Preparation and Characterization of Rice Husk-Polymer Particleboard Composites.

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ABSTRACT

Two types of rice husk (RH) -polymer particleboard composites were fabricated by mixing different ratios of RH having various particle sizes ranging from ≤ 0.5 mm to ≥ 1.25 mm with different ratios of epoxy resin (EP) and polyvinyl chloride (PVC) under hot pressure. The best mechanical properties were achieved at particle sizes 0.5 mm - 0.8 mm for the two composites. Also, RH-EP composites exhibited higher mechanical properties as compared to RH-PVC composites. Gamma irradiation doses of 5 kGy to 70 kGy were applied to composites. The irradiated composites showed an improvement as compared to unirradiated composites. SEM and TGA were studied.
Keywords: rice husk; epoxy resin; PVC; physico-mechanical properties; gamma–irradiation

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INTRODUCTION

In the present time, the use of natural fibers in the production of polymer particleboard composites gains a great importance. Natural fibers have many advantages as they are low-cost fibers with low density, biodegradable, nonabrasive, and they have a relatively good mechanical modulus. In addition, they are environmentally friendly and thus being used as an attractive alternative in polymer composites [1, 2]. RH is an agricultural waste material produced during the rice milling process. It is considered one of the most important natural fiber- reinforcing materials because it is inexpensive, abundantly available, and flexible during processing [3]. Many researchers were interested in using rice husk in several applications to reduce the environmental pollution instead of burning it or disposed of in the landfill. The main constituents of RH fibers are cellulose, hemicellulose, lignin, and silica and their properties are responsible for the overall properties of the fibers [4].

Recently, the incorporation of natural fiber in polymer composites has attracted many attentions as it can motivate the degradation of the polymers [5-7]. The use of natural fibers into polymeric matrices produces composites with a high specific stiffness and strength. The mechanical properties of natural fiber reinforced composites are depending on many factors, such as fiber strength, fiber length, modulus, orientation, and fiber- polymer interfacial bond strength. The interaction between the fiber and polymer depends on the type of fiber and its properties [8].

Polymer matrix plays a significant role in the performance of polymer composites. The matrix materials for composites include thermosets and thermoplastics. Thermoset composites are characterized by a large number of components which are chemically cured to a cross-linked, three-dimensional network structure. EP is one of the most important thermosetting polymers used in fiber-polymer composites due to its good properties such as heat resistance, low shrinkage, high modulus and relatively high strength [9]. On the other hand, thermoplastics have many advantages over thermoset polymers as their low processing costs, high flexibility, and facility of molding. PVC as an example of thermoplastics has excellent chemical and weathering resistance, therefore it is used in outdoor applications. The capability of PVC to mix with different fillers makes it usable in various functions as in automobile and electrical industries [10].

Over the past few decades, ionizing radiation, such as gamma rays has been used successfully to induce effective changes in the properties of natural fiber-polymer composites. Gamma radiation gives its energy to the solid cellulose of natural fibers by Compton scattering effect, and as a result, macro-cellulosic radicals are produced. These radicals have contributed to the physical and chemical changes in the properties of cellulosic fibers [11]. Many advantages have been offered by using gamma radiation, such as continuous operation, minimum time requirement, less atmospheric pollution, curing at ambient temperatures, and increased design flexibility through process control [12]. Also, radiation can introduce good surface cross-linking between natural fiber and polymer, and reduce its hydrophilic nature through the hydrophobic polymer. The application of gamma radiation technique is becoming so prevalent every year, primarily in the coating and adhesive industries. With continued this radiation technique, new products based on high efficiency and easy process control are produced in the field of composite materials [13].

In our study, we aim to prepare two different particleboard composites namely, RH-EP and RH-PVC particleboard composites also to evaluate the effects of RH fiber content; its particle size and gamma irradiation doses on the physico–mechanical properties of both RH-polymer particleboard composites. A comparative study of physico-mechanical properties between RH-EP and RH-PVC particleboard composites are carried out to determine the effect of these different factors which affect the behaviour of both composites and their properties.

EXPERIMENTAL AND METHODS

RH fibers were cleaned before using and they were sieved through different sieves. Three different particle sizes of RH were used ranged from (P. S. 1) less than 0.5mm, (P. S. 2) from 0.5mm to 0.8 mm and (P. S. 3) more than 1.25mm. Two polymers were used, epoxy resin (EP) with a trade name (KEMAPOXY 150) which was obtained from the Modern Building Chemicals Company, Egypt and polyvinyl chloride (PVC) that was obtained from Cedasa Company, Egypt. Properties and chemical structure of these two polymers are given in Table (1).

Table (1): Properties and chemical structure of the polymers.

Type of polymer	Appearance	Density (kg/m^3)	Solid content (%)	Chemical structure
Epoxy Resin (EP)	Transparent Liquid	1.11 ± 0.02	100	(epoxide ring structure with R^1, R^2, R^3, R^4)
Polyvinyl chloride (PVC)	White powder	1.39	-	(PVC repeating unit structure)
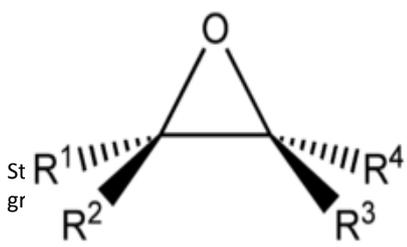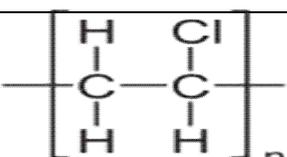
Preparation of RH -polymer particleboard composites

In this study RH fiber having three particle sizes were used and corporate with EP and PVC to prepare RH-polymer particleboard composites. The composite samples were designated as in Table 2. All mixtures were pressed in a mould of dimensions 16 x 16 x 0.8 cm, using an electric hot press type Carver-M-154. Hot pressing was performed at 250 ºf for EP composites and 310ºf for PVC composites, 5 minutes pre-heating and 10 minutes at 20000 PSI and the samples were then cooled at the same pressure for 5 minutes. Other groups have mix compositions (70% RH2: 30% EP) and (50% RH2: 50% PVC) were prepared under the same previous conditions and subjected to different doses of gamma irradiation namely 5, 10, 15, 30, 50 and 70 kGy.

Table (2): Mix proportions of different particleboard composites.

RH-polymer particleboard composites		
Polymer type	RH- particle size	Mix composition
Epoxy resin (EP)	P.S. 1 (≤ 0.5 mm)	50% RH1: 50% EP 60% RH1: 40% EP 70% RH1: 30% EP 80%RH1: 20% EP
	P.S.2 (0.5 to 0.8 mm)	50% RH2: 50% EP 60% RH2: 40% EP 70% RH2: 30% EP 80%RH2: 20% EP
	P.S.3 (≥1.25 mm)	50% RH3: 50% EP 60% RH3: 40% EP 70% RH3: 30% EP 80%RH3: 20% EP
Poly vinyl Chloride(PVC)	P.S.1(≤ 0.5 mm)	50% RH1: 50% PVC 60% RH1: 40% PVC 70% RH1: 30% PVC 80%RH1: 20% PVC
	P.S.2 (0.5 to 0.8 mm)	50% RH2: 50% PVC 60% RH2: 40% PVC 70% RH2: 30% PVC 80%RH2: 20% PVC
	P.S.3 (≥1.25 mm)	50% RH3: 50% PVC 60% RH3: 40% PVC 70% RH3: 30% PVC 80%RH3: 20% PVC

Gamma Irradiation

The irradiation process was carried out using Co-60 gamma cell-220 source (made in India) of the National Center for Radiation Research and Technology, Cairo, Egypt (dose rate 10 KGy/hr).

Characterization Techniques

Flexural Strength

Three point static bending have been performed on the specimens to evaluate its flexural strength under static loading. Four individual rectangular shaped samples (of dimensions 150 mm in length 25 mm in width and 8 mm in thickness) were subjected for testing and the arithmetic of the result values has been recorded. All the test procedures of static bending were carried out according to the ASTEM standard (D1037-11, 1987).

Flexural strength = $3PL/2bd^2$

Where,
- b = width of specimen in cm
- d = thickness of specimen in cm
- L = length of span in cm
- p = maximum load (kg/cm^2)
- p_1 = load at proportional limit (kg/cm^2)
- y = center of deflection at proportional limit load in cm.

Impact Strength

A pendulum impact apparatus PSW-4J , have been used in this test according to ASTM standards (D-256, 1987) The pendulum impact (PSW-4j) testing apparatus was used , has been supplied by Gerhard zorn Mechanische Werkestatten ,Stendal, Germany .

Four rectangular samples having a dimensions of 120 , 15and 10 mm (unnotched test samples) ,were subjected for testing and the arithmetic mean of the rsulte values have been recorded . The impact toughness (result of unnotched test samples), was calculated form the following equation,

$$a_n = A_n /b . h$$

where,
-a = the impact toughness J/cm^2
-A_n = absorbed impact energy in joule
-b = width of the sample in its center in cm
-h = height of the sample in its center in cm

Hardness

The hardness test was carried out by using shore D durometer, Baxlo instrumentos De Medida Precision S.L., Percelona, Spain. The method was carried out according to (ASTM D 2240, 2000) specification, and the units of hardness are expressed in Shore D.

Water absorption (%)

The specimens under test were submerged under distilled water at room temperature for 24+2 hours. After submersion the excess water was removed from the surface of the specimen (saturated with water) and immediately weighing the specimen. Then the specimen was dried in an oven at 103+2 ^{o}c for another 24+2 hours, and the specimen was weighed immediately after drying.

