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Research article

Mathematical function using mechanical properties to calculate chain scission as a function of radiation dose in electron beam treated styrene-butadiene-styrene block copolymer

Sanjoy Datta^{1*}, Ondřej Peter^{1,2}, Evghenii Harea¹, Radek Stoček¹, Kinsuk Naskar³

¹Centre of Polymer Systems, University Institute, Tomas Bata University in Zlín, tř. Tomáše Bati 5678, 760 01 Zlín, The Czech Republic

²Bonatrans Group a.s., Revoluční 1234, 735 81 Bohumín, The Czech Republic

³Rubber Technology Centre, Indian Institute of Technology Kharagpur, Kharagpur, India

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Abstract. Electron beam (EB) treatment of a high vinyl styrene-butadiene-styrene (SBS) block copolymer was accomplished by exposing the polymer to high-energy electrons generated from an electron accelerator. This resulted in the formation of free radicals of carbon on the polybutadiene units in the backbone of the elastomer and subsequent radical coupling to produce cross-links. In the process, some unavoidable chain scission (*CS*) also occurred. An attempt was made to mathematically trace the nature of the *CS* as a function of radiation dose with the aid of the experimentally determined cross-link density (*CLD*), tensile strength and tear strength, the latter three also obtained as functions of radiation dose. The radiation dose was varied from 12.5 to 300.0 kGy in multiples of 12.5 kGy. The novelty of the work was, in part to create a function that can be used to calculate chain-scission in dependence of EB radiation dose. It was found that a change in the ratio of *CS* to *CLD* occurred as a function of radiation dose over the previously calculated constant ratio, using the Charlesby-Pinner equation.

Keywords: electron beam radiation, thermoplastic elastomer, chain scission, cross-link density, tensile and tear strength

1. Introduction

Electron beam (EB) cross-linking is a process in which labile hydrogen atoms are knocked off the backbones of polymer chains, in effect creating free radicals. The union of these free radicals enhances the formation of effective chemical cross-links between the chains [1]. It has gained popularity over the years and is applicable along with many other polymers to styrene butadiene styrene (SBS) block copolymers [2].

This is because the EB cross-linking process is fast, pollution-free and simple. Another advantage is in the effectiveness of uniform cross-linking in materials having intricate dimensions, as the EB can uniformly

*Corresponding author, e-mail: <u>sdatta@utb.cz</u> © BME-PT reach all such intricate areas [3]. Also, if the thickness of the product is below a critical value, and the cross-link density is moderate, then the cross-linking is homogenous throughout the polymer matrix and the process does not ask for applying the beam from all the sides [1]. Obviously, this is applicable to a product of any shape, provided that the maximum thickness of the product is less than the effective precalculated depth of penetration of the EB for any specified effective radiation dose. The effective radiation dose is determined using dosimetry [4].

However, EB cross-linking of polymers can encounter some problems also. This is because an uncrosslinked polymer treated with high energy EB may simultaneously encounter some undesirable chain-scission, usually in the main chain, along with the desirable cross-linking, the latter usually occurring between the polymer chains. This chain-scission deteriorates the final properties of the polymer, and measures should be taken to reduce it to a minimum. From the experimental results of the present work, it was found that the ratio of chain scission to crosslinking was dose-dependent. Also, at any specified radiation dose, the ratio of chain scission to crosslinking is dependent on the individual polymer. Thus, for example, at some moderate radiation dose, an SBS block copolymer may show chain scission confined to the mid-block polybutadiene units over that of the polystyrene end blocks.

