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ANALYSIS OF GAMMA IRRADIATION EFFECTS ON DIELECTRIC PARAMETERS OF SIR-EPDM BLENDS

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Abstract

The endurance of a control and instrumentation systems in Nuclear Power Plant (NPP) is generally decided through the behaviour of the dielectric material used. The Cable Insulation Materials (CIM) should retain their remarkable qualities during their entire operating life in NPP. The CIM will be exposed to gamma irradiation at their operating environment. The short time accelerated testing has been carried out in order to anticipate the long-term operating behaviour of the CIM. Silicone Rubber (SIR) and Ethylene Propylene Diene Monomer (EPDM) are widely used polymeric materials due to their salient properties. The blending of these two polymers may result in the upgrading of their properties. The blends with varying proportions of SIR/EPDM (A-90/10; B-70/30; C-50/50; D-30/70; E 10/90) were prepared. The present investigation is directed towards the identification of the suitable composition of SIR-EPDM blend for nuclear environments. Hence, the blends were exposed to varying doses of gamma irradiation (250 kGy, 1000 kGy, 2000 kGy and 2500 kGy). The main dielectric parameters such as Breakdown Voltage (BDV), Dielectric Strength (DS), Dielectric Constant (DC) and Dissipation Factor (DF) of the un-irradiated and gamma irradiated samples were measured as per ASTM/IEC standards. It is observed that the 50/50, 30/70 and 10/90 are found to have superior dielectric performance while compared with 90/10 and 70/30 after the gamma exposure.

Keywords: BDV, DC, DF, DS, Energy dispersive X-ray analysis, EPDM, Fourier transform infrared spectroscopy, Gamma irradiation, Scanning electron microscopy, SIR.

1. Introduction

The secured operation of Nuclear Power Plant (NPP) is ensured through the control and instrumentation systems, which make use of cables at different voltage levels. Hence, it is the need of the hour that those cables should sustain their behaviour during their entire operating life in NPP. Those Control and Instrumentation (C and I) cables make use of Cable Insulation Materials (CIM). The CIM at the installed locations in the NPP should undergo the short period accelerated testing in order to estimate their long-term performance. Silicone Rubber (SIR) was blended with Ethylene Propylene Diene Monomer (EPDM) to produce a new material with improved behaviour. The blends with varying proportions of SIR/EPDM (A-90/10; B-70/30; C-50/50; D-30/70; E-10/90) were prepared. The effects of gamma irradiation on properties of the commonly used polymers and their blends have been analysed by various researchers [1-12]. However, the consequence of gamma irradiation on the dielectric performance of SIR-EPDM blends has been never reported.

The dielectric parameters of the CIM may be varied after the gamma exposure, because gamma irradiation may induce changes in the molecular level of the CIM [7-10, 13]. Hence, it is necessary to evaluate the consequence of gamma irradiation on the dielectric performance of the SIR-EPDM blends. For accelerated ageing of polymeric materials, IEEE 383 suggests the dose rate of 1500 kGy. Hence, two doses above and below the suggested one (1500 kGy) were selected for the present research. The various compositions of blends were exposed to 250, 1000, 2000 and 2500 kGy dose levels of gamma irradiation.

The dielectric parameters like BDV, DS, DC and DF of the blends have been measured using ASTM D 149 and ASTM D 150 standards before and after the gamma exposure. The physicochemical analysis such as FTIR, EDXA has been done in order to identify the factor behind the variation in dielectric parameters before/after the gamma exposure [14-18]. In addition, the surface morphology of the gamma-irradiated blends has been analysed through the SEM.

2. Gamma Irradiation

The ^{60}CO gamma chamber facility available at Radiological Safety Division, Indira Gandhi Centre for Atomic Research (IGCAR*)*, Kalpakkam, Tamil Nadu, India was used to irradiate the SIR-EPDM blends. The irradiation volume of gamma chamber is 1 litre with 3 kGy/hr dose rate. The doses applied were 250 kGy, 1000 kGy, 2000 kGy and 2500 kGy. This is to forecast the long-term existence of the newly formed blend during their operating life in NPP. The duration (time) of gamma irradiation was 83 hours, 333 hours, 649 hours and 817 hours respectively. The performance analysis was done on SIR-EPDM samples, which have been exposed to the same dose of gamma irradiation. The average of the three analysis made at similar conditions were reported in this paper.

3. Dielectric Analysis of SIR-EPDM Blends

The dielectric parameters of unirradiated and gamma-irradiated samples of SiR-EPDM blend were measured using ASTM D 149 (IEC 60243) and ASTM D 150 (IEC 60250) standards. Using ASTM D 149 (IEC 60243), break down voltage was measured. The test voltage has been raised at a steady rate of 500 V/s until

breakdown. The breakdown voltage was measured. The calculation of dielectric strength has been made. Using ASTM D 150 (IEC 60250), dielectric constant and dissipation factor were measured at 1 MHz.

4. Physico-Chemical Analysis

To recognize the type of variations in the virgin and gamma irradiated samples of SIR-EPDM blends, physicochemical analysing techniques such as Fourier transform infrared spectroscopy, energy dispersive X-ray analysis and scanning electron microscopy analysis were used. Using Perkin Elmer spectrophotometer (wave number 500 to 4000 cm^{-1}), FTIR spectra of all the samples were taken. All IR spectrums have four scans**.** The existence of functional groups was detected using FTIR, as FTIR generates IR spectra of the sample, which can absorb IR light. FTIR helps to measure modifications in the type and quantity of diverse functional groups by calculating the changes the absorbance of wavelengths of IR light, which are specific to those functional groups. To have an overview about the surface morphology of the un-irradiated and gamma exposed samples, SEM analysis was done using a Scanning Electron Microscope (Make HITACHI) with a 5- 3,00,000 magnification on a square shaped sample of size 1×1×0.3 cm. To find out the elemental content at the exterior of the virgin and gamma exposed samples, EDXA analysis has been done using EDAX analysis set up (Make HITACHI) on a square shaped sample of size 1×1×0.3 cm.

5. Results

5.1. Dielectric performance of un-irradiated SIR-EPDM blends

In comparison with leftover blends, un-irradiated SIR rich blends have higher BDV/DS and lower DC/DF. This may be due to the occurrence of the highest self cross-linking reaction in it during the blend preparation process itself [9, 10, 13]. Among the side chains of SIR and EPDM, the cross-linking reaction occurred. It is inferred that the SIR rich blend A has the lower DC and lowest DF. The other SIR rich blend (B) has the lowest DC and lower DF. The C blend has the lowest BDV, DS and higher DC, DF. The EPDM rich blend D has the lower BDV, DS and highest DC, DF. The blend E has medium BDV, DS, DC and DF. The reduced values of BDV and DS in C, D and E blends may due to the occurrence of least self cross-linking reaction in them during the blend preparation process.

