# Utilization of Emulsion Polymer for Preparing Bagasse Fibers Polymer–Cement Composites

**M. R. Ismail, H. A. Youssef, Magdy A. M. Ali, A. H. Zahran, M. S. Afifi**

*NCRRT, Atomic Energy Authority, Egypt*

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**ABSTRACT:** Sugarcane-bagasse fiber–polymer cement composites were prepared using three lattices namely, styrene butadiene, vinyl ester, and styrene acrylic. The lattices percentages ranged between 3 and 21% from the weight of the mixture. The pressed samples were irradiated at different irradiation doses by using electron beam (EB) accelerator. Comparative studies have been made for physicomechanical properties of unirradiated and irradiated samples. The results indicated that the flexural strength, modulus of elasticity, and impact toughness of the composites increase with the increasing polymer content up to 9.9 and 15% of styrene butadiene, vinyl ester, and acrylic styrene, and then decrease. It was also observed that the maximum values of flexural strength and modulus of elasticity obtained at EB-irradiation dose 45, 40, and 25 kGy for styrene butadiene, acrylic ester, and vinyl ester, respectively. The impact strength of the composites did not significantly improve above 10 kGy. The average values of hardness of irradiated composites were higher than that those of unirradiated and control composites. © 2007 Wiley Periodicals, Inc. J Appl Polym Sci 107: 1900–1910, 2008

**Key words:** irradiation; mechanical properties; ball hardness; emulsion; antioxidants; blending; block polymers; addition polymerization; adhesion

## INTRODUCTION

An industrial electron beam (EB) processing line is started to produce cement-bonded chipboard with radiation-cured acrylic-coating. EB-cured acrylate-coating improved the fireproof character and other aspects of cement-bonded wood particle board and makes them valuable structure materials.[1] Oligomers and monomers play the most important role in the formation of cenacle EB-coatings. Experimental investigations of the effect of varying latex contents on the physicomechanical properties of latex-modified carbon fibers-reinforced cement were reported.[2–4] It was concluded that latex content increase the flexural strength and impact resistance of carbon fiber-reinforced cement composites. Furthermore, a reduction of water absorption and drying shrinkage movements were also observed, and these were attributed to enhance the bonding of cementation matrices to carbon fiber. Mantegazza et al.[5] studied the effect of addition of various synthetic polymers in the form of the latex on the polypropylene fiber-reinforced cement mortars. The workability, low permeability, dimensional stability, mechanical resistance (compressive and flexural strength), Young's modulus of elasticity, ductility, toughness, and durability properties of the composites have been tested. It was also observed that the optimal characteristics have been obtained (given a minimum percentages of fibers) with a content of 10% of silica fume by weight of cement and by using acrylic acid copolymer water dispersion at rate of 9% of the solid polymer to cement. The sawdust clay composite was prepared by radiation-processing.[6] The comonomer system of unsaturated polyester and vinyl compound was found to be the ideal impregnation monomer for the preparation of clay–plastic composites. The sawdust clay–plastic composites, having higher content of clay (more than 50 wt %), were found to have the properties of stronger mechanical strength, good resistance to strong mineral acids, and weather proof. The purpose of this work is to study the effect of latex polymer contents and EB-irradiation doses on phsicomechanical properties of sugarcane-bagasse fiber–polymer cement composites.

## EXPERIMENTAL

### Materials

#### Natural fibers

Sugar cane bagasse are produced from sugar factories and sugar cane juice shops, from waste products. To treat the fibers of cane bagasse from sugar residues, the fibers were soaked in 4% NaOH solution and washed with water, and then soaked with 10% $NaHCO_3$ solution and washed with water again. The treated fibers were dried in air, and grinded in a rotary hammer mill. After grinding, the fibers were sieved and its length ranging from 4 mm to lower than 0.3 mm and diameter

*Correspondence to:* M. S. Afifi (afify_s@yahoo.com).

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TABLE I
Chemical Composition of the Portland Cement

| | |
|---|---|
| $SiO_2$ (%) | 20.32 |
| $Al_2O_3$ (%) | 4.2 |
| $Fe_2O_3$ (%) | 5.56 |
| CaO (%) | 63.96 |
| MgO (%) | 1.13 |
| $SO_3$ (%) | 1.57 |
| Ignition loss (%) | 2.22 |
| Free CaO (%) | 1.22 |
| Insoluble residue (%) | 1.64 |

0.5 mm. These fibers were used in the preparation of cement–fiber polymer composites.

### Cement

Fresh product sample of commercial-type Ordinary Portland cement was used. The chemical composition of the cement is given in Table I. The computed potential-phase composition of the Ordinary Portland cement is tricalcium silicate ($C_3S$), 51.15%; β-dicalcium silicate (β-$C_2S$), 20.93%; tricalcium aluminate ($C_3A$), 5.3%; and tetracalcium alumino ferrate ($C_4AF$), 17.3%. This type of cement has been brought from Suez Cement Company, Wady Hagoul, Suez, Egypt.