Charlesby and Pinner [5] and Lawton et al. [6] studied the physical and chemical changes in polymers and elucidated the mechanism of cross-linking and chain scission under exposure to radiation energy. Böhm and Tveekrem [7] studied the dependency of various factors like radiation dosage, rate, and time of exposure on the properties of radiation crosslinked polymers. Pearson and Böhm [8] studied the cross-linking process of certain polymers under irradiation at higher temperatures over the ambient and concluded that temperature was shown to have a positive effect in increasing the degree of crosslinking. Seguchi [9] studied the irradiation effect on polytetrafluoroethylene (PTFE) at ambient and at its melting temperature and concluded that PTFE undergoes chain scission at ambient temperature, whereas cross-linking predominates at melting temperature (327 °C). Salmone [10] studied the irradiation effect on polyethylene with special reference to temperature and reported that cross-linking efficiency increased significantly at melting temperature. Bhowmick and Vijayabaskar [11] carried out extensive studies on the irradiation effect on various polar and nonpolar polymers such as fluoroelastomer, nitrile rubber, ethylene propylene diene methylene (EPDM) rubber, ethylene vinyl acetate (EVA) and their blends [12-18] and opened up a spectrum of effects that EB radiation can bring about to these polymers.

Thus, it is seen that for the two opposing phenomena of cross-linking and chain scission occurring simultaneously, one may dominate over the other, mainly as functions of the polymer type, radiation dose, temperature, functional modification of the polymer and the use of other additives. Studies have been done on various rubbers as well. For natural rubber (NR), apparent changes in the microstructure were observed on irradiation with a decrease in unsaturation with accompanying cis-trans isomerism [19]. The yield of cross-links in 1,2 and 3,4 isomers of polyisoprene [20] was observed to be higher than that of high cis-1,4 polyisoprenes and natural rubber [21]. Oxygen has been found to increase the rate of scission and decrease cross-linking. Cross-link promoters, like maleimides and a number of halogenated compounds, increase the yield of cross-links.

Radiation-sensitive polybutadiene and radiation-resistant aromatic polystyrene are pertinent to the present work as we deal with the SBS block copolymer. In the case of poly-butadiene rubber (BR), the yield of cross-linking depends on the microstructure of BR and the purity of the polymer, as well as on the atmosphere of irradiation, like whether it is irradiated in air or vacuum. The cross-link yield has been calculated to be the lowest for the trans and the highest for the vinyl isomer [22]. The introduction of styrene into the butadiene chain leads to a greater reduction in the yield of cross-linking than that of the physical blends of polybutadiene and polystyrene [23]. Extremely fast cross-linking is observed in epoxidised cis 1,4-polybutadienes and this is due to a very efficient chain reaction process which gets progressively inhibited at higher doses. Carbon black and silica fillers are reported to enhance cross-linking, becoming either chemically linked to the polymer chain or resulting in a higher cross-link density near the surface of the reinforcing particle [24]. Aromatic oils have been found to enhance the yield of scission [25]. For materials acting as radiation-resistant polymers, it has been found that aromatic molecules like benzene, styrene, naphthalene, anthracene and aromatic plasticizers act as local traps for radiation energy after it is deposited in the material. The scission yield of polyisobutylene is found to be higher than that of poly (α -methylstyrene). The radiation stabilization of polymethylmethacrylate (PMMA) by the incorporation of various aromatic additives [26] and grafting of styrene onto a polymer backbone [23] has been demonstrated. This stability is attributed to the higher resonance energy of the aromatic groups. Since cross-linking and chain scission occur simultaneously under exposure to EB radiation, methods must be envisaged to understand them mathematically. Charlesby-Pinner method is often used to find

the ratio of chain scission to cross-linking for unit radiation dose [5].

In the present work, a simple and novel method was used to simultaneously understand the extent of chain scission (CS) and cross-link density (CLD) under the influence of EB radiation on a thermoplastic elastomer (TPE) of an SBS block copolymer type. The polymer was advantageously chosen for the following two reasons: (1) to obtain a greater number of cross-links in the mid-block poly-butadiene part because of the presence of the pendent vinyl mers [3], which are more susceptible to radiation crosslinking, and (2) to arrest some EB radiation energy by the polystyrene end groups [23]. This made it possible to obtain an overall CLD at a moderate level confined only to the mid-block polybutadiene units. In general, if the *CLD* is above a certain magnitude, then fracture failure of the cross-linked polymer may occur, in effect lowering the value of tensile strength [27]. Thus, being able to arrest the *CLD* at some low magnitude, it was assumed that this deterioration in the tensile strength did not occur which would have otherwise added to the already existing deteriorating effect due to CS. In that case, the nature of CS could not have been correctly ascertained. Thus, keeping the CLD at a moderate level allowed for the correct prediction of CS.

