

Improving the properties of reclaimed waste tire rubber by blending with poly(ethylene-co-vinyl acetate) and electron beam irradiation

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ABSTRACT: Scrap rubber reclamation is one of the most desirable approaches to solve the disposal problem of used tires. However, reclaimed tire rubber (RTR) has not gained enough attention due to its poor properties. In this work, the effects of poly(ethylene-co-vinyl acetate) (EVA) addition and electron beam (EB) irradiation on the properties of RTR were studied. The RTR/EVA blends containing 100–0 wt % of RTR were prepared in the internal mixer followed by EB irradiation with doses ranging from 50 to 200 kGy. The RTR/EVA blends were subjected to mechanical, gel content, thermal, and morphological analysis. It was found that the addition of EVA to RTR improved the mechanical properties of RTR. However, results revealed that RTR undergoes irradiation-induced cross-linking in a relatively lesser extent as compared to EVA. This observation is associated with the stabilization and radical scavenging effects of additives, which are present in the RTR matrix. © 2014 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2015**, *132*, 41649.

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INTRODUCTION

Increasing awareness on the environmental safety, coupled with new sets of rules and regulations have driven the recycling and reuse of polymeric materials.¹ This is due to the nature of polymeric materials, which do not decompose easily, whereby the disposal of these polymeric materials causes serious environmental problems. One such polymeric product is tires made of rubber. Sienkiewicz *et al.*,² quoted the annual global production of tires is 1.4 billion units, which corresponds to an estimated 17 million tonnes of used tires each year. Many ways have been adopted to recycle and reuse waste tires to address this problem. Shulman³ in his work, detailed the main treatments and technologies used to recycle and reuse tires; and the corresponding application of the recyclates. He categorized one of the applications for waste tires is to be incorporated into thermoplastic polymeric material to obtain “thermoplastic elastomer” by combining rubber elasticity and thermoplastic matrix properties.

Many thermoplastic elastomers, which use waste tire rubber as the elastomeric phase have been studied.^{4,5} However, most of them found that the interfacial adhesion of waste tire rubber

and thermoplastic matrix are lacking, which in turn results in very poor mechanical properties. This finding has led to various studies to improve the interfacial adhesion, namely, the incorporation of compatibilizing agent,⁶ modification of waste tire dust,⁷ dynamic vulcanization,⁶ and radiation crosslinking.⁸ Nevertheless, previous study⁹ has also discussed the improvement of interfacial adhesion between the matrix and rubber particle, could not lead to an effective thermoplastic elastomer.

Waste tire rubber can be further processed using different techniques^{1,3,10–12} to obtain reclaimed tire rubber (RTR). RTR is devulcanized rubber where the three-dimensional structure of the rubber is broken¹² using chemical, mechanical, or combinations of both methods.^{1,11} However, the properties and quality of RTR are inferior as compared to the virgin rubber due to the breakdown of rubber macromolecules during the reclaiming process. For this reason, only a small portion of RTR is used in the production of a new product such as tires.

Reclaimed rubber is often blended with virgin thermoplastic or rubber as it can be processed, compounded, and revulcanized in the same way as the virgin rubber.¹³ Furthermore, using

reclaimed rubber along with the virgin polymer system offers advantages such as easier mastication, shorter mixing time, and lower power consumption during mastication and mixing. It also has an influence in curing and aging and in addition, cost, and energy saving.¹ A large number of studies have been carried out on the blends of waste tire rubber or RTR with natural rubber (NR) and polyolefins such as polypropylene and polyethylene.^{9,10,14–16} However, only a small number of studies have been carried out on blends of waste tire rubber and (EVA).^{17–19} To date, no study has been carried out on blends of RTR and EVA.

EVA has been used in many applications due to their vinyl acetate (VA) content. For example, copolymers with low VA content (<20%) are usually employed as thermoplastic and those with a higher VA content are used as oil-resistant elastomer.²⁰ Blends of EVA with NR have been widely reported.^{21–23} Most of them are reporting at an approximate blend ratio of 40 : 60 or 50 : 50, the blend of NR : EVA exists as continuous phase with good properties. A blend of EVA and RTR might also render similar good properties as NR is one of the major components of RTR; along with improving the inferior properties of RTR.

Radiation processing of polymers is very commonly studied at present.^{24–26} Ionizing radiation can be used to modify chemical and physical properties of polymers as it is bound to crosslink, degrade, grafted, or cured when subjected to ionizing radiation. Employing radiation to improve properties of waste polymers could increase the possibility of waste polymer recycling and indirectly contribute to solving polymeric waste problem. This study aims to investigate the effects of EVA addition and EB irradiation on enhancing mechanical, thermal, and morphological properties of RTR.

