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Processing and Material Characteristics of a Reclaimed Ground Rubber Tire Reinforced Styrene Butadiene Rubber

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ABSTRACT

Mechanochemically partially devulcanized ground rubber tire (GRT) was revulcanized in composition with virgin styrene butadiene rubber (SBR). Reclaiming of GRT was carried out by tetra methyl thiuram disulfide (TMTD) in presence of spindle oil. The cure characteristics and tensile properties of SBR compounds were investigated. Results indicate that the minimum torque and Mooney viscosity of the SBR compounds increase with increasing reclaim rubber (RR) loading whereas the scorch time remain unaltered but optimum cure time exhibit a decreasing trend. Increasing RR loading also gives SBR compounds better resistance towards swelling but the 100% modulus, 200% modulus tensile strength, and the elongation at break increases. Thermogravimetric analysis of SBR/RR vulcanizates was carried out in order to get thermal stability of the vulcanizates. Scanning electron microscopy (SEM) studies further indicate the coherency and homogeneity in the SBR/RR vulcanizates.

Keywords**:** *Rubber Recycling, SBR, TMTD, Reclaimed Rubber, Thermogravimetric Analysis, Crosslink Density*

1. Introduction

Dwindling source and rising price of crude oil have become a serious concern for availability of feed stock to the synthetic rubber industry. Huge quantities of rubbers are used in tire industry and the world's rubber markets are dominated by two rubbers – one being natural rubber (NR) and the other being styrene butadiene rubber (SBR). Among different rubbers, tire industry consumed largest quantity of SBR which is mainly used in car tire tread. But after a long run when these tires are not serviceable only a few grams or kilograms of rubber are abraded out from the tire. The entire amount of rubber from the worn-out tires is discarded, which again require very long time for environmental degradation due to cross- link structure of rubbers. Various approaches such as land filling [1], incineration [2], pyrolysis [3,4], civil engineering [5,6] applications etc. have been adopted for reuse of waste discarded rubber products. But in almost all the applications no value is added from the product side.

Tire recycling or reclaiming are one of the preferable routes, according to the so-called waste management hierarchy, under environmental aspect. The recycling of tires not only saves our valuable resource of petroleum from which the synthetic rubbers are originated, but also protects our precious environment. Thus reclaiming of tires in alternative applications is actually the use of base polymer in new formulations with simultaneous cost saving in raw material and preserving both natural resource and environment. Incorporation and dispersion of reclaim rubber in fresh rubber play important roles towards the product quality, production economy and market competition. Compatibility of reclaim rubber with virgin rubber is an essential requirement for optimum mechanical properties of the vulcanizates. Therefore it is necessary to evaluate the performances of such fresh rubber/reclaim rubber blends.

In a review paper the author [7] have discussed the various reclaiming processes of vulcanized rubber in presence of different chemicals. The mechanical reclaiming of GRT by TMTD as reclaiming agent was studied by the author [8]. Here the extent of reclaiming was monitored by measurement of sol content, inherent viscosity of sol rubber, crosslink density and Mooney viscosity of reclaim rubber as function of milling time and concentration of reclaiming agent. The optimization of the reclaiming agent concentration and time of reclaiming was also reported. The performance evaluations of such type of reclaim rubber/virgin natural rubber blend was also studied [9] by the author. In this paper mechanochemically partially devulcanized GRT was blended with fresh NR in 20% - 60% level. The reclaim rubber, prepared in this investigation, when blended with fresh NR has been found to reduce the tensile strength by about 7% for 20% reclaim containing vulcanizate and 46% for 60% reclaim containing vulcanizate. It is observed that the aging performances of the reclaim rubber containing vulcanizates are better than the control formulation, which does not contain any reclaim rubber. TGA shows that the thermal stability of the vulcanizate increases with increasing reclaim rubber content. Noordermeer *et al.* [10] reclaimed waste latex rubber by diphenyl disulfide, 2-aminopheny disulfide and 2, 2'-dibenzamidodiphenyl disulfide as a function of concentration of reclaiming agent, time and temperature. The comparative study of the reclaiming efficiency of the three reclaiming agents was carried out. From the study it was evident that 2, 2'-dibenzamidodiphenyl disulfide is able to break the crosslink bonds at around 20˚C. Sombatsompop and Kumnuantrip [11,12] incorporated reclaim rubber from tire tread into two grades of NR and investigated various properties of the blend. They found that Mooney number, shear viscosity and cure rate increased with RR content but optimum cure time is independent of it. Sreeja and Kutty [13] studied the cure characteristics and mechanical properties of NR/RR blends, using the EV system. They reported that scorch time and tensile properties of the blend reduced with RR loading. The curing characteristics and mechanical properties of SBR/RR blend system was reported by the author [14]. Here reclaiming of waste rubber was carried by a simple process with an eco-friendly renewable resource material [15,16]. The main constituent of this material is diallyl disulfide. Other constituents are disulfides, mono sulfides, poly sulfides and thiol compounds. Nevatia *et al.* [17] mixed RR with recycled poly ethylene and evaluated physical properties, dynamic mechanical properties and rheological behaviors of the blend. They reported that 50/50, RR/PE vulcanizate showed optimum processibility, ultimate elongation and set properties. Here sulfur-accelerator cured system gave superior product properties than peroxide cured system.