Tensile strength, tear strength, and *CLD* of the polymer as functions of EB radiation dose were experimentally determined. The data obtained from the experiments were then used to form mathematical equations to predict the *CS* in the presence of linearly increasing *CLD*. The studies were done over the entire range of the radiation dose.

Earlier, the Charlesby-Pinner method [5] furnished a constant number ratio of chain scission to crosslinking for unit radiation dose, and this number was assumed to be a constant throughout the range of radiation. The objective of the present work was to elucidate the changing nature of *CS* and, subsequently, the changing ratio of *CS* to *CLD* over the entire range of the radiation dose from 0.0 to 300.0 kGy. Thus, the present work, in a noble manner, illustrated that over this constant number ratio, as demonstrated in the work of Charlesby and Pinner [5], the ratio of *CS* and *CLD* changed in dependence on the radiation dose, this changing ratio predicted from the changing nature of the tensile strength and tear strength.

2. Experimental

Styrene-butadiene-styrene (SBS) block copolymer, Kraton DKX222, was obtained from Kraton Polymers, Belgium. It contains 18 weight percent of chemically bound styrene and 82 weight percent of chemically bound butadiene. The microstructure of the polybutadiene midblock is about 50% 1,4 (trans, cis) and 50% 1,2 (vinyl) insertion in a random sequence. It has a density of 910 kg \cdot m⁻³ and weight average molecular weight $\overline{M}_{w} = 70\,000 \text{ g}\cdot\text{mol}^{-1}$ [28]. Moulded sheets $(k_{12.5,0}, k_{25.0}, k_{37.5}, k_{50.0}, k_{100.0}, k_{200.0})$ and $k_{300.0}$), having thicknesses of about 2 mm, were subjected to EB radiation. Here, k represents the polymer, followed by a number in subscript. The number represents the absorbed EB radiation dose in kGy. The samples were irradiated in the air with an industrial electron beam accelerator ILU-6 from Budker Institute of Nuclear Physics, Russia, under the following conditions: energy = 1.6 MeV, average current = 2.5 mA, pulse frequency = 25 Hz, at a conveyor speed of $0.03 \text{ cm} \cdot \text{s}^{-1}$, which delivered a dose of 12.5 kGy per pass, as was determined by nylon film dosimetry prior to irradiation. The number of crossings under the beam and their speed both define the irradiation dose, ranging from 12.5 to 300.0 kGy. The sample $k_{0.0}$ was the reference sample without subjecting it to any radiation.

Tensile tests were performed according to ASTM D 412 on dumbbell-shaped specimens (Type 2) using a Hounsfield tensile testing machine H10KS (Germany) at a constant crosshead speed of $500 \text{ mm} \cdot \text{min}^{-1}$. For each sample, the average of three readings not varying within wide limits were reported as the test results, with corresponding values of standard deviation calculated on a sample basis.

Tear strength was evaluated according to ASTM D 624 on Type C specimens at a crosshead speed of 500 mm \cdot min⁻¹.

Cross-linking was supposed to have taken place only in the mid-block polybutadiene units as has been stated earlier in the introduction section. *CLD* in these mid-blocks was determined on the basis of equilibrium solvent-swelling measurements in the solvent cyclohexane at 23 °C by the application of the well-known modified Flory-Rehner equation, as shown in Equation (1) [29]:

$$\nu = \frac{1}{2V_{\rm s}} \cdot \frac{\ln(1 - V_{\rm r}) + V_{\rm r} + \chi V_{\rm r}^2}{V_{\rm r}^{1/3} - 0.5V_{\rm r}}$$
(1)

