing (with conditions as optimized in the author's earlier work,⁶ i.e., temperature 150°C, pressure 60 psi and duration 38 min).

Test pieces for the tensile strength (BS ISO 37²⁰), elongation at break (BS ISO 37²⁰), and crescent tear strength (BS ISO 34-1²¹) were cut out from these molded sheets for directions parallel and perpendicular to the marked flow. Test pieces in disc shape (with thickness 6.3 mm and diameter 13 mm) that were needed for hardness measurement (BS 903-A26²²) were prepared by feeding the disc-shaped mold with layers of blended material direct from the two roll-mills (without taking count the flow direction). So, a random molecular orientation was assumed for test pieces prepared for hardness measurement. Test pieces were also prepared from the non-PAni.DBSA added vulcanized-NBR blend for control purpose. It was not possible to prepare the pure PAni.DBSA test piece by using this hot press-molding technique due to its glassy behavior (which could lead to the shrinkage of its test piece).

Mechanical property tests

All the basic mechanical properties (i.e., IRHD hardness, tensile properties, and tear strength) tests were performed according to BS or BS ISO standards. Six test pieces of each blend were used to repeat each test to define the final result as the mean value of a total of six measurements. The effect of PAni.DBSA particles alignment could be learned through these measurements for designing a brand new class of high strength, good elastomeric material with reversible electrical behavior.

Morphological study (optical microscopy)

All peroxide-vulcanized NBR-PAni.DBSA blends were studied with a Nikon OPTIPHOT-2 optical microscope (magnification 200 times). All observed images were captured digitally. Transparent films (1

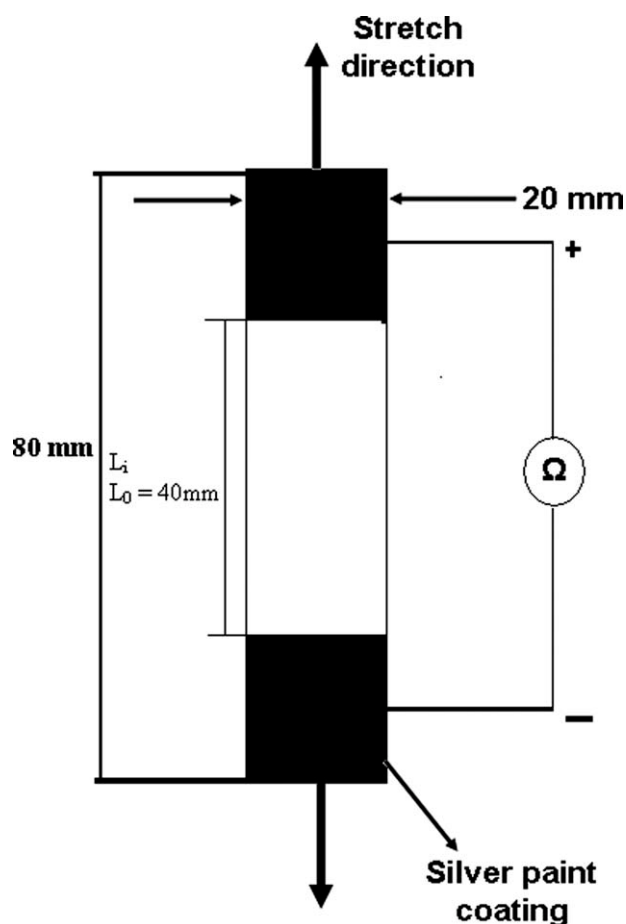


Figure 1 Electrical measurement setup (2-probe method) for the study of straining effect on the peroxide-vulcanized NBR-PAni.DBSA blends.

cm width \times 1 cm length \times 100 μ m thickness) were prepared by using a hot press (at 150°C, 5 min) for all the blends (after passing through the two roll-mills) to study the effect of stretching on the alignment of PAni.DBSA polymer chains within the rubber host matrix. Stretching of each thin sample (up to 30% elongation before it was torn) was performed manually using an in-house designed metal jig.

FTIR spectroscopy

Infrared (IR) spectra of the peroxide-vulcanized NBR and the peroxide-vulcanized NBR-PAni.DBSA blends were recorded on a Perkin-Elmer FTIR Spectrometer PARAGON 100. A small amount of each solid sample was hot-pressed (Bradley & Turton hot press at 150°C, 5 min) to obtain a transparent thin film (1 cm width \times 1 cm length \times 100 μ m thickness). The stretching of each thin sample (up to 30% elongation) was also performed manually by using an in-house designed metal jig.

Electrical conductivity determination

The effect of straining (up to 100% elongation of sample) on the peroxide-vulcanized blends' dc elec-

trical conductivities (prepared parallel and perpendicular to the flow direction when passed through the two roll-mills) were determined. A Keithley 617 programmable electrometer and a Keithley 224 programmable current source (both under computer control) were used. For each blend, six test pieces (in strip form with dimensions 80 \times 20 \times 1 mm³) were prepared using a hot press (150°C, 5 minutes) to obtain a mean value. Each of the test pieces was strained at a constant rate of 100 mm/min. Three separated cycles of straining process were carried out for all blends. Each cycle of straining process consisted 300 times of strain loading and unloading motion (i.e., with sample stretched to 100% elongation and then, returned back to 0% elongation). The mean result of each cycle was calculated and presented in Section "Electrical Conductivity Determination." The electrical "resistance" measurement set-up in this part of work is shown in Figure 1 based on the 2-probe method and Eq. (1).

$$\sigma = \left(\frac{1}{R}\right) \left(\frac{L}{A}\right) \quad (1)$$

where σ is the electrical conductivity, R is the mean value of apparent resistance (voltage/current ratio) for the pressed sample, L is the measured electrode spacing distance, and A is the cross-sectional area of pressed sample between the current-carrying electrodes.