This test was performed according to the ASTM standards (D1037-100, 1987) each specimen was tested four times and the arithmetic mean was calculated. Water absorption (%) can be calculated from the following equation,

Water absorption (%) = (W1-W2) / W2 × 100
Where,
W1=Weight of saturated sample.
W2= weight of dried sample

Thickness swelling (%)

This test was done according to ASTM standards D1037 specification. The thickness is measured at four point s midway along each side 25 mm. After 24 hours of submersion in distilled water, the thickness is measured at the same four points and the average is obtained. The following calculations can then be made:

$$\text{Thickness swelling (\%)} = (T_1-T_2)/T_2 \times 100$$

Where,
T_1 = wet thickness
T_2 = initial thickness

Scanning electron microscopy (SEM)

The morphology and microstructure of some selected samples were studied using SEM technique. The samples after being dried, a freshly fractured surface was coated with a thin layer of gold (about 300-400µ thickness) using a vacuum evaporation technique. A JEOL 7 SM-25 high-resolution scanning electron microscope was used. Shimadzu-Co., Japan has supplied it.

Thermal gravimetric analysis (TGA)

The thermal behavior of the different polymer composites were investigated by TGA technique using a TG-50 instrument from Shimadzu (Japan) with a heating rate of 10°C/min. The data obtained from TGA curves were used to determine the percentage of weight remain at different decomposition temperature and temperatures of the maximum values for the rate of decomposition.

RESULTS AND DISCUSSION

Flexural strength

The effects of RH content, as well as its particle size on the flexural strength values of RH-EP and RH-PVC particleboard composites are shown in figs.(1, 2) respectively. From fig. (1) it is clear that the flexural strength values of RH-EP composites increase gradually as the RH fiber content increases from 50 to 70 wt%. and then decrease. The ultimate flexural strength values are achieved for composites made with a fiber content of 70 wt %. This enhancement in the flexural strength values of RH-EP particleboard composites is due to the ability of cellulose in RH fibers to resist the bending force [14, 15]. On other words, the significant increase in flexural strength values of RH fiber content (70 wt %) is due to the increase in stress transferred to the fiber as a result of the increased bonding at the fiber-matrix interface. At a higher RH fiber content (80 wt%), the flexural strength reduces due to weak interfacial bonding for the composites as the maximum strength has been attained and further addition of fiber content weakened and disrupted the fiber- polymer bond [16, 17].

From fig. (1) it is also observed that, for a given RH fiber content, the maximum flexural strength values are achieved for composites with RH particle size P.S.2. The improvement of the mechanical properties of the RH-EP particleboard composites with RH of particle size P.S.2 is a result of particle geometry. According to the mechanics of fiber- polymer composite materials, one of the important factors affecting their mechanical properties is a fiber aspect ratio which defined as a fiber length to thickness ratio. Fibers with a higher aspect ratio enhance stress transfer from the polymer to the fibers and ultimately improve the composite mechanical properties [18-21].

On the other hand the results obtained in fig. (2) reveal that, the flexural strength values of RH-PVC particleboard composites gradually decrease with increasing fiber content. The highest flexural strength values are obtained for composites with fiber content 50 wt% and then decrease for 60, 70 and 80 wt%. This may be due to insufficient wetting of polymer to the fibers for higher fiber content [22] or may be attributed to the effect exerted by the concentration of stresses, attributable to the weak interfacial interaction between the fiber and PVC as a result of poor adhesion [23].

It is also observed from fig. (2), that for a given RH fiber content, Flexural strength values of RH-PVC composites increase with increasing particle size from P.S.1 to P.S.2 and
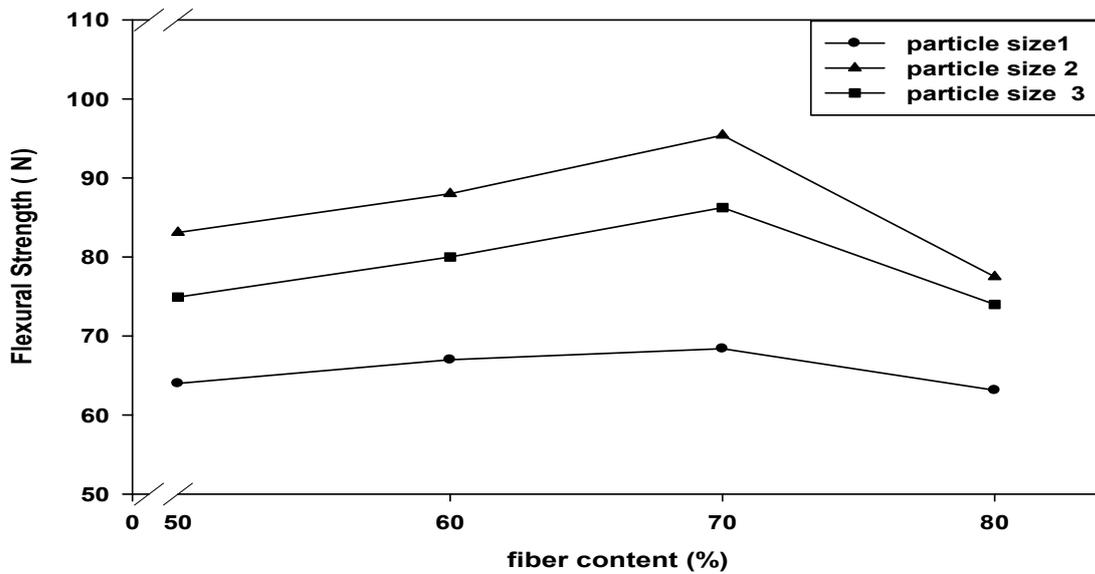
Fig. (1): Effect of fiber content (%) on flexural strength of various particle sizes of RH-EP particleboard composites.
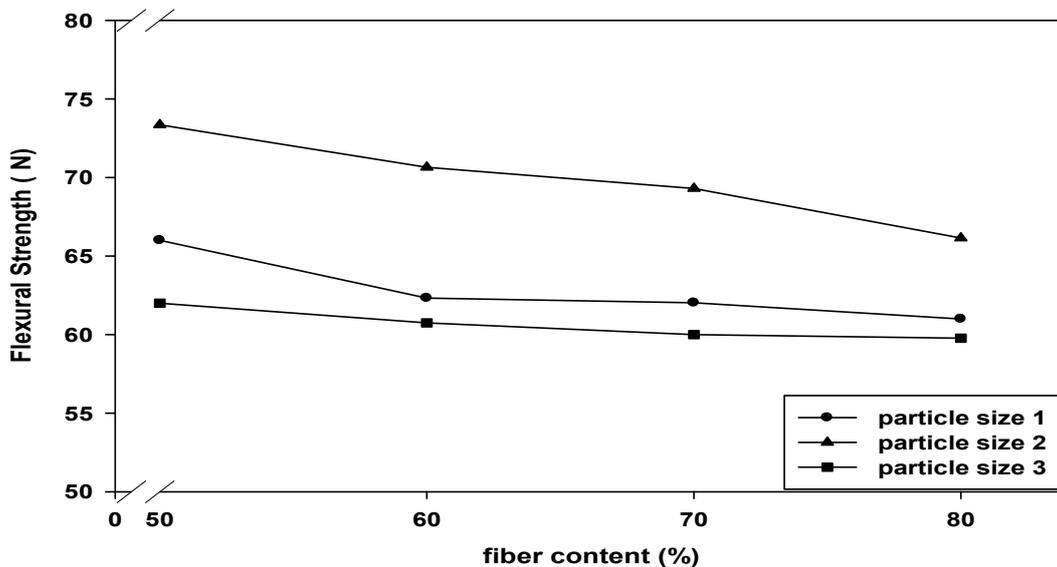
Fig. (2): Effect of fiber content (%) on flexural strength of various particle sizes of RH-PVC particleboard composites.

Then diminish when the fiber particle size increases to P.S.3. The maximum flexural strength values are obtained for the composites with a RH of particle size P.S.2 which is a result of the better dispersion and alignment of the fibers within the PVC polymer [24].

On the other hand, the effect of different γ-irradiation doses on the flexural strength values of both RH-EP and RH-PVC particleboard composites are shown in fig. (3). The results indicate that the flexural strength of both particleboard composites has a maximum value at 10 kGy and 5 kGy for RH-EP and RH-PVC particleboard composites respectively and then decreases. The results also show that, for a given gamma -irradiation dose the flexural strength values of RH-EP particleboard composites are higher than those of RH-PVC particleboard composites.

At lower gamma irradiation doses (10 kGy for RH-EP and 5 kGy for RH-PVC), crosslinking phenomena occurs which make strong bonds between the composite components leading to higher adhesive composites and as a result the flexural strength values increase [25]. While at higher irradiation doses, the flexural strength values decrease; these are mainly attributed to the chain scission and cellulosic fiber degradation leading to a lower adhesion between the composite components.
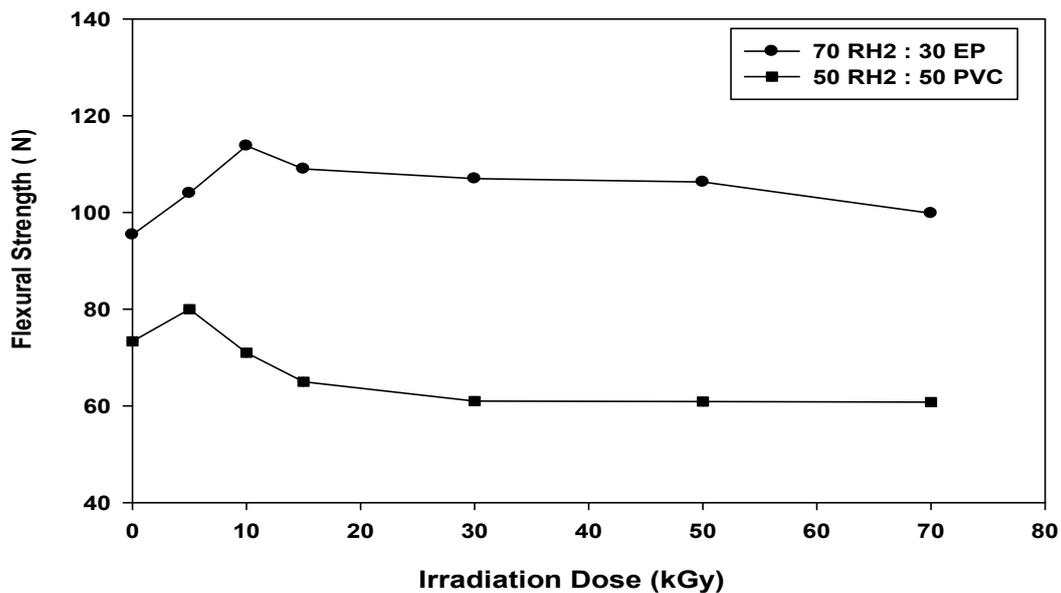
Fig. (3): Effect of gamma irradiation dose on flexural strength of RH-EP and RH-PVC particleboard composites.

