# Influence of Talc Content on Some Properties of Gamma Irradiated Composites of Polyethylene and Recycled Rubber Wastes

**Medhat M. Hassan,[1] Raouf O. Aly,[1] Jehan A. Hasanen,[2] El Sayed F. El Sayed[1]**

[1]*Department of Polymer Chemistry, National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt*
[2]*Department of Chemistry, Faculty of Science, Suez Canal University, Ismailia, Egypt*

Received 30 June 2009; accepted 17 January 2010
DOI 10.1002/app.32120
Published online 13 April 2010 in Wiley InterScience (www.interscience.wiley.com).

**ABSTRACT:** In this study, the synergistic effect of talc content % and gamma irradiation on some mechanical, thermal, electrical resistance, and microstructural properties of the molded waste polyethylene/recycled waste rubber powder (WPE/RWRP) 60/40 was investigated. The ternary composites of talc concentrations, 5, 10, 15, and 20 wt %, were irradiated with doses of 50, 75, 100, and 150 kGy. The composites mechanical properties: tensile strength, elongation at break, and elasticity modulus, and the thermal properties: melting temperature ($T_m$) and ($\Delta H$) were predicted. Also, scanning electron microscopy, thermogravimetric analysis, and electric conductivity were investigated. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 117: 2428–2435, 2010

**Key words:** waste polyethylene; recycled waste rubber powder; talc; ionizing radiation; mechanical properties; thermal properties

## INTRODUCTION

As polymeric materials do not decompose easily, disposal off is a serious environmental problem. Plastics have become one of the materials with the greatest growth in terms of consumption and in the amount of generated wastes.[1–3] The large number of waste tires has become a significant problem with the increase in the number of automobiles each year. Landfill is one of the early ways to dispose discarded rubber products; nevertheless, with decreasing available sites and cost increase, landfill is rapidly being discarded.

The difficulty in recycling waste tire is that the scrap of the tire is a crosslinked polymer, which is hard to melt and process.[4–6] Surface-modification techniques are used for recycling finely ground scrap rubber by modifying the exterior surface.[7,8] The technical and commercial feasibility of using modified waste rubber powders as filler with a polymer has been demonstrated and increasingly reported by many applications, such as in roofing material and shoe soles.[9] Other applications include using modified RP in road pavement[10] and in different composite materials[11] with polymers.

*Correspondence to:* M. M. Hassan (medhat_smh@yahoo.com).

Journal of Applied Polymer Science, Vol. 117, 2428–2435 (2010)


Postconsumer HDPE is an interesting source of recycled material because, on one hand, it cannot be used again in alimentary applications and, on the other hand, its high melting viscosity makes direct transformation via injection moulding very difficult. HDPE is also one of the large-consumption polymers and it is difficult to use it in a polymer blend or a composite due to its nonpolar characteristics, which often results in poor interfacial adhesion properties with other materials; thus, a third material is used to increase the compatibility between the two components. Maleic anhydride (MAH)-modified polyolefin is a widely used compatibilizer for polyolefin/polyamide blends.[8,9]

Irradiation of blended polymeric materials generates some effects depending on, the kind of polymers, involved parameters of irradiation, the state of the material under processing.[12]

One important material used as an additive is the talc mineral as it possesses unique reinforcing features as softness, lubricity, excellent wetting and dispersion in plastics, and other organics. Talc is a hydrated magnesium silicate mineral widely used in polymers as reinforcing filler. Its plate-like structure provide the talc-filled materials with tailored properties to be used in some industrial and commercial applications such as in refrigerator jackets, packaged components, blocking of infrared in agricultural films, and in automotive and appliance markets.[13,14]

Reviewing literature figured out scarcy in exploring the characteristics of irradiated competibilized waste blend in presence of the reinforcing filler, talc. The aim of this article is to evaluate the synergistic effect of gamma irradiation and talc powder content on some mechanical, thermal, electrical resistance, and microstructural properties of composites made of the waste polyethylene (WPE)/ recycled waste rubber powder (60/40) reinforced with talc.

## EXPERIMENTAL

### Materials

Recycled waste rubber powder (RWRP) was kindly provided by Narobine Company, Cairo, Egypt, of particle size 80 meshes (150 mm) of unclassified ground rubber from the tread and sidewalls of passenger and truck tires. WPE was obtained from the local market. The reactive compatibilizing agent maleic anhydride (MA) was obtained from Merck, Germany. Other rubber ingredients were of commercial grade.

### Preparation of composites

The preparation of WPE/RWRP composites was done on a Brabender-like apparatus. After melting WPE, RWRP was added into the apparatus, mixed for about 10 min within a temperature range of 170–175°C to disperse RWRP uniformly into WPE. The talc powder was thereafter added at various wt % (5, 10, 15, and 20) into the blend. After mixing, the samples were hot pressed at about 175°C under 10 MPa for 5 min into sheets of suitable thickness and size for analysis. The weight ratio of WPE/RWRP in all composites was 3 : 2 adding MA at 2 wt %.