This paper describes a new elastomer products based on virgin SBR and reclaimed GRT. Initial step involves the mechanochemical reclaiming of GRT by TMTD and subsequent incorporation of reclaimed GRT into virgin SBR in different proportion. The (re)vulcanization of different SBR/RR blends was found to give a new low cost product with adequate properties. The term (re)vulcanization was used because there are two simultaneous processes such as vulcanization of the virgin rubber and (re)vulcanization of partially devulcanized GRT and even the co-vulcanization of them. Curing characteristics and mechanical properties before and after aging of SBR/RR blend system have been studied. Thermal behavior of RR, SBR and different SBR/RR vulcanizates was also studied. Finally the dispersion of reclaim rubber into SBR was evaluated by scanning electron microscopy (SEM).

2. Experimental

2.1. Materials

GRT, purchased from local market was used in this investigation. The GRT was an unclassified ground rubber from the tread and side walls of passenger and truck tires. The particles of GRT were of various sizes ranging from a few millimeters to 100 microns. Styrene butadiene rubber (SBR 1502, Synthetics & Chemicals Ltd. India), tetramethylthiuram disulfide (TMTD) (Alpha Chemika, Maharashtra, India), zinc oxide (S. D. Fine Chem. India), stearic acid (Loba Chemi. India), sulfur (S. D. Fine Chem. India), spindle oil (MCI, India), carbon black (N330, Philips Carbon Ltd. India) and toluene (S. D. Fine Chem. India) were used as received.

2.2. Experimental Procedure

The optimization of reaction conditions and the concentration of TMTD used for reclaiming of GRT were reported in the author's previous work [8]. Hundred grams of ground rubber was thoroughly mixed with 2.75 g TMTD and 10 mL spindle oil. The mixture was then reclaimed mechanically in an open two-roll mixing mill at a friction ratio of 1.2 for 40 minutes near ambient temperature. It has been found that with progress of milling the materials become soft, sticky and band formation occurs on the roll. The extent of reclaiming was monitored by measurement of sol content (30.3%), inherent viscosity of sol rubber (0.3944), crosslink density (6.587 × 10^{-4} mol/cm^3), molecular weight between crosslink bonds (33.093 × 10^3), swelling ratio (4.099) and Mooney viscosity [ML (1 + 4) 100˚C] (70.6) of reclaim rubber [8].

2.3. Preparation of SBR/RR Vulcanizates

Mixing of fresh SBR, various proportions of reclaim rubber and compounding ingredients was carried out for 15 minutes at room temperature on an open two-roll mixing mill. Compound formulations are presented in **Table 1**. The amount of additives such as ZnO, stearic

Table 1. Mix formulation and curing characteristics of SBR/RR Compounds.

Ingredients (phr)	1	2	3	4	5	6	7	8	9	10
Styrene Butadiene rubber (SBR)	100	80	70	60	50	40	100	80	80	80
Reclaim rubber (RR)	-	20	30	40	50	60	-	20	20	20
Zinc oxide	5	5	5	5	5	5	5	5	5	5
Stearic acid	2	2	2	2	2	2	2	2	2	2
TMTD	2.16	1.61	1.335	1.06	0.785	0.51	2.16	1.61	1.61	1.61
Sulfur	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
carbon Black (N330)	-	-	-	-	-	-	40	20	30	40
Spindle oil	-	-	-	-	-	-	4	2	3	4
Curing Characteristics										
Optimum cure time (t_{90}, min)	7.5	5.5	5.25	4.75	4.5	4.25	10	5.25	6.0	4.5
Scorch time (t_{s2}, min)	1.5	0.5	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.5
Extent of cure, (dNm)	49	54.2	55.5	55.6	56	58	68.5	58	63	68
Cure rate index, (min^{-1})	16.7	20	23.5	26.7	28.6	30.8	10.5	21	18.2	25
Mechanical Properties										
100 % Modulus, MPa	1.255	1.59	1.62	2.10	2.13	2.28	3.5	2.146	3.267	4.196
200 % Modulus, MPa	1.698	2.25	2.31	3.08	3.19	3.32	5.477	3.264	4.985	6.465
Tensile Strength, MPa	2.335	2.781	2.974	3.835	4.573	5.017	12.014	7.515	9.946	12.577
% Elongation at break	432	377	382	390	427	445	537	587	521	509
Hardness, (Shore A)	50	60	65	64	62	60	65	60	63	65
Crosslinking value, (1/Q)	0.238	0.292	0.324	0.358	0.376	0.406	0.300	0.300	0.325	0.337
Mooney Viscosity [ML (1 + 4) 100˚C]	40.7	51.0	65.7	70.6	71.8	75.0	-	-	-	-

acid and sulfur were used based on 100 g of rubber irrespective of the amount of reclaim rubber, because it was reported that the additives in reclaim rubber originated from parent compound are inactive [18]. The amount of TMTD was maintained at 9 m mol in all the vulcanizates based on the amount of TMTD used during reclaiming of GRT. This is due to the fact that in sulfur, TMTD vulcanization system the optimum concentration of TMTD is chosen as 9 m mol *i.e.* 2.16 g per hundred gm of fresh rubber (*i.e.* RR and SBR). Formulation 1 contains no reclaim rubber and formulation 2 - 6 contains different proportion of reclaim rubber from 20 - 60 wt%. In order to study the effect of carbon black, various proportion of carbon black was added in SBR/RR (80/20) blend system. Formulation 7 contains only SBR with 40 phr carbon black and formulation 8 - 10 contain different proportion of carbon black (20, 30 and 40 phr) in SBR/RR blend. It has been observed that with increase in the proportion of carbon black its incorporation and dispersion become gradually difficult. With higher proportion of carbon black loading the compounds become stiff and the temperature rises due to high shearing action required for better dispersion.