EXPERIMENTAL

Materials

Poly(ethylene-co-vinyl acetate) (Grade EVA N8045), EVA, having 18% VA content with melt flow index, MFI, value of 2.3 g/10 min and density of 0.947 g/cm³ was purchased from the TPI POLENA Public Company Limited, Thailand. Reclaimed tire rubber (RECLAIM Rubberplas C), RTR, from waste heavy duty tires used in this study was supplied by Rubplast Sdn. Bhd., Malaysia. General properties of RTR are 48% rubber hydrocarbon, 5% ash content, 15% acetone extract, 25% carbon black fillers, and density of 1.3 g/cm³.

Preparation of RTR/EVA Blends

RTR and EVA were melt blended in an internal mixer (Brabender Plasticoder PL2000-6 equipped with corotating blades and a mixing head with volumetric capacity of 69 cm³). The rotor speed was set at 50 rpm while the blending temperature was set at 120°C. The RTR content was set to 0, 30, 50, 70, and 100 wt %. EVA was fed into the internal mixer chamber and allowed to melt for 2 min followed by the addition of RTR. Both EVA and RTR were allowed to mix for 8 min before collecting the blends from the internal mixer. The total mixing time was 10 min. The collected materials were kept in sealed

plastic bags for subsequent compression molding. The designation of the prepared blends is shown in Table I.

Materials obtained from the internal mixer were compression molded to obtain the test specimens. The compounded materials were placed in a steel frame mould covered with aluminum plates on both sides. The materials were pressed at 130°C into sheets of 1, 2, and 5 mm thickness. The molding cycles involved 3 min of preheating without pressure, 20 s of venting, and 3 min of compression under 14.7 MPa pressure using a hot pressing machine (LP-S-50 Scientific Hot and Cold Press). Cooling was done immediately between two platen of cold press equipped with chiller at 20°C for 2 min.

Electron Beam Irradiation

The molded sheets were irradiated using the 3 MeV electron beam (EB) accelerator (model NHV-EPS-3000) at doses ranging between 0 and 200 kGy. The acceleration energy, beam current, and dose rate were 2 MeV, 5 mA, and 50 kGy per pass, respectively.

Gel Content

The samples gel content were determined according to ASTM D2765. The samples were placed in a stainless steel wire mesh of 120 mesh size and extracted in boiling Toluene using Soxhlet apparatus for 24 h. The samples were then collected and dried in an oven at 70°C until a constant weight is obtained. The gel content was calculated as per eq. (1) below:

$$\text{Gel content} = \frac{W_1}{W_0} \times 100 \quad (1)$$

where W_0 and W_1 are the dried weight of sample before extraction and after extraction, respectively.

Tensile Properties

The tensile test specimens were punched out using Wallace die cutter from compression molded sheets. The specimens had a gauge length of 25 mm, width of 6 mm, and thickness of 1 mm. Tensile properties measurements were done at room temperature according to ASTM D412 using a computerized tensile tester (Toyoseiki) with a load cell of 10 kN. The crosshead speed was set at 50 mm/min for all samples. The data for tensile strength, modulus at 100% elongation and elongation at break were recorded. At least 7 specimens were used for each set of blends and the average results were taken as the resultant value.

Tear

The tear test specimens were manually cut out using a sharp blade from the compression molded sheets. The specimens were

Table I. Designation of the Prepared RTR/EVA Blends

Designation	RTR content (wt %)	EVA content (wt %)
RTR	100	0
RTR70	70	30
RTR50	50	50
RTR30	30	70
EVA	0	100

cut out according to ASTM D624 Trouser test piece type. The test pieces had a length of 150 mm, width of 15 mm, and thickness of 2 mm. The testing was conducted at room temperature using a computerized tensile tester (Toyoseiki) with the load cell of 10 kN. The crosshead speed was set at 50 mm/min for all samples. The mean force required to propagate the tear in the trouser test piece was determined and divided by the thickness of the test piece to obtain the tear strength. At least 7 specimens were used for each set of blends and the average results were taken as the resultant value.

Hardness

The hardness test specimens were directly compression moulded according to ASTM D2240 (Type Shore A) samples. The test pieces had a length of 100 mm, width of 100 mm, and thickness of 5 mm. The testing was conducted at room temperature using the hardness tester with a blunt indenter (Durometer Hardness model Zwick 7206). At least 9 hardness readings were recorded for each sample and the average results were taken as the resultant value.

Thermo Gravimetric Analysis

The TGA test was done using a computerized thermo gravimetric analyzer (Mettler Toledo TGA/DSC 1 equipped with the STAR^c System) to determine samples thermal stability. Thermal stability was assessed by the dynamic TGA experiments. The test was done by heating the sample from room temperature to 600°C to obtain mass loss versus temperature thermogram. All analysis was carried out using 5–10 mg of samples in Nitrogen atmosphere (flow rate 50 mL/min) and a heating rate of 10°C/min.

Morphology Study

The examination of the fractured surfaces was performed using the field emission scanning electron microscope (FESEM, FEI Quanta 400). The surface of the tensile fractured samples was sputter coated with gold before the examination to avoid electrostatic charging and poor image resolution.