### Polymer lattices

The three types of polymer emulsions have been supplied by Union Carbide Company, Midland, Michigan. They are as follows:

1. DL 455, styrene butadiene latex dispersion (SBR latex), the solid content, PH value, and viscosity are 48 wt %, 10.5, and 50–120 cps, respectively.
2. UCAR latex 2300 (vinyl ester latex), their solid content, PH value, and viscosity are 55 wt %, 4.0–5.0, and 50–200 cps, respectively.
3. UCAR latex S-53 (styrene-acrylic copolymer), their solid content, PH value, and viscosity are 50 wt %, 8.0–9.0, and 2500–8000 cps.

### Preparation of sugarcane-bagasse fiber–polymer cement composites

Natural fibers (sugar cane bagasse) cement–polymer composites were prepared using natural fiber 4.0–0.3 mm length, and water to cement ratios, (W/C) 0.25. The mixing procedure was carried out as follows: the fibers were put into a variable speed two-spindle mechanical mixer, and the cement was added to fiber dryly with continuous mixing for 5 min. The water was added gradually to the mixture while mixing for further 5 min. After adding water, mixing continued for another 5 min to ensure that a good homogeneous mixing has been obtained. Polymer emulsions were added to the mixture of fiber–cement composites through mixing and after complete addition of water for a period of 10 min. Their weight percent were 3, 6, 9, 12, 15, 18, and 21% to the weight of the mixture. The homogeneous mixture was poured into a mold that has dimensions of $16 \times 16 \times 0.8$ cm$^3$. The sample pressed in an electric hot press-type Carver M-154 at a temperature of 100–110°C and a pressure of 30,000 psi for 35 min. The samples were cooled and kept for mechanical and physical testing. Specimens were irradiated in air at ambient temperature for different doses 10, 20, 30, 40, 50, 60, and 70 kGy. The accelerator has energy of 1.5 MeV, 25 mA beam current, power of 37.5 kW, and scan width variable up to 90 cm. The physicomechanical properties of the composite samples were carried out according to ASTM standards procedures. The morphology of the fracture surface of bagasse fiber–cement composites was investigated by SEM. The SEM micrographs were taken with a JSM-5400 (Jeol/Japan).

## RESULTS AND DISCUSSION

### Effect of polymer latex ratios

#### Flexural strength

The influence of different ratios of SBR (styrene-butadiene latex), vinyl-esters, and styrene-acrylic polymer lattices on the flexural strength of the bagasse fiber–cement composite, which is prepared using 30 wt % of fibers, of length less than 4–0.3 mm and 0.5 mm in diameter, w/c ratio 0.25, and then pressed at 30,000 psi at 100°C (Fig. 1). The experimental results demonstrated that the flexural strength of the bagasse fiber/polymer–cement composite increases with increasing the polymer latex ratio up to maximum values and then decreases. The optimal values of the flexural strength attained at polymer latex ratio of SBR, vinyl-esters, and styrene-acrylic were 9, 9, and 15%, respectively. It was observed that the flexural strength of the polymer lattices having the order as follows:

$$\text{Vinyl-esters} > \text{SBR} > \text{styrene-acrylic}$$

These observations are essentially depended upon the adhesive forces between the composite components during the hot-pressing process. When polymer emulsion is allowed to dry through loss of water by evaporation or absorption into a substance, the suspended resin or polymer particles are crowded together. The capillary forces because of the concave menisci at the water–air interface generate forces of sufficient magnitude to overcome the repulsive forces between polymer particles, which are then through into contact, at the same time causing an increase in

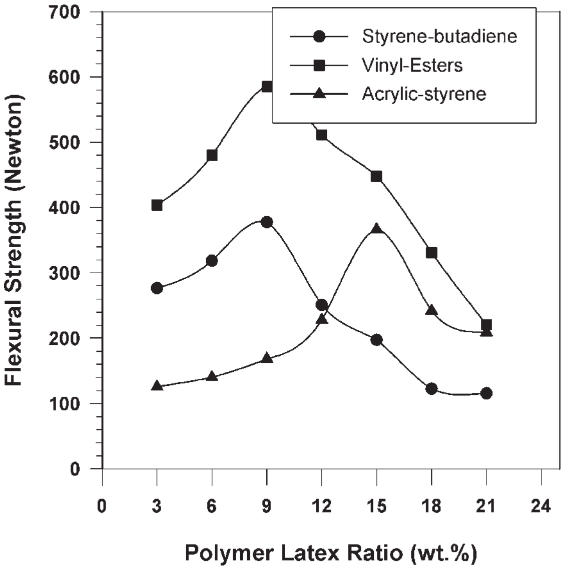


**Figure 1** Effect of polymer latex ratio on flexural strength of bagasse fiber–cement composites prepared using different kinds of latex 4–0.3 mm.