The cure characteristics of SBR/RR compounds were determined with the help of a Monsanto Oscillating Disc Rheometer, R-100 at 160˚C. It has been found that all cure curves were level off in the region of 60 minutes, where torque-time gradient of each sample was constant or did not change significantly.

The compounded rubber stock were then cured in a compression molding machine at 160˚C and at applied pressure of 34.5 MPa for the respective optimum cure time ($t = t_{90}$) obtained from rheographs. After curing, the vulcanized sheet was taken out of the mold and immediately cooled under tap to restrict from further curing.

2.4. Measurement of Mechanical Properties

The mechanical properties such as modulus, tensile strength and elongation at break was measured by a Hounsfield, model H10 KS tensile testing machine as per ASTM D 412-51T at room temperature (25 ± 2˚C) at a uniform speed of separation 500 mm/min. Hardness (Shore A) of the vulcanizates were measured by a Hirosima Hardness tester as per ASTM D 1415-56T. The values reported were based on the average of five measurement of each sample. The aging characteristics of the vulcanizates was evaluated by accelerated aging test in an air aging oven at 100 ± 2˚C after 24, 48 and 72 h aging.

Mooney viscosities of rubber compounds were determined by a Monsanto Mooney viscometer 2000 at ML (1 + 4) 100˚C as per ASTM D 1646.

2.5. Swelling Value of the Vulcanizates

The swelling value (Q) was determined with about 0.5 g of cured samples (accurately weighed). The sample was immersed in 250 mL toluene for 72 h to attain equilibrium swelling. After equilibrium swelling the sample was taken out and the solvent was blotted from the surface of the sample and weighed immediately. It was then dried under vacuum at 100˚C upto constant weight. The crosslinking value of the vulacanizates was calculated from the following equation [19].

$$\frac{1}{Q} = \frac{W_S - W_D}{\left(\dfrac{W_0 \times 100}{W_F}\right)} \tag{1}$$

where W_S, W_D, W_O and W_F are swollen weight, dried weight, weight of the original sample and formula weight respectively. Formula weight (W_F) is the total weight of rubber plus compounding ingredients based on 100 parts of rubber.

2.6. Determination of Crosslink Density

The crosslink densities of SBR/RR vulcanizates were determined by the Flory-Rehner equation [20] by using swelling value measurement.

$$-\ln\left(1 - V_r\right) - V_r - \chi V_r^2 = 2V_s \eta_{swell}\left(V_r^{\frac{1}{3}} - \frac{2V_r}{f}\right) \tag{2}$$

where V_r is the volume fraction of rubber in the swollen gel, V_S is the molar volume of the toluene (106.2 $cm^3 \cdot mol^{-1}$ in this study), χ is the rubber-solvent interaction parameter (0.378 in this study), η_{swell} is cross-link density of the rubber ($mol \cdot cm^{-3}$) and f is functionality of the crosslinks (being 4 for sulphur curing system).

The volume fraction of a rubber network in the swollen phase is calculated from equilibrium swelling data as:

$$V_r = \frac{\left(\dfrac{W_2}{d_2}\right)}{\left(\dfrac{W_1}{d_1}\right) + \left(\dfrac{W_2}{d_2}\right)} \tag{3}$$

where W_1 is the weight fraction of solvent, d_1 is the density of the solvent, W_2 is the weight fraction of the polymer in the swollen specimen and d_2 is the density of the polymer.

2.7. Thermo Gravimetric Analysis (TGA)

The thermo gravimetric analysis (TGA) of SBR/RR vulcanizate was carried out by using a TGA 50, Shimadzu, Japan, thermo-gravimetric analyzer in nitrogen (flow rate 50 mL/min) within the temperature range of 20 to 800˚C. All these analysis were carried out at heating rate of 10˚C/min.

2.8. Scanning Electron Microscopy

The tensile fracture surface of the samples were studied in scanning electron microscope (SEM) (JEOL, JSM 5800) at 0˚ tilt angle after coating the surface with sputtered gold.

3. Results and Discussion

3.1. Curing Characteristics

Curing characteristics of different SBR/RR blend system and SBR/RR (80/20) blend system with various proportions of carbon black loading are given in **Table 1**. The optimum cure time decreases but scorch time remain unaltered with increase in reclaim rubber content in all the cases. From **Table 1** it has been found that with increase in the proportion of reclaim rubber extent of cure increases due to the presence of crosslinked gel in the reclaim rubber. It is also evident that with increase in carbon black loading the optimum cure time and scorch time remain unaffected but extent of cure increases with increasing carbon black loading.