### Gamma irradiation

The composites were subjected to gamma radiation at ambient conditions. The total implemented integral doses were 50, 75, 100, and 150 kGy at a dose rate of ≈5 kGy/h.

### Mechanical testing

Tensile properties of the composites were determined by using HOUNS FILD computer aided testing machine, England. The ISO 37–1977 (E) and ISO 34–1975 (E) standards were followed in measuring tensile strength and elongation at break, respectively.

### Thermal analysis

The thermal properties of all composites were investigated by means of the DSC Shimadzu Type DSC-50 system in a nitrogen atmosphere at 20 mL/min within the temperature range from ambient to 200°C at a heating rate of 10°C/min. Thermogravimetric analysis (TGA) was performed with a Shimadzu TGA-50 system, Kyoto, Japan and heated within the temperature range 20–600°C at a rate of 20°C/min under a controlled dry nitrogen flow of 20 mL/min.

### Electric conductivity

Volume resistivity was examined by the Electrometer 6517, Keithly Instruments Inc. Ohio, USA. The electrometer is connected externally with a resistance text fixture Model 9008 for automatic display of the volume resistivity reading. The measurment was carried out at room temperature on circular type probes of diameter (mm).Conductivity of each specimen was calculated by the following equation:

$$\text{Conductivity} = L/R.A$$

where $L$ is the thickness of the sample (cm), $R$ is the reading resistance ($ohm^{-1}\ cm^{-1}$ ) and $A$ is the area of the sample ($cm^2$).

### Morphological characterization

An ISM-5400 scanning electron microscope, JEOL, Tokyo, Japan, was used for the morphological observation of fracture samples in liquid nitrogen coated with gold before testing, equipped with an energy-dispersive energy X-Ray analyzer (EDAX). It has been supplied by Shimadzu-Co., Japan.

## RESULTS AND DISCUSSION

### Mechanical properties

Figure 1 shows the typical stress–strain behavior of WPE blended with RWRP and MA at different talc contents. The tensile stress increases with the talc content up to 10%. The observed behavior suggested that, by increasing talc content, samples gradually lose the original polymer chain rearrangement mobility most probably because of the creation of specific particle–polymer interactions. The high aspect ratio of talc increases the wettability of the filler by the polymer matrix, which thus creates fewer microvoids and increases the interaction between the filler and the matrix. However, beyond that content 10%, the relative decrease in tensile stress can be related to the nonhomogenous distribution of talc as clearly evidenced by scanning electron microscopy (SEM) studies [Fig. 11(c)].

Figure 2 shows the stress–strain curve of WPE/RWRP/MA blend 60/40/2 wt % in presence of 5% talc content at different gamma irradiation doses up to 150 kGy. It is obvious that tensile strength of the blends increases with the irradiation dose up to 50

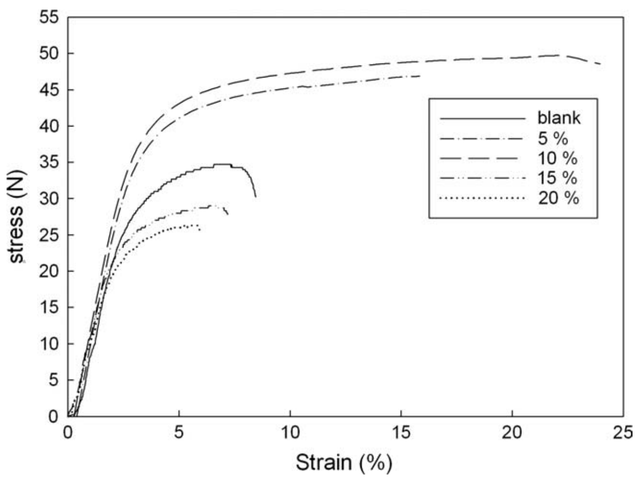


**Figure 1** Stress–Strain curve of WPE/RWRP/MA 60/40/2 wt % at different talc content.

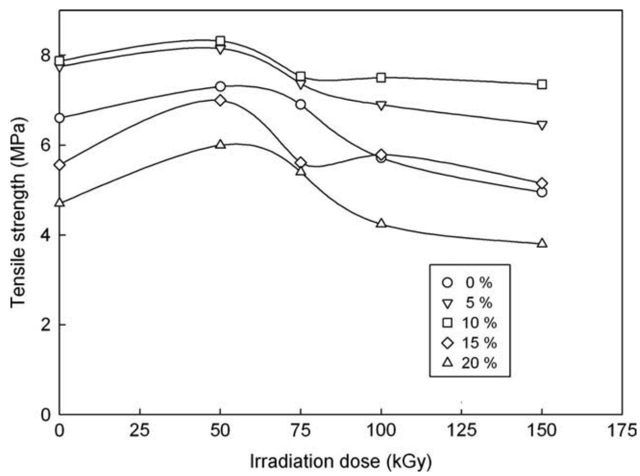


**Figure 3** Effect of talc content % on the tensile strength of WPE/RWRP/MA 60/40/2 wt % at various gamma irradiation doses.

kGy, indicating that crosslinking is the predominant process, beyond which the degradation dominates over the crosslinking process in all samples. The data obtained from stress–strain curves were used for the construction of diagrams shown in Figures 3–5.