concentration of the material soluble in water-phase. Further evaporation of the retained water will exert considerable capillary pressure, leading to a closer contact between suspended polymer particles in the latex. So, the driving forces for the coalescence of the polymer particles arise from surface tension and capillary forces.[7] These forces increase with decreasing particle size resulting from either water loss or from autohesion. The quantity of emulsion also exerts an influence on the development of the final mechanical properties. The second-order transition point of a polymer is the physical transition point connected to the mobility of the polymer chains, and known as the glass transition temperature ($T_g$). At a temperature below $T_g$ of a polymer, the chains can be regarded as immobile, except for the movements around the equilibrium position. Below $T_g$, it would be very difficult for emulsion polymer particles to form a continuous film or coalesce. Above $T_g$, appreciable movements of segments in the polymer chains occur. Accordingly, the flexural strength of the bagasse fiber–plastic cement composite increases with increasing the emulsion percentage at a certain ratio as results of the diffusion of the emulsion latex into the hollows of the bagasse fiber. When the samples were hot-pressed at a temperature of 100°C, the water evaporated and the latex particles reacted with the bagasse fibers, and at the same time, the latex particles could be reacted with the cement constituents to form a three-dimensional structure. These lead to a strong adhesive of the composite components.

More addition of the emulsion latex is associated by improvements of the flexural strength of the composite up to the maximum values of the emulsion latex. Above these values, a decrease in the flexural strength will be noticed as a result of high water content in the mixture, which leads to a high porous structure of the composite after hot pressing. It was also observed that the higher values of the flexural strength of the composite obtained by using vinyl-esters emulsion in the mixture because of its high $T_g$ values when compared with the other polymer emulsions.

## Modulus of elasticity

Figure 2 illustrates the change of the modulus of elasticity of the bagasse fiber–polymer cement composite prepared with different polymer latex ratios. The results showed that the modulus of elasticity values increase with the increasing polymer latex percentages in the mix composition up to certain values, and then are sharply decreased. The optimal values of the composites prepared by using vinyl-esters and styrene-acrylic latex are very close to each other and more than the optimal value obtained by the composite containing SBR latex. These are mainly attributed to the transition temperature ($T_g$) values of the polymer latex, where the composites containing vinyl-esters and styrene-acrylic latex have a higher $T_g$ values, so, the segment of the latex in the composites are moved in the chain. This leads to the increase in the ductility of the bagasse fiber–polymer cement composites prepared using vinyl-esters and styrene-acrylic lattices compared to the composite made by the SBR latex. A more addition to the polymer latex in the mix composition, higher ductile composites are attained up to certain percentages of polymer latex. Beyond

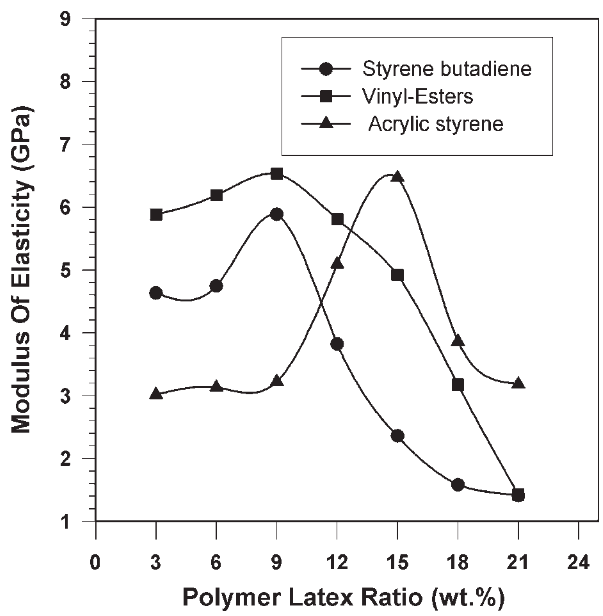


**Figure 2** Effect of latex ratio on modulus of elasticity of bagasse fiber–cement composites prepared using different kinds of polymer lateces and fiber length of 4–0.3 mm.

these percentages, the modulus of elasticity sharply decreased as a result of the increase of the water content resulting from polymer latex, which leads to a porous structure of the bagasse fiber–polymer cement composite.