where v is the *CLD* [mol·cm⁻³], $V_s = 108.7 \text{ cm}^3 \cdot \text{mol}^{-1}$ is the molar volume of cyclohexane, $\chi = 0.315$ represents polymer-swelling agent interaction parameter (Flory-Huggins parameter), as has been reported in [30] and V_r is the volume fraction of the polymer in the swollen network at equilibrium with the solvent. Taking into consideration the weight correction for the insoluble polystyrene units, V_r can be deduced from Equation (2) [17]:

$$V_{\rm r} = \frac{\frac{D - FT}{\rho_{\rm r}}}{\frac{D - FT}{\rho_{\rm r}} + \frac{A_0}{\rho_{\rm s}}}$$
(2)

where *D* is the de-swollen weight of the test specimen, *F* is the weight fraction of the solvent insoluble components in the specimen (here F = 0.18 due to 18 weight percent of the polystyrene supposed to have been insoluble in cyclohexane), *T* is the initial weight of the test specimen, A_0 is the weight of the absorbed solvent, ρ_r is the density of rubber (0.910 g·cm⁻³ for the mid-block polybutadiene units) and ρ_s is the density of the solvent (0.779 g·cm⁻³ for cyclohexane).

Cyclohexane was chosen as the swelling solvent due to its solubility parameter of 16.8 MPa^{1/2} [31], which is close to that of the mid-block poly-butadiene units $(17.5 \text{ MPa}^{1/2})$ [31] of the SBS block copolymer. Thus, only the chain scissioned and cross-linked polybutadiene units physically interacted with the solvent. The end-block polystyrene units, having a solubility parameter of 21.3 MPa^{1/2} [2], were considered as the insoluble mass in cyclohexane. Here for the sake of simplicity, only the dispersion components of the solubility parameters have been mentioned. A 2 mm thick EB cross-linked sample was submerged in cyclohexane. After 24 h the cyclohexane was refreshed to remove any extractable matters. After another 24 h of swelling, the swollen sample was weighed, dried and weighed again. From the degree of swelling, the CLD, was calculated.

The Charlesby-Pinner equation [5, 32], as is shown in Equation (3), is a good mathematical method for the determination of chain scission to cross-link ratio:

$$s + s^{1/2} = \frac{p_0}{q_0} + \frac{10}{q_0 \mu D}$$
(3)

where *s* is the sol-fraction and is a unitless parameter of the simultaneously cross-linked and chain scissioned polymer in the solvent, μ is the number

average degree of polymerization of the polymer, a number without any unit, D is the radiation dose in kGy absorbed by the polymer, q_0 is the density of cross-link per unit dose of radiation in kGy⁻¹ and p_0 is the density of main chain fracture per unit dose of radiation in kGy⁻¹.

3. New theoretical background of the work with proposed mathematical equations

For a given low elongation (say 100 %), the stress, σ is proportional to $1/\overline{M_c}$, where $\overline{M_c}$ is the average number of mers or repeating units between two cross-links. Thus, a lower value of $\overline{M_c}$ reflects a higher number of cross-links in a given volume, which in turn will increase the value of σ , which is a measure of modulus at that given elongation. Thus, if *CLD* linearly increases as a function of radiation dose, then the modulus at any specified elongation must also increase linearly as a function of radiation dose.

However, the tensile strength of a cross-linked elastomer depends on (a) the number of cross-links and (b) the homogeneous distribution of the cross-links. Stress sharing must be uniform through the polymer to see an increase in the tensile strength. Thus, the tensile strength may initially increase with increasing cross-links, but with further increase in the number of cross-links, there may be an inhomogeneity, and the tensile strength may decrease [27].

In the present work, an initial increase followed by a decrease in the tensile strength as a function of radiation dose was also observed, simultaneously with a continuous increase in *CLD* in dependence on the radiation dose. The mid-block poly butadiene unit was simultaneously cross-linked and chain scissioned at relatively moderate radiation doses [3]. The end block polystyrene units only played the role of absorbing a part of the whole radiation dose, otherwise remaining inert to any chemical changes under the stated moderate radiation doses, as is again evidenced through literature [23]. As a result, the midblock was prone to changes, while the end-blocks were not so much because they are much more inert to EB radiation, based on the literature.