Impact strength

The impact strength of RH-EP and RH-PVC particleboard composites as a function of fiber content (%) at various particle sizes of RH fibers is graphically represented in figs. (4, 5) respectively. The results indicate that the impact strength values of RH-EP particleboard composites increase gradually with increasing fiber content up to 70% and then decrease with more fiber content. The ultimate impact strength values are achieved for composites with fiber content 70 wt%. This is related to the presence of RH fibers in an EP polymer which raises the ability of these composites to absorb impact energy leading to high impact strength [17]. In other words, we can say that fibers play an important role in the impact resistance of the composite as they interact with the crack formation within the polymer and act as a stress transferring medium [26]. At a higher RH fiber content (80 wt%), the reduction of the impact strength values may be due to that the fibers debonded from the polymer as a result of the poor interaction between the polymer and the fibers. This is attributed to the presence of voids and air entrapments in the composite of the fracture that created the poor bonding between fiber/ polymer and ultimately affected the composite properties resulted in a low impact strength of composites [17].

The results in fig. (4) also denote that, the impact strength values of RH-EP particleboard composites increase with increasing particle size of RH fiber up to P.S.2 and then decrease. For instance, at RH fiber content 70 wt%, the impact strength value of composite with P.S.1 is 2.99 J/cm^2 and it increases to 3.20 J/cm^2 for P.S.2 and then decreases to 2.91 J/cm^2 for P.S.3. The possible reasons proposed for this kind of behavior may be due to the improved interfacial adhesion between the polymer and fibers.

However, in case of RH-PVC particleboard composites, as shown in fig. (5), there is a decrease in impact strength values as RH fiber content increases. The highest impact strength values are for composites with fiber content 50 wt% and then diminish in 60, 70 and 80 wt%. This may be attributed to the weak interfacial interaction between the fiber and polymer for higher fiber content that is beyond 50 wt %. This negative effect may be ascribed to the reduction of polymer content and poor compatibility between the fiber and polymer [27, 28].

Fig. (5) also exhibits that, the impact strength values of RH-PVC particleboard composites increase with increasing particle size of RH fiber up to P.S.2 and then decrease as the particle size increases. For example, the impact strength value of composite with P.S.1 is 2.85 J/cm^2 and it rises to 3.05 J/cm^2 for P.S.2 and then drops to 2.95 J/cm^2 for P.S.3 for a composite with 50% RH fiber content.
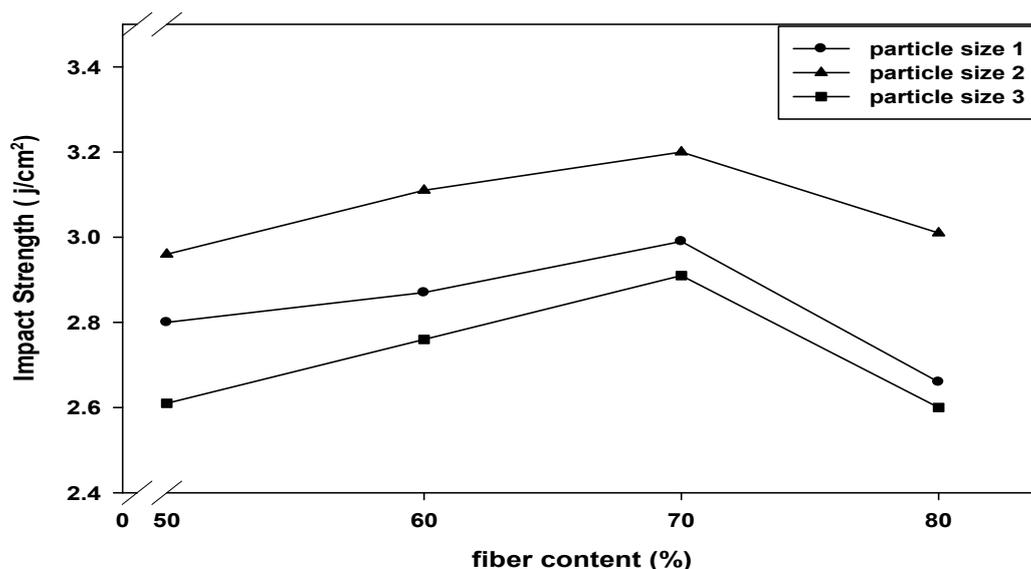
Fig. (4): Effect of fiber content (%) on impact strength of various particle sizes of RH-EP particleboard composites.
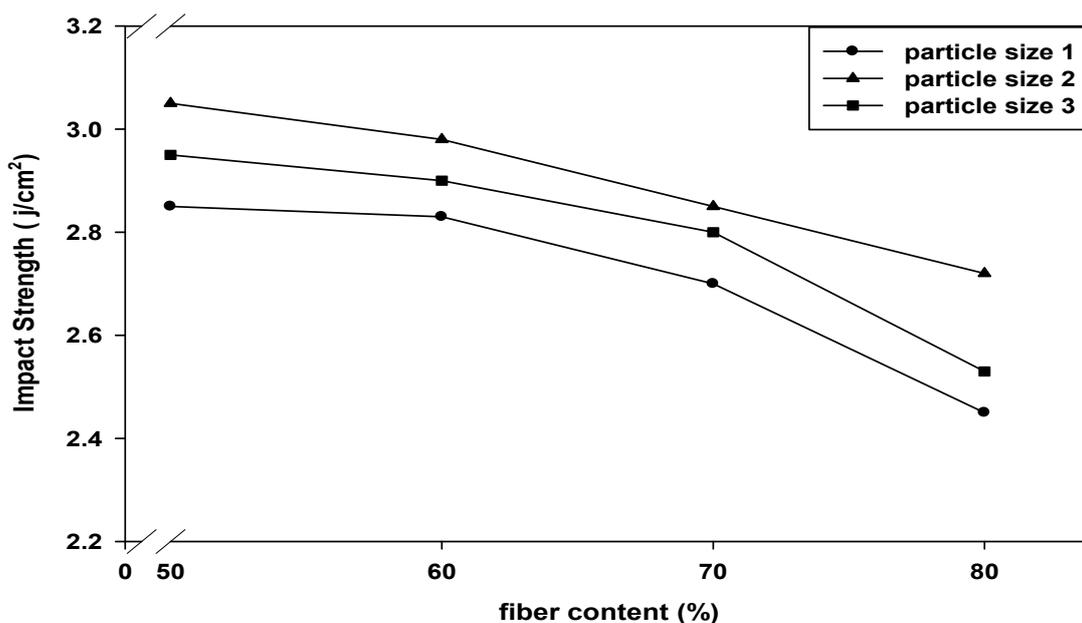
Fig. (5): Effect of fiber content (%) on impact strength of various particle sizes of RH-PVC particleboard composites

The influence of different gamma-irradiation doses on the impact strength of RH-EP and RH-PVC particleboard composites are graphically demonstrated in fig. (6). The results mention that the highest impact strength values are gained at 10 kGy and 5 kGy for RH-EP and RH-PVC particleboard composites respectively. It is found that the maximum values of the impact strength are 3.35 and 3.15 J/cm^2 for RH-EP composites at 10 kGy and RH-PVC composites at 5 kGy respectively, which are higher than those of unirradiated composites which their impact strength values are 3.2 and 3.05 J/cm^2 for RH-EP and RH-PVC composites respectively. This behavior can be explained according to the same reasons mentioned before. It is also clear that the impact strength values for RH-EP composites are higher than those of RH-PVC composites for any given dose of gamma -rays. It is may be attributed to the higher efficiency of the ionic species of the EP during the irradiation process.
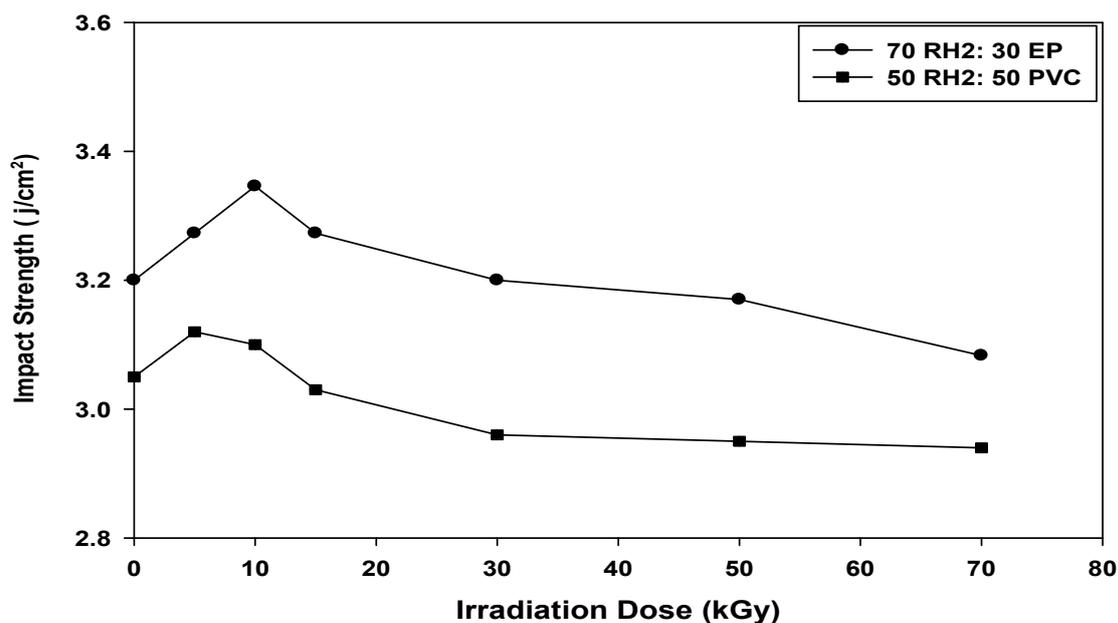
Fig. (6): Effect of gamma irradiation dose on impact strength of RH-EP and RH -PVC particleboard composites.