### Impact toughness

The effect of polymer latex ratios on the impact strength of bagasse fiber–polymer cement composite, which made from 30% bagase fiber, w/c ratio 0.25, and different ratios of the previous polymer emulsions (and hot pressed at 100°C), is represented in Figure 3. The results demonstrate that the impact toughness increase with the increasing polymer latex percentage up to a certain value. Beyond this value, the impact strength started to decrease with the increasing polymer latex. The optimal values of impact of the bagasse fiber–polymer cement composites were 0.93, 0.87, and 0.85 J/cm$^2$ for the composite prepared using SBR, vinyl-esters, and styrene-acrylic, respectively. The improvements in the impact toughness with the increasing polymer latex are essentially because of a great distribution of the emulsion latex through the mix composition, which is accompanied by good adhesive composite after hot pressed at 100°C. Higher optimum value of the impact strength for the composite prepared by using SBR latex is probably attributed to the higher rubbery characteristics of the SBR latex when compared with the other emulsion latex. The decreasing of the impact toughness at higher polymer latex ratio is mainly because of the excess of water content in the mix composition resulting from the emulsion. This is associated with a porous structure of the final products, and this leads to a reduction of the impact toughness.

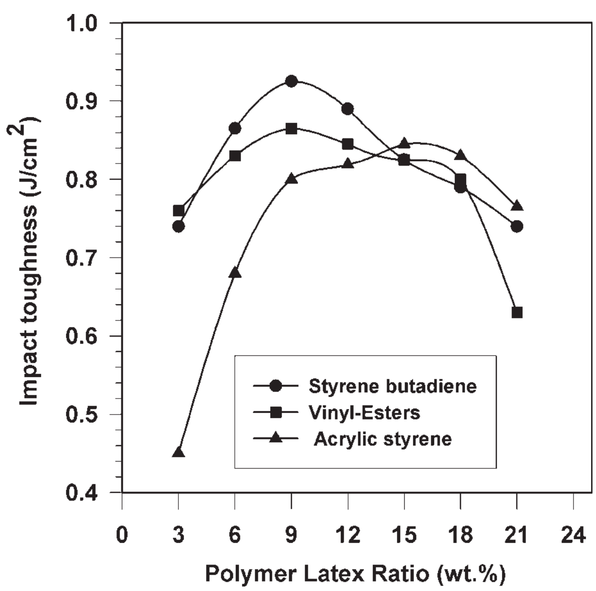


**Figure 3** Effect of latex ratio on the impact strength of bagasse fibers–cement composites prepared using different kinds polymer lateces and fiber length of 4–0.3 mm.

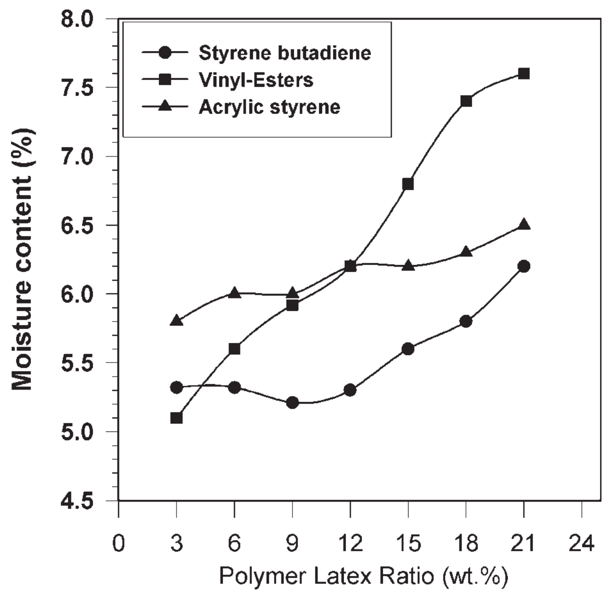


**Figure 4** Effect of polymer latex ratio on moisture content of bagasse fiber–cement composites prepared using different kinds of polymer lateces and fiber length of 4–0.3 mm.

### Moisture content

The influence of the polymer latex ratios on the moisture content of the bagasse fiber–polymer cement composite prepared under the same above-mentioned conditions is shown in Figure 4. The experimental results indicate that the moisture contents of the composites are continuously increased with the increasing polymer latex percentages for all the specimens. It was found that the bagasse fiber–polymer cement composite prepared by using SBR latex showed lower moisture content. It was also evident that the increase of the percentage of polymer latex in the mix composition increases the water content in the mix composition as the polymer latex consists of 45–50% water from its weight. This leads to a higher moisture content of the final products of composite after pressed at 100°C. The higher moisture content of vinyl ester and acrylic styrene than SBR is attributed to the presence of ester and acrylic polar groups which can combine with moisture via hydrogen bonding.

