Effect of Epoxidized Natural Rubber on Thermal Properties, Fatigue Life, and Natural Weathering Test of Styrene Butadiene Rubber/Recycled Acrylonitrile-Butadiene Rubber (SBR/NBRr) Blends

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ABSTRACT: The utilization of waste rubber powder in polymer matrices provides an attractive strategy for polymer waste disposal. Addition of recycled acrylonitrile-butadiene rubber (NBRr) in rubber compounds gives economic (lowering the cost of rubber compounds) as well as processing advantages. In this study, the properties of styrene butadiene rubber (SBR)/NBRr blends with and without epoxidized natural rubber (ENR-50) as a compatibilizer were determined. The results such as thermal gravimetric analysis (TGA), fatigue life, and natural weathering test of SBR/NBRr blends with and without ENR-50 were carried out. Results showed that TG thermograms of SBR/NBRr blends with ENR-50 show lower thermal stability compared blends without ENR-50. The incorporation of ENR-50 into SBR/NBRr blends has reduced char residue compared SBR/NBRr blends without ENR-50. The incorporation of ENR-50 in SBR/NBRr blends has increased the rigidity of the blends thus lowering the fatigue life. The increment in tensile properties retention of SBR/NBRr blends with ENR-50 indicated the enhancement on weathering resistant. The surfaces of SBR/NBRr blends with ENR-50 after 6 months exposure showed a minimal severity of crack compared with SBR/NBRr blends without ENR-50. It revealed that the scale of cracks has reduced indicating well-retaining interfacial adhesion between SBR and NBRr with the presence of ENR-50 as a compatibilizer. © 2011 Wiley Periodicals, Inc. J Appl Polym Sci 123: 779–787, 2012

Key words: SBR/NBRr blends; ENR-50; TGA; natural weathering; scanning electron microscopy

INTRODUCTION

In recent years, the practice of recycling has been encouraged and promoted by increasing awareness in environmental matters and the subsequent desire to save resources. Together with the relatively high cost of polymers and sometimes high levels of scrap material generated during manufacture, recycling becomes a viable and attractive option.[1]

Recycled latex has become a focus of attention compared with reclaimed rubber due to the lightly crosslinked and high quality nature of rubber hydrocarbon.[2] As for polymer latex such as NBR (acrylonitrile-butadiene rubber) latex, unlike NR (natural rubber), is not traded on any futures exchange. The use of NBR latex in glove production mostly in healthcare, food industry, and examination applications has increased all over the world due to its excellent resistance to puncture and tears as well as the nonexistence of leachable allergenic proteins, unlike NR latex. Currently, Malaysia is the world's largest exporter and producer of both nitrile and NR gloves. Malaysia at this time caters between 60% and 65% of the world's natural glove market and also supplies about half of the world's nitrile glove market.[3] Malaysia is the leading supplier of examination and surgical gloves, satisfying 45% of the world's demand. According to Department of Statistics of Malaysia, in year 2005, the value export of gloves including surgical and other gloves were 3793.23 million Malaysian ringgit and rise accordingly to 5991.92 million ringgit Malaysia in year 2009.[4] Owing to such aspect like emergence of diseases such severe acute respiratory syndrome (SARS), influenza A (H1N1), increase affluence and health awareness of the world population, and recession proof industry as glove is a necessity regardless of economic condition, the growing in world's glove market has been rising. However, after a certain period of time, these polymeric materials are not serviceable and mostly discarded, and as a result, significant quantities of discarded gloves are generated.

A number of possible applications of various forms of waste rubber in broad disciplines have been studied and reported.[5–14] The authors[15] reported the comparison properties of virgin NBR (NBRv) and recycled NBR (NBRr) of styrene butadiene rubber (SBR)/NBRr blends. It revealed that most of SBR/NBRr blends properties such as tensile strength and fatigue life showed a better value compared with SBR/NBRv (virgin) blends particularly up to 15 phr of NBRr and then decreased. Furthermore, the SBR/NBRr blends with smallest size of NBRr particles show better mechanical properties (tensile, elongation-at-break, M100, and fatigue) compared with all other blend ratios of bigger sizes of NBRr particles.[16] The SBR/NBRr blends with smallest size of NBRr also show a better retention of tensile properties which able to withstand better weathering than coarser size of NBRr in SBR/NBRr blends.[17] The effect of electron beam (EB) irradiation in the presence of polyfunctional monomer, trimethylolpropane triacrylate (TMPTA) on cure characteristics, and mechanical properties of SBR/NBRr blends were also investigated.[18] Results showed that the tensile strength of irradiated blends were higher than unirradiated blend particularly at 25, 35, and 50 phr of NBRr. Such increase in tensile strength on irradiation attributed to the formation of irradiation-induced crosslinks in the blend.

In recent year, there have many of papers investigating epoxidized natural rubber (ENR) as a compatibilizer with whole variety of rubber and other elastomer blends.[19–24] Rajasekar et al.[25] studied the development of nitrile butadiene rubber-nanoclay composites with ENR as compatibilizer. By incorporating ENR-50, results showed enhancement in overall mechanical properties, higher swelling resistance in oil and solvent, and decrease in compression set due to higher reinforcing efficiency of nanoclay in the NBR matrix. Effects of ENR as a compatibilizer in melt compounded NR-organoclay nanocomposites was studied by Teh et al.[26] They found that the best clay dispersion was achieved by adding ENR-50 which was reflected in the stiffness of the nanocomposites derived from both dynamic mechanical thermal analysis (DMTA) and tensile tests.