Hardness

The hardness of a material is often one of the first criteria considered when choosing materials for particleboard composites. It is the measure of a material's resistance to surface indentation, also it is a function of the stress required to produce some specific types of surface deformation [29]. Figs. (7, 8) illustrate the effects of RH content as well as its particle size on the hardness values of RH-EP and RH-PVC particleboard composites respectively. The results present that the hardness values for RH-EP particleboard composites increase gradually as RH fiber content increases from 50 to 70 wt % and then drop. The ultimate hardness values are achieved with a fiber content of 70 wt %. This trend of results could be because as more fiber was incorporated into the polymer, the elasticity of the polymer chain reduced resulting in more rigid composites. While the reduction of the hardness values at higher RH fiber content (80 wt%) is due to weak interfacial bonding as a further addition of RH fibers weakened or disrupted the fiber- polymer bond [30].

From Fig. (7), it is also spotted that, for a given RH fiber content, the superior hardness values of RH-EP particleboard composites are achieved for composites with RH fiber of particle size P.S.2. Generally, increasing fiber particle size improves the mechanical properties of the composites. The hardness values of composites with RH of P.S.3 dropped as a result of poor particle distribution and/or orientation.
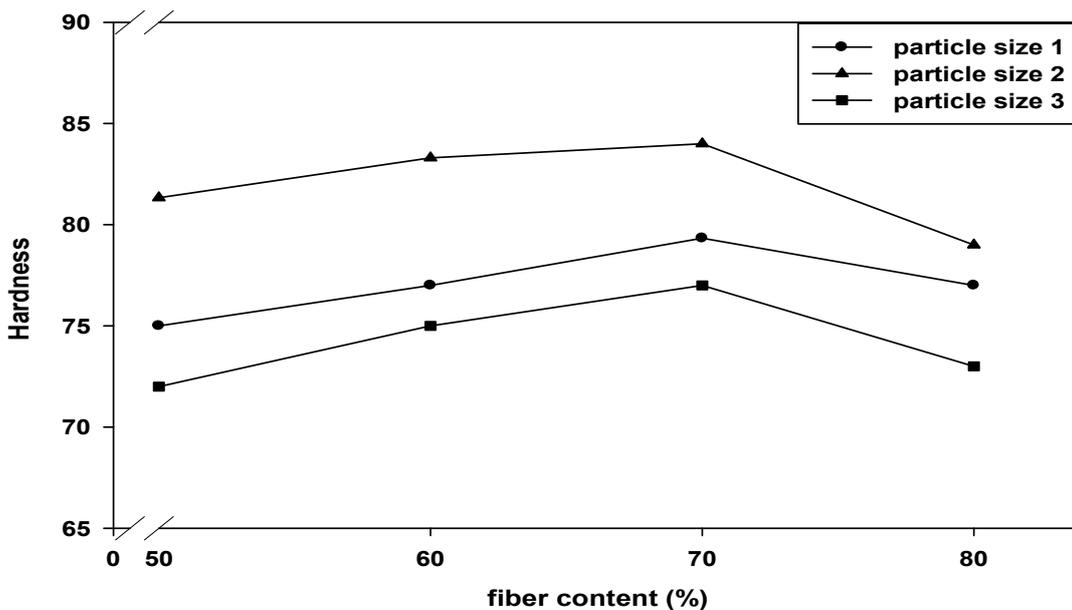
Fig. (7): Effect of fiber content (%) on hardness of various particle sizes
of RH-EP particleboard composites.
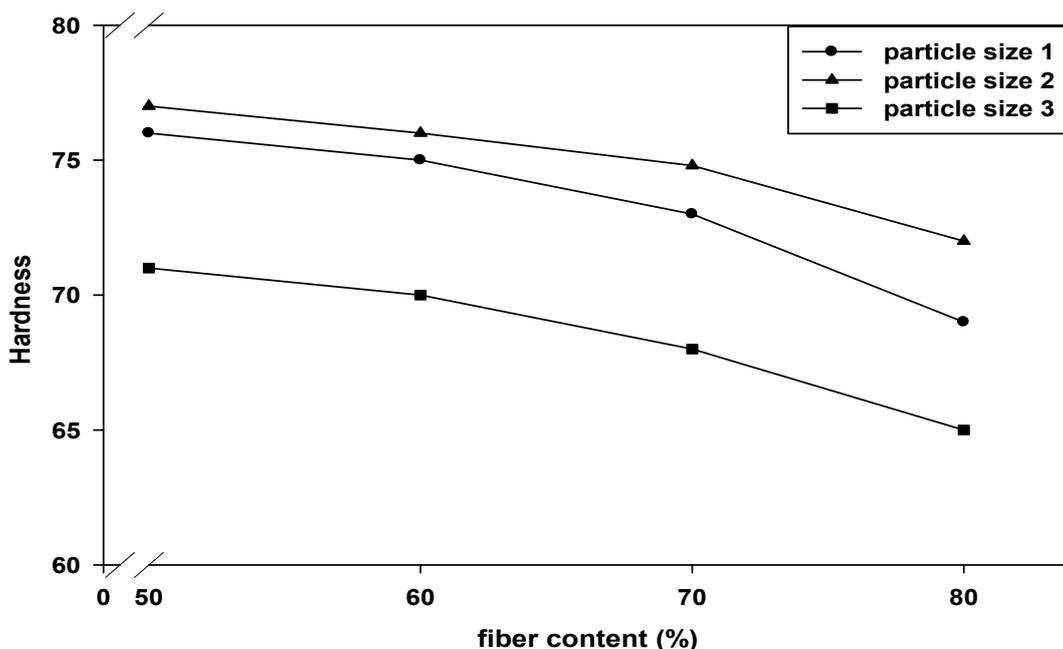
Fig. (8): Effect of fiber content (%) on hardness of various particle sizes
of RH-PVC particleboard composites.

On the other side, the hardness values of RH-PVC particleboard composite diminish gradually as the RH fiber content increases from 50 to 80 wt % as seen in fig. (8). The maximum hardness values are achieved for composites with a fiber content of 50 wt %. It is also clearly observed that, for any given fiber content, RH-PVC composites made with RH fibers of P.S.2 have the highest hardness values as compared to other particle sizes.

The variations in hardness values of RH-EP and RH-PVC particleboard composites as a function of γ-irradiation dose are graphically shown in fig. (9).The results prove that the hardness of both composites increases with increasing the irradiation dose up to a certain dose and then decreases. The hardness values of RH-EP particleboard composites reach its maximum value at 10 kGy then slightly decrease. Also, the hardness values of RH-PVC particleboard composites reach its maximum value at 5 kGy and then decrease. The hardness values of RH-EP particleboard composites are higher than those of RH-PVC particleboard composites for any

given γ-irradiation dose. It is considered that the increase in hardness was due to the effect of irradiation process which produces a harder composite.
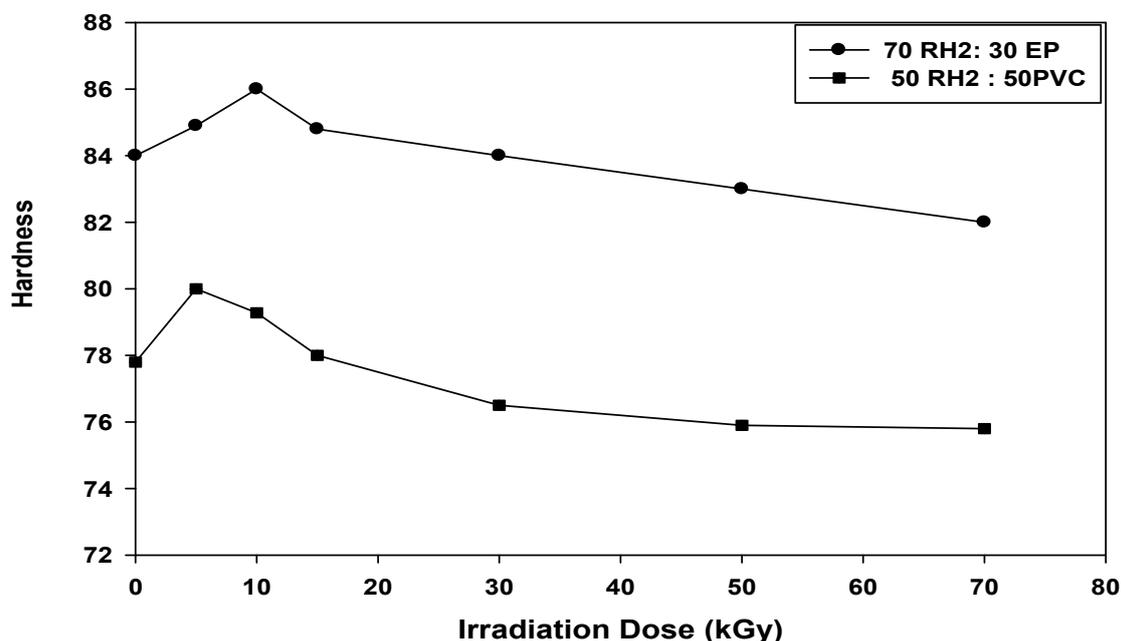
Fig. (9): Effect of gamma irradiation dose on hardness of RH-EP and RH-PVC partcleboard composites.