5.2. Consequences of Gamma-irradiation on dielectric performance of SIR-EPDM blends

5.2.1. Consequence on BDV and DS

Figures 1(a) and 2(a) describe the variations in breakdown voltage and dielectric strength of blends A and B for different doses of gamma irradiation. The figures 1(b) and 2(b) describe the variations in breakdown voltage and dielectric strength of blends C, D and E for different doses of gamma irradiation.

From Figs. 1(a) and 2(a), it is inferred that the SIR rich blends have higher BDV and DS compared to the remaining blends at 250 kGy. The decrease in BDV and DS for above 250 kGy was due to the instantaneous occurrence of cross-linking and chain scission reaction in them. It is inferred from 1(b) and 2 (b), that the

breakdown voltage and dielectric strength of the blend C and EPDM rich blend D are observed to raise for every dose of gamma irradiation. This might be due to the occurrence of the dominant cross-linking reaction in them (due to higher EPDM content). The breakdown voltage and dielectric strength of the blend E are enhanced only at 2000 kGy and 2500 kGy. At 2500 kGy, maximum BDV and DS of the blends C and E have been noticed. However, blend D has its highest BDV and DS values at 2000 kGy.

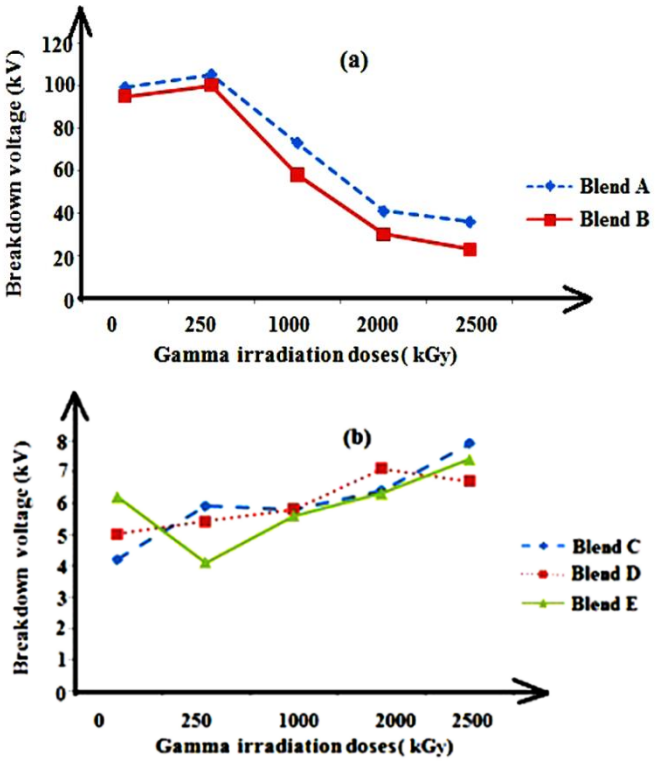
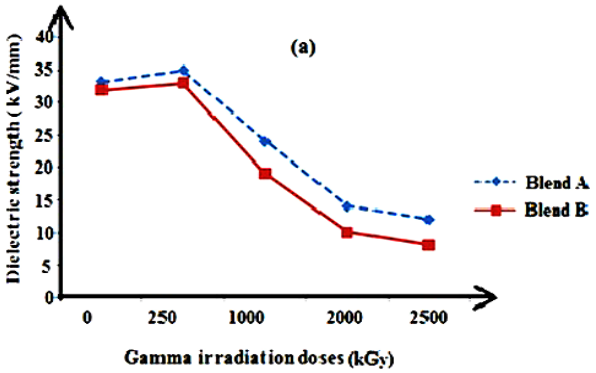


Fig. 1. Variations in breakdown voltage SIR-EPDM blends for different doses of gamma irradiation (a) Breakdown voltage of the blends A and B, (b) Breakdown voltage of blends C, D and E.



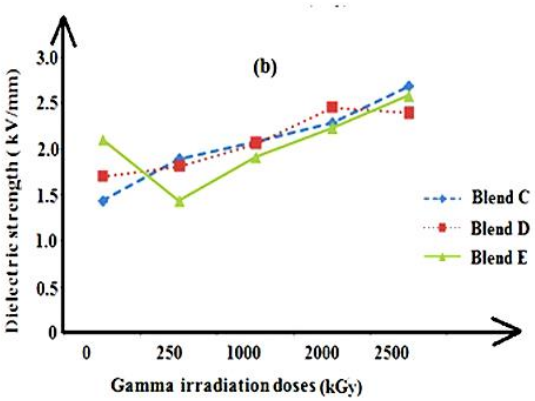


Fig. 2. Variations in dielectric strength of SIR-EPDM blends for different doses of gamma irradiation (a) Dielectric strength of blends A and B, (b) Dielectric strength of blends C, D and E.

5.2.2. Consequence on DC and DF

Figures 3 and 4 illustrate the variations in DC and DF of various compositions of blends for different gamma irradiation doses.

It is observed from Fig. 3 that the DC of blends A, C and E were increased at 250 kGy doses of gamma irradiation. For higher doses of gamma irradiation, a decrease in DC of the blends C and E is observed. However, the increase in DC of blend B was noticed for 250/1000 kGy doses of gamma irradiation. The DC of the blend D is found to decrease for all doses of gamma irradiation. It is noticed from Fig. 4, that the dissipation factor of SIR rich blends is raised for every dose of gamma irradiation. Dissipation factor of blends C and D is improved (values are less than their virgin values) for all doses of gamma irradiation. Except at 250 kGy, the dissipation factor of the blend E is decreased for every dose of gamma irradiation. The decrease in the dissipation factor is usually an indication of improvement in the dielectric property of insulating material.

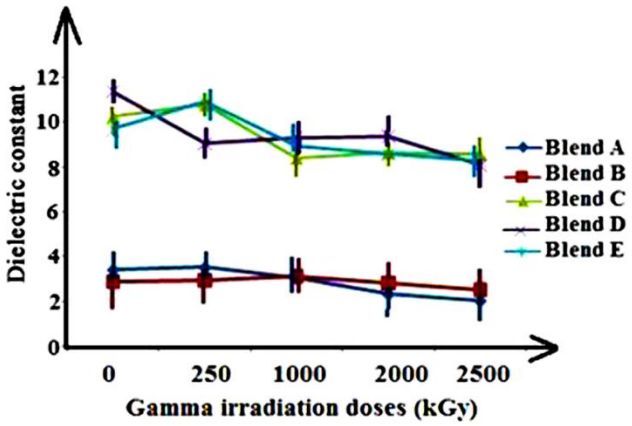


Fig. 3. Variations in dielectric constant of blends for various gamma irradiation doses.