Previously, the author has carried out the studies on the effect of ENR-50 as a compatibilizer in SBR/NBRr blends.[27] The incorporation of ENR-50 has improved the tensile strength, tensile modulus (M100, stress at 100% elongation), hardness, and crosslinked density of SBR/NBRr blends compared with SBR/NBRr blends without ENR-50. Therefore, regarding to the present output of nitrile glove, perhaps the utilization of nitrile waste (glove) will be a great deal of interest in the rubber industry about the development of cost-effective techniques to convert waste and used rubber into a processable form in future. The aim of this study is to have better knowledge regarding NBRr with SBR blends in presence of compatibilizer. This paper reports the study on fatigue life, thermal gravimetric analysis (TGA), and weathering properties of SBR/NBRr blends with and without ENR-50 as a compatibilizer.

EXPERIMENTAL

Materials, blends preparation, compounding, cure characteristics, and vulcanization

The materials and their characteristics used in this study are shown in Table I. The SBR/NBRr blends with and without ENR-50 were formulated with blends ratio as given in Table II, respectively. The rubber was preblended, and the mixing procedure was carried in room temperature using a two-roll mill according to American Society for Testing and Materials [ASTM D3184-89 (2001)]. Temperature of mixing was in range 55–65°C. Cure characteristics were studied using a Monsanto Moving Die Rheometer (MDR 2000) according to ASTM D2084-01 (2001). About 4 g samples of the respective compound were used to test at vulcanization temperature (160°C). The rubber compounds then were compression molded at 160°C using a hot press according to respective cure times, t_{90}.

Thermal gravimetric analysis

Thermogravimetric analyses of the blends were carried out with a Perkin–Elmer Pyris 6 TGA analyzer. The samples, which weighed about 15 mg, were scanned from 30 to 600°C at a nitrogen air flow of 50 mL/min at a heating rate of 20°C/min. The sample sizes were kept nearly uniform for all tests.

Measurement of fatigue life

Fatigue test of SBR/NBRr blends with and without ENR-50 was carried out using a Monsanto Fatigue-to-Failure Test (FTFT) operating at 100 rev min^{-1}, and the extension ratio was 1.6. Six specimens were used, and the number of cycles was recorded automatically. The fatigue test was calculated based on the Japanese Industrial Standard (JIS) average, which was determined from the four highest values recorded using equation:

$$\text{JIS average} = 0.5A + 0.3B + 0.1\,(C + D)$$

where A is the highest value followed by B, C, and D.

2.4 Scanning electron microscopy

Scanning electron microscopy (SEM; VPFESEM), model Zeiss SUPRA 35VP, was used to analyze

TABLE I
Characteristics of Materials

Materials	Description	Source
Styrene butadiene rubber (SBR)	1502	Bayer (M)
Recycled acrylonitrile-butadiene rubber (NBRr)	Size: 117–334 μm	Juara One Resources Sdn Bhd, Bukit Mertajam, Penang, Malaysia
Epoxidized natural rubber (ENR-50)	Grade EPOXYPRENE 50 Specific gravity; 1.03	Malaysian Rubber Board
Carbon black	N330	Malayan Carbon (M)
N-cyclohexyl-2-benzothiazyl sulfenamide (CBS), zinc oxide, stearic acid, sulfur, and processing oil		Anchor Chemical Co. (M)

the surface aspects concerning the quality of bonding and to detect the presence of microdefect if any. The surfaces of the samples were mounted on aluminum stubs and sputter coated with a thin layer of gold about 2 nm thickness prior to avoid electrostatics charging and poor resolution during examination.

Weathering exposure

The natural weathering test was performed at School of Materials and Mineral Resources Engineering Universiti Sains Malaysia, Nibong Tebal, Seberang Perai Selatan, Penang, Malaysia, for a period of 6 months; from June 2009 to December 2009. Figure 1 shows the weather condition such as average rainfall, minimum and maximum temperature, and relative humidity which obtained from the Butterworth Meteorological Station, Penang, Malaysia.[28] The natural weathering test was done accordingly to ISO 877.2. The exposed specimens were plates of dumbbell-shaped samples. The specimens were arranged on the expose rack at angle of 45°C which located at an open area without being exceeded by other objects. The specimens were collected after 6 months exposed to environmental effects to determine the degree of degradation. The specimens were dirt-free using towel and left in air for 24 h at room temperature before proceeding to the required test.