Both opposite faces and edges of each test piece were coated with a large area of quick-drying silver paint (Acheson Electrodag 915) to minimize the effect of contact resistance. A fine copper wire with length 5 cm was attached to the middle of each side of these silver paint coated-areas for connection to the ohmmeter. All the contacting surfaces between the tensile tester and the test piece were properly insulated by a layer of PTFE sheet (\sim 1.0 mm thick). All readings were made at 10 s after each elongation step to standardize the effect of stress relaxation. The new length (L_i) and thickness (d_i) values of each test piece were also measured after each elongation step to calculate the new values of cross-sectional area (A_i).

RESULTS AND DISCUSSION

Mechanical property tests

IRHD hardness measurement

Results (error $\pm 1^\circ$ hardness) of the IRHD measurement are summarized in Figure 2. The degree value of hardness of blend (IRHD) increased with increasing proportion of added PAni.DBSA. This was due to the glassy nature of PAni.DBSA²³ and the increased stiffness of blend as the content of conductive polymer

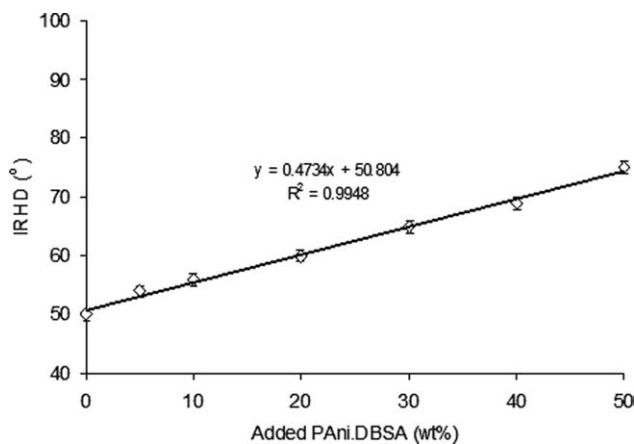


Figure 2 Hardness (IRHD) of the peroxide-vulcanized NBR and peroxide-vulcanized NBR-PANi.DBSA blends prepared by thermomechanical mixing.

increased. The higher the IRHD value, the stiffer the prepared material. Both of these two parameters could be linearly related with a slope of 0.4734 and intercept of 50.804 as shown in Figure 2.

Tensile strength and elongation at break percentage measurement

Results (error ± 0.05 MPa) of the tensile strength experiments are shown in Figure 3. For test pieces cut and strained parallel to the flow direction, PANi.DBSA acted as a reinforcing agent, so their tensile strength increased with the proportion of PANi.DBSA (5–30 wt %). The tensile strength decreased for blends with ≥ 40 wt % of PANi.DBSA (due to the increase of phase-separated PANi.DBSA regions). For test pieces stretched perpendicular to the flow direction, it was observed that there were some smaller reinforcing effects for blends up to 30 wt % of PANi.DBSA,

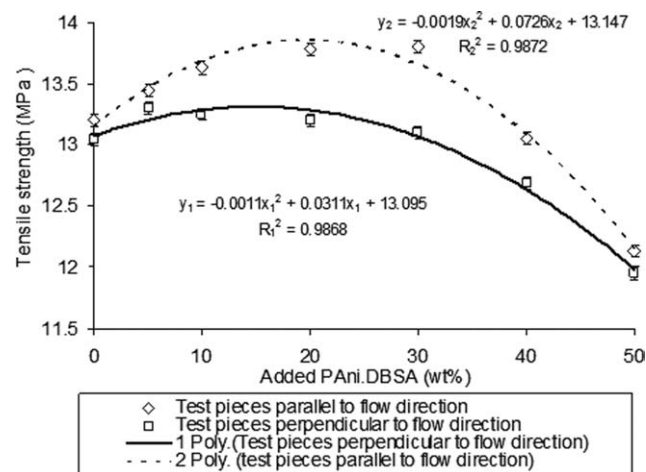


Figure 3 Tensile strength of peroxide-vulcanized NBR and peroxide-vulcanized NBR-PANi.DBSA blends (test pieces stretched parallel and perpendicular to the flow direction when passing through the mill).

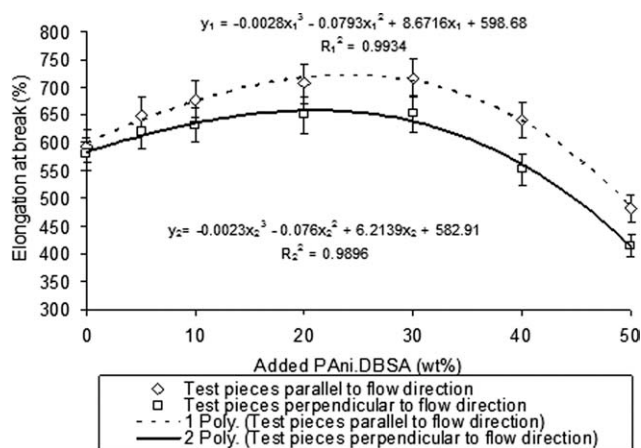


Figure 4 Elongation percentage at break (EB%) of peroxide-vulcanized NBR and peroxide-vulcanized NBR-PANi.DBSA blends (test pieces stretched parallel and perpendicular to flow direction when passing through the mill).

i.DBSA, by comparing to test pieces stretched parallel to the flow direction. Both sets of tensile strength versus concentration data (strained parallel and perpendicular to the flow direction) could be modeled by quadratic equations (correlation coefficients, ~ 0.99) as shown in Figure 3.