Figure 3 shows the variation in tensile strength of WPE/RWRP/MA blend with variant talc weight percentage at different irradiation doses. In general, lower talc contents showed remarkable increases in the composite tensile strength, where tensile strength increased up to 10 wt % talc then tended to decrease by higher talc contents. This behavior may be explained on the basis of a settled proportionate that led to a homogenous distribution of the filler and strong adhesion between matrix and filler.[15] Meanwhile, the tensile strength of the composite samples increased with the irradiation dose up to 50 KGy, where cross-linking was the predominant process beyond which the degradation dominated leading to a decrease in tensile strength.

## Elongation at break

Figure 4 shows the effect of talc on the elongation at break. As can be seen from the figure, elongation at break decreased by talc content increase. Incorporation of talc, 5 wt % significantly decreased elongation at break; however, higher talc contents caused elongation at break to decrease more slowly. As reported in the literature, this decrease can be related to the matrix reinforcement as filler restricts the mobility of the matrix. In addition, the figure illustrates the general decrease in the value of elongation at break for all cases as radiation dose increases. These results can be explained by the fact that the density of cross-linking increases nearly

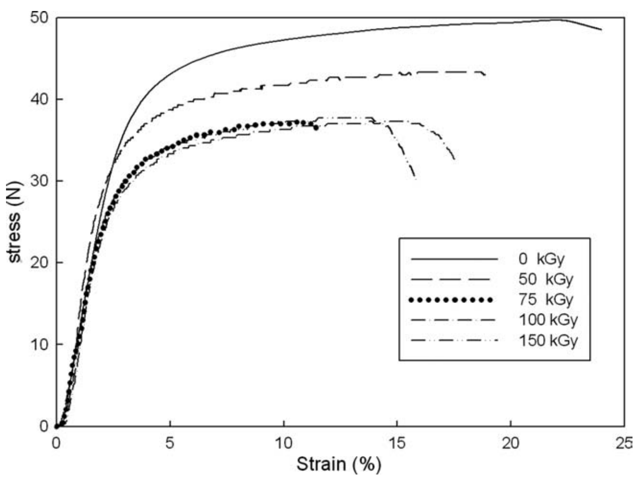


**Figure 2** Stress–strain curve of WPE/RWRP/MA/talc 60/40/2/5 wt % at various irradiation doses.

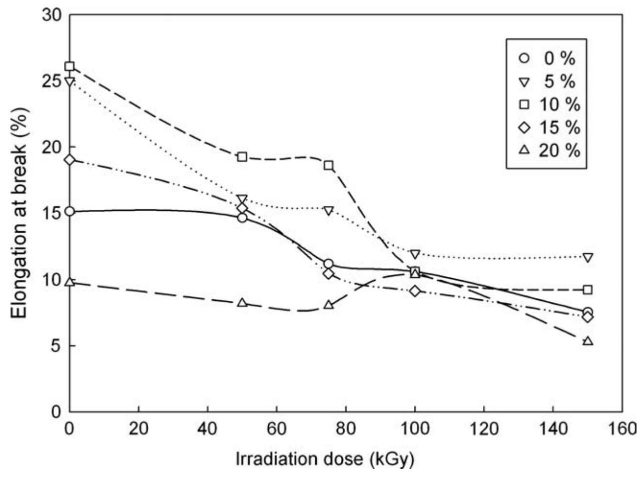


**Figure 4** Effect of talc content % on the elongation at break of WPE/RWRP/MA 60/40/2 wt % at different gamma irradiation doses.

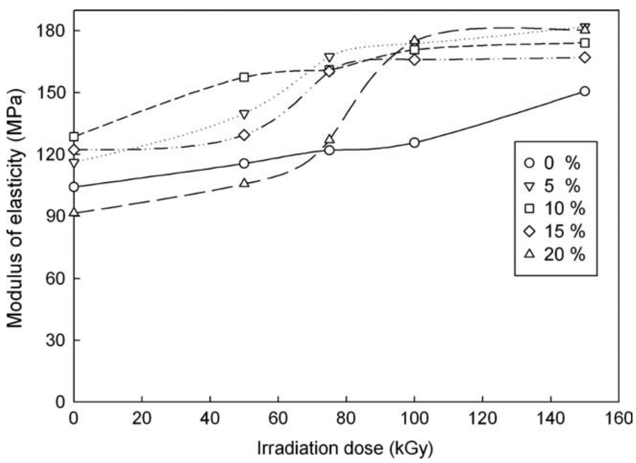


**Figure 5** Effect of talc content % on the modulus of elasticity of WPE/RWRP/MA 60/40/2 wt % at various gamma irradiation doses.