Measurement of tensile properties

Tensile tests were performed before and after weathering exposure using Universal Testing Machine (model Instron 3366) according to ASTM 412-98a (2002). The exposed specimens were pulled at a constant crosshead speed of 500 mm/min at a temperature of 25 ± 3°C. The readings of tensile strength, elongation at break (EB), and tensile modulus, M100 (stress at 100% elongation), were recorded. The retention of each property was evaluated according to eq. (1).

$$\text{Retention (\%)} = \text{Value after weathering}/\text{Value before weathering}$$

RESULTS AND DISCUSSION

Thermogravimetric analysis

TG thermograms of 95/5 SBR/NBRr blends with ENR-50 (R05/ENR) and 50/50 SBR/NBRr blends with ENR-50 show lower thermal stability than SBR/NBRr blends without ENR-50 (Fig. 2). The decrement in thermal stability for SBR/NBRr blends with ENR-50 is highly related due to the formation of hydroxyl in the proposed interactions of SBR and NBRr with the presence of ENR-50.[27] These hydroxyl groups were shown through a small hump in differential thermal gravimetric (DTG) curves at

TABLE II
Formulation of SBR/NBRr Blends for Effects of ENR-50 as Compatibilizer

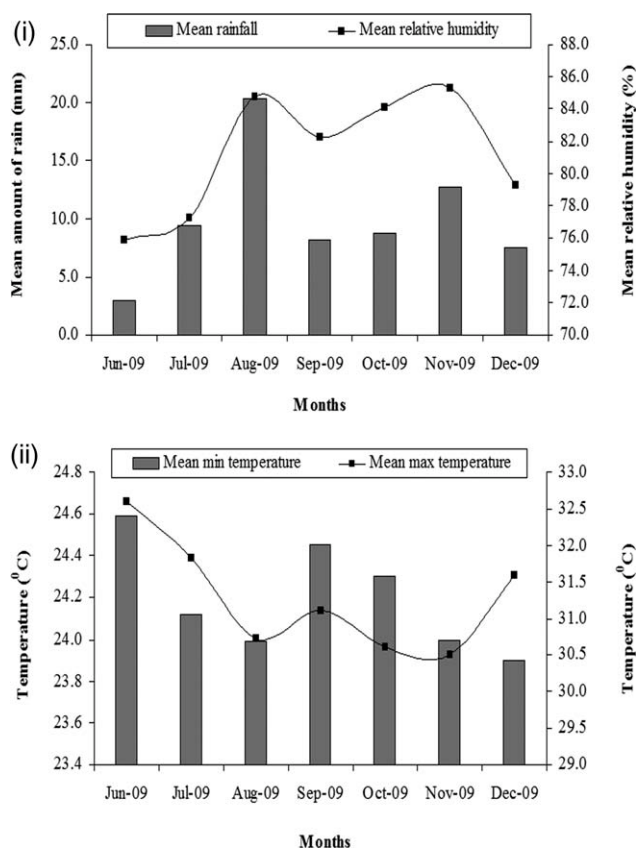| Ingredients (phr) | Blend ratio | | | | |
	R05	R15	R25	R35	R50
SBR	95	85	75	65	50
NBRr	5	15	25	35	50
ENR-50	0 and 10	0 and 10	0 and 10	0 and 10	0 and 10
Zinc oxide	5	5	5	5	5
Stearic acid	2	2	2	2	2
Sulfur	2	2	2	2	2
CBS	1	1	1	1	1
Processing oil	5	5	5	5	5
Carbon black (N330)	50	50	50	50	50

Figure 1 Weather parameters throughout weathering test (Jun 2009 until December 2009) (i) mean rainfall and relative humidity and (ii) mean minimum and maximum temperature.

temperature range 220–330°C (Fig. 3). The hydroxyl volatiles at higher temperature range than trapped moisture, because it is covalently bond to epoxide ring opening of ENR-50 structure.

The thermal stability of blends is more reliable to the presence of ENR-50 than various NBR ratios. Both of functional groups presence in ENR-50, i.e., epoxide ring and double bond were fully utilized to
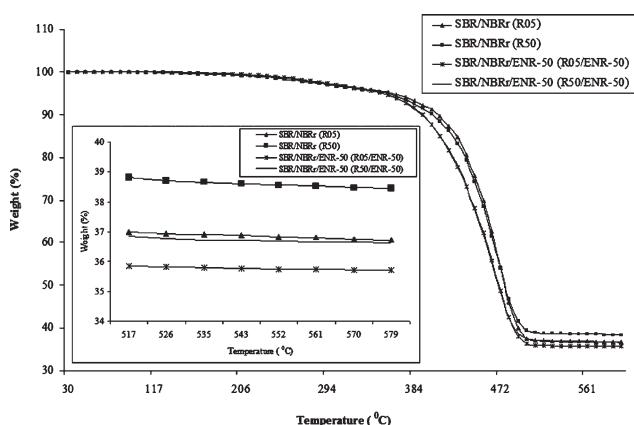
Figure 2 TGA thermograms of R05/ENR-50, R50/ENR-50, R05, and R50.
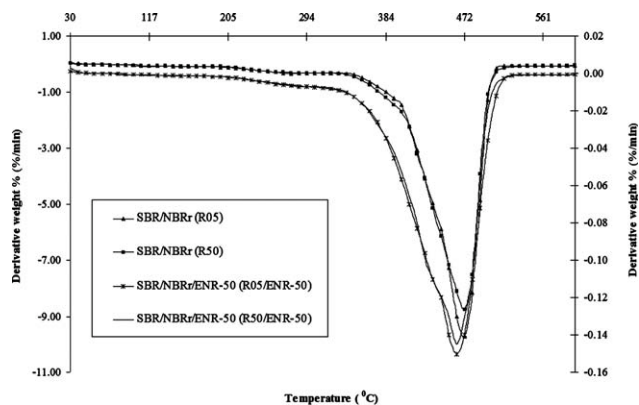
Figure 3 DTG thermograms of SBR/NBRr (R05), SBR/NBRr/ENR-50 (R05/ENR-50), SBR/NBRr (R50), and SBR/NBRr/ENR-50 (R50/ENR-50).