Results (error $\pm 5\%$) of the elongation percentage at break (EB%) measurement are summarized in Figure 4. For test pieces stretched parallel to the flow direction, the EB% values increased with the proportion of PANi.DBSA (5–30 wt %). The EB% was reduced for blends with >30 wt % of PANi.DBSA. For test pieces stretched perpendicular to the flow direction, it was observed that the EB% also increased with increasing proportion of PANi.DBSA up to 30 wt % of PANi.DBSA. However, their EB% values were lower than the values obtained for test pieces stretched parallel to the flow direction. Both of these data sets (stretched parallel and perpendicular to the flow direction) could be modeled by equations (correlation coefficients, ~ 0.99) as shown in Figure 4.

When a test piece with PANi.DBSA contents up to 30 wt % was extended by a tensile force (stretched parallel to the flow direction), it is proposed that the reinforcing effect observed was due to the elongation and alignment of the PANi.DBSA polymer chains that moved closer to each other (as illustrated by Fig. 5). As a result, they attracted each other more strongly and possibly paracrystallized. Test pieces stretched perpendicular to the flow direction (with ≤ 30 wt % PANi.DBSA) showed smaller reinforcing effects compared to those stretched parallel to the flow direction. This was likely attributable to the higher proportions of well-blended regions (involving some very small and well-dispersed PANi.DBSA particles) produced for those samples (see Section “Electrical Conductivity Determination”). For test pieces with PANi.DBSA

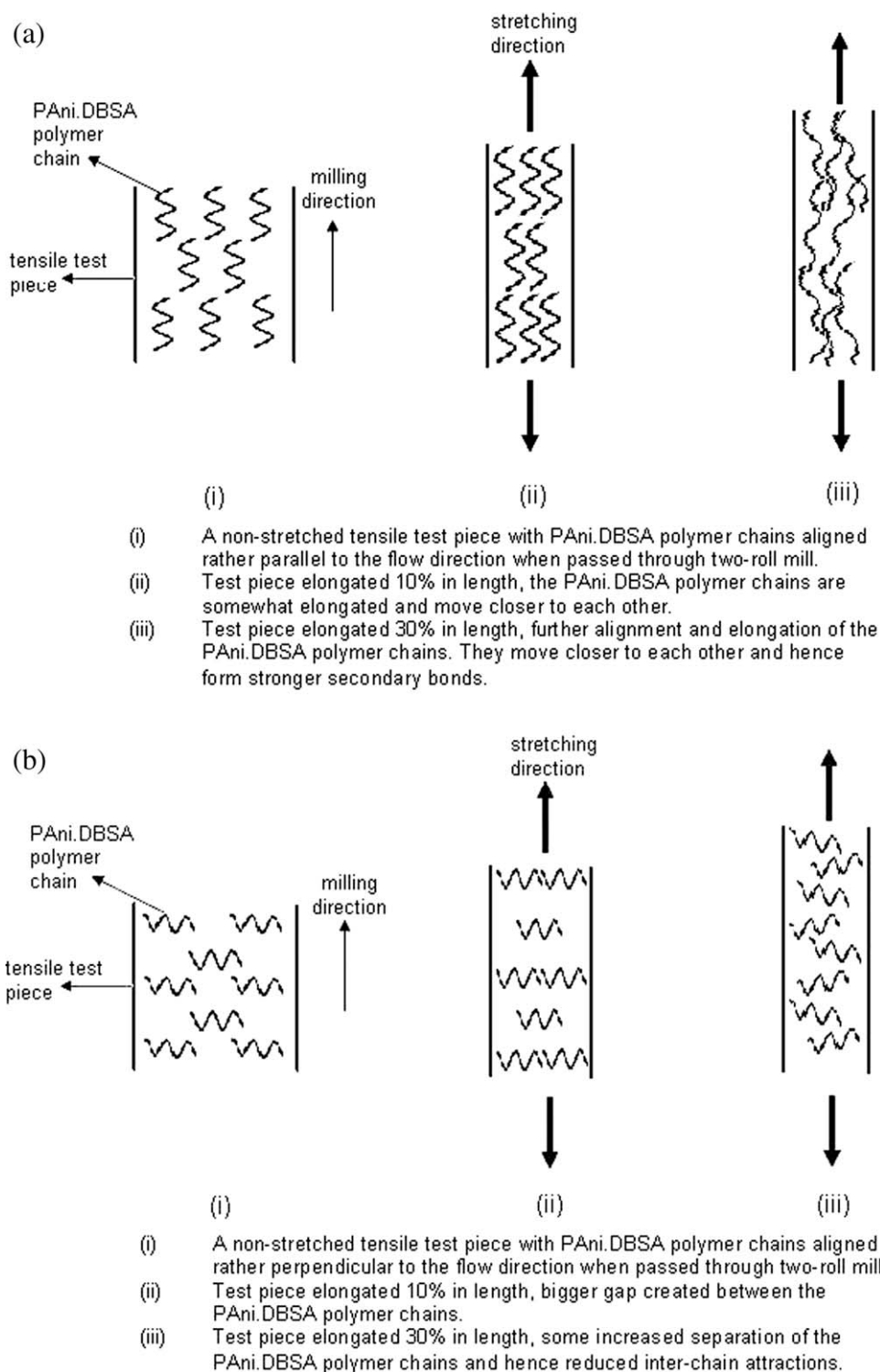


Figure 5 Two-dimensional illustrations of the majority alignment of PAni.DBSA polymer chains for a tensile test piece during the stretching process; (a) test piece stretched parallel to the flow direction when passed through the two roll-mills and (b) test piece stretched perpendicular to the flow direction.