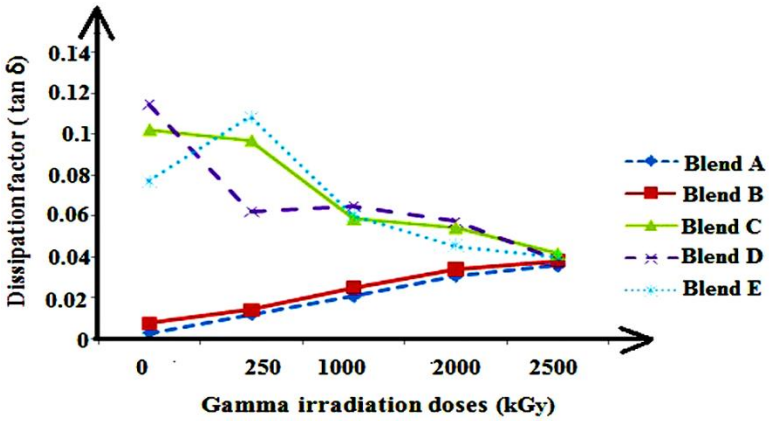


Fig. 4. Variations in dissipation factor of blends for various gamma irradiation doses.

6. Results and Discussion

The chain scission and cross-linking reactions, which has been occurred might vary the macromolecular chains of SIR-EPDM blends. The outcome of the reactions can be distinguished from the changes in dielectric parameters. For higher doses of gamma irradiation, the density of the cross-linked network raises. Hence, the free movement of free radicals is banned. Deepalaxmi et al. [13] explained that this results in decreased cross-linking probability. This is clear from the decrease in BDV and DS at 1000 kGy and 2500 kGy in SIR rich blends.

6.1. FTIR Investigations

The FTIR spectra for samples were obtained for every dose of gamma irradiation, in order to sort out the means for the alteration in dielectric parameters. FTIR analysis confirmed the creation of different functional groups (or) chemical bonds after the gamma irradiation. Figures 5, 6, and 7 represent the FTIR spectra of the un-irradiated and gamma exposed samples of blends A, C and E.

The SIR rich blends have their highest BDV and DS at 250 kGy. This is due to the high OH (alcohol-free) group content at 3781 cm^{-1} and 3444 cm^{-1}. The blend C has its highest BDV and DS values at 2500 kGy**.** This is due to the existence of acid (COOH) at 2554 cm^{-1} with the 3% absorbance. It is inferred that alcohol (OH) free group is shifted from 3793 cm^{-1} to 3904 cm^{-1} (higher wave number) in blend D and from 3796 cm^{-1} to 3853 cm^{1} in blend E for 2500 kGy dose of gamma irradiation. Based on studies by Tvaaruzkova and Bosacek [19], this shifting may be responsible for the improvement in BDV and DS in EPDM rich blends D and E. At 2000 kGy, blend D has its highest BDV and DS values, because of the existence of Si_2Ogroup at 1114 cm^{-1} and 1018 cm^{-1} with 20% and 24% absorbance, also the rise in alcohol (OH), free group at (3855 cm^{-1} - 3752 cm^{-1}) with higher absorbance. The blend E has its highest BDV and DS values at 2500 kGy, because of changing of OH (alcohol-free) group to 3905 cm^{-1}.

The blends C and E are found to have improved DC values at 250 kGy. The appearance of Si_2O group with 19% absorbance at 1018 cm^{-1} and 17% absorbance at 1083 cm^{-1} is the reason behind this. The reduction in DC values is noticed for

higher doses of gamma irradiation in them. The absence of Si_2O group at 1000/2000 kGy in blend C and at 2000/2500 kGy in blend E is accountable for the decline in DC. In addition, the drop in Si_2O group content at 1020 cm^{-1} with 14 % in blend C at 2500 kGy and at 1037 cm^{-1} with 2% in blend E at 1000 kGy has been inferred. The DF of blend C and D have been improved (smaller values in comparison with their un-irradiated case) for all doses of gamma irradiation. Because of the appearance of COOH (acid) group in blend C and emergence of Si_2O group content in blend D for all doses of gamma irradiation. Improvement in DF values of the blend E is noticed at 1000/2000/2500 kGy. This might be due to the existence of COOH (acid) and Si_2O groups at 1000 kGy. The blend D has its highly improved DF value at 2500 kGy, because of the rise in Si_2O content at (1148-1000) cm^{-1} with (26-32) %.

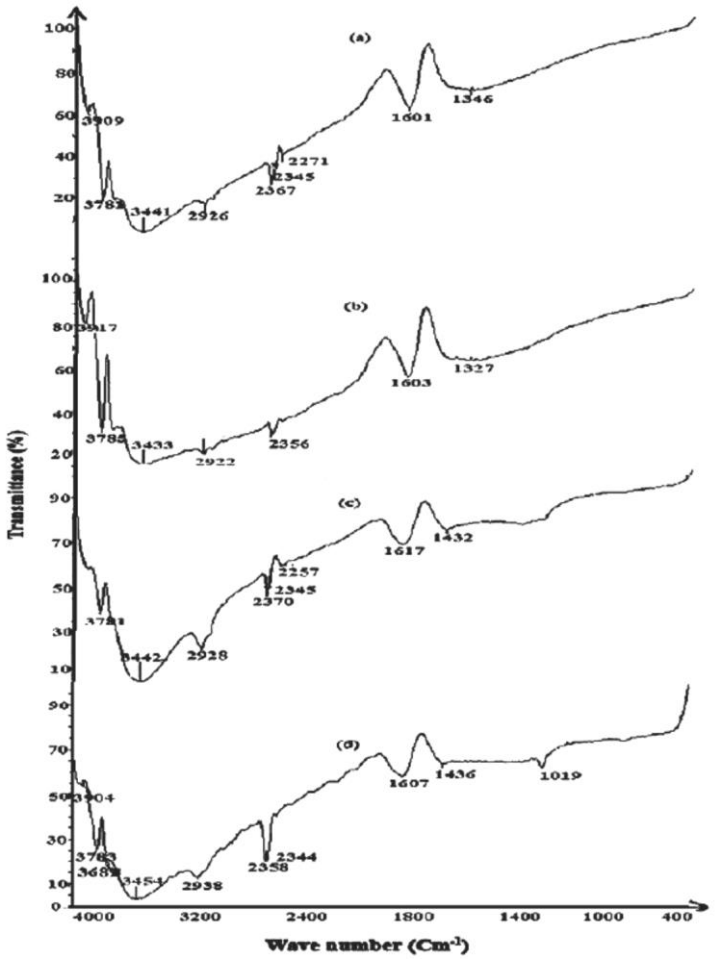


Fig. 5. FTIR spectra of gamma exposed samples of blend A (a) 250 kGy, (b) 1000 kGy, (c) 2000 kGy, (d) 2500 kGy.