Water Absorption (%)

The evaluation of the water absorption (%) as a function of the RH fiber content and its various particle sizes for RH-EP and RH-PVC particleboard composites are shown in Figs. (10, 11) respectively. It can be seen in fig. (10) that water absorption (%) of RH-EP particleboard composites increases with an increase in fiber content. This result is expected due to the hydrophilic nature of cellulose fibers. Moreover, cellulose fibers have a central hollow region (i.e. the lumen) which allows much water to be absorbed via the capillary effect [16]. Thus, as fiber loading increases in the composites, a more interfacial area exists leading to an increase in water absorption.

Fig. (10) also indicates that RH-EP particleboard composites with RH fiber of P.S.2 have the lowest water absorption (%) values while particleboard composites with P.S.3 have the highest water absorption values. Particle size strongly affects water absorption (%) the larger the particle size, the higher the water absorption [31]. With regard to RH-PVC particleboard composites, the water absorption (%) is also found to increase with increasing RH fiber content from 50 wt% to 80 wt% as shown in fig. (11). Composites with fiber content 50 wt% have the lowest water absorption value; this may be due to lower void space in composite arising at better bonding between fibers and polymer. Generally, water absorption increases with increase in fiber content. When the fiber content increases in the particleboard, the number of free OH group of cellulose also increases. Hence, the water absorption (%) increases.

From fig. (11) it can be also noticed that the RH-PVC particleboard composites with RH of P.S.2 have the lowest water absorption values while particleboard composites with P.S.3 have the highest water absorption values. I.e. the higher the particle size, the higher the water absorption values. This can be explained in two ways: (i) larger particles lead to greater hydrophilic exposed surfaces; and (ii) poor adhesion between fiber particles and the polymer generates void spaces around the fiber particles. These voids in the bulk polymer are readily filled with water [32].
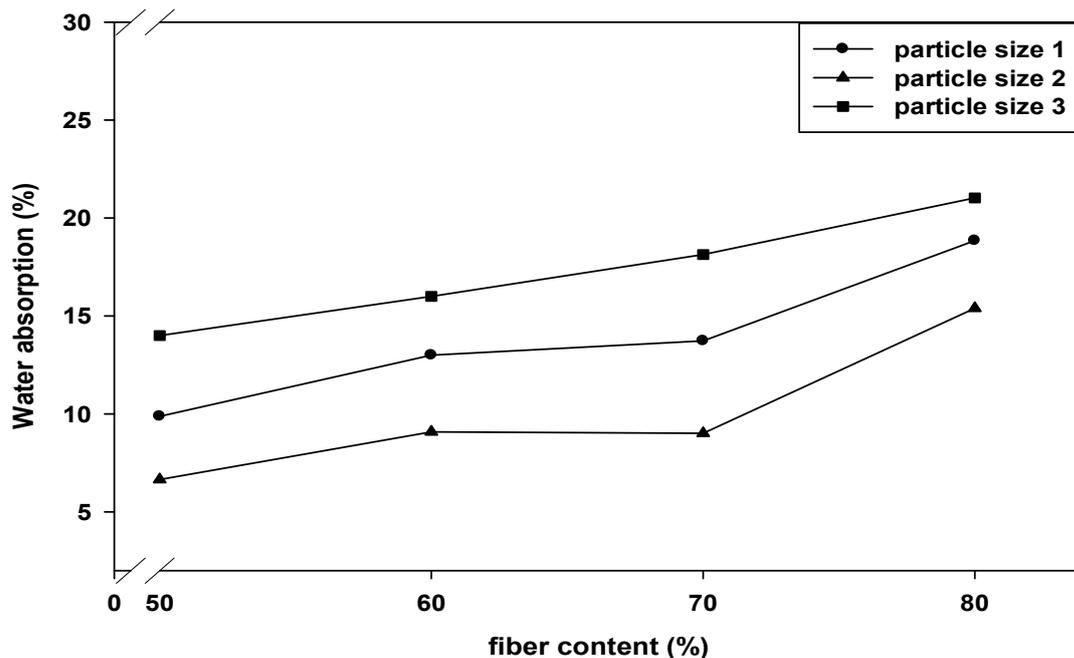
Fig. (10): Effect of fiber content (%) on water absorption (%) of various particle sizes of RH-EP particleboard composites.
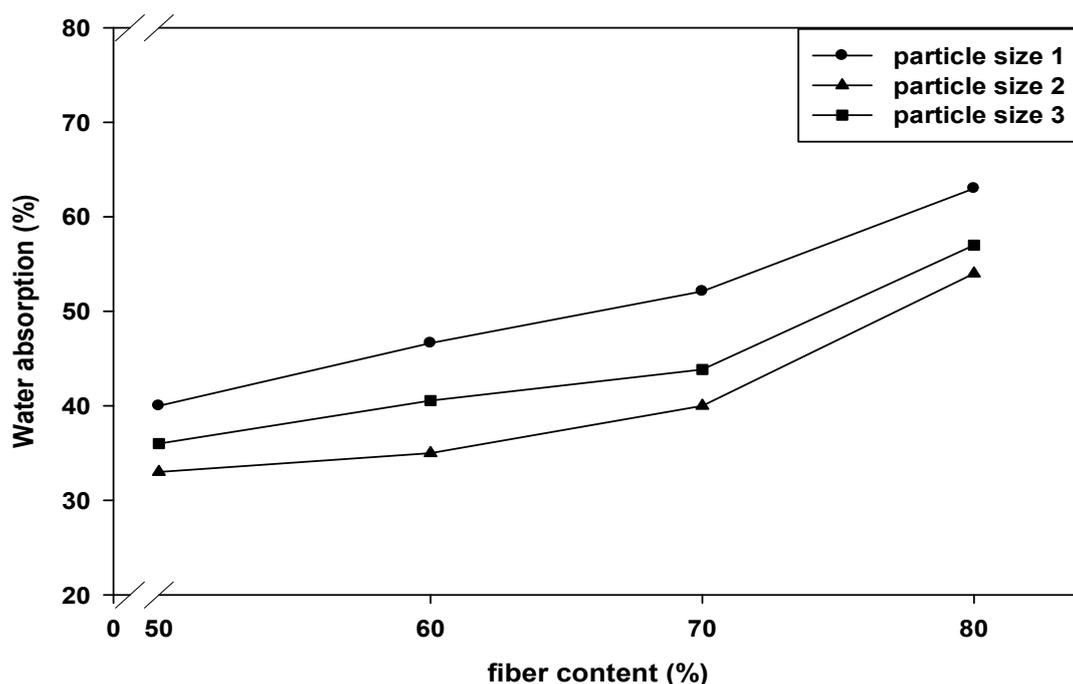
Fig. (11): Effect of fiber content (%) on water absorption (%) of various particle sizes of RH-PVC particleboard composites

The effect of γ-irradiation dose on the water absorption percentages of RH-EP and RH-PVC particleboard composites are given in fig. (12). The results display that the water absorption percentage values decrease with increasing the exposure dose of γ-irradiation up to 10 kGy and 5 kGy for RH-EP and RH-PVC particleboard composites then drop beyond these γ-irradiation doses. The water absorption percentage values of RH-EP are lower than those of RH-PVC particleboard composites for any given γ-irradiation dose. Water absorption percentages are essentially dependent on the volume of the pores of the composites, after irradiation which

causes a further of solid materials (through cross-linking and chemical interaction between the polymer and fibers) deposited in the pores. This is accompanied by diminishing in the volume of pores in the composite and a reduction of the water diffusion through the composite and consequently, the water absorption percentage is also decreased [33]. Another possible explanation is that the fibers contain -OH groups in the amorphous phase, which may react with the polymer molecules by hydrogen bonding during the irradiation processes. These are accompanied by a strong adhesion between the composite components and consequently, the water absorption percentages of the composite are reduced [34].
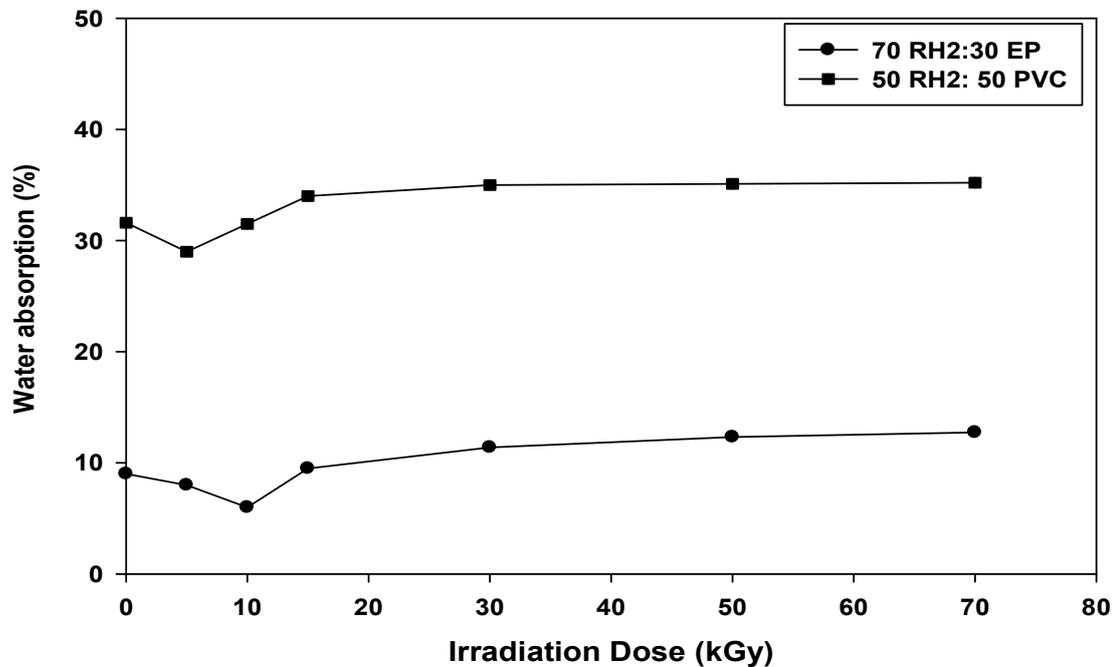
Fig. (12): Effect of gamma irradiation dose on water absorption(%) of RH-EP and RH-PVC particleboard composites.