content ≥ 40 wt % (either stretched parallel or perpendicular to the flow direction), it is proposed that phase-separated PAni.DBSA regions had started to determine the blends' mechanical properties, making the tensile values decrease and approach those of pure PAni.DBSA.²⁴

Crescent tear strength measurement

Results (error ± 0.2 kN/m) for crescent tear strength are summarized in Figure 6. For test pieces stretched parallel to the flow direction, the PAni.DBSA was acting as a reinforcing agent, and so the crescent tear

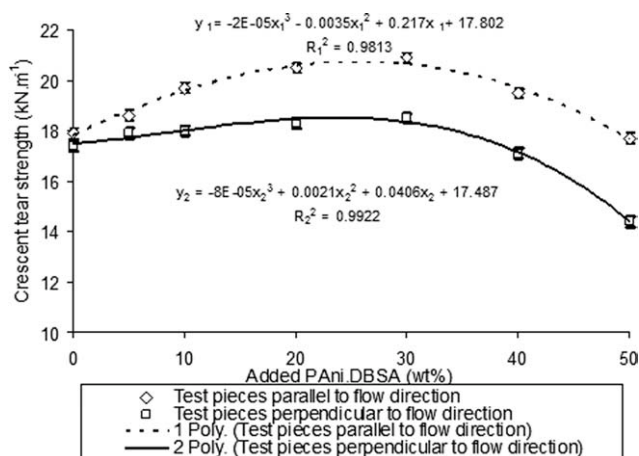


Figure 6 Crescent tear strength of peroxide-vulcanized NBR and peroxide-vulcanized NBR-PANi.DBSA blends (test pieces stretched parallel and perpendicular to the flow direction).

strength values increased with the proportion of PANi.DBSA (up to 30 wt %). For test pieces stressed perpendicular to the flow direction, their crescent tear strength values were lower than the ones obtained by stretching parallel to the flow direction. This phenomenon can be described with the simple 2D models as illustrated by Figure 7. The cubic equations (with correlation coefficients, ~ 0.99) shown in Figure 6, successfully fit both of these two data sets (parallel and perpendicular to the flow direction).

Morphological study (optical microscopy)

The effect of stretching on the alignment of PANi.DBSA polymer chains within the NBR host matrix

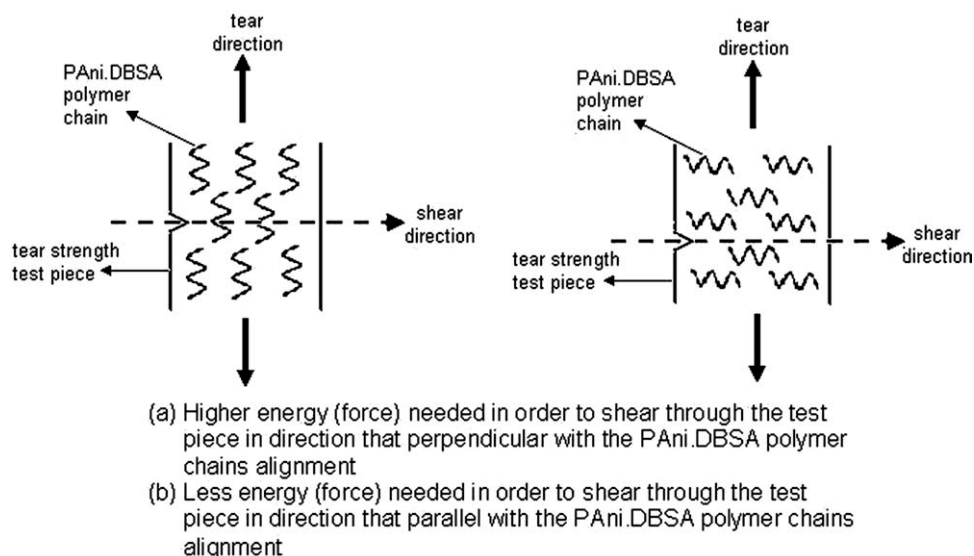


Figure 7 Two-dimensional illustrations of the majority alignment of PANi.DBSA polymer chains for a test piece during crescent tear strength test; (a) test piece stretched perpendicular to the flow direction when passed through the two roll-mills and (b) test piece stretched parallel to the flow direction.

was studied by optical microscope. Figure 8 shows the example of optical micrographs for blends with 30 wt % of PANi.DBSA. All micrographs showed the two classic regions, that is, dark colored (dark green in actual)-ones (rich in PANi.DBSA) and pale colored (pale green in actual)-ones (rich in NBR). As observed from Figure 8, majority of the isolated dark colored-regions were aligned rather to the flow direction when passed through the two roll-mills.

Some elongated dark colored-regions were observed for sample that was stretched $\geq 10\%$ in length [see Fig. 8(b) for example] parallel to the original flow direction. For sample that was stretched $\geq 10\%$ in length perpendicular to the flow direction [see Fig. 8(c) for example], the gaps between the dark colored-regions (rich in PANi.DBSA) became bigger. The patterns of the majority alignment of these dark colored-regions as captured by the optical micrographs are in agreement with the proposed 2D illustrations (see Figs. 5 and 7).

FTIR spectroscopy

The effect of stretching was not obvious (in terms of peak shift and absorbance intensity) for the blends with low proportion of PANi.DBSA (10 wt % or below) and this is almost certainly due to the reasonably high compatibility between the two mixed components as this level (less separated phases as observed by microscopy). This phenomenon explains why the mechanical properties (see Figs. 3, 4, and 6) of both sets of test piece (either stretched parallel or perpendicular to the flow direction) at these levels of added PANi.DBSA are very similar.