RESULTS AND DISCUSSION

Gel Content Analysis

Figure 1 shows the changes in the gel content of RTR/EVA blends on irradiation. Generally, the gel content is an estimation of yield of irradiation induced crosslinking. RTR shows 68% of the gel content prior to irradiation (0 kGy), affirming the presence of existing crosslinks within its matrix. During the reclaiming process, both crosslinks and macromolecular chains breakdown will happen. The breakdown of crosslinks is favorable as it increases the plasticity of the rubber. However, the breakdown of macromolecular chains should be kept minimal to ensure the optimal properties of the resulting RTR. Previous study²⁷ showed the importance of keeping both crosslinks and macromolecular chains breakdown balanced for the resulting reclaimed rubber to have the optimum plasticity and properties. Therefore, it is common for the reclaimed rubber to have a gel content ranging from 50 to 80%.²⁷

The gel content of RTR increased only marginally with the increase in irradiation dose. Similar findings were also discussed by Ratnam *et al.*,²⁸ who explained the stabilization of the rubber

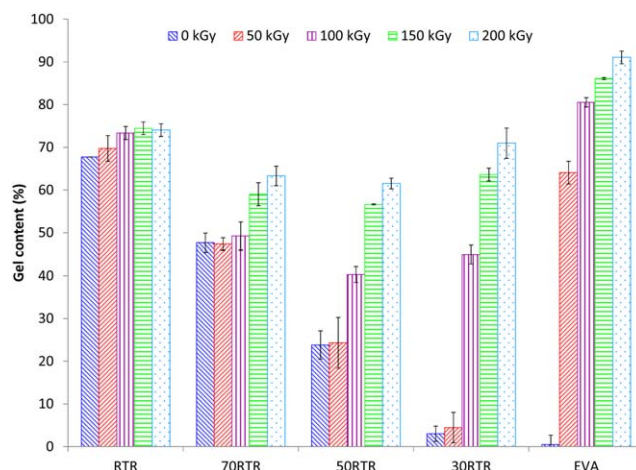


Figure 1. Gel content of RTR, EVA, and RTR/EVA blends as a function of irradiation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

and the radical scavenging effects by the additives causing a marginal increment in the gel content upon irradiation. Tires have myriad of additives, among them are stabilizers, antioxidants, and antiozonants used to prevent tire degradation due to sunlight and ozone attacks. The presence of these additives in the reclaimed rubber might be responsible in stabilizing and scavenging the radicals formed within the matrix through the EB irradiation, hence retarding the crosslinking process in the RTR and RTR/EVA blends. Work on chlorosulfonated polyethylene rubber/chlorinated NR/waste rubber powder blends found that incorporating the waste rubber powder enhanced the irradiation resistance of the blends due to the presence of active additives in waste rubber powder.²⁹ Al-Malaika and Amir¹³ who worked on thermoplastic elastomer blends, found the properties retention of the PP/NR/RTR blends on aging was far better than the blends of PP/NR and PP/EPDM due to the presence of antioxidants and stabilizers in the RTR. The finding of this study agrees well with the finding of the said studies. Another possible inference is the presence of residual reclaiming agent in RTR, which could also stabilize and scavenge the radicals formed by EB irradiation.

The existing crosslinks within the RTR matrix are also noticeable in the gel content of the unirradiated blends, which are proportionate to the content of RTR in the blend. The unirradiated EVA and 30RTR samples were found to be easily dissolved in boiling toluene. However, these EVA and 30RTR samples, which were irradiated above 50 and 100 kGy, respectively, were insoluble due to the formation of three-dimensional networks.³⁰

Additionally, it is observed that the blends require an irradiation dose above 50 kGy in order to observe a significant increase in the gel content. This might be due to the presence of additives in the RTR, which retards the crosslinking process in these blends as discussed earlier. At above 100 kGy irradiation dose, the gel content of the blends increases slowly and exhibits a marginal difference. A smaller increment in gel content with increasing irradiation dose was observed in blends with higher content of RTR. These might also suggest that at or above

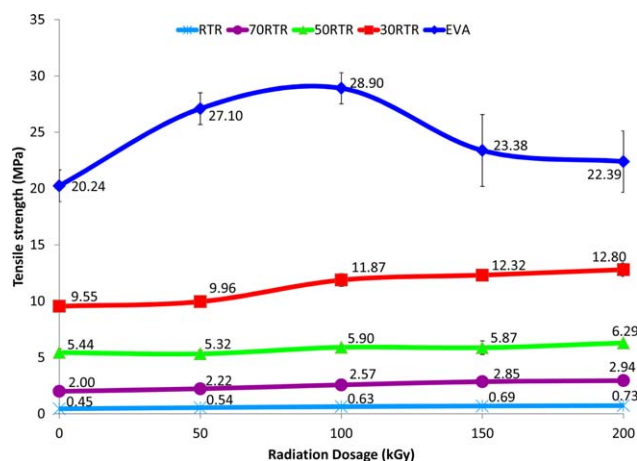


Figure 2. Strength of RTR, EVA, and RTR/EVA blends as a function of irradiation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

certain irradiation dose, the formation of radicals via EB irradiation exceeds the ability of the additives in RTR to stabilize and scavenge the radicals, permitting crosslinking to happen in the blends. However, the slow and marginal increment in the gel content with irradiation dose; with the increase in RTR loading, reflects that the RTR phase undergoes irradiation induced crosslinking at a lower extent as compared to EVA. This finding will be further elaborated along with the discussion on the tensile, tear, and hardness results in the following sections.