The reason behind a decrease in the tensile strength at higher radiation doses because of an enormous increase in the *CLD*, as has been evidenced in [27], that may not be applied to the SBS block copolymer used in the present work. This was because it was relatively low to moderately cross-linked, with a lowest of $0.77 \cdot 10^{-5}$ mol·cm⁻³ at 12.5 kGy and the highest of $21.04 \cdot 10^{-5}$ mol·cm⁻³ at 300 kGy. These relatively low to moderate *CLD* are shown in Figure 1 as compared to the usually encountered similar or even somewhat higher cross-link densities [33] in styrene-butadiene types of rubbers. In another work with an SBS block copolymer [34], it was shown that the gel content increased with increasing EB radiation dose and also, low molecular weight material was generated after exposure to EB, whereby it was concluded that both cross-linking and *CS* reactions took place, with the cross-linking reaction being the dominant one.

Thus, the other probable explanation of the decrease in tensile strength after passing through a maximum was in the relative increase in CS over the linearly increasing CLD as a function of radiation dose. This is more evident because, even though the modulus at 100% elongation increased as a function of CLD, the tensile strength showed a decrease after passing through a maximum. This can be picturized as a lesser number of polymer units between cross-links - attributed to more CLD, and simultaneously, the formation of a greater number of CS units on these lesser number of polymer units. These scissioned units may not always be torn off the polymer backbone. This is evident when only one scission occurs on the backbone between two consecutive crosslinks. These CS units, in the three-dimensional matrix of the polymer, were then thought to be the areas of mechanical weaknesses, affecting a decrease in the tensile strength.

Based on this assumption and the availability of experimental data on *CLD* and tensile strength as functions of radiation dose, a simple equation to find the *CS*, shown as Equation (4), has been proposed in the present work:

$$\frac{TS_{(D)}}{TS_{(0)}} = \alpha \frac{CLD_{(D)}}{CS_{(D)}}$$
(4)

where *TS* is the tensile strength, *CLD* is the crosslinked density, *CS* is the chain scission, (*D*) is the effective radiation dose applied on the sample, and α is a dimensionless constant of proportionality and can conveniently referred to as the 'weighting factor'or the 'scaling factor' that assigns weighted significance to the ratio between *CS* and *CLD*.

However, in reality, this may not be the exact case, and research areas remain open to investigate the dependence of α on radiation dose, if any. The left-hand

side of the equation describes the ratio of tensile strength at radiation dose, $(TS_{(D)})$ to the tensile strength at 0 radiation dose $(TS_{(0)})$. The right-hand side of the equation describes the ratio of cross-link density $(CLD_{(D)})$ to the chain scission $(CS_{(D)})$ at any defined dose of radiation, D. equated to the left-hand side with the multiplicative constant α . This means that if the tensile strength increases with radiation, the ratio $(CLD_{(D)})/CS_{(D)})$ on the right side must also increase, and vice versa. Since both the tensile strength and $CLD_{(D)}$ at any radiation dose is known, $CS_{(D)}$ at that dose can be calculated. Here, instead of the tensile strength, tear strength can also be used to find CS. In fact, in this article, both, tensile strength and tear strength have been used with proficiency to separately calculate CS and thereafter to compare the results.

4. Results and discussion

The Charlesby-Pinner plot for this SBS block copolymer in cyclohexane as the solvent showing $s + s^{1/2}$ against 1/D at the range of radiation dose from 0.0– 300.0 kGy has already been reported in an earlier work by some of the authors of the present work [2]. The plot showed a very agreeable linear fit, having regression squared to a value of 0.99.

From the plot, the intercept $(p_0/q_0) =$ a measure of chain scission to the cross-linking ratio for a unit dose of radiation of 1 kGy was reported as 0.053. This proves the enormous dominance of cross-linking over chain scission. The plot proved that chain scission occurred, even at a theoretical radiation dose of 1 kGy. Thus, hypothetically, chain scission must have taken place at all other higher radiation doses chosen for the present work.