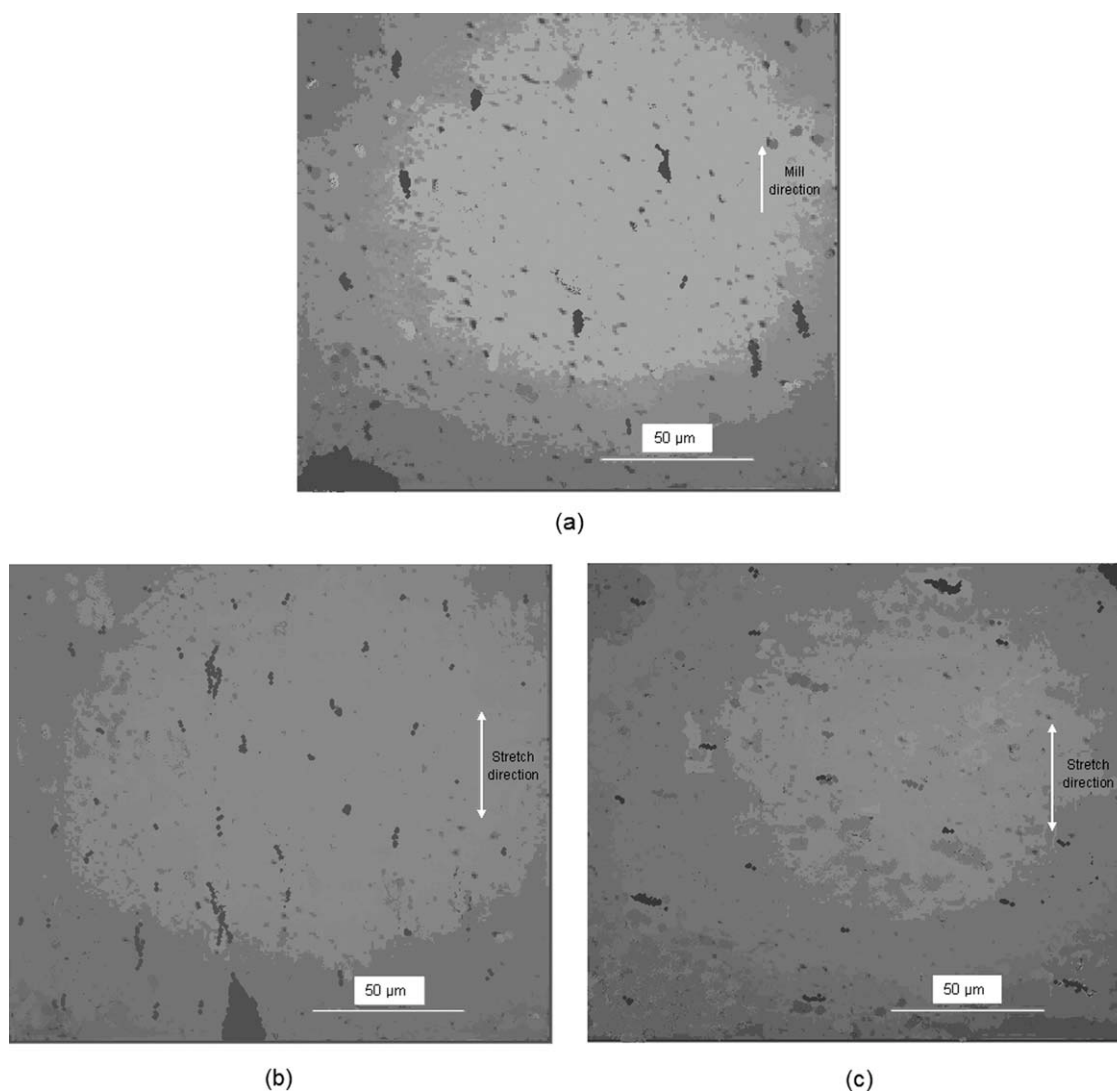


Figure 8 Optical micrographs ($\times 200$ magnification) for the peroxide-vulcanized NBR-PAni.DBSA blends (70 wt % : 30 wt %) prepared by thermomechanical mixing. Samples are (a) nonstretched but aligned parallel to the flow direction when passed through the two roll-mills, (b) 30% elongation parallel to the flow direction, and (c) 30% elongation perpendicular to the flow direction.

Characteristic FTIR absorptions of NBR are presented at peaks 2238 cm^{-1} ($\text{—C}\equiv\text{N}$ stretching), 1630 cm^{-1} ($\text{C}=\text{C}$ stretch) and $1440\text{--}1445\text{ cm}^{-1}$ (out of plane C—H wagging). Meanwhile, the spectrum of PAni.DBSA has characteristic peaks at 3448 cm^{-1} ($=\text{N—H}$ stretching), 1559 cm^{-1} ($\text{N}=\text{quinoid}=\text{N}$), 1478 cm^{-1} (N—benzoid—N), 1295 cm^{-1} ($\text{quinoid}=\text{N—benzoid}$), 1240 cm^{-1} (C aromatic—N stretching), and 1030 cm^{-1} ($\text{S}=\text{O}$ stretching).

Greater peak shifts (both of the $=\text{N—H}$ and $\text{S}=\text{O}$ functional groups) towards the values of pure PAni.DBSA and absorbance intensity changes (see Fig. 9 for examples) were observed for blends (≥ 20 wt % of PAni.DBSA) stretched parallel to the flow direction, as the elongation of their samples increased. It is likely that this was due to the existence of higher levels of interaction (e.g., secondary bonding) among the elongated PAni.DBSA polymer chains as

observed from the optical micrographs [see Fig. 8(b) for example]. However, no obvious peak shifts and changes of peak absorption intensities were observed for the blends stretched perpendicular to the flow direction. This was attributed to the decreased level of intermolecular interaction and different alignment of the PAni.DBSA polymer chains as illustrated in Figure 5(b).