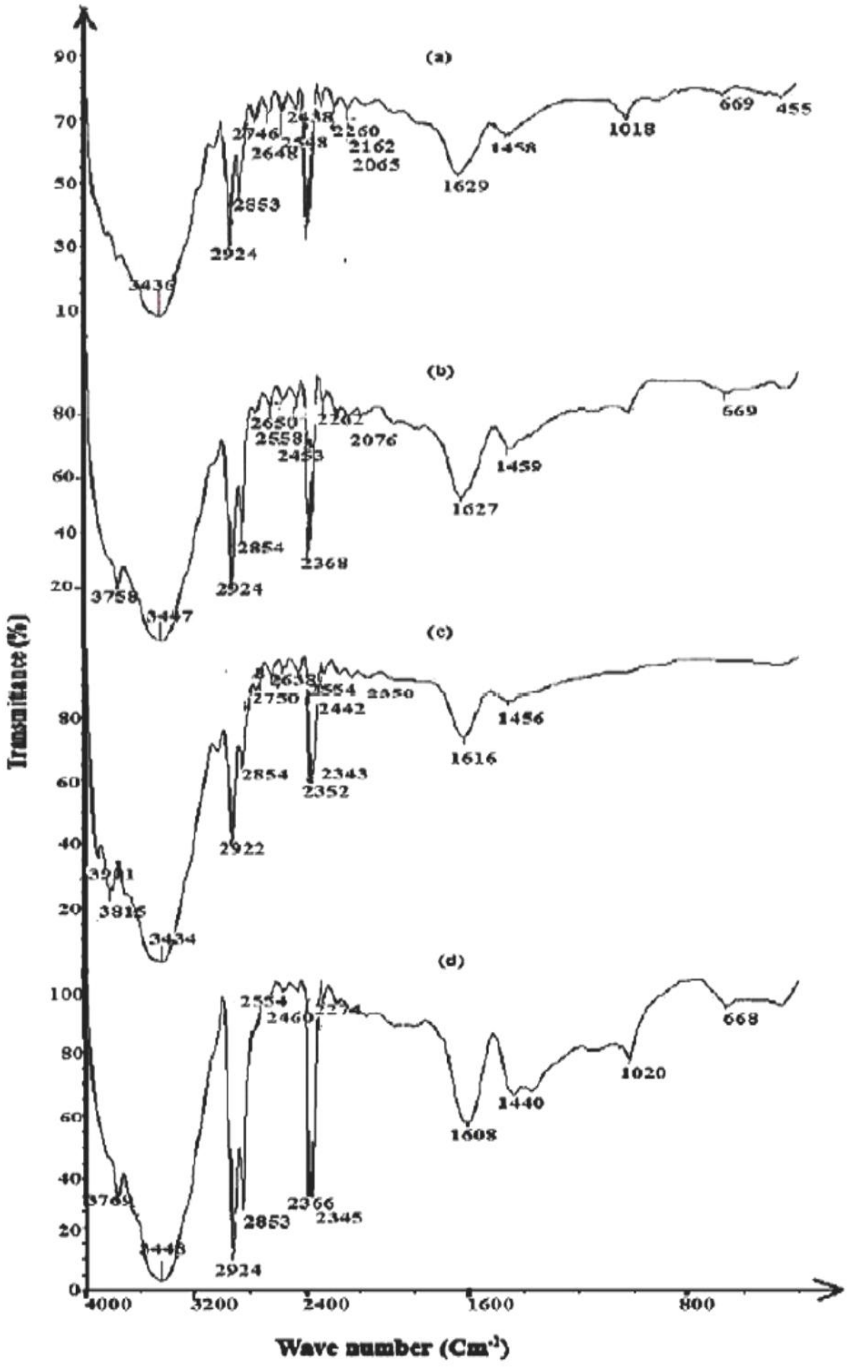


Fig. 6. FTIR spectra of gamma exposed samples of blend C (a) 250 kGy, (b) 1000 kGy, (c) 2000 kGy, (d) 2500 kGy.

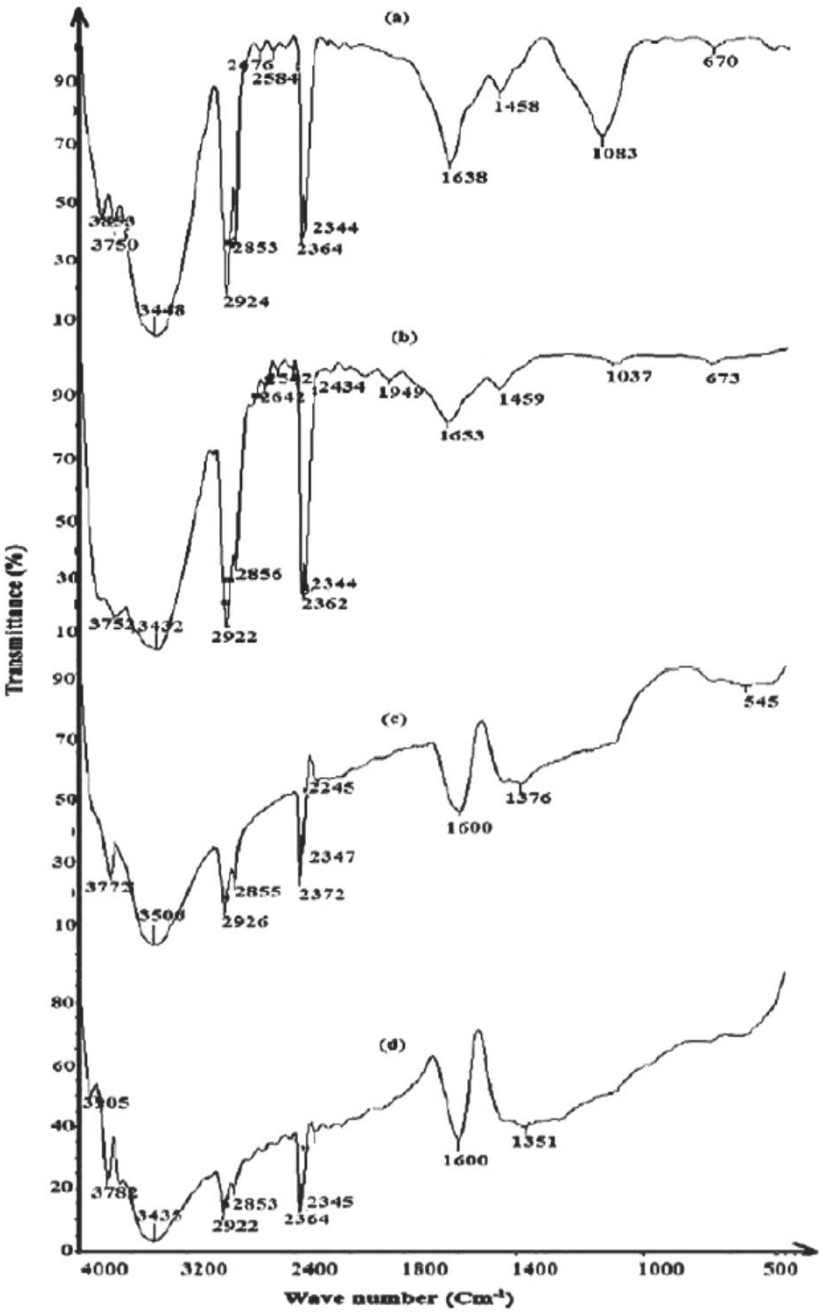


Fig. 7. FTIR Spectra of gamma exposed samples of blend E (a) 250 kGy, (b) 1000 kGy, (c) 2000 kGy, (d) 2500 kGy.