Mechanical Properties

Figures 2–4 show the tensile properties of RTR/EVA blends as a function of irradiation dose. Tensile strength, modulus 100, and elongation at break increased with increasing EVA content. Tensile strength, modulus, and elongation at break improved by 2018%, 1934%, and 1637%, respectively at 70% EVA content (0 kGy) as compared to RTR (0 kGy). This agrees well with the aim of this study, which is to improve the inferior properties of RTR by blending with EVA. The improvement in tensile properties

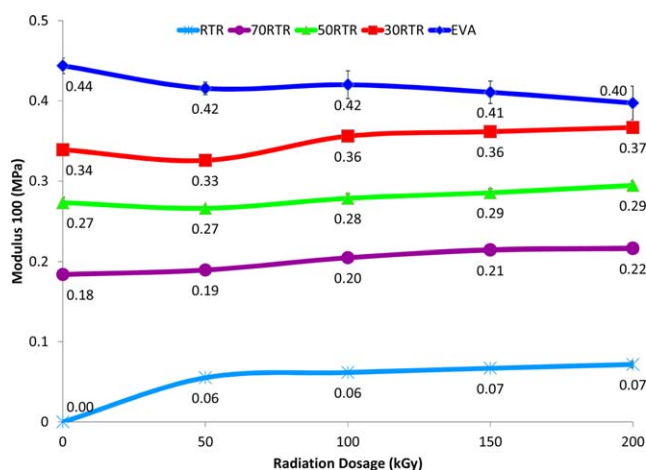


Figure 3. Modulus at 100% elongation of RTR, EVA, and RTR/EVA blend as a function of irradiation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

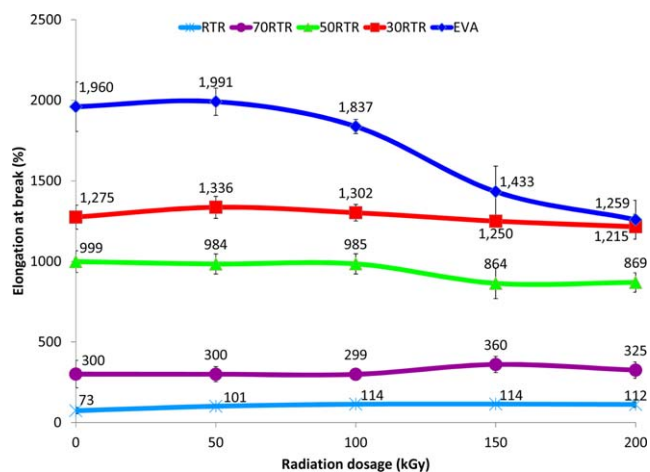


Figure 4. Elongation at break of RTR, EVA, and RTR/EVA blends as a function of irradiation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

with the incorporation of EVA can be attributed to the addition of EVA, which has a higher tensile strength, modulus 100, and elongation at break as compared to RTR. RTR/EVA blends approximately followed the rule of mixture over the whole composition range.

Tensile strength and modulus of RTR and RTR/EVA blends showed a slight increment with increasing irradiation dose. High energy radiation of polymers creates free radicals by the scission of the weakest bonds. This new entities react with each other forming crosslinks within the matrix.³¹ Increasing the irradiation dose increases the network of crosslinks, which are shown in the increase of tensile strength and modulus. It is also worth noting that the marginal increments in the tensile strength (<50% at 200 kGy) and modulus (<20% at 200 kGy) are in relation to the gel content analysis of RTR and RTR/EVA blends.

EVA shows a different trend where the tensile strength increases (43%) up to 100 kGy irradiation dose followed by a drop. This drop might be associated to the excessive formation of crosslinks above 100 kGy irradiation dose, which in return causes the embrittlement of EVA. A similar observation was reported by Ratnam *et al.*,²⁶ while working on radiation induced crosslinking of polyvinyl chloride/epoxidised NR blends. In the beginning of irradiation, larger network structure is formed through radiation induced crosslinking resulting in an increase of the strength. However, at higher radiation doses, crosslinking are formed between the already crosslinked polymer chains breaking the larger network structure into smaller networks (microgel) resulting in the embrittlement of the polymer matrix.^{24,32,33}