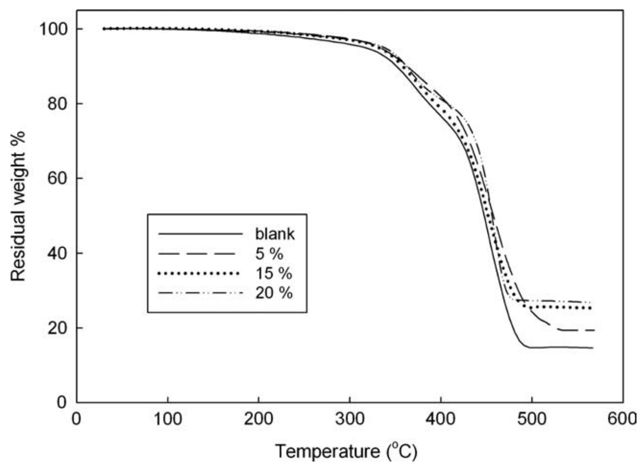


**Figure 6** TGA thermograms of unirradiated WPE/RWRP/MA 60/40/2 wt % of different talc contents.

linear with increasing irradiation dose reaching maxima by 10% talc content. Meanwhile, the increase in dose slows down the failure in elongation over the range of irradiation till almost the observed value at 0% talc content.

Figure 5 shows the effect of talc content on the elasticity modulus of WPE/RWRP/MA/talc composites. It can be seen that elasticity modulus of the ternary composites increased as talc content increased up to 10 wt % talc. The increase in elasticity modulus can be related to both the rigid filler particle and the role of filler in restricting the mobility and deformability of the matrix.[16] However, elasticity modulus started to decrease as talc content exceeds 10%. This decrease in modulus can be related to the nonhomogenous distribution of talc as its content increased. The thermal treatment of composites resulted in an increase in the elasticity modulus. This increase can be related to the good adhesion between matrix and talc.

## Thermogravimetric analysis

The TGA thermograms of the unirradiated and irradiated samples are shown in Figures 6 and 7; data are all listed in Table I. All WPE/RWRP/MA/talc composites show significant thermal stability and degrade in one step. Figure 6 shows the influence of talc content on the thermal degradation of the composites. The onset temperature of thermal degradation, $T_{onset}$, is designated by 5 wt % weight losses, the mid-weight loss temperature, $T_{0.5}$, by 50 wt % weight loss and the yield of charred residue at 600°C.

Figure 7 shows the TGA thermograms of WPE/RWRP/MA/ talc (60/40/2/20) composites exposed to 75 and 150 kGy. The curves show a relative improvement in thermal stability of composites in presence of talc in terms of $T_{0.5}$ by γ-irradiation. The increment in WPE/RWRP/MA thermal stability could be explained on the basis of a positive synergistic effect of γ-irradiation and incorporation of talc on the thermal stability of composites. The very high thermal stability of the incorporated talc assists the polymeric matrix to survive to a higher temperature. Alternatively, talc content may also increase the compatibility amongst polymer phase, by acquiring the composite a higher state of homogeneity. On the other hand, γ-irradiation could establish a developed molecular structure to the polymeric matrix.

## Differential scanning calorimetry

DSC scans were used to evaluate the effects of γ-rays exposure on transition temperature and melting enthalpy. First, the melting temperature ($T_m$) of the unirradiated filled samples was slightly higher with

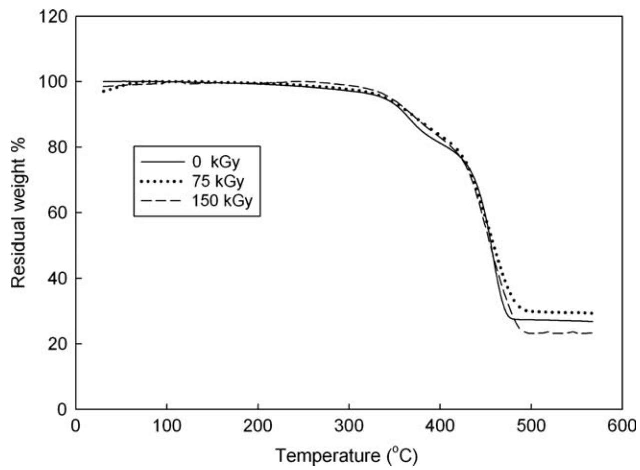


**Figure 7** TGA thermograms of WPE/RWRP/MA 60/40/2 wt % with talc ratio 20% at various irradiation doses.

**TABLE I**
**TGA Results of the Thermal Degradation of Irradiated and Unirradiated WPE/RWRP/MA 60/40/2 wt % Composites at Different Talc Contents**