## Effect of electron beam irradiation

### Flexural strength

The effect of different electron beam (EB) irradiation dose on the flexural strength of bagasse-polymer cement composite prepared under the above-mentioned con-

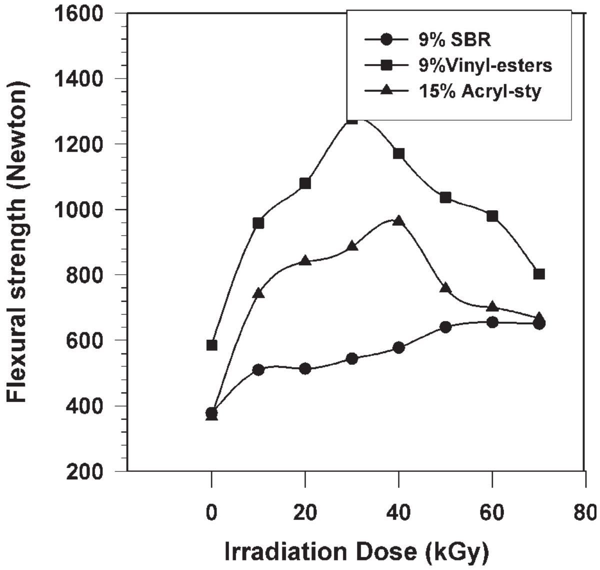


**Figure 5** Effect of electron beem irradiation dose on flexural strength of bagasse fiber–cement composites prepared using different kinds of polymer lateces and fiber length of 4–0.3 mm.

ditions is graphically shown in Figure 5. The results indicated that the flexural strength values of bagasse-polymer cement composite increase with increasing the irradiation dose up to a certain dose and then decrease for the composite prepared by using vinyl-esters and styrene-acrylic lattices. However, the flexural strength of bagasse-SBR cement composites is continuously enhanced with the beam accelerator irradiation dose. It was also observed that the improvement of the flexural strength values of the three composites, which prepared using the three different polymer emulsions, having the order of vinyl-esters > styrene-acrylic > SBR. When the polymers are exposed to high-energy, radiation will undergo changes in their physical and chemical properties and polymers may undergo chain-scission, cross linking, and recombination of broken chains.[8] The EB irradiation of saturated polymers makes it capable of dislocating or abstracting hydrogen atoms from the polymer chain.[9] The sites from which hydrogen has been abstracted can instantly join together with other sites on adjacent molecular chains to form permanent bonds. Accordingly, when the bagasse-polymer cement composites are exposed to a radiation dose (using EB accelerator after pressing at 100°C), the hydrogen atoms present in the polymer lattices and that present between cement particles (cement-hydrated product) in the hollow fibers can be dislocated or abstracted. These sites, which lose the hydrogen atoms, are easily joined together forming a strong bond between the composite components, and these processes lead to higher adhesive composites. A further irradiation dose, a more of these processes take place, and consequently, the flexural strength of both bagasse-vinyl-esters cement and bagasse-styrene-acrylic cement composites decrease, and these are mainly attributed to the chain scission and cellulosic fibers degradation, and these lead to a lower adhesion between the composite components. Consequently, the flexural strength of the composites will be reduced. It was also observed that the flexural strength of bagasse-SBR cement composite is continuously increased with the exposure dose and at the same time has lower values when compared with the other composites. These are essentially because of the presence of the styrene molecules in the SBR latex. Similar conclusions have been obtained by Kuzminskii et al.[10] and Witt.[11] They found that the minimum dose required to producing gel increases with the increasing styrene content in SBR. The introduction of styrene into the butadiene chain leads to a reduction in the yield of cross linking.

### Modulus of elasticity

The influence of EB-irradiation dose on the bagasse-polymer composite is shown in Figure 6. The results indicated that the modulus of elasticity increased with the increasing irradiation dose up to 30 kGy for the bagasse-vinyl-esters and bagasse-styrene-acrylic cement composites and 50 kGy for the bagasse-SBR cement composite and then decreased. It was also found that the optimal values of modulus of elasticity were 21, 9.6, and 9 GPa for the composites prepared using vinyl-esters, styrene-acrylic, and SBR, respectively. The enhancement of the modulus of elasticity of the different composites with irradiation dose is mainly because of the formation of chemical bonds

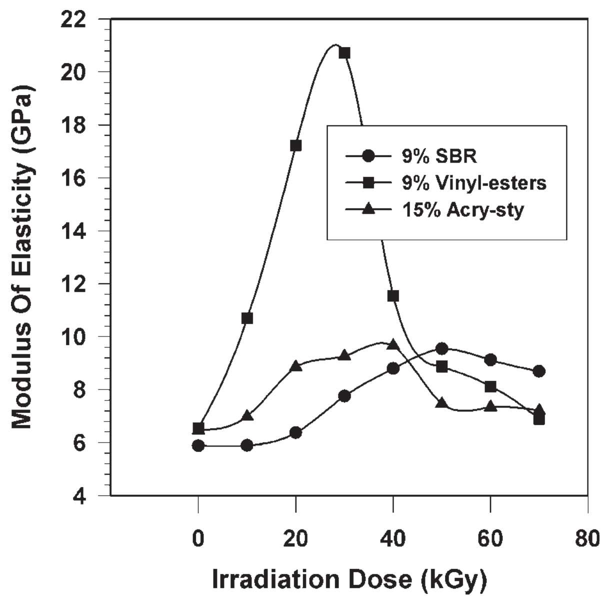


**Figure 6** Effect of electron beem irradiation dose on modulus of elasticity of bagasse fiber–cement composites prepared using different kinds of polymer lateces and fiber length of 4–0.3 mm.