3.2. Tensile Properties of Rubber Compound

The stress-strain behavior of SBR/RR vulcanizates with various proportion of reclaim rubber are shown in **Figure 1**. The moduli at 100% and 200% elongation increases with increasing reclaim rubber content in all the SBR/RR vulcanizates. The stress strain was decreased with increasing reclaim rubber content. From the Figure it is shown that the stress-strain of SBR/RR vulcanizates was decreased after 50% elongation compare to that of the fresh SBR vulcanizate. Tensile properties, Mooney viscosity and crosslinking value of the SBR/RR vulcanizates are presented in **Table 1**. From the values in **Table 1** it is seen that moduli at 100% and 200% elongation, tensile strength, elongation at break and hardness increases with increasing reclaim rubber content. The reason for higher 100% and 200% moduli may be due to higher crosslink density (**Figure 2**) of the vulcanizates, arising out of the gel present in reclaim rubber or may be due to the presence of active functional sites in reclaim rubber which may participate in crosslinking during the process of vulcanization. As crosslink density of the vulcanizates increases with increasing reclaim rubber content, chain mobility decreases and more load is required for 100% and 200% elongation. The increasing value of tensile strength with reclaim rubber content is probably due to the presence of carbon black left in the reclaim rubber [12]. It is known [7,21,22] that the partial devulcanization of ground rubber tire (GRT) facilitates the interface adhesion between the surface chains of reclaim rubber (RR) particles and surrounding rubber matrix due to their co-crosslinking in the interphase layer. The increase in the value of elongation at break with reclaim rubber content can indicate a better compatibility in interphase layer of the rubber matrix and reclaimed rubber particles [23,24]. The growth of the values of hardness observed at increasing RR content in SBR/RR (re)vulcanizates obviously evidences of more intensive post vulcanization process in the blends due to presence of additional sulfur released at the devulcanization of GRT [15].

Effect of carbon black loading was studied in SBR/RR (80/20) blend system. It is seen that with increase in carbon black loading 100% and 200% moduli, tensile strength increases. This can be explained by corresponding increase in crosslinking value data. The higher crosslinking value of the vulcanizates is conclusive evidence

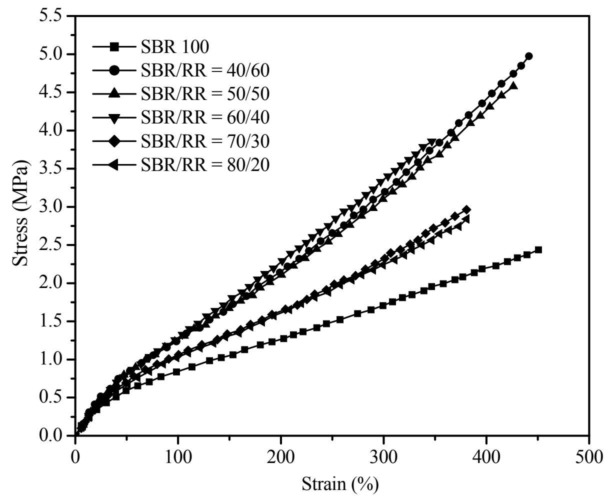


Figure 1. Stress – Strain behavior of SBR/RR blend system.

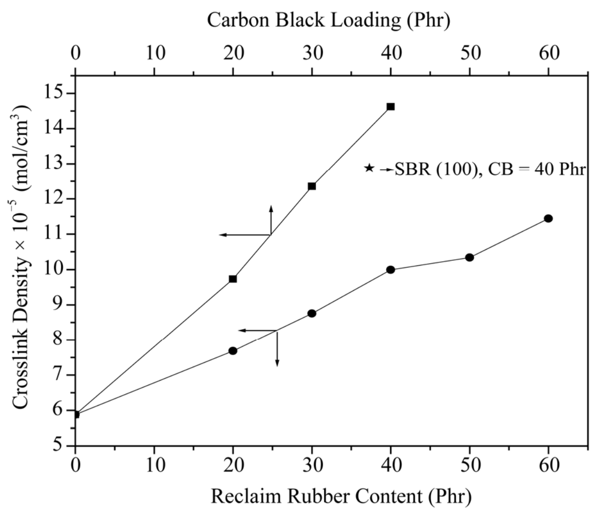


Figure 2. Crosslink density of SBR/RR blend system as a function of reclaim rubber content and carbon black loading.

for the presence of a network with a greater number of filler polymer interactions, constraining molecular mobility in the polymer. The tensile strength of 40 phr carbon black loaded SBR/RR (80/20) vulcanizate is higher compared to that of the control formulation 7 *i.e.* vulcanizate containing no reclaim rubber. Elongation at break decreases with increasing carbon black loading. Hardness increases because with increasing carbon black loading vulcanizates become stiff and hard. The increase in the value of Mooney viscosity with carbon black loading further indicates that the processing of the rubber compound become difficult if higher amount of carbon black is incorporated into the rubber matrix.

3.3. Effect of Thermal Aging

The aging characteristics of SBR/RR vulcanizates should be given proper attention because reclaim rubber itself is a degraded mass. Thus accelerated aging test were performed for SBR/RR vulcanizates. Percent retention of 100% and 200% modulus are shown in **Figures 3** and **4**. In all the cases it was observed that percent retention of 100% and 200% modulus increases with increasing reclaim rubber content and with progress of aging. This may be due to residual crosslinking during progress of aging which is further enhanced due to the presence of reclaim rubber, containing active functional sites. Percent retention of tensile strength is shown in **Figure 5**. From the figure it is evident that percent retention of tensile strength decreases with progress of aging but increases with increasing reclaim rubber content at a particular time of aging. This may be due to increasing crosslink density of the vulcanizates with progress of aging. The percent retention of elongation at break for the various SBR/RR systems at different RR content after aging is shown in **Figure 6**. But percent retention of elongation at break values at higher reclaim content such as 50 and 60 wt% reduces considerably; this is a result of both thermo-oxidative degradation and post vulcanization of SBR/RR (re)vulcanizates studied. Percent retention of hardness is shown in **Figure 7**. With progress of aging as the vulcanizates become stiff therefore hardness increases.