Electrical conductivity determination

The electrical conductivities of all peroxide-vulcanized NBR-PAni.DBSA blends were determined by stretching them both parallel and perpendicular to the flow direction when passed through a two-roll mill. The charts of log electrical conductivity (in mean value) versus strain for the representative examples are presented in Figures 10 and 11. It is

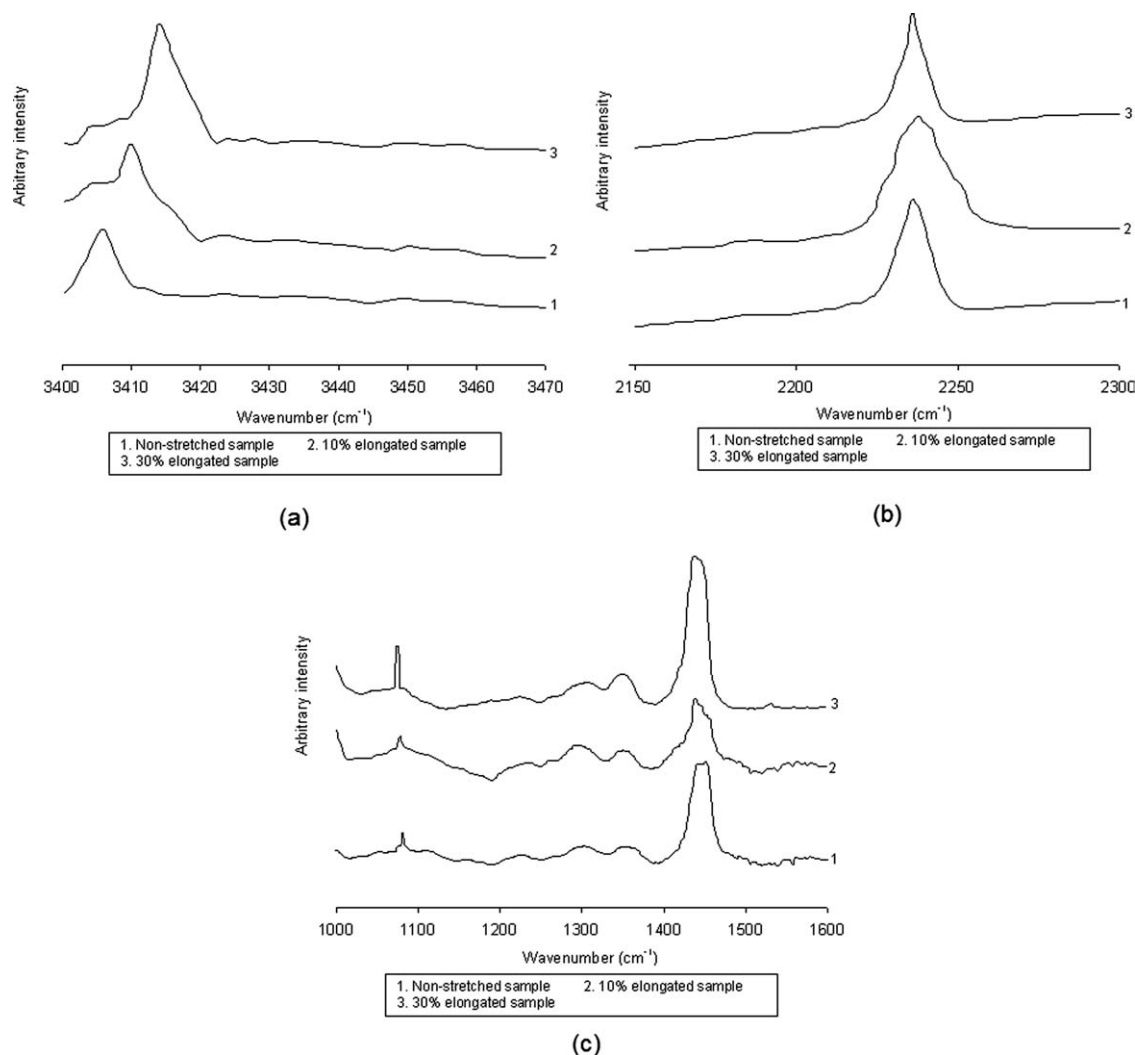


Figure 9 FTIR spectra of nonstretched and stretched peroxide-vulcanized NBR-PAni.DBSA blends (70 wt % : 30 wt %) stretched parallel to the flow direction when passing through the two roll-mills. (a) 3400–3470 cm^{-1} , (b) 2150–2300 cm^{-1} , and (c) 1000–1600 cm^{-1} .

proposed that the realignment of PAni.DBSA polymer chains in the phase-separated regions gave rise to the measured electrical conductivities for all these blends. As a result, the effect of strain on the electrical conductivities was less obvious for blends with low content of PAni.DBSA (≤ 10 wt %) which had relatively good compatibility.

For the peroxide-vulcanized blends stretched parallel to the flow direction (see Fig. 10), the electrical conductivities increased when the percentage of strain increased ($>40\%$ of straining for blends with ≤ 10 wt % PAni.DBSA and $\geq 10\%$ of straining for blends with ≥ 20 wt % PAni.DBSA). It is likely that this was attributed to the alignment and the increasing of interactions (e.g., secondary bonding) between the conductive filler particles in the phase-separated regions (as reported in the literatures^{13,14} and as shown by Fig. 5). It was observed that all the blends cut and stretched parallel to the flow direction had

good historical memory in terms of their electrical conductivities during the strain unloading process, where they had at least equal or slightly higher electrical conductivity values compared to the original ones.