Elongation at break of RTR was relatively low as compared to normal rubber compound. This is due to the breakdown of sulfur vulcanizations as well as the rubber backbone during the process of reclaiming. The presence of additives such as carbon black might act as stress concentration points and contribute to such a low elongation at break of RTR. Interestingly, the elongation at break of RTR was not influenced by the irradiation dose. This trend might again be associated to the marginal increments in the gel content of RTR with irradiation dose and also suggests

that no prominent degradation occurred because of the EB irradiation of RTR. EVA and RTR/EVA blends containing 30% and 50% of RTR on the other hand, showed a drop after 50 kGy irradiation dose. The drop is associated with the decreased ductility of EVA due to the formation of radiation induced crosslinks.^{34,35} This could also be observed in the SEM micrographs, which will be discussed in the morphological study section. Another salient point to note is that the RTR/EVA blend containing 70% of RTR shows an upward trend at above 100 kGy irradiation. Such increase in elongation at break is believed to be associated with the increase in the compatibility of the blend upon irradiation.

Figure 5 shows the tear strength of samples as a function of irradiation dose. Similar to tensile strength, tear strength increases with the addition of EVA (2600%, 30 RTR). However, there was only a marginal improvement (<10% at 200 kGy) in the tear strength of RTR/EVA blends with increasing irradiation dose. On the contrary, EVA showed a distinct increase (18%) in tear strength up to 100 kGy irradiation followed by a decrease beyond 100 kGy irradiation dose. Such a drop in the tear strength at above 100 kGy is in agreement with the observation on tensile strength in which EVA is believed to undergo embrittlement because of the occurrence of excessive radiation induced crosslinking at higher irradiation doses.^{24,26,32,33}

Figure 6 shows the hardness of samples as a function of irradiation dose. Similar to the tensile properties, hardness (Shore A) increases with the addition of EVA, which reflects the effect of EVA addition, which has a higher hardness value as compared to the RTR. The hardness of EVA, RTR, and RTR/EVA blends shows an upward trend upon irradiation. Similar to the tensile strength, tear strength, and modulus 100; the improvement in hardness of the samples upon irradiation is attributed to the occurrence of irradiation induced crosslinking of EVA and RTR. By definition, hardness is referred to as the resistance of material to the local deformation,³⁰ and the results proved that even at a low irradiation dose, the crosslinked RTR and RTR/EVA blends were more resistant toward the local deformation consequently

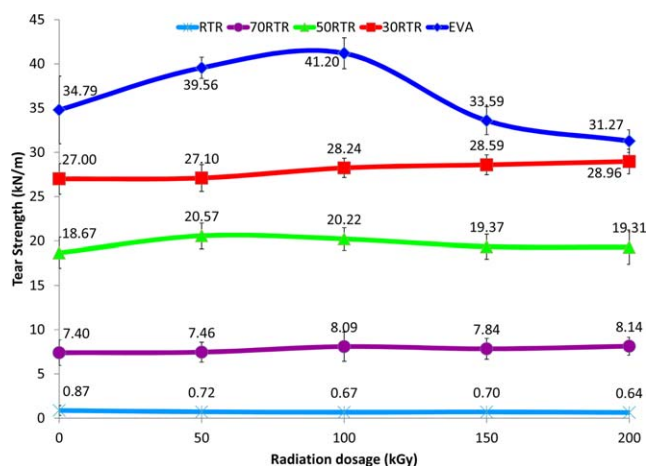


Figure 5. Tear strength of RTR, EVA, and RTR/EVA blends as a function of irradiation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

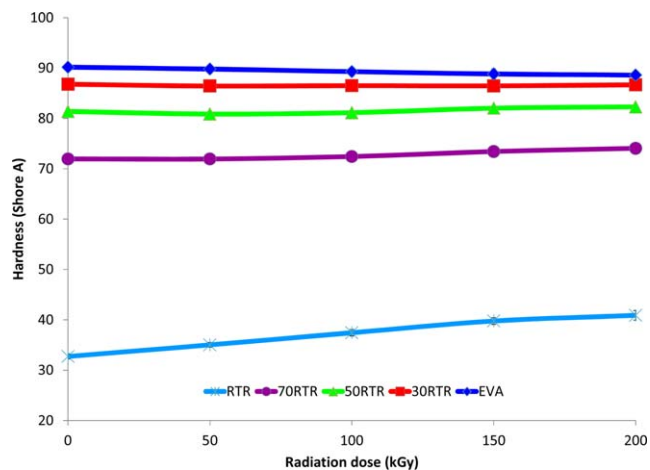


Figure 6. Hardness shore A of RTR, EVA, and RTR/EVA blends as a function of irradiation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

leading to the increase in hardness values. The hardness of RTR improved by 25% at 200 kGy irradiation dose as compared to the unirradiated RTR although RTR did not exhibit a remarkable increase in the gel fraction upon EB irradiation. This observation indicates that RTR had achieved a better resistance towards the local deformation although the radiation induced crosslinking in RTR occurred at a relatively lower extent compared to EVA.