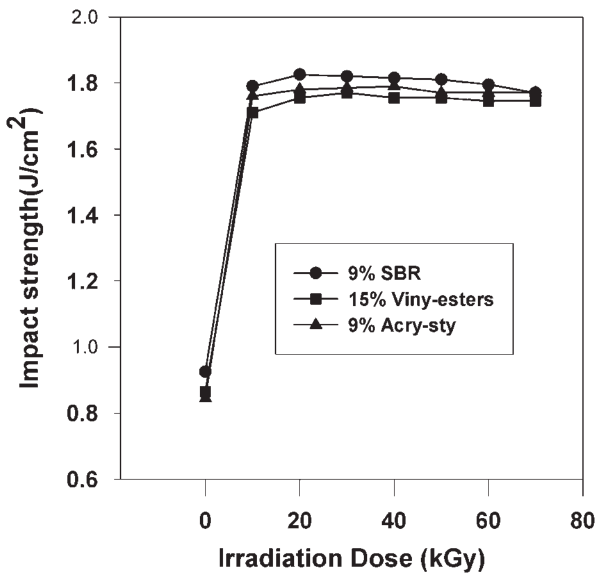


**Figure 7** Effect of electron beem irradiation dose on impact strength of bagase fiber–cement composites prepared using different kinds of polymer lateces and fiber length of 4–0.3 mm.

between the ionic polymer and both cellulosic fibers and hydrated cement products. During the mixing of the composite components, polymer lattices diffuse into the hollow fibers with cement-hydrated particles. When the composite is subjected to EB irradiation, the chemical bonds between these components are formed. As a result, the interaction of hydroxyl group of both cellulosic fibers and hydrated cement with an ionic polymer leads to the improvement of adhesion between the composite components. These processes are accompanied by a development of the modulus of elasticity, a further irradiation dose a more of interaction between the composite components and consequently, the modulus of elasticity improved. At higher EB-irradiation dose, the scission and degradation of the polymer and fibers take place, and these associate with a reduction of the modulus of elasticity. The high modulus of elasticity of vinyl-ester is attributed during irradiation, the double bonds of vinyl ester generates free radicals capable to form crosslinks.

## Impact strength

The smaller changes of the impact toughness between the different composites as result, the effect of EB-irradiation dose, are graphically presented in Figure 7. The results demonstrated that the impact toughness values of the three bagasse-polymer cement composites are sharply increased with increasing the irradiation dose up to 20 kGy and then no significant change in the impact toughness of these composites occur with the increasing irradiation dose. It was also observed that there is a small difference between the impact strength values of the three composites are smaller. The improvement in the impact strength of the three bagasse-polymer cement composites is mainly attributed to the formation of the strong chemical bonds between the composite components during the EB irradiation, such as chemical bonds between the hydroxyl groups presented in the bagasse fiber surface or hydrated cement and the ionic polymer species. The highest average values of the impact toughness of these composites are achieved at 20 kGy of EB-irradiation dose. Beyond this irradiation dose, no further enhancement of the impact toughness of the three composites has been achieved. These are most probably due to the chemical bonds formed between the composite components. There are small differences in the impact toughness values between the three bagasse-polymer cement composites, as they are prepared under the same conditions and at constant ratios of cement, except SBR latex, because of its rubber-like state, which needs more energy to break. Since the influence of EB irradiation on this property of the three composites is almost very close to each other.

## Moisture content

The moisture contents of the bagasse-polymer cement composite as a function of EB-irradiation dose are represented in Figure 8. The experimental results show that the moisture content of the three bagasse-polymer cement composites are found to decrease sharply with the increasing irradiation dose up to 10 kGy and then