form crosslink compared with limited reactive sites available in recycled NBR. Therefore, the bulk NBRr contributes to thermal stability of the blends and not the NBRr ratio. The temperature of 5% weight loss abbreviated as $T_{5\%}$ of R05/ENR was at 348°C compared with R05 at 362°C, whereas R50/ENR was at 353°C compared with R50 at 360°C, respectively, (Table III). The temperature at 50% weight loss abbreviated as $T_{50\%}$ for R05/ENR and R50/ENR were recorded at lower temperature, i.e., 392°C than without ENR-50 (Table III). It shows R05/ENR and R50/ENR inherit the thermal properties of ENR-50.

The degradation of methyl fragment in ENR-50 structure contributes to the percentage of weight loss because it degrades after hydroxyl groups were volatile. As R05 and R50 do not have this methyl fragment of ENR-50, hence they extend their $T_{50\%}$ at higher temperature than SBR/NBRr blends with ENR-50. DTG curves show temperature at maximum peak decomposition abbreviated as $T_{\max dec}$ for R05/ENR and R50/ENR at 462°C recorded lower temperature than R05, i.e., 471°C and R50 at 473°C, respectively, as shown in Table III. This proves that incorporation of ENR-50 alters $T_{\max dec}$ for SBR/NBRr blends and inherits thermal stability of ENR-50 in conjunction with $T_{\max dec}$ of ENR-50 recorded at 416°C. However, recorded height of DTG peaks in R05/ENR at -0.150% min^{-1} and R50/ENR -0.145% min^{-1} are lower than R05 at -9.718% min^{-1} and R50 -8.762% min^{-1} (Fig. 3). This indicates that the decomposition process for R05/ENR and R50/ENR are slower than R05 and R50 due to the presence of crosslink between ENR-50 with SBR and NBRr.

TG thermograms recorded percentage of char residue for R05/ENR and R50/ENR were 34.8% lower than R05 at 36.7% and R50 at 38.3% (Table III). ENR-50 and SBR are neat polymer contributes to low content of char residue, whereas NBRr is a recycled polymer contained fillers and additives during manufacturing. Therefore, incorporation of ENR-50 in

TABLE III
Experimental Data of TG and DTG of R05 ENR-50, R50 ENR-50, R05, and R50

Blends (phr/phr)	Temperature at 5% weight loss, °C ($T_{5\%}$)	Temperature at 50% weight loss, °C ($T_{50\%}$)	Temperature at maximum peak decomposition, °C ($T_{max\ dec}$)	Char residue (%)
SBR/NBRr/ENR-50 (R05/ENR-50)	348	392	462	34.8
SBR/NBRr (R05)	362	477	471	36.7
SBR/NBRr/ENR-50 (R50/ENR-50)	353	392	462	34.8
SBR/NBRr (R50)	360	480	473	38.3

SBR/NBRr blends reduced char residue compared without ENR-50.

The effect on fatigue life

Figure 4 shows the effect of fatigue life of SBR/NBRr blends with and without ENR-50. It can be seen that, both fatigue life value decreased as NBRr content increased. In our previous study,[27] we reported that the SBR is less rigid than NBRr, thus when more NBRr was blended in the SBR matrix particularly at 50 phr of NBRr, more rigid SBR/NBRr blends were obtained, which led to a higher value of hardness. At all blend ratio, it can be seen that the fatigue life value of SBR/NBRr/ENR-50 lower than blend without ENR-50. It is believed that the presence of ENR-50 in SBR/NBRr blends has increased the rigidity of the blends thus lowering the fatigue life. According to Poh et al.,[29] two rubbers reinforce each other when subjected to cyclic tensile stress, as reflected by the higher N values. The decrease in N values can be explained by the higher cyclic tensile stress experienced by the rubber molecules.

Figures 5 and 6 show the fatigue fracture surface of SBR/NBRr blends with and without ENR-50 at R05 and R50 blend ratio. As can be seen from Figure 5(a,b), the failure surface demonstrated two failure phases. Zone 1, indicates the propagation of cracks that occur within the samples. The rough nature designates that the fracture process is relatively slower, and this will allows matrix tearing to take place. Zone 2, explained that the stress distribution in the blends is no longer consistent and cannot go up against the crack propagation, consequently the catastrophic failure will take place. The mechanism of the crack propagation appears to be by (a) formation of ligaments, (b) their extension to form a blunt crack, (c) formation of new sharper crack tip, and (d) formation of new ligaments and then the process repeats.[30] It can be seen that the failure surface of SBR/NBRr blend with ENR-50 [Fig. 5(a)] showed rougher surface compared with blend without ENR-50 [Fig. 5(b)] means that having a better fatigue life value as discussed earlier.