Several authors have studied the effects of ionizing radiation (gamma or EB) on waste tire dust blends.^{9,15,16,25} All of them used a single blend with smaller content (either 30 or 50 wt %) of waste tire dust to study the effects of irradiation on blend properties. This has ensured that the influence of waste tire dust on resistance towards ionizing irradiation goes unnoticed in the literature. One of the works which used gamma irradiation on HDPE/RTR blends³⁶ (0–100 wt % RTR) failed to discuss the reasons behind the poor properties enhancement of the blend with the increasing RTR content. The possibility of waste tire rubber properties enhancement employing ionizing radiation has neither been fully understood nor fully exploited.

Thermo Gravimetric Analysis

Figures 7 and 8 show the TGA and derivative TGA curve for RTR, EVA, and RTR/EVA blends. In general, two step degradation was observed for all samples. Table II lists the data obtained from the TGA curve and derivative TGA curve. RTR undergoes two step degradation, which starts rather early. At first, a continuous mass loss was observed up to 319°C (refer to inset of Figure 8). This is associated with the evaporation of volatile content such as processing oil, plasticizer, and low molecular weight substances. The volatile content in RTR corresponds to 8.25%. The following degradation process observed is associated with the intensive thermal depolymerization of the rubber backbone.¹⁰ The first degradation peak (T_{1st}) was observed at 390°C whereas the second degradation peak (T_{2nd}) was observed at 444°C in derivative TGA curve, which corresponds to two types of rubber in the RTR. The degradation temperature of 390°C is associated with the degradation

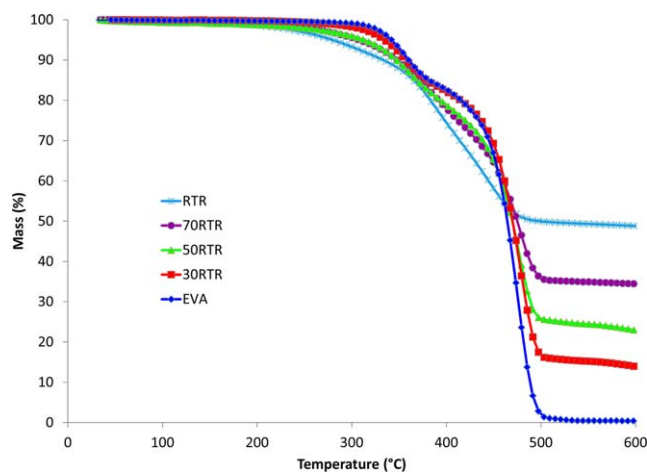


Figure 7. TGA curve for controls and blends. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

of NR³⁷ while the degradation temperature of 444°C is associated with the degradation of either styrene butadiene rubber (SBR)³⁸ or butadiene rubber (BR).³⁷ All NR, SBR, and BR are the common rubber compounds used in the manufacture of tires. Since the source of this study was heavy duty tires, the presence of BR could be more plausible as it is more commonly used in heavy duty tire formulations.³ The mass loss associated with NR and BR (or SBR) was 21.75% and 20%, respectively. This might indicate that NR and BR (or SBR) are present in ~50:50 blend ratio of the total rubber compound in the RTR. The total rubber content according to the TGA curve is 41.75%. The residual weight of RTR was 50% at about 500°C, which is char of filler, additives, and impurities from waste tire such as carbon black. EVA also undergoes a two step degradation, where the first step is associated with loss of acetic acid group ($\approx 17\%$) and the second one corresponds to the degradation of the main chain, polyethylene backbone.²³

The blends also show a similar 2 step degradation shown by EVA and RTR. However, they appear to have an intermediate thermal stability. The amount of volatile content and residual weight was proportionally lowered with the decreasing amount of RTR in the blends. The first and second degradation process in RTR was found to be merged with the first and second degradation process of EVA, respectively. The merge of degradation process pushes the T_{1st} to a lower temperature and the T_{2nd} to a higher temperature as compared to the RTR with the increasing EVA content. As expected, T_{1st} decreased with the increasing

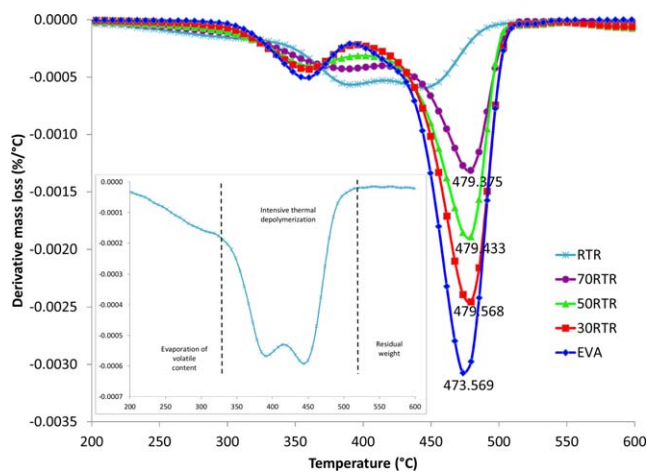


Figure 8. Derivative TGA curve for controls and blends. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

EVA content as EVA records a lower T_{1st} value as compared to RTR. Surprisingly however, all the blends showed a higher T_{2nd} value as compared to both EVA and RTR. Similar to T_{1st} , the temperature at mass losses of 5% ($T_{5\%}$), 10% ($T_{10\%}$), 25% ($T_{25\%}$), and 50% ($T_{50\%}$) of the blends showed an intermediate values between RTR and EVA. Clearly, all three blends showed a higher thermal stability as compared to the RTR up to $\approx 450^\circ\text{C}$.