In other words, gamma radiation plays an important role in repelling water molecules. Hydroxyl (-OH) is one of the important functional groups in natural fiber, which causes the formation of a lot of hydrogen bonds and induces their swelling. The decrease of water sorption of the irradiated composites can be achieved by reducing hydroxyl groups and introducing cross-linking between fiber and polymer [35]. The differences in the water absorption percentage values between the two composites are may refer to the nature of the polymer itself.

Thickness swelling (%)

The variations of thickness swelling (%) with respect to fiber content and its various particle sizes for RH-EP and RH-PVC particleboard composites are illustrated in figs. (13, 14) respectively. Fig. (13) elucidates that the thickness swelling (%) values for RH-EP particleboard composites increase gradually as the RH fiber content increases. It is predictable that the higher the fiber content, the higher the thickness swelling. As water can penetrate micro-gaps in the interface and result in swelling of the composite as a result of partial de-bonding at the interface region [36]. Thickness swelling (%) of these composites is also significantly affected by particle size. The highest thickness swelling values correspond to larger particle sizes as seen from fig. (13). It can be also perceived that RH-EP particleboard composites made with RH of P.S.2 have the lowest thickness swelling values while composites with RH of P.S.3 have the highest thickness swelling values. In the case of larger particles, the initial volume is higher; therefore the composite material can more easily swell by water absorption. Thickness swelling shows close dependency on water absorption. Therefore, larger particle sizes, having higher water absorption will exhibit higher thickness swelling as well. In other words, we can say that exposure to moisture causes the fibers to swell, resulting in the formation of microcracks and voids at the fiber- polymer interface region. This, in turn, leads to increase in water diffusion via these microcracks and voids [37].

Concerning RH-PVC particleboard composites, fig. (14) demonstrates that the thickness swelling (%) values increase gradually as the RH fiber content increases from 50 to 80 wt %. The lowest value of thickness swelling (%) is related to 50 wt% of RH fiber content, but, the highest value of thickness swelling (%) is associated with 80% of the RH fiber content. Noteworthy is that functional groups of hydroxyl existing in the reinforcement phase and there are some bondings between these materials and polymers. Once the composite is exposed to water, its connections or bondings will break and form new connections, which can lead to increased water absorption and thickness swelling as well.

It can be also revealed from Fig. (14) that RH-PVC particleboard composites with RH of P.S.2 have the lowest thickness swelling values while composites with RH of P.S.3 have the highest thickness swelling values. This is due to the low diffusion rate in a particleboard with higher compaction that had reduced the porosity and thus lowered the capacity of a particleboard in absorbing water due to its limited surface area in case of lower particle size. Higher compaction reduced water penetration into the particleboard and consequently, the water needs a longer time to diffuse into the particles and panel [38].

Composites made with RH of P.S.3 have the highest thickness swelling (%) value. As during the soaking process, the thickness swelling value increased because the particles had expanded and some particles were released from the particleboards. In addition, thickness swelling is also influenced by the geometry of particles, their structure and the presence of many voids in the boards that allow internal swelling as well [39].
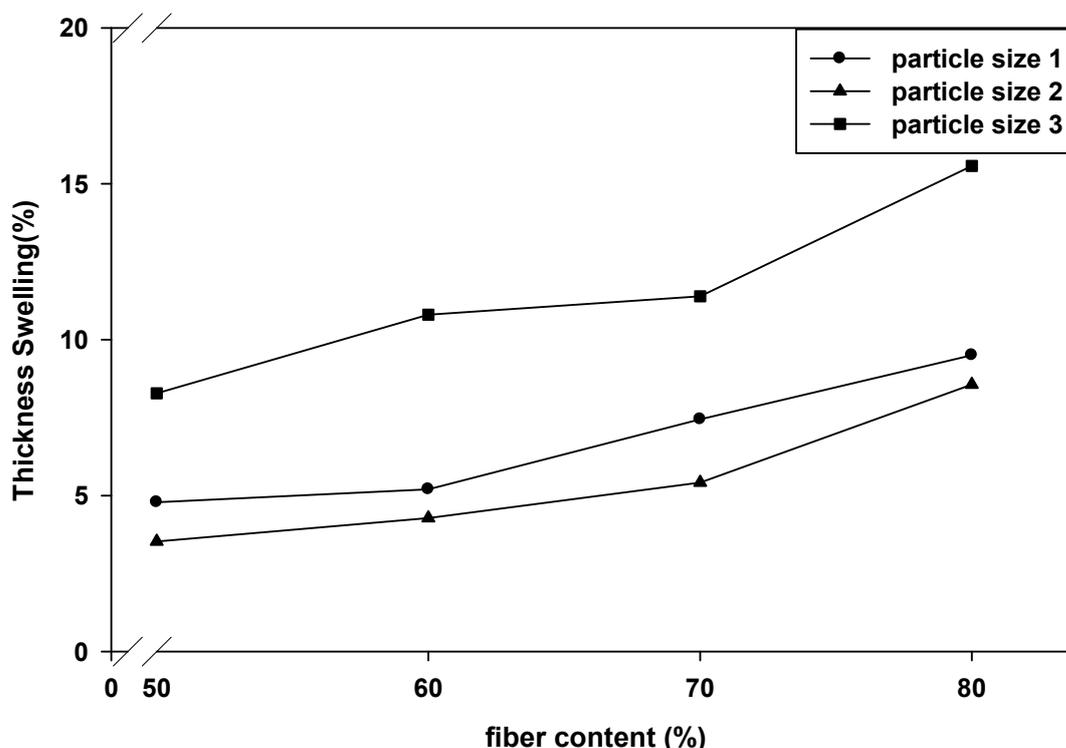
Fig. (13): Effect of fiber content (%) on thickness swelling (%) of various particle sizes of RH-EP particleboard composites.
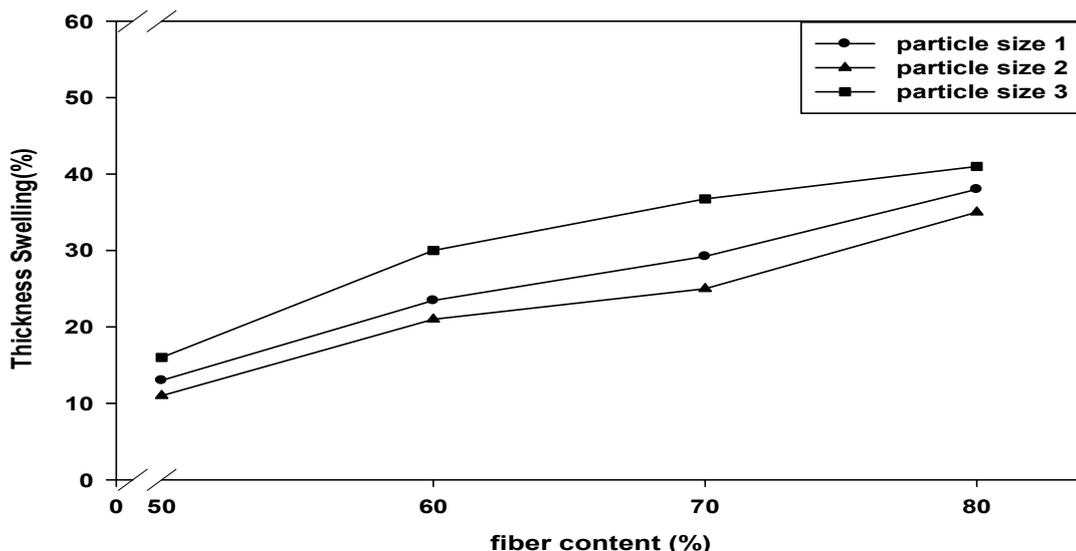
Fig.(14): Effect of fiber content (%) on thickness swelling (%) of various particle sizes of RH-PVC particleboard composites.

Fig. (15) explicates the effect of γ-irradiation dose on the thickness swelling (%) for both RH-EP and RH-PVC particleboard composites. The results manifest that the thickness swelling (%) values decrease with increasing the irradiation dose up to certain dose and then increase for both particleboard composites. For RH-EP and RH-PVC particleboard composites, the thickness swelling (%) values decrease up to 10 kGy and 5 kGy respectively, indicating an enhancement in gamma irradiation induced-crosslinking and good adhesion of the composite components during the irradiation process. The thickness swelling (%) values of RH-EP particleboard composites are lower than those of RH-PVC particleboard composites for any given γ-irradiation dose. It is obvious that RH-EP particleboard composites require a relatively high γ-irradiation dose to create reactive species.
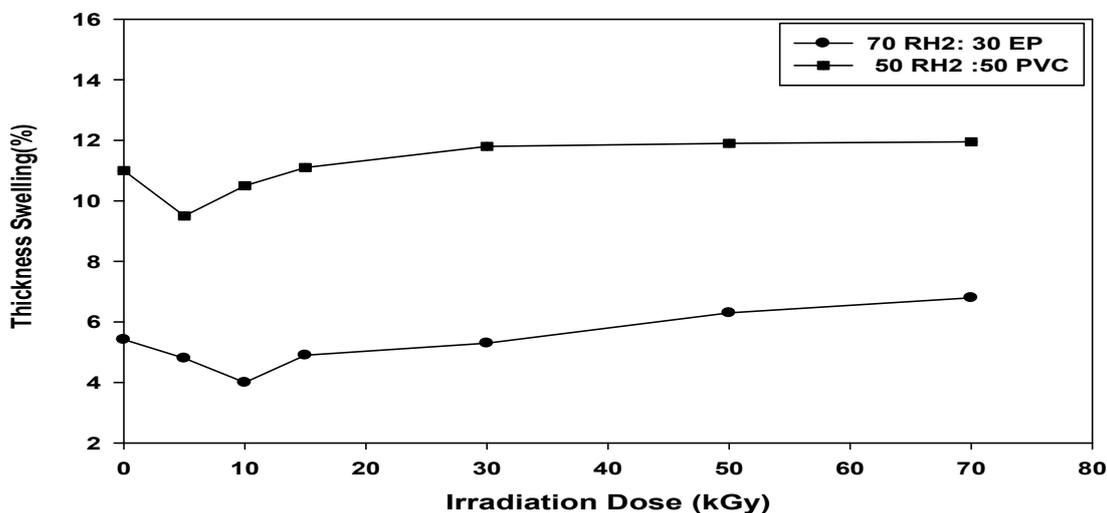
Fig. (15): Effect of irradiation dose on the thickness swelling (%) of RH-EP and RH-PVC particleboard composites.