Meanwhile, SBR/NBRr blends with ENR-50 at R50 [Fig. 6(a)] also shows rougher surface compared with blends without ENR-50 [Fig. 6(b)]. As can be seen in Figure 6(b), the recycled particles act as a blockage for stress transmission within a continuous matrix which resulting in fatigue failure. The stress builds up on the interface between the recycled particles and the SBR matrix. Here, the failure fractures will start to deteriorates. As the NBRr content increases, the concentration of weak area will increases and weaken the strength of the blends. Cho et al.[31] reported that the smooth surface indicates sharp tear, whereas the rough surface results from blunt tear, contributes to lowering of fatigue resistance of elastomer, since the strength of elastomer is strongly dependent on the radius of crack tip.

The effects on natural weathering test

Tensile retention

Figure 7 shows the tensile strength of SBR/NBRr blends with and without ENR-50 decreased after exposed to 6-month weathering. It is believed that the combination effects of atmospheric factors such as solar radiation, temperature, and humidity, as well as seasonal variations and environmental pollutants had contributed to the degradation of the samples thus lowered the strength values. Apart from those, microorganisms, ozone, and chemical pollutants significantly affect the degradation of materials when expose to outdoor environment.[32] However, with the incorporation of ENR-50 into SBR/NBRr blends, there was a minimal changed on tensile retention of the blends. The tensile retention of SBR/NBRr/ENR-50 blends was slightly higher than blends without ENR-50 (when having more NBRr, particularly at 50 phr of NBRr). This probably due to presence of chemical interactions such as crosslinking along with the presence of ENR-50 which might contribute to the stability of SBR/
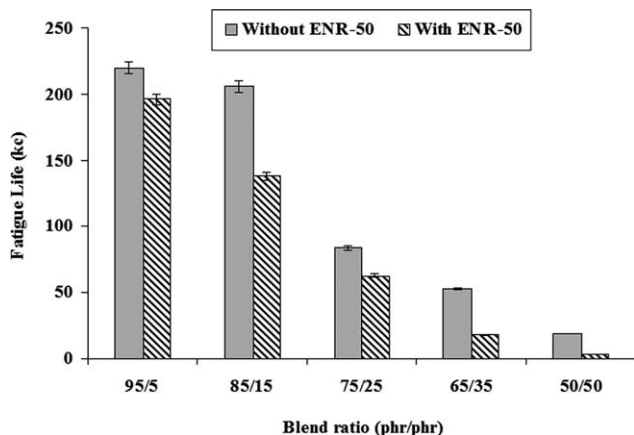
Figure 4 The effect of fatigue life of SBR/NBRr blends with and without ENR-50.

NBRr/ENR-50 blends toward weathering when compared with SBR/NBRr blends without ENR-50. Furthermore with a better physical interaction
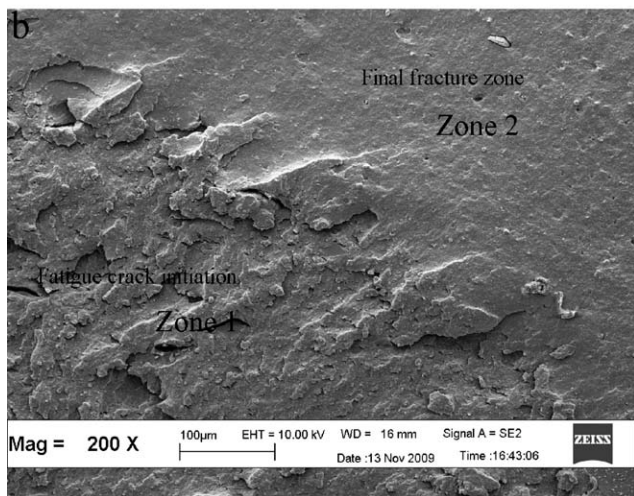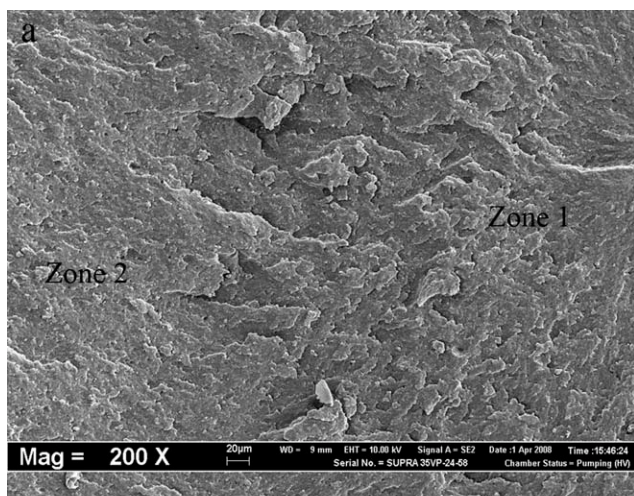