Morphological Study

Figures 9–11 depict the SEM micrographs of the tensile fracture surface of RTR, 50RTR, and EVA, respectively. RTR shows a brittle fracture surface whereby the matrix phase failed to elongate or prematurely ruptured. The fracture shows an irregular crack path in different direction, which makes RTR susceptible to low elongation at break. The presence of filler (such as carbon black) with voids around (indicated by arrows) is also evident on the surface of RTR fracture surface. This, as discussed in the earlier section would lead to a low tensile strength and elongation at break. It is observed that with the addition of EVA, the brittle nature of RTR [Figure 9(a)] changes to a fibrillated ductile fracture in the 50RTR blend [Figure 10(a)]. This finding is in agreement with tensile studies where the tensile properties of RTR improved tremendously with the addition of EVA. The presence of filler and rubber particle was also visible in 50RTR blends (indicated by arrows). Also, there is no significant change in the morphology of RTR with the increasing irradiation dose. However, 50RTR did show a slight difference between the fracture surface before and after irradiation.

Table II. Degradation Temperatures and Residual Weight of EVA, RTR, and Blends

Sample designation	Volatile content wt (%)	Degradation temperature ($^\circ\text{C}$)						Residual wt (%)
		$T_{5\%}$	$T_{10\%}$	$T_{25\%}$	$T_{50\%}$	T_{1st}	T_{2nd}	
RTR	8.25	282.0	333.3	399.2	497.2	390.3	443.9	48.8
70RTR	5.40	306.0	348.0	413.9	474.2	384.1	479.4	34.3
50RTR	4.06	312.0	348.2	419.9	471.5	360.3	479.4	23.0
30RTR	2.13	333.2	355.3	437.9	470.6	360.2	479.6	13.9
EVA	0.00	342.1	360.1	431.0	465.0	360.0	473.6	0.4

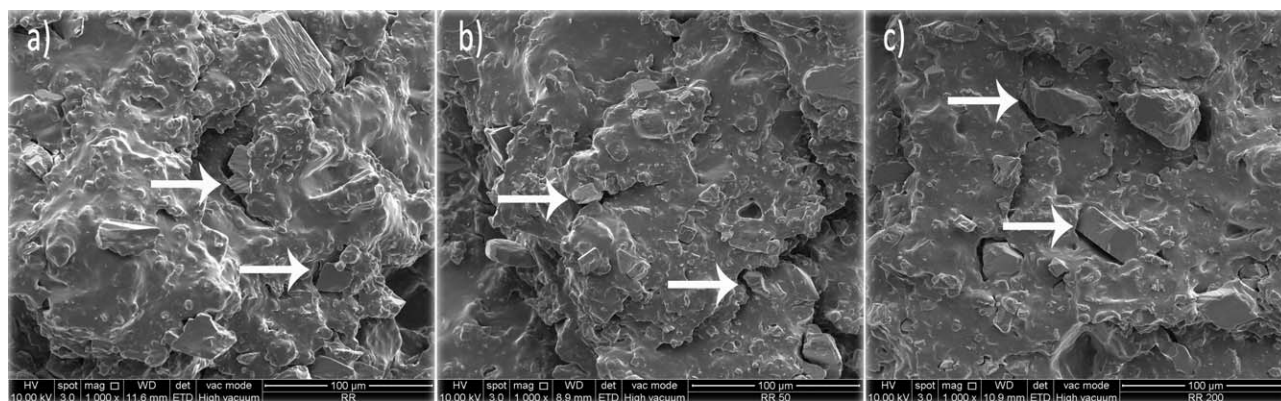


Figure 9. SEM micrograph of RTR tensile fracture surface (a) 0 kGy, (b) 50 kGy, and (c) 200 kGy.