Scanning electron microscopy (SEM)

The microstructure morphology of the fractured surface of unirradiated RH-EP particleboard composites (70% RH2: 30% EP), irradiated at 10 kGy and at 70 kGy is given in fig. (16 a, b, c respectively). Also, the microstructure morphology of the fractured surface of unirradiated RH-PVC particleboard composites (50% RH2: 50% PVC), irradiated at 5 kGy and at 70 kGy is shown in fig. (17 a, b, c respectively). The micrographs of

the unirradiated composites display a considerable fiber pull-out together with fiber-tearing also large amounts of the voids are distinguished. On the contrary, micrographs of the irradiated composites show that the fiber is coated with polymer indicating the good adhesion between the fiber and polymer due to the reaction between –OH groups of fiber and the polymer. Also, it appears that there is a reduction in the voids between the fiber and polymer which are leading to improvement in the mechanical properties of the irradiated composites [40].

It is also observed from the micrographs of RH-EP and RH-PVC particleboard composites irradiated at higher doses that there are more cavities and the sample is more porous as seen in figs. (16c, 17c), these are mainly attributed to the chain scission and cellulosic fibers and polymer degradation; these are leading to lower adhesion between the composite components. But at lower gamma irradiation doses (5 and 10 kGy), resulted in increased cross-linked density and good polymer coating and dispersion in the fibers as seen in figs. (16b, 17b), which produces higher mechanical properties up to certain dose [41].

(a)

(b)

(c)
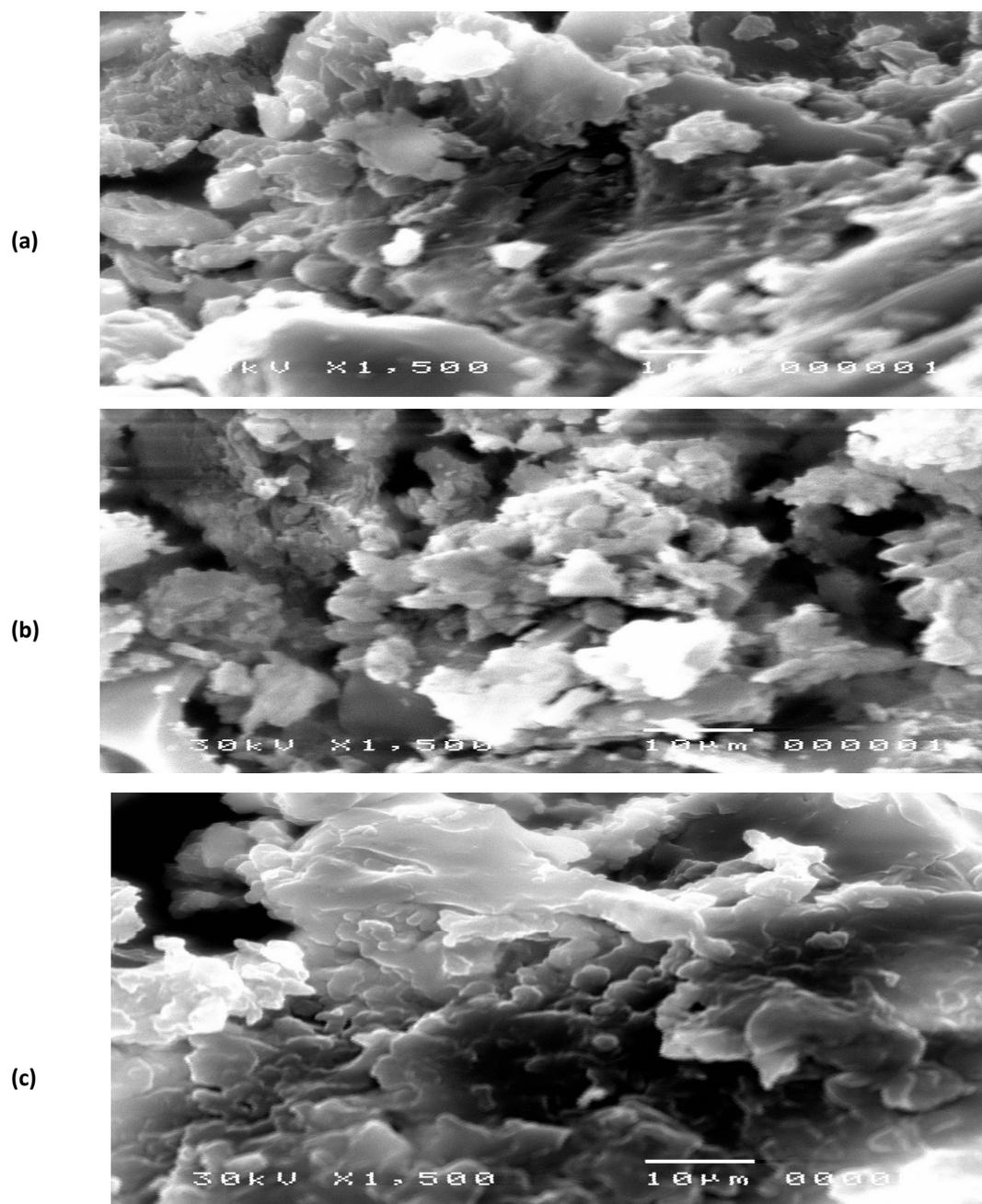
Fig. (16): SEM micrographs for (a) unirradiated RH-EP particleboard composite (b) irradiated RH-EP particleboard composite at 10 kGy (c) irradiated RH-EP particleboard composite at 70 kGy.
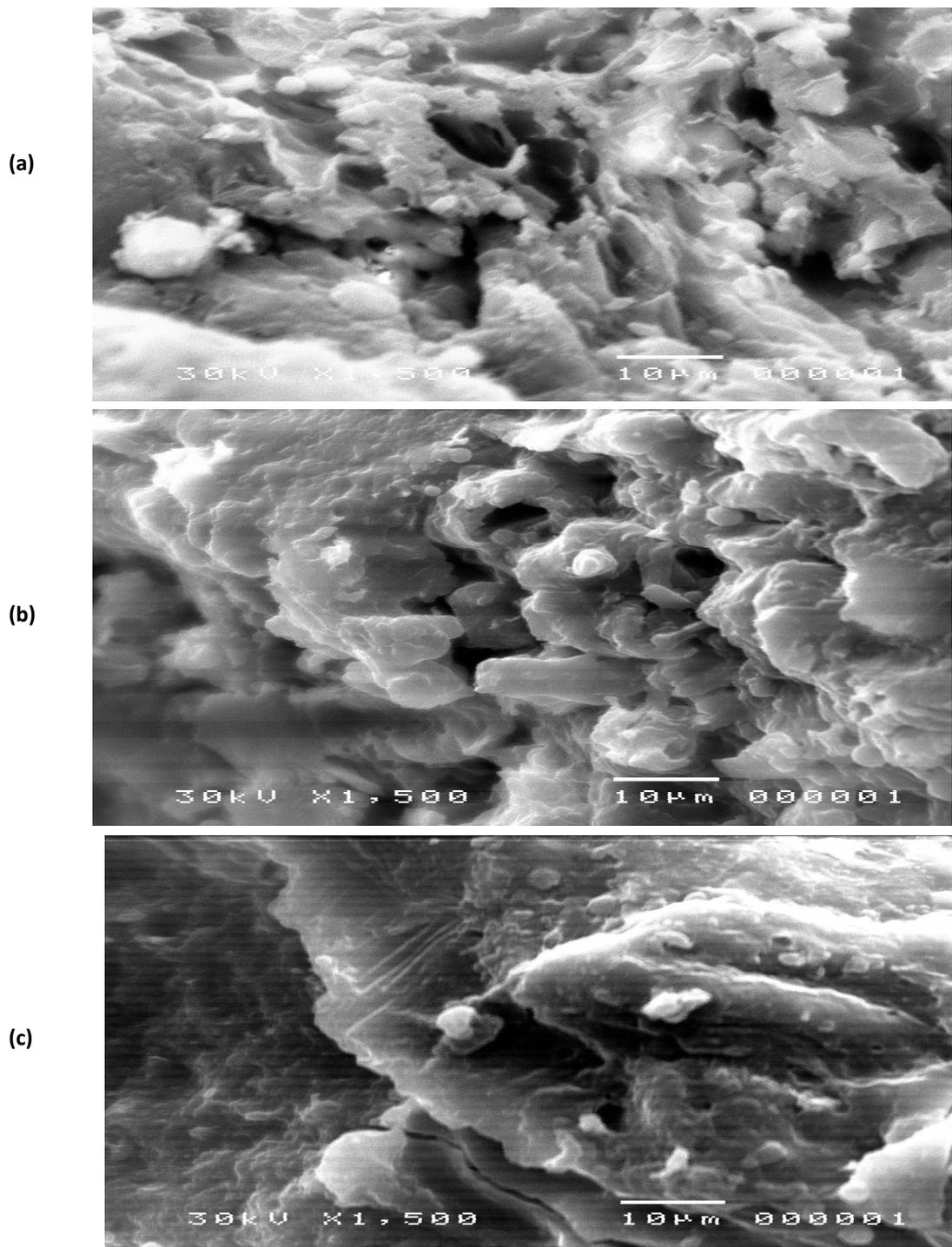
Fig. (17): SEM micrographs for (a) unirradiated RH-PVC particleboard composite (b) irradiated RH-PVC particleboard composite at 5 kGy (c) irradiated RH-PVC particleboard composite at 70 kGy.