Effect of carbon black loading on % retention of properties after 72 h aged SBR/RR (80/20) blend system was shown in **Figure 8**. The percent retention value of both 100% and 200% modulus continuously increases with increasing carbon black loading. But the percent retention values of tensile strength and elongation at break shows a different behavior. Both the properties shows maximum percent retention values for 20 phr carbon black loading compared to that of the control formulation.

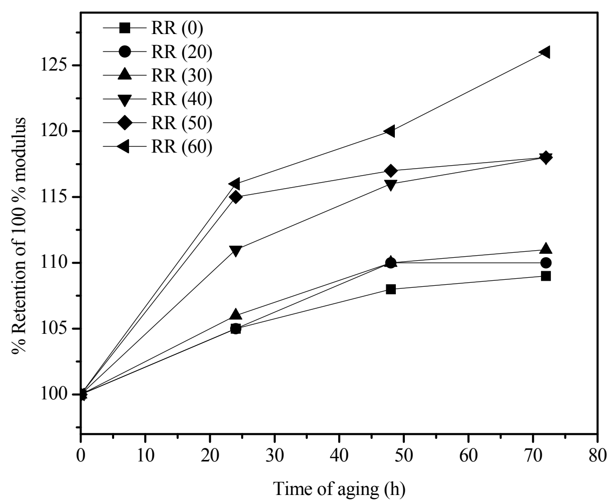


Figure 3. Effect of reclaim rubber content on % retention of 100% Modulus.

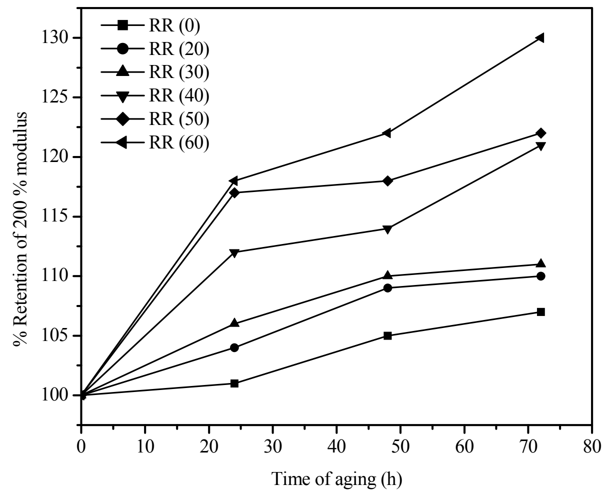


Figure 4. Effect of reclaim rubber content on % retention of 200% Modulus.

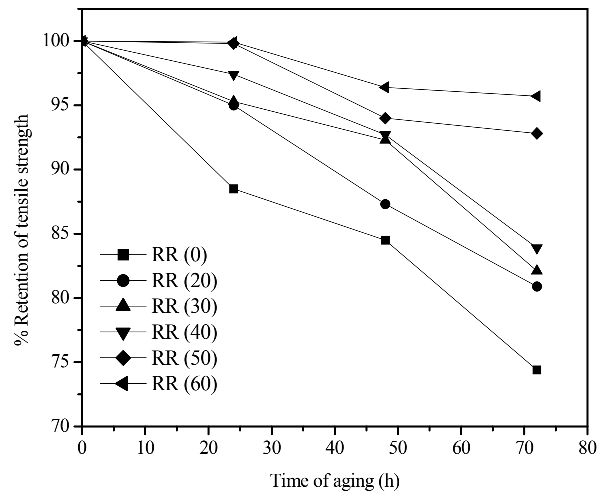


Figure 5. Effect of reclaim rubber content on % retention of Tensile Strength.

However, for 30 and 40 phr carbon black loading the percent retention values considerably decreases due to aging. Although the percent retention of tensile strength for 30 and 40 phr carbon black loading is not less than that of the control formulation. It is seen from **Figure 8** that percent retention of hardness was almost constant with increasing carbon black loading. These results show the effectiveness of 20 phr carbon black in the SBR/RR (80/20) blend system. Thus the aging performances of formulation containing reclaim rubber are superior than that of the control formulation which does not contain any reclaim rubber. This phenomenon indicates the anti-aging characteristics of reclaim rubber.

3.4. Thermogravimetric Analysis

Thermal degradation of different SBR/RR vulcanizates

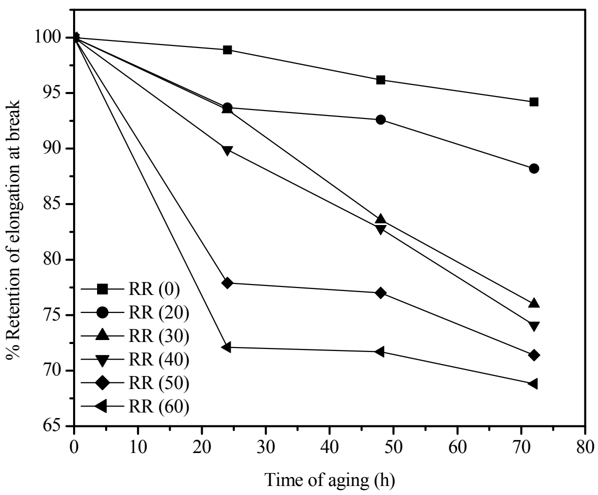


Figure 6. Effect of reclaim rubber content on % retention of Elongation at Break.