Though at moderate *CLD* and at low *CS*, as was observed in the present work, cross-link as well as chain scission distribution was assumed to be homogeneous in the polymer matrix.

Taking all these into consideration, the aim of this work was to decipher the *CS* as a function of radiation dose over the entire range of radiation chosen for the work.

Figure 1 shows the *CLD*, modulus 100% (stress at 100% elongation), tensile strength and tear strength values of the polymer under unirradiated conditions as well as under different magnitudes of EB radiation. The values required to plot the figure have been obtained from a table found in an earlier work by an author of the present work [2].



Figure 1. a) *CLD*, b) modulus at 100%, c) tensile strength, d) tear strength of the SBS block copolymer as functions of radiation dose.

From the figure, it can be interpreted that the *CLD* increased as a function of radiation dose, as also the modulus at 100% elongation, yet both, the tensile strength and the tear strength increased to a maximum and then decreased. The reason behind such an initial increase to a maximum followed by a decrease is argued on the basis of the relative amount



Figure 2. CLD as a function of radiation dose.

of formation of *CLD* and *CS* and their effects on the polymer over the range of EB radiation. Figure 2 shows the fitting of the plot of *CLD* as a function of radiation dose.

fit The equation of the linear was y = 0.08377 + 0.07105x with a regression squaredvalue of 0.99 and passing almost through the origin, interpreting as no cross-link at zero radiation dose. Thus, it was inferred that the CLD increased linearly as a function of the radiation dose from $0.77 \cdot 10^{-5} \text{ mol} \cdot \text{cm}^{-3}$ at 12.5 kGy to $21.38 \cdot 10^{-5}$ mol·cm⁻³ at 300 kGy. The *CLD* at 0 radiation was assumed to be $0.00 \cdot 10^{-5} \text{ mol} \cdot \text{cm}^{-3}$.

Figure 3 highlights the superimposed tensile strength and the tear strength as functions of radiation dose, normalized to the values of the reference sample, where the normalized tensile strength initially increased from 1.00 at 0 kGy to 1.62 at 25 kGy and then exponentially decreased to attain the final value of 0.45 at 300 kGy. The calculated values for every dose are shown in Table 1.

Table 1	. The ca	lculated	l val	ues of	tensil	e and	tear	strengths	s normali	zed t	o the	: valı	ies o	f th	e ref	erence	e samp	ole.
								<u> </u>										

Sample designation	<i>k</i> _{0,0}	k _{12.5,0}	k _{25.0}	k _{37.5}	k _{50.0}	k _{100.0}	k _{200.0}	k _{300.0}
Tensile strength	1.00	1.21	1.62	1.26	1.21	0.74	0.57	0.45
Tear strength	1.00	1.34	1.73	1.45	1.34	1.04	0.81	0.54



Figure 3. Superimposed tensile strength and tear strength as functions of radiation dose.

This decrease was attributed to the proportionately higher number of chain scissions per volume of the irradiated polymer. The normalized tear strength also initially increased from 1.00 at 0 kGy to 1.73 at 25 kGy and then exponentially decreased to 0.54 at 300 kGy. This striking similarity in the trends between the tensile strength and the tear strength promised good modelling, playing with these parameters one at a time.

Based on Equation (3), and using the experimental values of *CLD*, tensile strength and tear strength (from Figure 2) in dependence on the radiation dose, and further taking into consideration that for 1 kGy, the ratio of *CS* to *CLD* (p_0/q_0) = 0.053, a calculation was done to find the values of the dimensionless constant α in case of tensile strength and tear strength, where the meaning of α has been stated in Equation (4).