Thermogravimetric Analysis (TGA)

TGA thermograms of unirradiated RH-EP particleboard composites (70% RH2: 30% EP), irradiated at 10 kGy and at 70 kGy are shown in fig. (18). The results indicate that the remaining weight percentages of these composites are slightly decrease in the temperature range 120-210°C. This is followed by a sharp decrease in the remaining weight within the temperature range 250-500°C and started leveling off in a plateau at 550°C.It is also observed that for a given temperature the remaining weight percentage of irradiated RH-EP particleboard composites at 10 kGy is almost higher as compared to unirradiated and irradiated at 70 kGy composites.

The rate of thermal decomposition reaction dw/dt of unirradiated RH-EP particleboard composites (70% RH2: 30% EP), irradiated at 10 kGy and at 70 kGy are plotted versus temperature in fig. (19). The results show that the maximum value of the reaction rate of thermal decomposition is shifted towards a higher temperature in the case of irradiated composites at 10 kGy, which means that these composites are more thermally stable as compared to other composites. This result is mainly attributed to the formation of the strong chemical bonds between the composite components during the γ- irradiation such as chemical bonds between hydroxyl groups presented in the RH fiber surface and the polymer.

Fig. (20) shows the TGA thermograms of unirradiated RH-PVC particleboard composites (50% RH2: 50% PVC), irradiated at 5 kGy and at 70 kGy. The results exhibit that a slight loss of weight in the temperature range 100-250°C occurs. At higher temperature than 260°C the weight loss values are suddenly dropped and then started leveling off in a plateau at 580°C. This is due to the thermal decomposition of these particleboard composites. It is also noticed that, for a given temperature the remaining weight percentage of irradiated composites at 5 kGy is the highest as compared to the other composites.

Fig. (21) displays the reaction rate of thermal decomposition as a function of temperature for unirradiated RH-PVC particleboard composites (50% RH2: 50% PVC), irradiated at 5 kGy and at 70 kGy. The results denote that, the maximum value of the reaction rate of thermal decomposition is shifted towards a higher temperature in the case of irradiated composites at 5 kGy, which means that irradiated composites at 5 kGy are more thermally stable as compared to other composites. This result is attributed to the same reasons mentioned before.
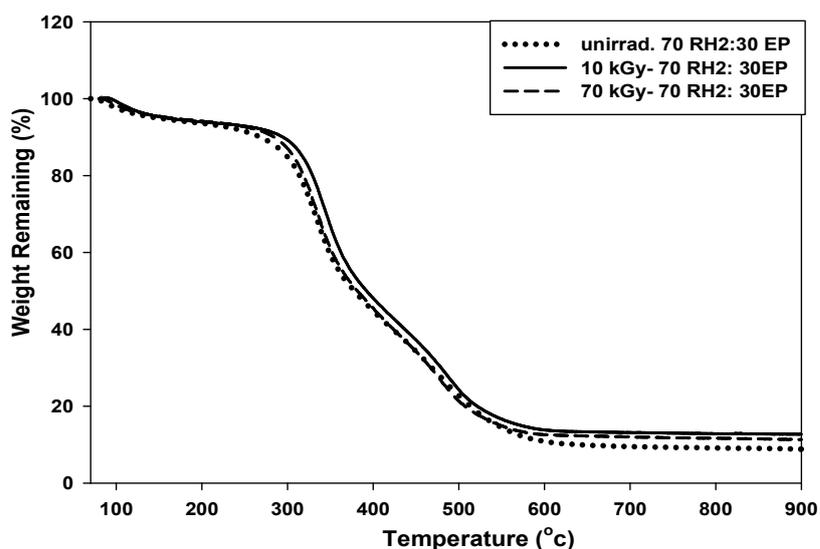
Fig. (18): TGA thermograms for unirradiated RH-EP particleboard composites, irradiated RH-EP particleboard composites at 10 kGy and irradiated RH-EP particleboard composites at 70 kGy.
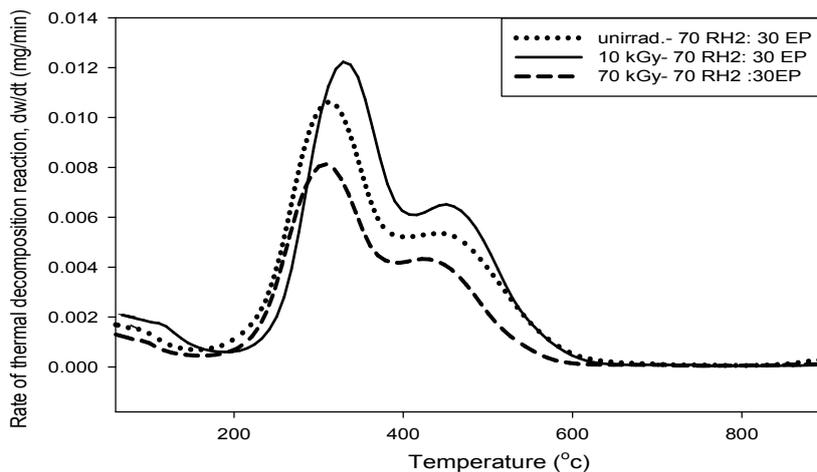
Fig. (19): DTG for unirradiated RH-EP particleboard composites, irradiated RH-EP particleboard composites at 10 kGy and irradiated RH-EP particleboard composites at 70 kGy.
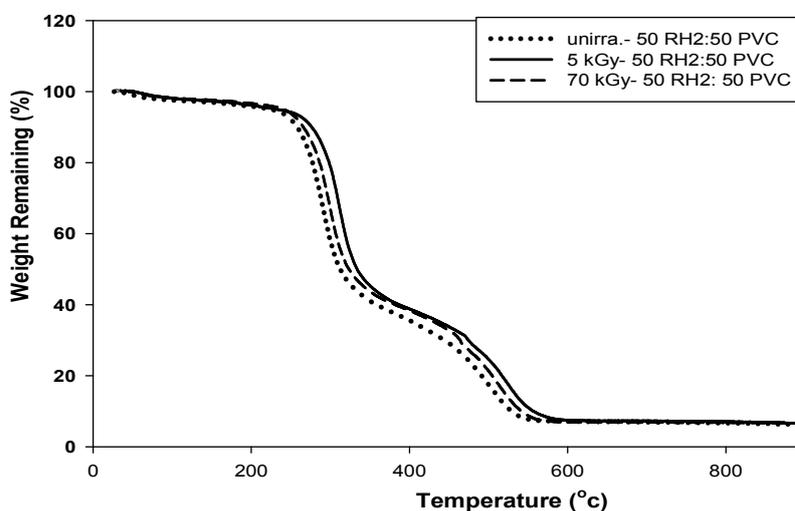
Fig. (20): TGA thermograms for unirradiated RH-PVC particleboard composites, irradiated RH- PVC particleboard composites at 5 kGy and irradiated RH- PVC particleboard composites at 70 kGy.
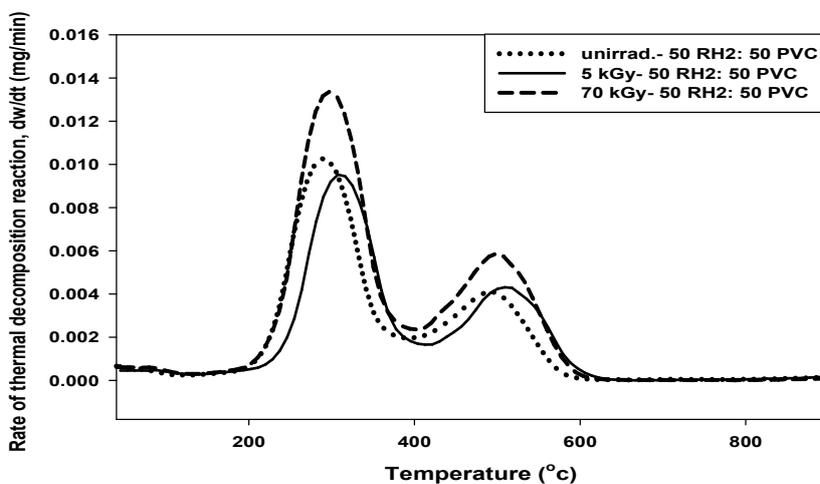
Fig. (21): DTG for unirradiated RH-PVC particleboard composites, irradiated RH-PVC particleboard composites at 5 kGy and irradiated RH-PVC particleboard composites at 70 kGy.

CONCLUSION

Generally, the results have shown that RH-EP particleboard composites exhibit better properties compared to RH-PVC particleboard composites. The results also mention that the flexural strength, impact strength and hardness values of RH-EP particleboard composites increase gradually as the RH fiber content increase from 50 to 70 wt%. and then decrease. Both water absorption (%) and thickness swelling (%) values increase with increasing the fiber content from 50 to 80 wt%.

On the other side, the flexural strength, impact strength and hardness values of RH-PVC particleboard composites gradually decrease with increasing RH fiber content. The highest flexural strength, impact strength, and hardness values are achieved for composites with fiber content 50 wt% and then decrease for 60, 70 and 80 wt% of the RH fiber content. The water absorption (%) and thickness swelling (%) values are found to increase with increasing RH fiber content from 50 to 80 wt%.

Also, the results indicated that particle size 2 of RH (ranging from 0.5mm to 0.8 mm) gives better results compared to other particle sizes used for all prepared particleboard composites.

For RH-EP particleboard composites, the irradiated composites at 10 kGy are more thermally stable compared to unirradiated and irradiated composites at 70 kGy. For RH-PVC particleboard composites, the irradiated composites at 5 kGy are also more thermally stable as compared to unirradiated and irradiated composites at 70 kGy.

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