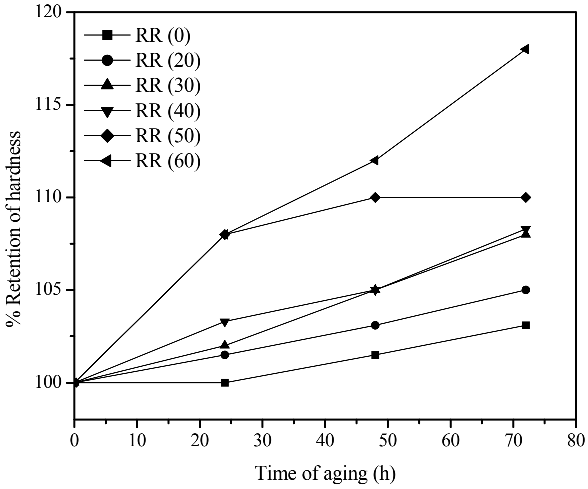


Figure 7. Effect of reclaim rubber content on % retention of Hardness.

in inert atmosphere was analyzed and corresponding results are given in **Figure 9**. The thermogravimetric analysis were performed in nitrogen atmosphere, which shows only thermal degradation behavior compare to the combine effect of thermal as well as termooxidative degradation in presence of oxygen or air. The tempera- ture interval of degradation stages evaluated from DTG curves, temperature of the stages maximum rate of degradation, sample weight loss at the temperatures and char residue values are listed in **Table 2**. All SBR/RR blend system shows two characteristic degradation peak in DTG curve between 320˚C - 530˚C (**Figure 9**). But for all the vulcanizates initial weight loss occurs between 50 - 300˚C. Pure SBR shows 3.6% wt loss up to 300˚C whereas with increase in reclaim rubber content it goes up to 10% for SBR/RR blend system. This initial weight loss under N_2

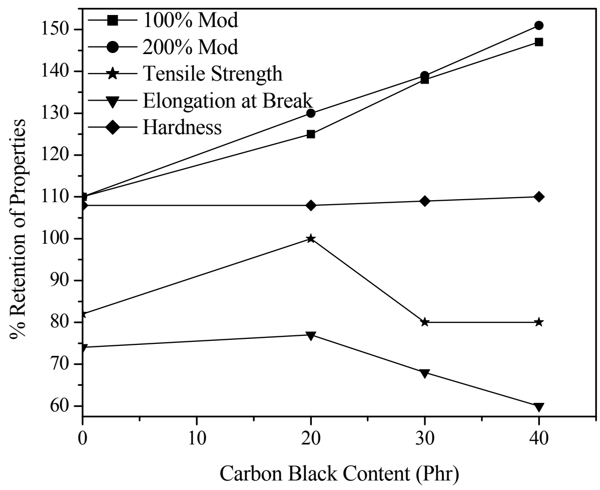


Figure 8. Effect of carbon black loading on % Retention of properties after 72 h aged SBR/RR (80/20) blend system.

atmosphere between 50˚C - 300˚C is due to the volatilization of processing oil or any other low boiling point component present in pure and blend system. As reclaim rubber contain large amount of processing additives compare to virgin rubber, so with increasing reclaim rubber content initial weight loss increases from 3.6% to 10%.

As RR contain some NR for that reason SBR/RR blend shows two distinct peak in DTG curve which was also observed for NR/SBR blend system [25]. Pure SBR shows 10.57% wt loss in 1st degradation step. With increase in reclaim rubber content % wt loss in 1st degradation step gradually increases and maximum 24.13% was observed at 40phr SBR containing SBR/RR blend system. 1st degradation was faster with increase in RR content in SBR/RR blend system. Low temperature degradation was much pronounced with increase in RR content in SBR/RR blend system. If we compare our TGA results with pure RR system, it was observed that reclaim rubber shows three steps degradation. Out of three steps, 2nd degradation step occurs in between 334.4˚C - 507.5˚C. Actually 2nd degradation step of pure reclaim rubber partially merge with the 1st degradation step of SBR/RR blend system. As a result of which % wt loss increases in 1st degradation step of SBR/RR blend system with increase in reclaim rubber content.