(i) Calculation of α in case of tensile strength: $CS_{(D=1)}/CLD_{(D=1)} = 0.053$, which implies that $CLD_{(D=1)}/CS_{(D=1)} = 1/0.053 = 18.87$ $TS_{(D)}/TS_{(0)} = \alpha \cdot CLD_{(D)}/CS_{(D)}$

 $TS_{(0)} = 5.3$ MPa and $TS_{(12.5)} = 6.8$ MPa. Therefore $TS_{(1)} = 5.42$ MPa. This is obtained by linear interpolation of the plot for *TS versus* radiation dose in this range of radiation dose.

Therefore, $TS_{(1)}/TS_{(0)} = \alpha \cdot CLD_{(1)}/CS_{(1)}$ which implies that 5.42/5.3 = $\alpha \cdot 18.87$, from where $\alpha = 0.0542$. If we put the calculated value of α in



Figure 4. *CS*, as a function of radiation dose, using the values of tensile strength and tear strength in Equation (4).

Equation (4), the *CS* at every radiation dose was separately obtained.

(ii) Calculation of α in case of tear strength:

Similar interpolation generated $\alpha = 0.0540$ in the case of tear strength. Accordingly, substituting tear strength in place of *TS* in Equation (4) and putting the value of $\alpha = 0.0540$, the *CS* at every radiation dose was calculated from the obtained values of tear strength.

Figure 4 shows the calculated CS values, calculated from Equation (4), separately obtained from tensile strength and tear strength at various radiation doses. The trends in the obtained values of calculated CS as a function of radiation dose were very similar when the tensile strength values and the tear strength values were used separately in Equation (4), thus proving the correctness of the approach in the calculation. Since the tensile strength to rupture and tear strength to propagate a crack to rupture is different in their physical behavior, only trends in the CS were the same, with the generated values close but not the same.

The reason behind the initial increase in both tensile strength or tear strength up to certain maximum values followed by a continuous decrease as a function of radiation dose is strictly related to the ratio of *CS* to *CLD*. This, according to the present finding, was not a constant but continuously changing, going through a minimum and then increasing as a function



Figure 5. Ratio of *CS* to *CLD* as a function of radiation dose for tensile strength and tear strength.

of the radiation dose as is clearly understood from Figure 5.

Earlier, abiding by Figures 2 and 4, it was observed that at the initial phase of the radiation dose, up to about 25 kGy, both *CLD* (Figure 2) and *CS* (Figure 4) increased almost linearly. However, after that, though the *CLD* kept on marching linearly (Figure 2), the *CS* increased exponentially (Figure 4). This explains the initial increase in tensile strength and tear strength followed by a decrease later.

Though the magnitudes of *CS* were much less than those of *CLD* at equivalent radiation doses, since the rate of increase of the former was more, and since that was in the form of a defect in the system, it went far to explain for the observed decrease in the mechanical properties.

5. Conclusions

The effect of electron beam radiation on a styrenebutadiene-styrene (SBS) block copolymer in relation to the cross-link density (CLD) and tensile strength as functions of radiation dose was studied. The CLD monotonously increased with radiation dose, whereas the tensile strength initially increased and then decreased as a function of the same variable. The probability of the decrease in tensile strength due to non-uniform stress concentration because of an enormous increase in CLD was ruled out as the magnitude of the highest CLD at the highest radiation dose was moderate. The other probability was an increase in the chain scission (CS) as a function of radiation dose. Abiding by this hypothesis, an attempt was made to find the changing nature of CS over the entire spectrum of effective radiation dose. This was achieved through simple mathematical modelling, relating the three parameters – CLD, tensile strength and CS to an equation with a constant, which was made dimensionless on both sides. The same trend in the changing behavior of CS was observed when, instead of tensile strength, the tear strength values were used in the proposed equation. This further supported the propounded hypothesis.

The novelty of the work was in a simple approach to predicting the changing ratio of *CS* and *CLD* for the entire range of the radiation dose over the already predicted constant ratio of *CS* and *CLD* for unit radiation dose by the Charlesby and Pinner method. The entire theme of the article was to mathematically approach to the conclusions without experimentally validating the results. Of course, this will be open to scientific questions. and experimental validation.

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