Tables 1, 2, 3, 4 and 5 give the relation between changes in dielectric parameters of SIR-EPDM samples before/after the gamma exposure using FTIR.

Table 1. Relation between changes in dielectric parameters of SIR rich blend before/after the gamma exposure using FTIR.

Doses (kGy)	SiR rich blend A -Improvement in BDV and DS at 250 kGy
0	OH (alcohol stretch free)(3940-3861) cm^{-1} with 35 % , 33% and 32 % OH (alcohol free, strong, sharp) at 3676 cm^{-1} with 109% OH (alcohol bonded, broad, strong) at 3499 cm^{-1} and 3473 cm with 149% and 151 % COOH (acid strong) (3278-3057) cm^{-1} with 79%, 68% and 50%
250	OH (alcohol stretch free)at 3781 cm^{-1} with 73%
1000	OH (alcohol stretch free)at 3917 cm^{-1} , 3785 cm^{-1} with 18% and 74 %
2000	Absence of OH (alcohol-free, strong, sharp)
2500	Absence of OH (alcohol-free, strong, sharp)

Table 2. Relation between changes in dielectric parameters of SIR rich blend B before/after the gamma exposure using FTIR.

Doses (kGy)	SiR rich blend B -Improvement in BDV and DS at 250 kGy
0	OH (alcohol stretch free) (3942-3749) cm^{-1} with 21-49% OH (alcohol-free, strong, sharp) at 3678 cm^{-1} with 28% OH (alcohol bonded, broad, strong) at 3578 cm^{-1} and 3434 cm^{-1} with 17% and 12 % COOH (acid strong) at 3268 cm^{-1} with 11%
250	OH (alcohol bonded, broad, strong) at 3444 cm^{-1} with 92%
1000	OH (Alcohol stretch free) at 3797 cm^{-1} and 3674 cm^{-1} with 67% and 62%
2000	Absence of OH (alcohol-free, strong, sharp)
2500	Absence of OH (alcohol-free, strong, sharp)

Table 3. Relation between changes in dielectric parameters of blend C before/after the gamma exposure using FTIR.

Doses (kGy)	C (50:50) Improvement in BDV and DS (all doses) and decrease in DF
0	OH (alcohol stretch free) at (3928-3719) cm^{-1} with 9%, 66% and 79 % OH (alcohol bonded, strong , broad) at 3593 cm^{-1} with 75% [Absence of OH (alcohol free, strong, sharp)/COOH (acid)]
250	Presence of COOH (acid) group at (2746-2549) cm^{-1} with (17-19)%
1000	Presence of COOH (acid) group at 2650 cm^{-1} and 2558 cm^{-1} with 11% and 10%
2000	OH (alcohol stretch free)at 3901 cm^{-1}, 3815 cm^{-1} with 45% and 60% shifting of COOH (acid) to high wave number 2750 cm^{-1}
2500	OH (alcohol stretch free) at 3769 cm^{-1} with 52% COOH (acid) at 2554 cm^{-1} with 3%

Table 4. Relation between changes in dielectric parameters of EPDM rich blend D before/after the gamma exposure using FTIR.

Doses (kGy)	C (50:50) Improvement in BDV and DS (all doses) and decrease in DF
0	OH (alcohol stretch free) at (3928-3719) cm^{-1} with 9%, 66% and 79 % OH (alcohol bonded, strong, broad) at 3593 cm^{-1} with 75% [Absence of OH (alcohol-free, strong, sharp)/COOH (acid)]
250	Presence of COOH (acid) group at (2746-2549) cm^{-1} with (17-19)%
1000	Presence of COOH (acid) group at 2650 cm^{-1} and 2558 cm^{-1} with 11% and 10%
2000	OH (alcohol stretch free)at 3901 cm^{-1}, 3815 cm^{-1} with 45% and 60% Shifting of COOH (acid) to high wave number 2750 cm^{-1}
2500	OH (alcohol stretch free) at 3769 cm^{-1} with 52% COOH (acid) at 2554 cm^{-1} with 3%

Table 5. Relation between changes in dielectric parameters of PDM rich blend E before/after the gamma exposure using FTIR.

Doses (kGy)	EPDM rich blend E -Improvement in BDV and DS (2000/2500 kGy) and decrease in DF
0	OH (alcohol stretch free) at 3796 cm^{-1} and 3709 cm^{-1} with 60 % and 69 % OH(alcohol bonded, strong, broad) at 3418 cm^{-1} with 106% [Absence of OH (alcohol free, strong, sharp)/COOH(acid)]
250	Emergence of COOH (acid stretch, strong) at 2676 cm^{-1} and 2584 cm^{-1} with 2.5 %
1000	Shifting of OH (alcohol-free) group to high wave number 3853 cm^{-1} Emergence of Si_2O at 1037 cm^{-1} with 2%
2000	COOH (acid) at 2642 cm^{-1}, 2542 cm^{-1} with 6% and 3% OH (alcohol stretch free) at 3772 cm^{-1} with 60%
2500	Shifting of OH (alcohol) to high wave number 3905 cm^{-1}

6.2. EDXA investigations

Figures 8, 9 and 10 depict the EDXA curve of the gamma exposed samples of SIR rich blend (A), blend C and EPDM rich blend (E). Tables 6 and 7 present the information obtained from the EDXA curves of gamma exposed samples of SIR-EPDM blends.

Table 6. Information obtained from EDXA curves of gamma exposed SIR rich blend samples.

Elements	Carbon weight (%)		Silicon weight (%)		Oxygen weight (%)	
Doses (kGy)	**Blend A**	**Blend B**	**Blend A**	**Blend B**	**Blend A**	**Blend B**
0	38.82	54.2	**13.17**	**6.51**	28.69	19.26
250	**64.42**	**64.73**	3.39	2.44	26.55	24.9
1000	50.66	63.57	4.73	3.58	35.38	27.03
2000	51.13	57.35	6.24	4.41	33.83	30.67
2500	47.5	50.47	6.51	4.58	**35.42**	**35.33**

Table 7. Information obtained EDXA of gamma exposed blend C and EPDM rich blends samples.