But in case of second degradation the complete opposite train was observed. Pure SBR shows around 80% weight loss in second degradation step. This is the characteristic degradation peak for pure SBR in thermo-gravimetric analysis. The % wt. loss of blend vulcanizates is decreased in 2nd degradation step with increase in reclaim rubber content. This may be due to the low SBR content in SBR/RR blend system. The same reason was also ap-

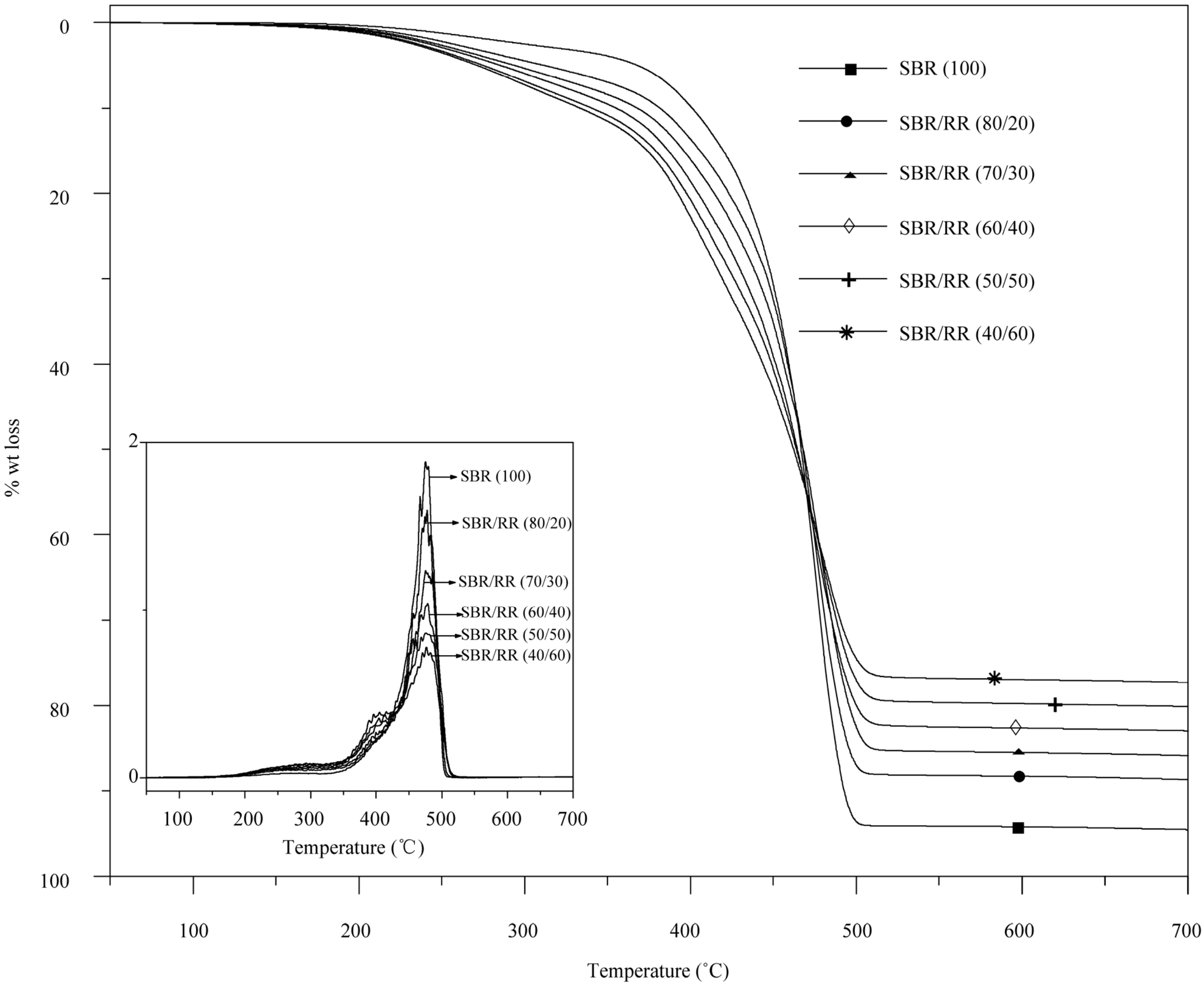


Figure 9. Thermogravimetric analysis of SBR/RR Vulcanizates.

Table 2. Degradation temperature and % weight loss of SBR/RR vulcanizates.

Blend	Initial wt. Loss	1st degradation				2nd degradation				% residue
		Start	Peak	End	% wt loss	Start	Peak	End	% wt loss	
SBR (100)	3.66	343.53	395.44	417.12	10.57	417.12	476.85	512.75	79.83	5.384
SBR/RR (80/20)	6.76	346.38	395.44	418.90	11.83	418.90	476.85	514.18	69.49	11.195
SBR/RR (70/30)	7.77	340.69	395.44	423.17	15.16	423.17	479.69	512.64	62.35	14.045
SBR/RR (60/40)	8.77	340.69	388.33	421.75	16.98	421.75	476.85	512.64	56.62	16.945
SBR/RR (50/50)	10.00	340.69	398.29	431.70	22.08	431.70	476.85	523.07	47.42	19.784
SBR/RR (40/60)	9.63	328.96	394.02	428.86	24.13	428.86	478.27	531.59	43.01	22.607

RR	Initial wt. Loss	1st degradation				2nd degradation				3rd degradation				
		Start	Peak	End	% wt Loss	Start	Peak	End	% wt Loss	Start	Peak	End	% wt Loss	9.81
	15.00	160	274	336	13.28	336	400	507	49.99	507	566	671	25.79	