| Talc content (%) | Dose (kGy) | $T_{onset}$ (°C) | $T_{0.5}$ (°C) | Charred residue at 600°C (wt %) |
|---|---|---|---|---|
| 0 | 0 | 314 | 444 | 14.6 |
| 5 | 0 | 331 | 449 | 17.3 |
| | 75 | 338 | 452 | 17.4 |
| | 150 | 340 | 458 | 19.4 |
| 15 | 0 | 331 | 450 | 24.2 |
| | 75 | 337 | 452 | 23.6 |
| | 150 | 333 | 454 | 23.8 |
| 20 | 0 | 338 | 456 | 26.8 |
| | 75 | 341 | 458 | 29.3 |
| | 150 | 344 | 459 | 23.5 |

talc content than for the unfilled polymer, Figure 8. Presumably, this results from the nucleating effect of talc that enhances the structural stability of the crystals. The melting temperature showed a progressive decrease by increasing exposure dose for WPE/RWRP/MA 60/40/2 wt % with 15% talc, Figure 9. Table II displays results from DSC measurements of WPE/RWRP/MA 60/40/2 wt % with different talc contents. Moderate modification illustrates the increase in crystallinity, as expressed by the $\Delta H_m$ value. The melting-peak temperature $T_m$ also rose which indicates that more stable crystals were formed. These results are concurrent with those obtained by TGA shown above and indicate that talc particles display a stabilizing role in the matrix. Lowering in melting point by elevated dose reflects the scission of tie molecules, chain folds at the crystal surfaces, and higher surface free energy, which lead to the formation of WPE chains with lower molecular weight.[17]

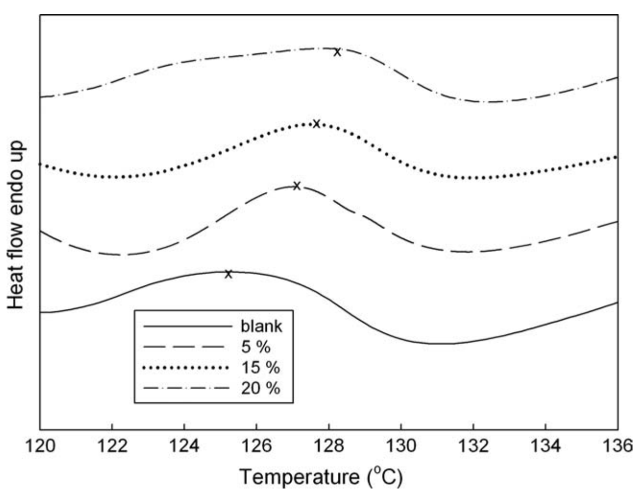


**Figure 8** DSC thermograms of unirradiated WPE/RWRP/MA 60/40/2 wt % of different talc contents; $x$ = the melting peak, $T_m$.

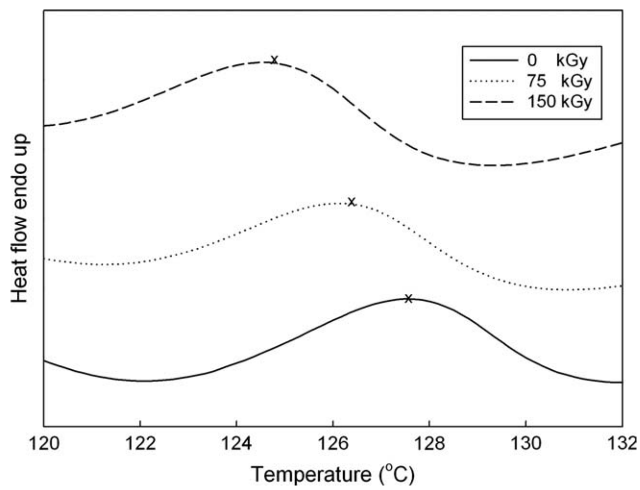


**Figure 9** DSC thermograms of WPE/RWRP/MA/talc 60/40/2/15 wt % at various irradiation doses; $x$ = the melting peak, $T_m$.

## Electric conductivity

The electric conductivity of a composite is generally characterized by its dependence on the filler volume fraction. At a low filler loading, the conductivity of the composite is still very close to that of the pure polymer matrix. At some critical loading, called the percolation threshold, conductivity increases several orders of magnitude with a very little increase in the filler amount. After this region of drastic increase, the conductivity once again levels off and is close to that of the filler material. WPE/RWRP blend is an insulator with a volume resistivity at the order of $10^{13}$ V cm, Meanwhile, talc has electrical characteristics that are semimetallic in nature and exhibits a volume resistivity that varies considerably with its origin and chemical state but is generally never less than about $10^{13}$ V cm. The conductivity behavior of the WPE/RWRP/MA 60/40/2 wt % at different talc content composites is illustrated in Figure 10. The electric conductivity revealed a relative increase as