Elements	Carbon weight (%)			Silicon weight (%)			Oxygen weight (%)		
Doses (kGy) /blends	C	D	E	C	D	E	C	D	E
0	71.4	**84.9**	**89.1**	2.1	0.7	0.8	11.8	3.7	3.1
250	75.9	75.5	77.5	**2.7**	**2.4**	1.0	9	5.5	6.3
1000	74.8	82.3	80.	1.9	1.7	1.1	10.2	4.1	5.9
2000	68.4	81.5	71.7	1.7	1.2	1.1	14.3	4.3	10.5
2500	**76.0**	73.8	74.9	2.3	1.8	**2.1**	4.4	6.2	7.4

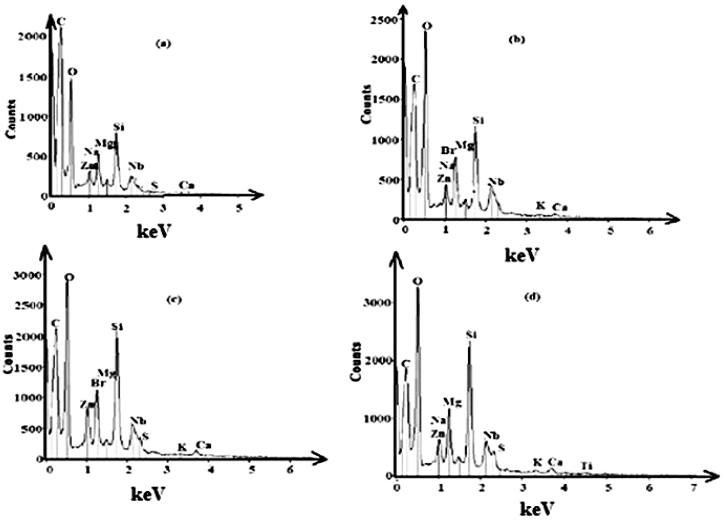


Fig. 8. EDXA curves of gamma-exposed samples of SIR rich blend A (a) 250 kGy, (b) 1000 kGy, (c) 2000 kGy and (d) 2500 kGy.

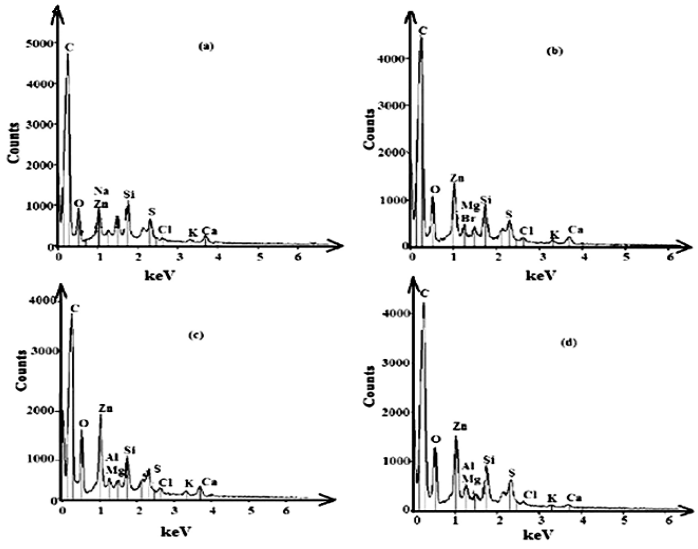


Fig. 9. EDXA curves of gamma-exposed samples of blend C (a) 250 kGy, (b) 1000 kGy, (c) 2000 kGy and (d) 2500 kGy.

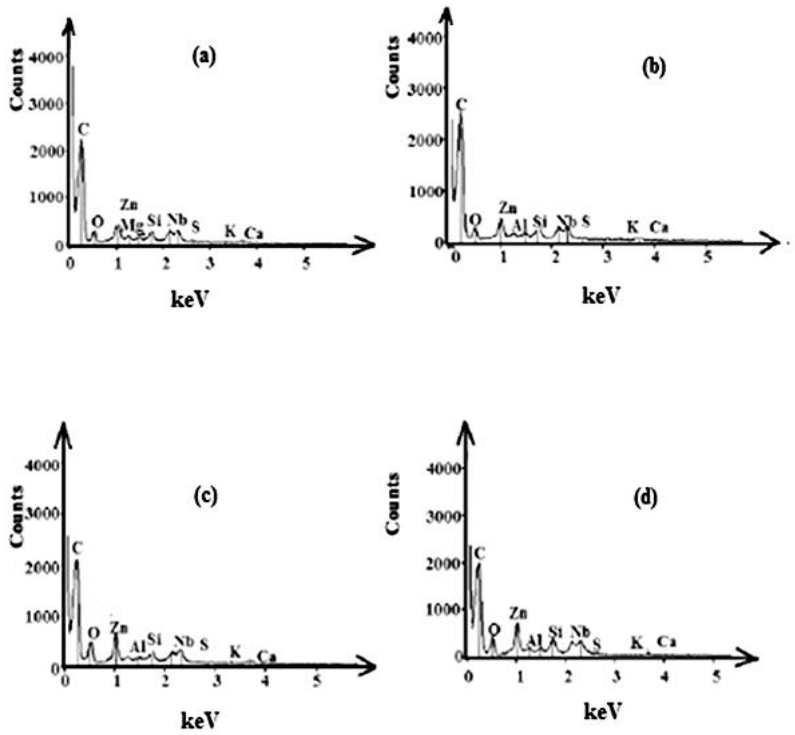


Fig. 10. EDXA curves of gamma-exposed samples of EPDM rich blend E (a) 250 kGy, (b) 1000 kGy, (c) 2000 kGy, (d) 2500 kGy.

The SIR rich blends (A and B) were found to have the highest values of carbon and oxygen content at 250 kGy and 2500 kGy respectively. However, the decrease in silicon content has been noticed for all doses of gamma irradiation in them.

The blend C is found to have the highest values of carbon, oxygen contents at 2500 kGy and silicon content at 250 kGy. The decline in carbon content and raise in silicon and oxygen contents have been noticed for all doses of gamma irradiation in EPDM rich blends.

They contain their highest silicon content values at 250 kGy and 2500 kGy. The blends D and E have their highest oxygen values at 2500 kGy and 2000 kGy respectively.

This is because of shifting of alcohol (OH) free group from 3793 cm^{-1} to 3904 cm^{-1} (higher wave number) in blend D and from 3796 cm^{-1} to 3853 cm^{1} in blend E for 2500 kGy dose of gamma irradiation.

6.3. Validation of EDXA results with FTIR

The relationship among FTIR/EDXA of the gamma exposed samples of SiR-EPDM blends are given in Tables 8, 9 and 10.

Table 8. Relationship among FTIR and EDXA of gamma exposed samples of SIR rich blend A.