The blends stretched perpendicular to the flow direction (see Fig. 11) had smaller changes of electrical conductivity with strain than those stretched parallel to the flow direction. This is believed to be due to the lower levels of inter-chain interaction formed among the elongated PAni.DBSA polymer chains (consistent with the results obtained using both optical microscopy and FTIR spectroscopy). As a result, the electrical conductivities measured during the strain-unloading process were also slightly lower than those measured during the strain loading.

The effect of strain on the peroxide-vulcanized blends prepared by thermomechanical mixing was very small since the changes of the measured

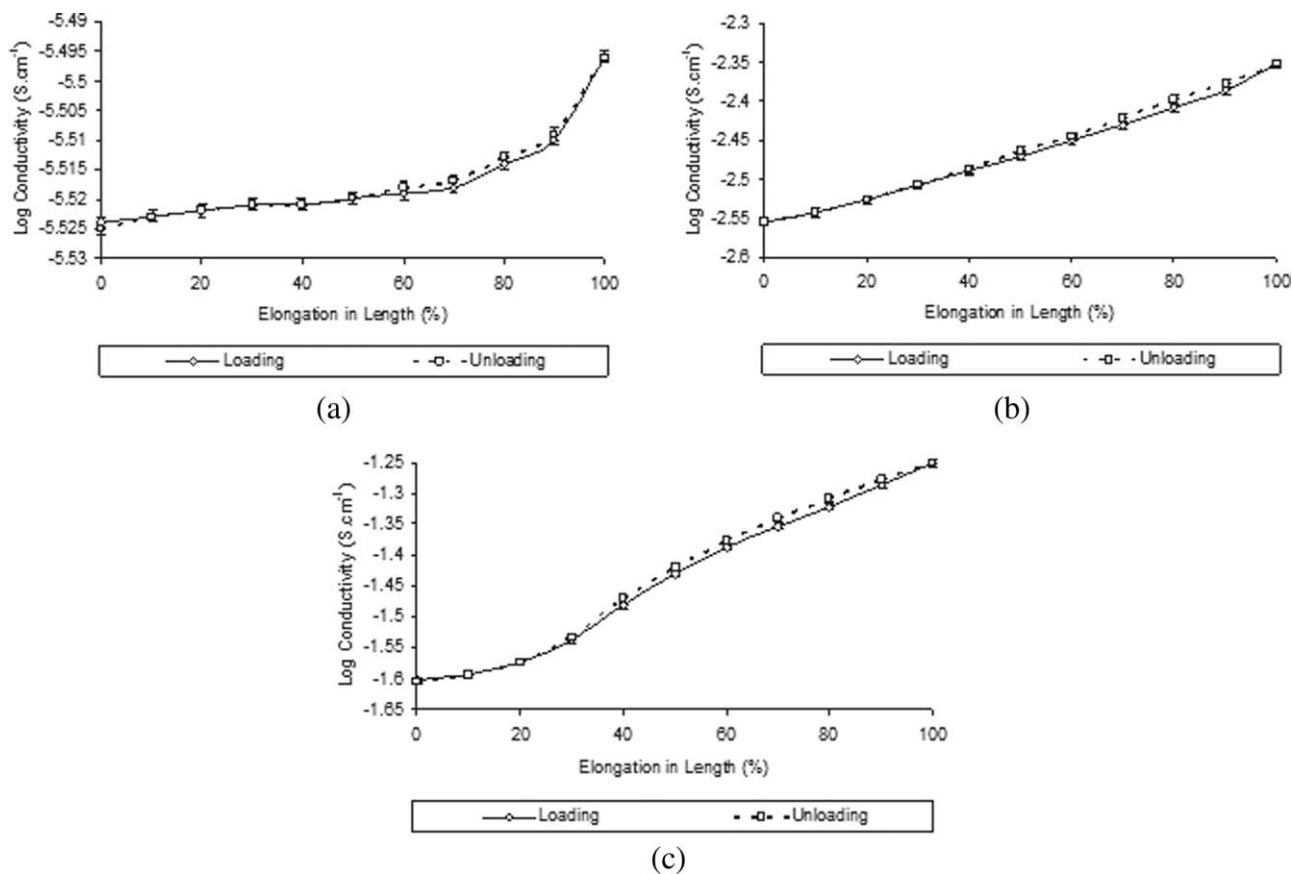


Figure 10 Charts of log electrical conductivity versus strain (third cycle of straining process) for the peroxide-vulcanized NBR-PAni.DBSA blends stretched parallel to the flow direction when passed through the two roll-mills; (a) blend with 10 wt % PAni.DBSA, (b) blend with 30 wt % PAni.DBSA, and (c) blend with 50 wt % PAni.DBSA.

electrical conductivities were observed to be within the same order. This was attributed to the morphology nature of these high temperature-produced blends, where more well blended regions (which involved mixing on the nano scale level that was not easily affected by the alignment effect) between the two polymers were obtained.⁷

After completed the third cycle of straining, all the peroxide-vulcanized blends could retain at least 99% of their original unstrained electrical conductivities. This was again due to the large amounts of well-blended region produced for all these blends. For the blends stretched parallel to the flow direction, the flexibility of the conductive networks build-up by the elongated PAni.DBSA particles within the phase-separated regions [see Fig. 10(b)] probably also contributed to the good historical memory in terms of their electrical conductivities during the cycles of strain.

The electrical properties of all peroxide-vulcanized blends prepared in this work were in contrast with those of the blends prepared with the commonest conventional conductive filler, that is, carbon black. According to the literature,¹¹ the electrical conductivities of test pieces prepared from the natural rub-

ber-carbon black composites decreased permanently during the first cycle of strain. This was attributed to the high levels of phase separation between the two constituent materials and the permanent destruction of conductive carbon black networks within the phase-separated regions after straining. The carbon black particles were also reported¹¹ to be spherical in shape rather than the elongated one observed for PAni.DBSA in this work.