**TABLE II**
**DSC Data of Irradiated and Unirradiated WPE/RWRP/MA 60/40/2 wt % Composites at Different Talc Contents**

| Talc content (%) | Dose (kGy) | $T_m$ (°C) | $\Delta H_m$ (J/g) | Onset temperature |
|---|---|---|---|---|
| 0 | 0 | 125 | 1.37 | 120.9 |
| 5 | 0 | 127 | 2.55 | 123.4 |
| | 75 | 125.8 | 1.96 | 118.3 |
| | 150 | 124.8 | 3.3 | 120.74 |
| 15 | 0 | 127.5 | 2.4 | 123.4 |
| | 75 | 126.3 | 1.92 | 122.5 |
| | 150 | 124.6 | 1.90 | 120.8 |
| 20 | 0 | 128 | 2.5 | 121 |
| | 75 | 124.8 | 2.3 | 120.2 |
| | 150 | 122 | 2.5 | 117.6 |

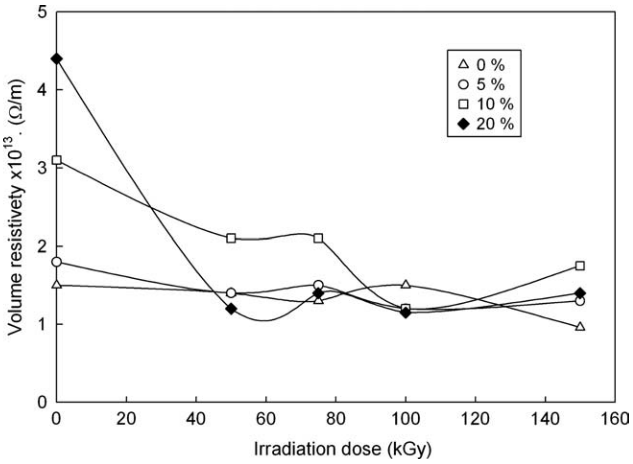


**Figure 10** Variation of the volume resistivity of WPE/RWRP/MA 60/40/2 wt % composites at different contents of talc versus irradiation dose.

talc content increases, manifesting the production of talc-filled WPE/RWRP/MA composites. Consequently, the volume resistivity of a talc-filled WPE/RWRP composite varies as talc content increases from that of pure WPE/RWRP composite to that of pure talc. Also, Figure 10 represents the evolution of volume resistivity as a function of irradiation dose. All over the applied irradiation range volume resistivity exhibited respective decrease, i.e., the higher dose the level of matrix degradations is and the molecular bonds weaken and the free volume rises. The phenomenon of reduction in the volume resistivity leads to an increase in the mobility of the charge carriers.

### Scanning electron microscopy

SEM was used to examine the tensile fracture of WPE/RWRP/MA 60/40/2 wt % composites based on 5, 15 and 20 wt % of filler with and without irradiation. Micrographs of the fracture surface of composites are shown in Figure 11(a) (without talc), 11(b) (with 5% talc), 11(c) (with 15% talc), and 11(d) (with 20% talc). It can be seen that the fracture surface of matrix composites without talc demonstrates detachments of rubber. This suggests poor adhesion taking place between molecules of matrix constituents. Figure 11(b) shows better adhesion and talc platelet crystals of 10–30 mm are dispersed in the polymer matrix with some orientation of the crystals to the bottom side of the micrograph. The filler platelets are surrounded by big voids and holes. The observed voids were created during fracture by extraction of some talc crystals from their places on the fractured surface. The fracture surface in Figure 11(c) shows matrix tearing indicating higher interfacial strength that exists between filler and polymer