Figure 5 Fatigue failure surfaces of SBR/NBRr blends (a) without ENR-50 at 95/5 blend ratio at 200× magnification and (b) with ENR-50 at 95/5 blend ratio at 200× magnification.
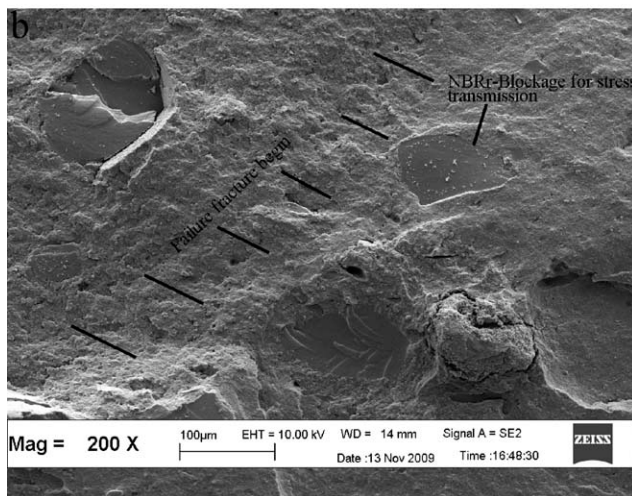
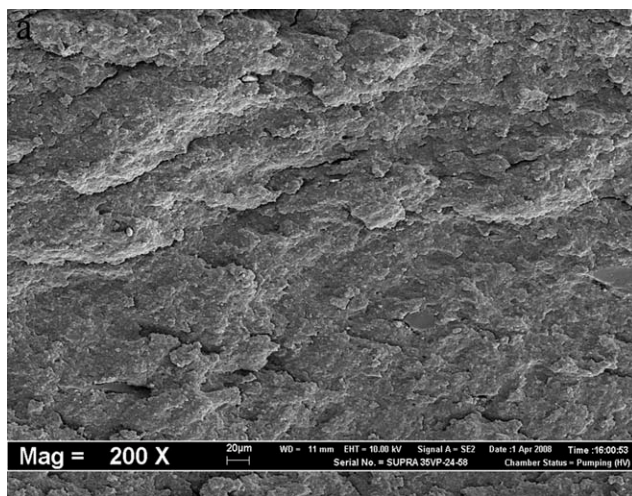**Figure 6** Fatigue failure surfaces of SBR/NBRr blends (a) without ENR-50 at 50/50 blend ratio at 200× magnification and (b) with ENR-50 at 50/50 blend ratio at 200× magnification.

between the phases would contribute to a better interfacial adhesion. The presence of ENR-50 has made a better distribution of NBRr in the SBR matrix thus improving the interfacial adhesion of SBR/NBRr blends by reducing the interfacial energy between phases.

Figure 8 illustrates the relationship between E_b and its retention of SBR/NBRr and SBR/NBRr/ENR-50 blends. It can be seen that, both E_b decreased after 6 months exposure. The decrement in E_b value probably due to the breakdown of polymer chains mainly on the surface of the specimen making it more brittle and entanglements. On retention value, both blends illustrate slightly increased percentages (from R05 to R50). As noticed, the changes in E_b retention for both blends were negligible. Interestingly, with the addition of ENR-50 into SBR/NBRr blends, there was a small changed on retention value of E_b particularly at R05 and R15 blend ratio. It is believed that ENR-50 acted as a
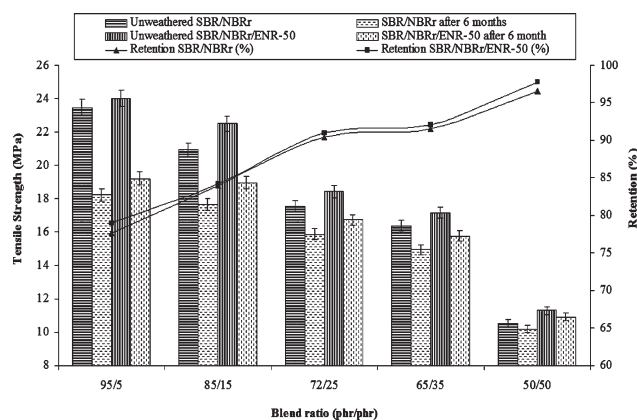
Figure 7 The tensile strength and retention of SBR/NBRr blends and SBR/NBRr/ENR-50 blends after 6 months of natural weathering.

Figure 8 The E_b and retention of SBR/NBRr blends and SBR/NBRr/ENR-50 blends after 6 months of natural weathering.

Figure 9 The M100 and retention of SBR/NBRr blends and SBR/NBRr/ENR-50 blends after 6 months of natural weathering.

protective layer at interfacial area (between NBRr particles and SBR matrix) and shielded the existing interfacial adhesion between the NBRr particles and SBR matrix from the detrimental effects of weathering. When more NBRr added into blends (particularly at 25, 35, and 50 phr of NBRr), the E_b retention of both blends was almost identical. According to Jacques,[33] during outdoor weathering, the rate of oxygen uptake and CO and CO_2 formation, the increase in carbonyl absorbance and the rate at which the elongation at break changes depend on the climate factors to which the polymer is exposed.