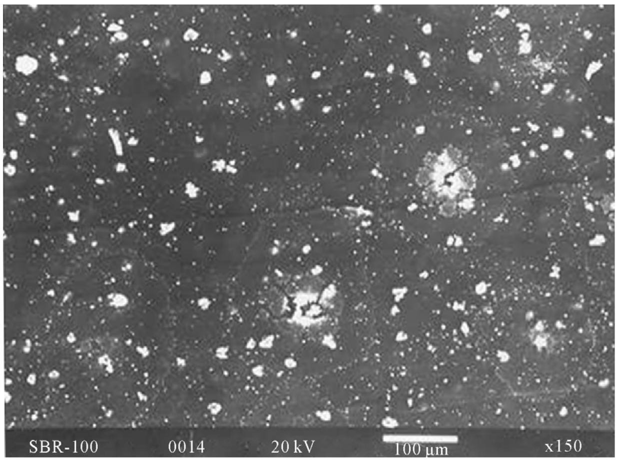
plicable for 2nd degradation step in blend system which shows less % wt loss with increase in RR content. This is due to the fact that the 3rd degradation step of pure reclaim rubber affects the 2nd degradation step of SBR/RR blend system. The lower % wt loss in the second step is due to both the higher carbon black content and to the greater % wt loss of the first step.

3.5. SEM Study

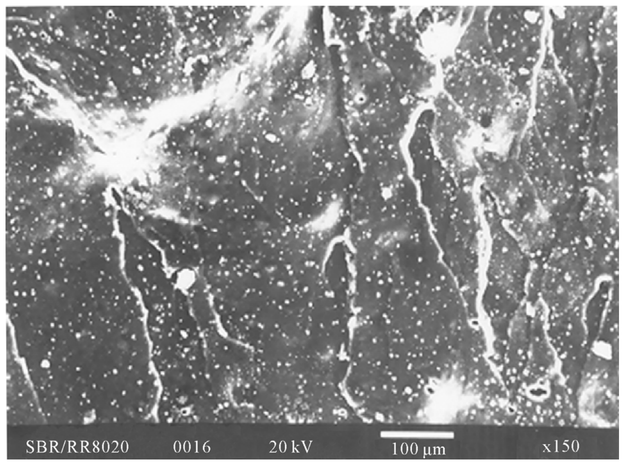
Scanning electron micrograph of the tensile fractured surface of fresh SBR and different SBR/RR vulcanizates are displayed in **Figure 10**. The micrograph of fresh SBR vulcanizate showed homogeneous surface morphology. Whereas in the reclaim rubber containing vulcanizates several number of crack paths in different directions was observed which is making the vulcanizate susceptible under mechanical stress. Here in case of reclaim rubber containing vulcanizate, the fracture mode showed the failure mode that was less rubbery in nature, due to higher cross link density of the vulcanizate.

4. Conclusions

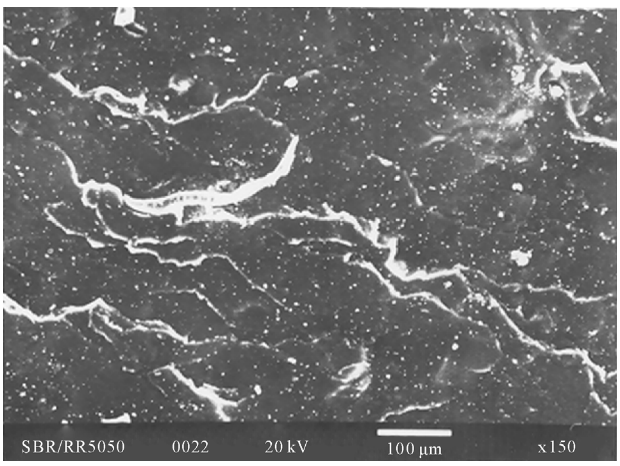
Mechanochemical reclaiming of GRT was carried out by multifunctional reclaiming agent, TMTD. The reclaimed rubber prepared in this investigation, when mixed with fresh SBR has been found to increase the tensile strength by about 19% for 20% reclaim containing vulcanizate and 115% for 60% reclaim containing vulcanizates. It is observed that the aging characteristics of the reclaim rubber containing vulcanizates are superior compared to that of the control formulation, which does not contain any reclaim rubber. TGA shows that the thermal stability of the vulcanizate increases with increasing reclaim rubber proportion. SEM studies indicate that reclaim rubber containing vulcanizates are vulnerable under mechanical stress. Another advantage of this reclaiming agent is the



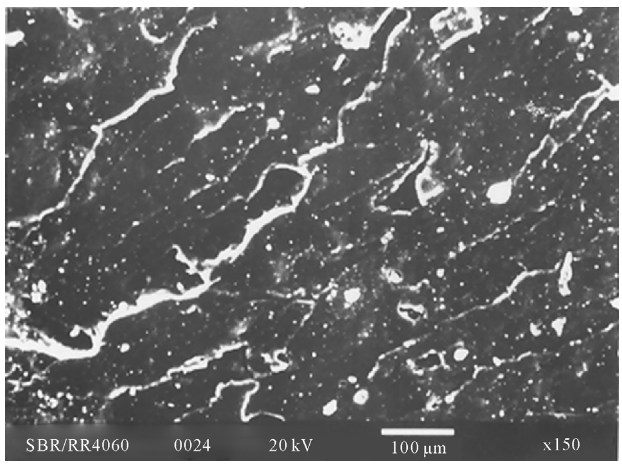
(a)



(b)



(c)



(d)

Figure 10. Tensile fractured surface of (a) SBR (100) (b) SBR/RR (80/20) (c) SBR/RR (50/50) and (d) SBR/RR (40/60) blend system.

reduced smell during the reclamation process and of the final reclaims, one of the most important short comings of other disulfides used for this purpose.

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