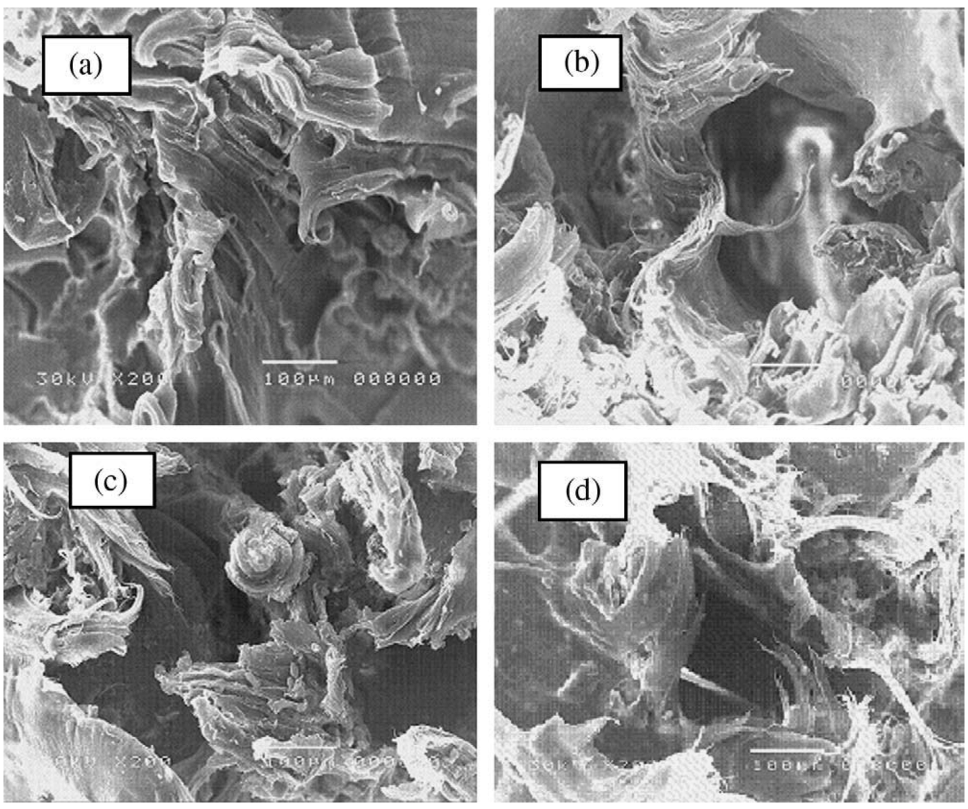


**Figure 11** SEM micrograph of tensile fracture surface of WPE/RWRP/MA 60/40/2 wt % composite of different contents of talc: (a) blank, (b) 5%, (c) 15%, and (d) 20%.

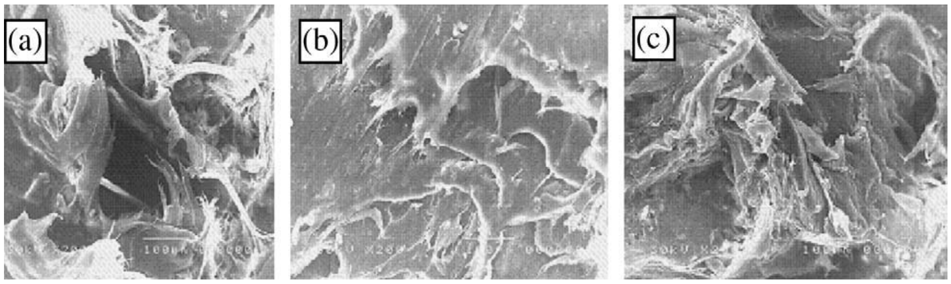


**Figure 12** SEM micrograph of tensile fracture surface of WPE/RWRP/MA/talc 60/40/2/20 wt % composites at various irradiation doses: (a) blank, (b) 75 kGy, and (c) 150 kGy.

matrix; the former is coated by the system matrix as a result of better interaction with polymer moiety. For talc 20% filled WPE/RWRP/MA composite, fracture surface shows some matrix tearing and many holes due to detachment of talc aggregates from matrix indicating a weak talc-WPE/RWRP/MA interaction at such a high level of talc content.

Figure 12(c) emphasizes that the impact of a dose of 150 kGy almost restores the talc free composite matrix. Meanwhile, micrograph 12b represents the best phase adhesion with nearly maximum cross linking by 75 kGy dose as previously predicted by tensile strength, elongation at break, and modulus elasticity investigations. Figure 13 shows the EDX spectra of the mineral in the as composed state and in the composite matrix at 5, 15, 20 wt %. The presence of Mg and Si indicating that talc was all over the three cases distributed. Figure 14 represents the EDX spectra of the composites containing 20 wt % talc irradiated with 75 and 150 kGy doses. Obviously, the presence of Mg and Si corroborates that its distribution in the composite is still confirmed. Nevertheless, further research is currently in progress to ascertain this issue at managed conditions.

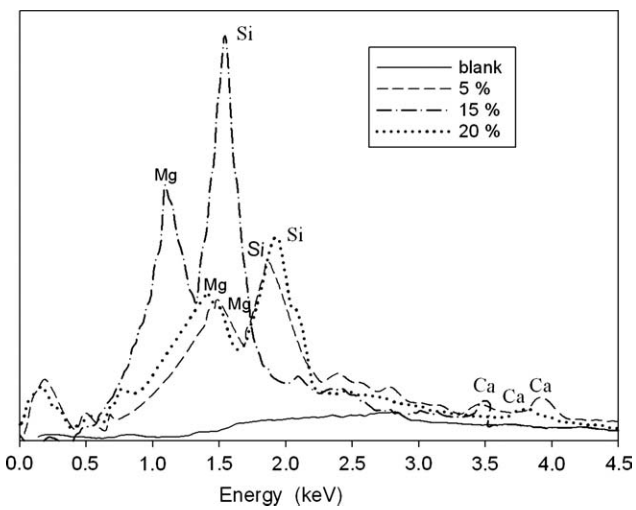


**Figure 13** EDX patterns of fracture surface of WPE/RWRP/MA 60/40/2 wt % composite at different contents of talc, the peaks of Si, Mg, and Ca are ingredients of talc.