Elemental behaviour/ doses (kGy)	Raise in carbon content	Decline in silicon content	Raise in oxygen content except 250 kGy
250	Raise in CH_3-CH_2-CH content emergence of C-H alkane, bending strong group	Non-existence of Si_2O	Non-existence of Si_2O
1000	-	-	Emergence of N-O group
2000	-	-	-
2500	-	-	Reappearance of N-O group

Table 9. Relationship among FTIR and EDXA of gamma exposed samples of blend C

Elemental behaviour/ doses (kGy)	Raise in carbon content except at 2000 kGy	Raise in silicon content except at 1000 and 2000 kGy	Raise in oxygen content except 250 kGy and 100 kGy
250	Raise in CH_3-CH_2-CH content Alkane (C-H), bending strong and Aromatic stretch (C = C)	Raise in Si-H content and emergence of Si-H (amorphous Si) and Si-O-Si group	Emergence of Si_2O group, COOH (acid strong, stretch) group
1000	-	Decline in Si-H content and disappearance of Si-O-Si group	-
2000	Absence of C = C (alkene, stretch, variable) and decrease in CH_3-CH_2-CH content	-	-
2500	Increase in CH_3-CH_2-CH content and C-H(alkane, bending, strong)/C = C (aromatic stretch)	Raise in Si-H quantity and Emergence of Si-O-Si group	Emergence of C = O (carbonyl, stretch, strong)

Table 10. Relationship among FTIR and EDXA of gamma exposed samples of blend E.

Elemental behaviour/ doses (kGy)	Decline in carbon content	Raise in silicon content	Raise in oxygen content
250	Moderate decline in C content due to the appearance of C-H (alkane, bending, strong)	Raise in Si-O-Si content	Emergence of acid (COOH) strong and raise in Si_2O content
1000	Lower decline in C content due to the appearance of C = C (alkene, asymmetric, stretch)	Raise in Si-H content	-
2000	Larger decline in C content due to the absence of C = C (alkene, stretch, variable)	-	Emergence of (N-O) Nitro stretch group
2500	-	-	-

The following inferences were obtained from Table 8. An increase in carbon content in the EDXA curve of blend A is responsible for the rise in CH_3-CH_2-CH quantity and also for the emergence of C-H (alkane, bending, strong) group of FTIR spectra. The decrease in silicon content in the EDXA curve validates the absence of Si-O-Si group in FTIR spectra of blend A after the gamma exposure. An increase in oxygen content in the EDXA curve justifies the emergence of N-O (nitro) group at 2000 kGy in FTIR spectra of blend A. The following inferences were obtained from Table 9. A rise in CH_3-CH_2-CH content, alkane- bending- strong (C-H) and aromatic stretch (C = C) group content at 250/1000/2500 kGy in FTIR spectra of blend C is validated through a rise in carbon content in EDXA curve of blend C. In addition, it is inferred from the EDXA curve of blend C, that there is a rise in silicon content. This justifies the increase in Si-H content and emergence of Si-O-Si group at 250 kGy/2500 kGy in FTIR spectra of blend C.

Similarly, the emergence of Si-O-Si group, COOH (acid, stretch, strong) at 2000 kGy and carbonyl stretch, strong (C = O) at 2500 kGy in FTIR spectra of blend C is validated through raise in oxygen content of EDXA curve. The following inferences were obtained from Table 10. The larger reduction in C content in EDXA curve of blend E validates the non-existence of C = C (alkene, stretch variable) group at 2000/2500 kGy of FTIR spectra. Lower/ moderate drop in C content in EDXA curve of blend E is due to the emergence of alkane, strong, bending (C-H) at 250 kGy and appearance of alkene asymmetric stretch (C = C) at 1000 kGy. The appearance of COOH (acid strong) and raise in Si_2O group content at 250/1000 kGy in FTIR spectra of blend E is validated by the rise in oxygen content in EDXA curve. In addition, the emergence of N-O (nitro stretch) group is noticed in FTIR spectra at 2000/2500 kGy is justified by the rise in oxygen content in the EDXA curve of blend E.

6.4. SEM investigations

Figures 11 and 12 are the SEM micrographs of all the blends exposed to 1000 kGy and 2000 kGy doses of gamma irradiation for 500 and 4000 magnification respectively. After the 1000 kGy exposure of gamma irradiation, the appearance of larger cracks has been noticed on the surface of SIR rich blends. This is due to the happening of higher cross-linking reaction in them. In addition, the decrease in silicon content was noticed from the EDXA curve. The surface smoothness of EPDM rich blends is moderate. This might be due to the rise in silicon and oxygen quantity in them after the gamma exposure. Due to the higher cross-linking reaction in blend C, smaller cracks have been noticed on the surface. However, the exterior of the EPDM rich blends have some white particles. This might be due to the drop in carbon quantity in them after the gamma exposure.

It is inferred from the Figs 12(a1), (a2), (b1), and (b2), deeper cracks were noticed on the surface of SIR rich blends. This might be due to the happening of the dominant chain scission reaction in them. Smaller cracks were observed on the surface of blend C, because of higher cross-linking reaction in it. In addition, the decrease in silicon content at 2000 kGy has been noticed from the EDXA curve. The surface of EPDM rich blends is found to have some rough portions for 500 magnifications. Erosion starts visible from 500 magnification. At 4000 magnification, erosion has been observed in blends D and E. The surface of the EPDM rich blends have white particles, this might due to the drop in carbon quantity in them.