CONCLUSION

It is concluded that all peroxide-vulcanized NBR-PAni.DBSA blends prepared and strained parallel to the flow direction had their electrical conductivities enhanced with increasing strain, as a result of the alignment and increasing of interactions (shown as the peak shifts of FTIR spectra) among the elongated PAni.DBSA chains in the phase-separated regions (shown as the dark colored-regions in the optical micrographs). All these peroxide-vulcanized blends also had good historical memory in term of their electrical conductivities even after 900 times of strain loading and unloading process. This was thought to

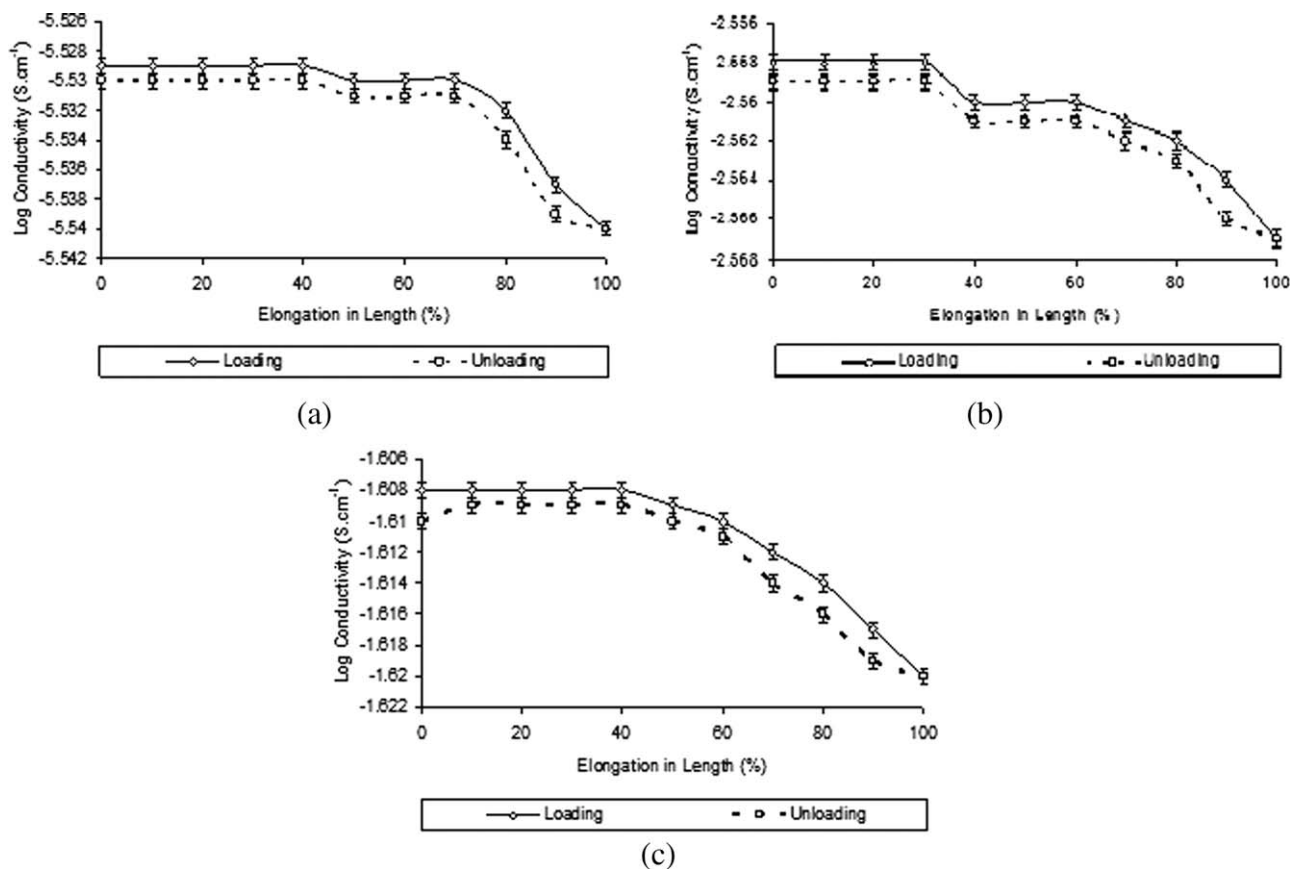


Figure 11 Charts of log electrical conductivity versus strain (third cycle of straining process) for the peroxide-vulcanized NBR-PAni.DBSA blends stretched perpendicular to the flow direction when passed through the two roll-mills; (a) blend with 10 wt % PAni.DBSA, (b) blend with 30 wt % PAni.DBSA, and (c) blend with 50 wt % PAni.DBSA.

be due to the high levels of well-blended region produced in all these blends.

Tensile properties and tear strengths of these blends were enhanced by increasing PAni.DBSA content up to 30 wt %, where PAni.DBSA exhibited reinforcing effect before they were facing major phase separation problem. Samples stretched parallel to the flow direction when passed through the two roll-mills also had better mechanical properties (i.e., tensile strength and tear strength) if compared to the “perpendicular” ones, due to the better levels of interaction and alignment of PAni.DBSA polymer chains within the rubber host. Recommended dosages of PAni.DBSA for preparing the peroxide-vulcanized electrical conductive NBR based blends are ranging from 6.0 to 50.0 wt % (as agreed with the author’s previous work⁷). With the ideal mechanical properties and reversible electrical behavior, these peroxide-vulcanized blends can potentially emerge as a new class of flexible smart material.

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