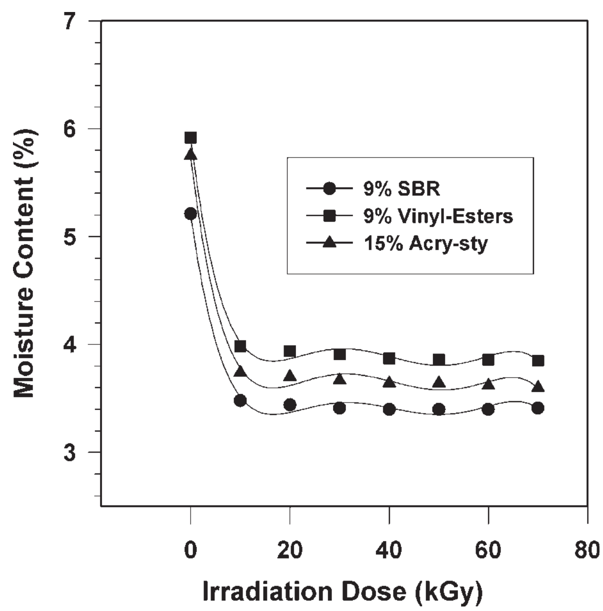


**Figure 8** Effect of electron beem irradiation dose on moisture content of bagasse fiber–cement composites prepared using different kinds of polymer lateces and fiber length of 4–0.3 mm.

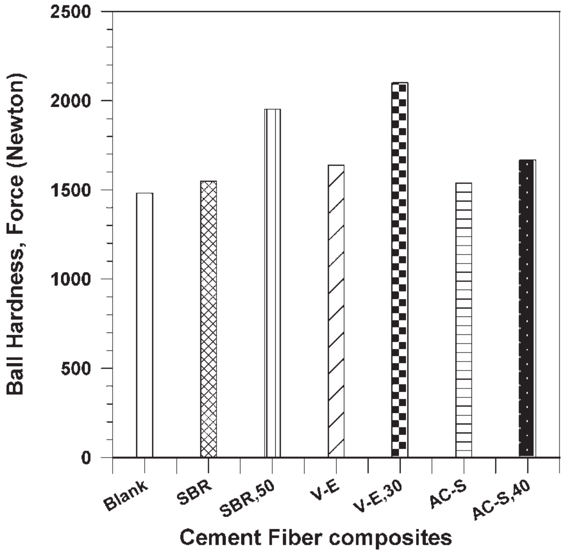


**Figure 9** Ball hardness force of bagasse fiber–cement composites prepared without adding latex (blank), and those prepared using polymer lateces with and witout electron beem irradiation.

leveling off plateau with higher absorbed dose. At higher absorbed dose more than 10 kGy, the moisture content values of the bagasse-SBR cement composite are observed to be more than that of both other composites. The reduction of the moisture content values is essentially related to the formation of chemically hydrogen bonds between the composite constituents, and the evaporation of some water molecules from the composites during the irradiation process. After irradiation dose of 10 kGy, no significant decrease in moisture content values for the three composites was observed, as result of the same reasons mentioned earlier. The lower moisture content values of the bagasse-styrene-acrylic cement composites when compared with the other composites are may be because of the higher initial latex percentage of the styrene-acrylic percentage in the mix composition. This is associated with the decreasing of water contents in the composite after pressing at 100°C.

## Ball hardness

Comparative studies of ball hardness, for different bagasse-polymer composite, are shown in Figure 9. This comparison results showed that EB irradiation can effectively enhance the ball hardness of different composites. It was also observed that the average ball hardness of bagasse fiber-SBR cement composite irradiated at 50 kGy using EB was more than the average values of ball hardness for the unirradiated composite and control composite (without SBR latex). These are mainly attributed to the formation of chemical bonds between the composite constituents during the irradiation process. The average ball hardness values of bagasse-vinyl-esters composite irradiated at 30 kGy were higher than its values of both the unirradiated and control composite specimens. Comparing the irradiated bagasse-styrene-acrylic cement composite with the unirradiated and controls (without styrene-acrylic latex), specimen results indicated that the irradiated bagasse-styrene-acrylic cement composite might be better in ball hardness than that of the unirradiated and control specimens. These are also because of the chemical interaction (during irradiation) between the composite components. These are associated with a strong adhesion between these components inside the composite structure when compared with the unirradiated and control specimens. Finally, the optimal ball hardness of these composites was the irradiated bagasse-vinyl-esters cement composite.

## Abrasion resistance

The experimental results of the abrasion test based on the weight loss (milligram per revolution) of different bagasse fiber–polymer cement composites are shown in Figure 10. The comparison results between three different composites and blank specimens indicated that the average abrasion values (weight loss) of the three bagasse-polymer cement composites are lower than that of the abrasion resistance values of blank specimens. These are mainly because of the transfer of the polymer latex and cement particles into the hollow and pores of the fibers, and then strongly adhesive together during hot pressing at 100°C. It was also observed that the abrasion resistance values (milligram