Figure 9 exhibits M100 and retention of SBR/NBRr blends and SBR/NBRr/ENR-50 blends after 6 months of natural weathering. It can be seen that, both blends show an increment in M100 for both exposure periods (when having more NBRr, from R05 to R50). These results can be attributed to the enhanced stiffness of the blends caused by photo-oxidation which increase in crosslinking that happened due to the high rate of radical termination in the bulk of the polymer. According to Ismail et al.,[32]
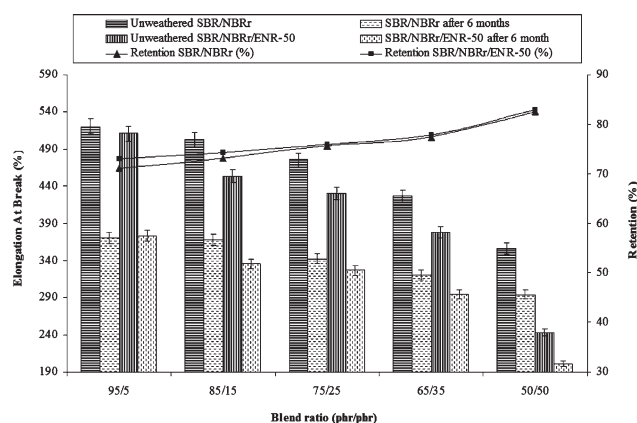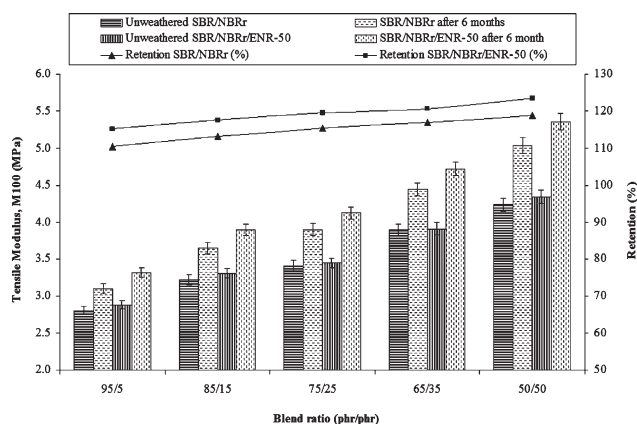
photo-oxidation only concentrated near the surface of the blends, and the process mainly takes place in the amorphous region because of higher permeability to oxygen. Longer exposure times cause the development of more surface cracks and allow degradation and water absorption to take place. The chemical degradation and water absorption can be caused by exposure of the blends to acidic rainwater and moisture, which can seep through the cavity of the surface cracks, causing chemical attack to the polymer bonds and might enhance some crosslinking reaction to happen due to radical recombination during exposure.[34–36] Again, as discussed for tensile strength results, SBR/NBRr blends with ENR-50 exhibit higher M100 retention than blend without ENR-50 at all blend ratios.

Morphology

Figure 10 shows the surface morphology of SEM micrograph of (a) SBR/NBRr blends without ENR-50; (b) SBR/NBRr blends with ENR-50 at R05 blend ratio after 6 months natural weathering, at magnification 1000×, respectively. It can be observed that, a minimal severity of crack attacked by thermal, photo-rain, wind, and ultraviolet (UV) degradation was found on the surface of SBR/NBRr/ENR-50 blends [Fig. 10(b)] compared with SBR/NBRr blends [Fig. 10(a)]. This indicates that the SBR/NBRr/ENR-50 blends have a better resistant toward weathering. It can be noticeable from the surface of SBR/NBRr/ENR-50 blends [Fig. 10(b)]; the scale of cracks has reduced indicating well-retaining interfacial adhesion between SBR matrix–NBRr particles–ENR-50, compared with SBR/NBRr blends [Fig. 10(a)] which still extensive.

Meanwhile, Figure 11 designates the SEM inspection on the surface of (a) SBR/NBRr blends without ENR-50; (b) SBR/NBRr blends with ENR-50 at R50 blend ratio after 6 months exposure, at
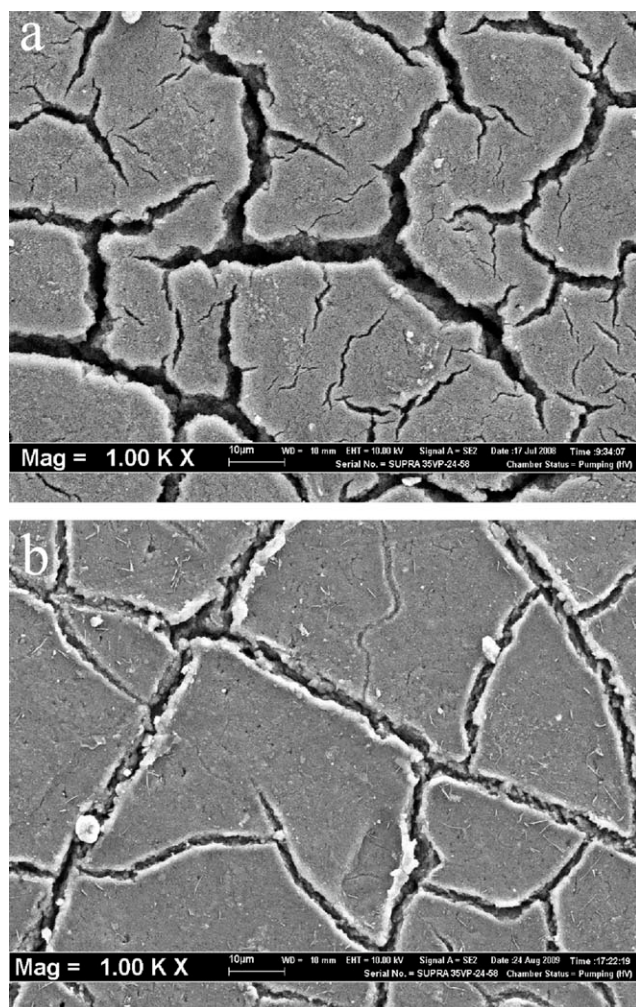
Figure 10 SEM micrograph of (a) SBR/NBRr blends without ENR-50 at 95/5 blend ratio after 6 months natural weathering, at magnification 1000× and (b) SBR/NBRr blends with ENR-50 at 95/5 blend ratio after 6 months natural weathering, at magnification 1000×.