## CONCLUSIONS

This work examined the effects of talc and γ- irradiation on thermal and mechanical properties of WPE/RWRP/MA/talc composites. The mechanical, thermal, morphological, and electrical properties of composites were studied. The results obtained lead to the following remarks:

1. The tensile strength increases with the talc content up to 10%, meanwhile elongation at break decreased by talc content increase. Also, it is obvious that tensile strength of the blends increases with the irradiation dose up to 50 kGy, indicating that crosslinking is the predominant process.
2. The TGA measurements showed a relative improvement in thermal stability of composites in presence of talc in terms of $T_{0.5}$ by γ-irradiation.
3. The DSC measurements showed that the melting temperature of the unirradiated filled samples was slightly higher with talc content than for the unfilled polymer.

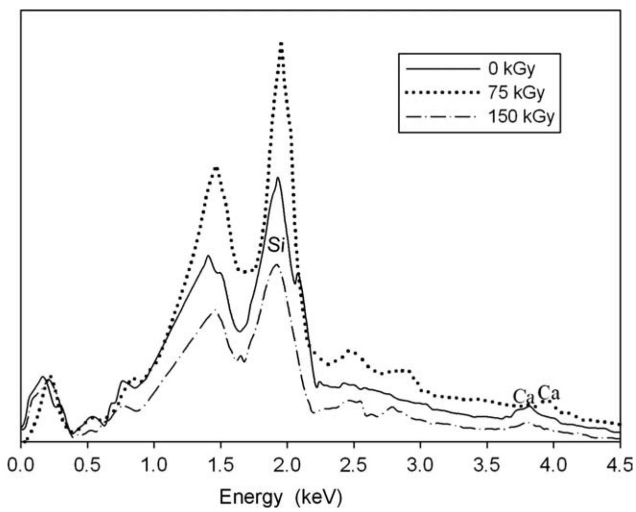


**Figure 14** EDX patterns of fracture surface of WPE/RWRP/MA/talc 60/40/2/20 wt % composite at different irradiation doses, the peaks of Si, Mg, and Ca are ingredients of talc.

4. The electric conductivity revealed a relative increase as talc content increases, manifesting the production of talc-filled WPE/RWRP/MA composites.
5. The SEM micrograph shows longitudinal and platelet talc particles embedded in the polymer matrix, with some holes and voids around.

## References


1. European Environment Agency. The European Environment—State and Outlook; European Environment Agency: Copenhagen K, Denmark, 2005.
2. Lei, Y.; Wu, Q. L.; Yao, F.; Xu, Y. J. Compos Part A Appl Sci Manuf 2007, 38, 1664.
3. Marzouk, O. Y.; Dheilly, R. M.; Queneudec, M. Waste Manage 2007, 27, 310.
4. James, A. R.; Sbarski, I.; Masood, S. H.; Kosior, E. J Polym Eng 2007, 27, 55.
5. Yehia, A. A.; Ismail, M. N.; Hefny, Y. A. J Elast Plast 2004, 36, 109.
6. Sung, H. L.; Sung, H. H.; Marianna, K.; Sridhar, V.; Zhen, X. Z.; Deng, X.; Jin, K. K. J Appl Polym Sci 2009, 112, 3048.
7. Maziad, N. A.; Hassan, M. M. J Appl Polym Sci 2007, 106, 4157.
8. Hong, C. K.; Isayev, A. I. Elastom Plast 2001, 33, 47.
9. Chou, L. H.; Lu, C. K.; Chang, J. R.; Lee, M. T. Waste Manage Res 2007, 25, 68.
10. Manual, H.-J.; Dierkes, W. Vredestein Rubber Resources BV, Maastricht, The Netherlands, Rubber Division, ACS, Fall Meeting, Orlando, Florida, September 21–24, Paper No. 133, 1999.
11. De, D.; Maiti, S.; Adhikari, B. J Appl Polym Sci 2000, 75, 1493.
12. Saq'an, S.; Zihlif, A.; Ragosta, G. Thermoplast Comp Mater 2008, 21, 457.
13. Mahanwar, P.; Bose, S.; Raghu, H. Thermoplast Comp Mater 2006, 19, 491.
14. Salem, E. F.; Mostafa, N.; Hassan, M. M.; Mohsen, M. J App Polym Sci 2009, 113, 1.
15. Abu Bakar, M. B.; Leong, Y. W.; Ariffin, A.; Ishak, Z. A. M. J Appl Polym Sci 2007, 104, 434.
16. Hattotuwa, G. B.; Premalal, H.; Baharin, A. Polym test 2002, 21, 833.
17. Hassan, M. M.; El-Kelesh, N. A.; Dessouki, A. M. Polym Compos 2008, 29, 156.