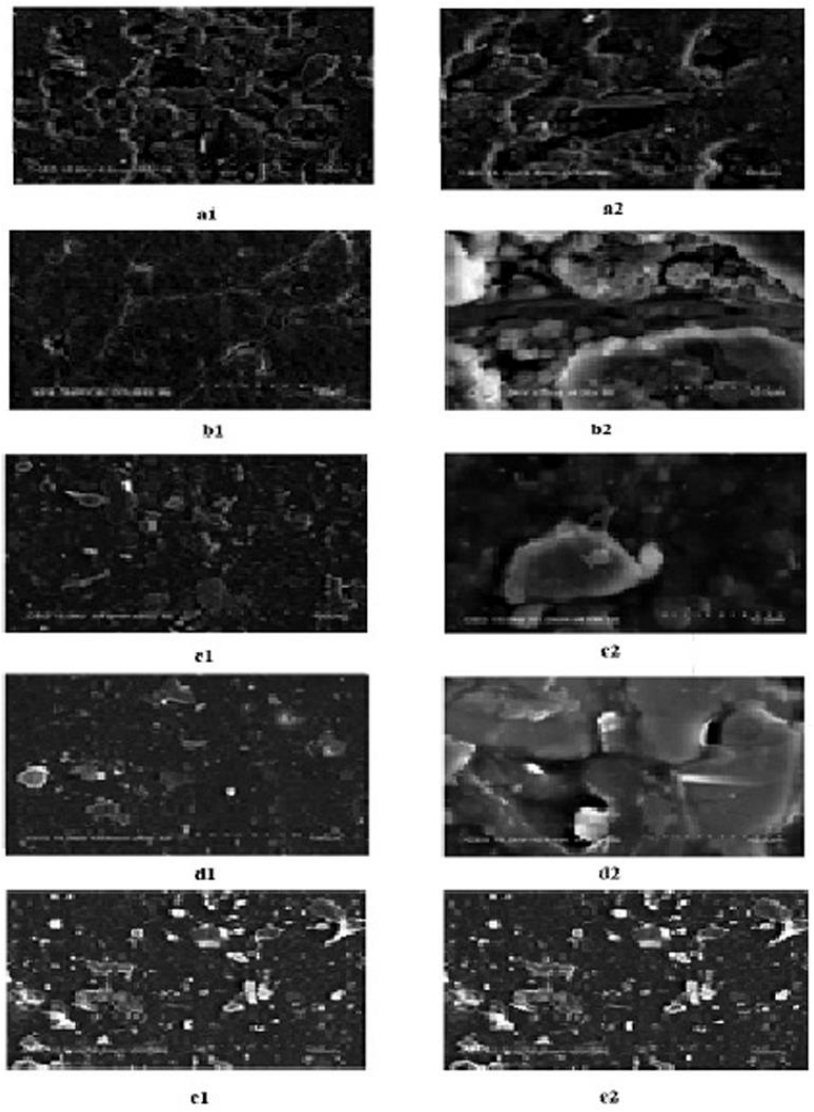


Fig. 11. SEM micrographs of all gamma irradiated (1000 kGy) samples of SIR-EPDM blends (a1) Blend A, (b1) Blend B, (c1) Blend C, (d1) Blend D and (e1) Blend E - 500 magnification, (a2) Blend A, (b2) Blend B, (c2) Blend C, (d2) Blend D, (e2) Blend E-4000 magnification.

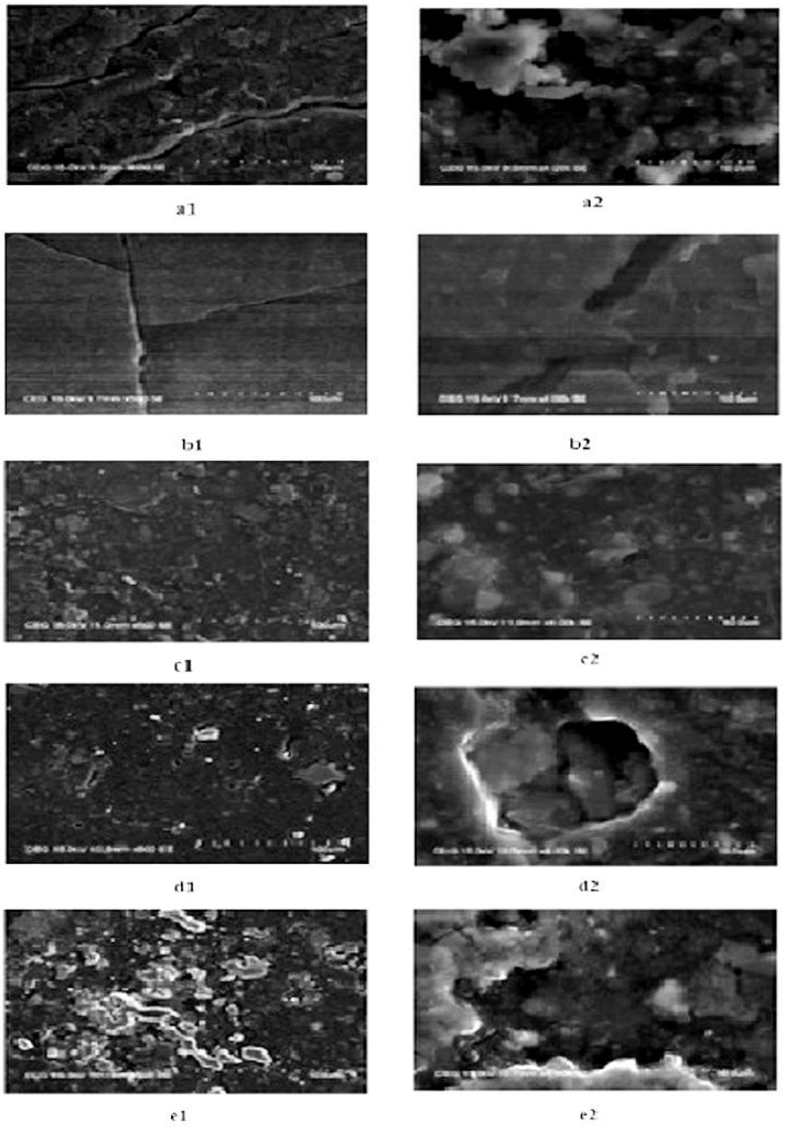


Fig. 12. SEM micrographs of all the gamma irradiated (2000 kGy) samples of SIR-EPDM blends (a1) Blend A, (b1) Blend B, (c1) Blend C, (d1) Blend D, (e1) Blend E-500 magnification, (a2) Blend A, (b2) Blend B, (c2) Blend C, (d2) Blend D, (e2) Blend E - 4000 agnification.

7. Conclusions

The SIR rich blends (A and B) were found to have the highest breakdown voltage and dielectric strength at 250 kGy. This is due to the dominant cross-linking reaction. However, for the higher doses of gamma irradiation, BDV and

DS decreased. This is due to the occurrence of dominant chain scission reaction in them along with a lesser probability of cross-linking.

The breakdown voltage and dielectric strength of the EPDM rich blend (D) and blend C were improved for all doses of gamma irradiation. The BDV and DS of the EPDM rich blend E improve at 2000/ 2500 kGy. The breakdown voltage and dielectric strength of blends C, D and E have improved.

The dissipation factor is higher for SIR rich blends compared to the remaining blends. The DF of the blends C and D were reduced for every dose of gamma irradiation. Hence, it is concluded that the blends C, D and E were found to have the superior dielectric performance when compared with SIR rich blends after the gamma exposure. Hence, among the blends C, D and E, a suitable blend can be selected for a specific nuclear power plant application.

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Nomenclatures

BDV	Breakdown Voltage
DC	Dielectric Constant
DF	Dissipation Factor
DS	Dielectric Strength
EDXA	Energy Dispersive X-ray Analysis
EPDM	Ethylene Propylene Diene Monomer
FTIR	Fourier Transform Infrared Spectroscopy
SEM	Scanning Electron Microscopy
SIR	Silicone Rubber

Abbreviations

ASTM	American Society for Testing and Materials
CIM	Cable Insulation Materials
IEC	International Electro Technical Commission
NPP	Nuclear Power Plant

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