Figure 11 SEM micrograph of (a) SBR/NBRr blends without ENR-50 at 50/50 blend ratio after 6 months natural weathering, at magnification 1000× and (b) SBR/NBRr blends with ENR-50 at 50/50 blend ratio after 6 months natural weathering, at magnification 1000×.

magnification 1000×. Apparently, the SBR/NBRr/ ENR-50 [Fig. 11(a)] demonstrates minor cracks compared with SBR/NBRr blends without ENR-50 [Fig. 11(b)]. This remark is indeed the effect of better distribution of NBRr in SBR matrix with the presence of ENR-50, which contributed for a better interaction between the phases thus accountable for better resistance properties toward weathering.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. TG thermograms of 95/5 SBR/NBRr with ENR-50 (R05/ENR) and 50/50 SBR/NBRr with ENR-50 show lower thermal stability than SBR/NBRr blends without ENR-50. The incorporation of ENR-50 into SBR/NBRr blends
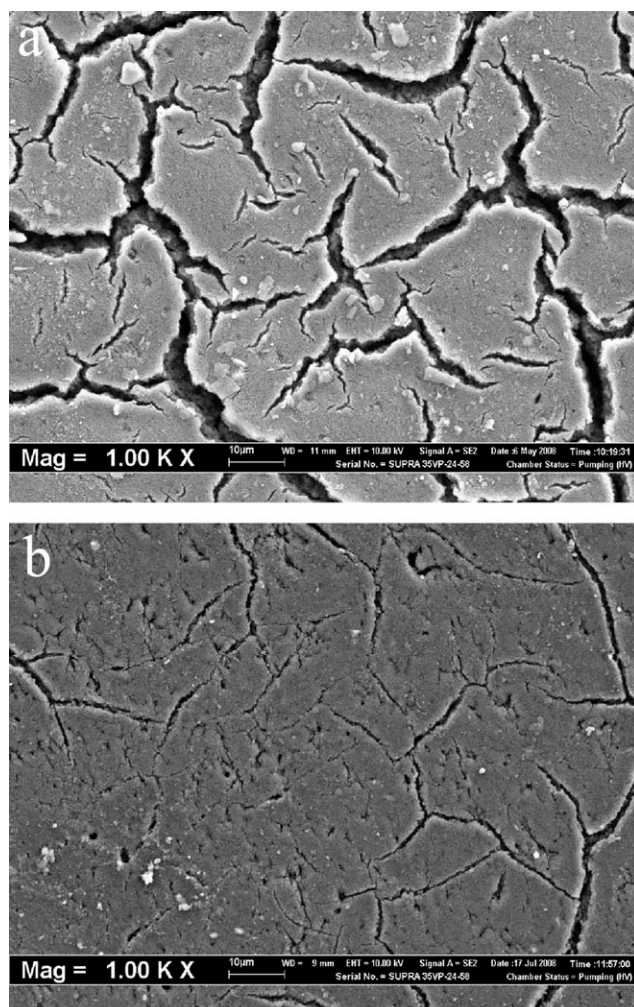
reduced char residue compared SBR/NBRr blends without ENR-50.

2. Incorporation of ENR-50 in SBR/NBRr blends has increase the rigidity of the blends thus lowering the fatigue life. The deterioration of fatigue life at higher NBRr content due to friction between NBRr particles. The recycled particle acts as a blockage for stress transmission within a continuous matrix which resulting in an initiation of fatigue failure. As the NBRr content increases, the concentration of weak area will increases and weaken the strength of the blends.

3. The increment in tensile properties retention of SBR/NBRr blends with ENR-50 indicated the enhancement on weathering resistant. ENR-50 acted as a protective layer at interfacial area (between NBRr particles and SBR matrix) and shielded the existing interfacial adhesion

between the NBRr particles and SBR matrix from the detrimental effects of weathering.

4. The surfaces of SBR/NBRr blends with ENR-50 after 6 months exposed period shows a minimal severity of crack compared with SBR/NBRr blends without ENR-50. The scale of cracks has reduced indicating well-retaining interfacial adhesion between SBR and NBRr with the presence of ENR-50 as a compatibilizer.

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