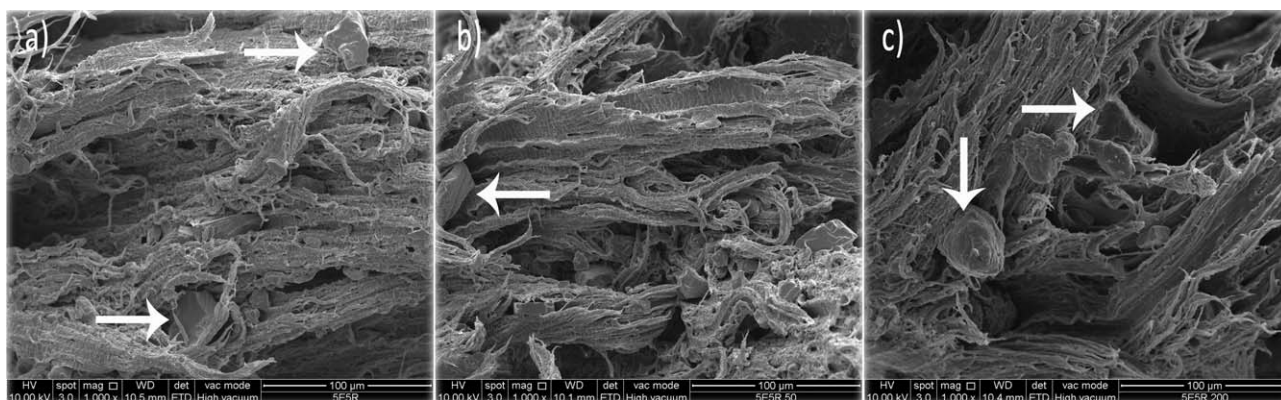


Figure 10. SEM micrograph of 50RTR tensile fracture surface (a) 0 kGy, (b) 50 kGy, and (c) 200 kGy.

The fibril ends/edges of 50RTR fracture surface before irradiation was thinner and longer as compared to fibril ends/edges after irradiation. This could be due to the decrease in ductility of the 50RTR sample upon irradiation. These observations are also in line with the gel content analysis where the gel content of RTR and blends were increasing in a less remarkable manner as compared to EVA due to the stabilization and radical scavenging effect of the additives within the RTR matrix. The fracture surface of EVA evolved from wavy structure before irradiation to fibrillated waves at 50 kGy irradiation dose and then smoother surface at 200 kGy irradiation dose. Fibril like

structure (indicated by arrows) in unirradiated EVA was tiny and showed only a slight elongation [Figure 11(a)]. However, upon radiation (50 kGy) the fibrils elongated enormously [Figure 11(b)]. Further irradiation (200 kGy) [Figure 11(c)] resulted in the diminishing fibril structures (indicated by arrows). Embrittlement of EVA was also evident from Figure 11(c) where the surface was found to be having some sort of coalesced globular surface, which is clearly different from the surface before irradiation and 50 kGy irradiation. These observations confirm the findings of the tensile properties where the tensile properties of EVA were improved due to the occurrence of irradiation

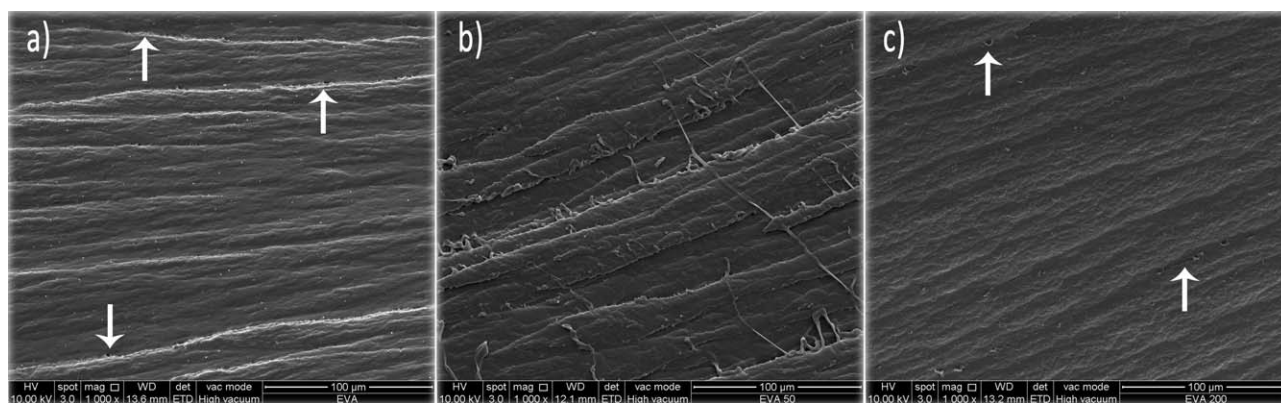


Figure 11. SEM micrograph of EVA tensile fracture surface (a) 0 kGy, (b) 50 kGy, and (c) 200 kGy.

induced crosslinking until 100 kGy irradiation and declined upon further irradiation as a consequence of embrittlement caused by excessive crosslinking.

CONCLUSIONS

Results revealed that the addition of EVA to RTR improved the tensile properties, tear strength, hardness, and thermal properties of RTR. The enhancement in the mechanical properties of RTR/EVA blends upon EB irradiation is attributed to the irradiation induced crosslinking of the EVA and RTR phase. However, the neat RTR shows only a marginal increment in the mechanical properties and gel fraction upon EB irradiation, implying a lower degree of radiation induced crosslinking achieved in RTR. The presence of additives such as antioxidants and carbon black in the RTR offers stabilization and radical scavenging effects, which in return retards the radiation induced crosslinking in RTR.

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