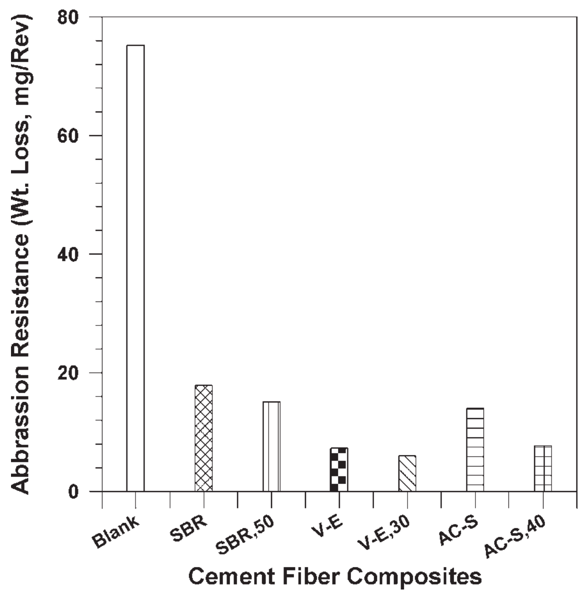


**Figure 10** Abbrasion resistance of bagasse fiber–cement composites prepared without adding latex (blank), and those prepared using polymer lateces with and without electron beem irradiation.

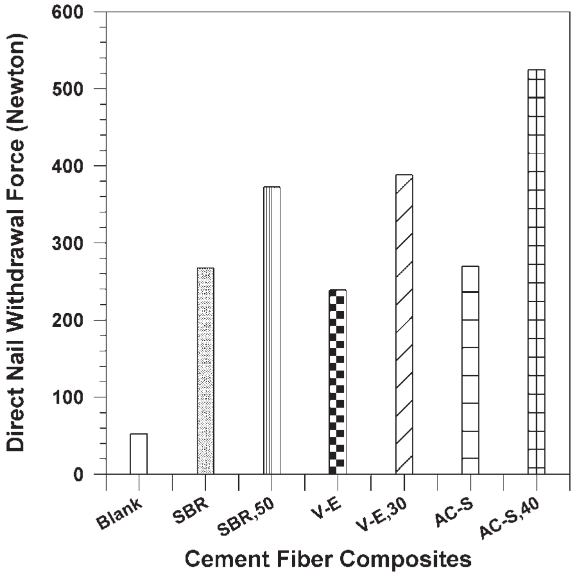


**Figure 11** Direct-nail withdrawal of bagasse fiber–cement composites prepared without adding latex (blank), and those using polymer lateces with and wihtout electron beem irradiation.

per revolution) of the irradiated bagasse-polymer cement composites were lower than that of both unirradiated bagasse-polymer cement composite and control specimens. These are also attributed to the formation of network structure composites after the composite was subjected to EB irradiation. The irradiated bagasse-vinyl-esters cement fiber had the lowest abrasion weight loss per revolution (in other words, the best abrasion resistance) when compared with the other composite specimens. This is probably associated with high reactivity of the vinyl-esters emulsion during irradiation process.

## Direct-nail withdrawal force

The average force that has been required to withdraw the nail from the different composite specimens are graphically represented in Figure 11. The results illustrated that the average force values, which have been required to withdraw the nail from the blank specimens, were very low when compared with that required for the unirradiated or the irradiated bagasse-polymer cement composite specimens. These can be largely attributed to the higher force values, which required to drive the nail through the unirradiated or irradiated bagasse-polymer cement composites when compared with the blank specimens. After driving the nail in the specimens, the bagasse fibers and polymer twisted around the nail, and this leads to a higher force required to withdraw these nails from the composites. It was also observed that the average force values required to withdraw the nail from the irradiated bagasse-polymer cement composite were higher than that required for withdrawing the nails from the unirradiated specimens. These are related to the formation of the network structure between the composite components (polymer, fibers, and cement) during the irradiation process, and these lead to a strong twist of the fibers and polymer around the nail in the irradiated composite. The average force values required to remove the nail from the bagasse-styrene-acrylic cement composite irradiated at 40 kGy were higher than that of the forces needed to remove the nails from all other composites. These may be related to their hardness, and is associated with the strong catch of the nails.

## Screw-nail withdrawal

The average values of the withdrawal forces required for removing the screw-nails from different bagasse-polymer cement composites are shown in Figure 12. It was observed that the average values of the withdrawal force required for removing the screw-nails from the bagasse-polymer cement composite were higher that that required to withdraw the screw-nails from the control specimens. The reason of this behavior may be attributed to the presence of polymer latex in mix composition, which makes a strong adhesion composite after hot pressing at 100°C. The screw-nails, driven in the irradiated bagasse-polymer cement composite, required a higher withdrawal force to drive or pull out from the composite when compared with the withdrawal force required to drive out the screw-nails from the unirradiated composite and control specimens. It was also observed that the bagasse styrene-acrylic cement composite irradiated at 40 kGy of EB-irradiation dose has been acquired the highest withdrawal force to

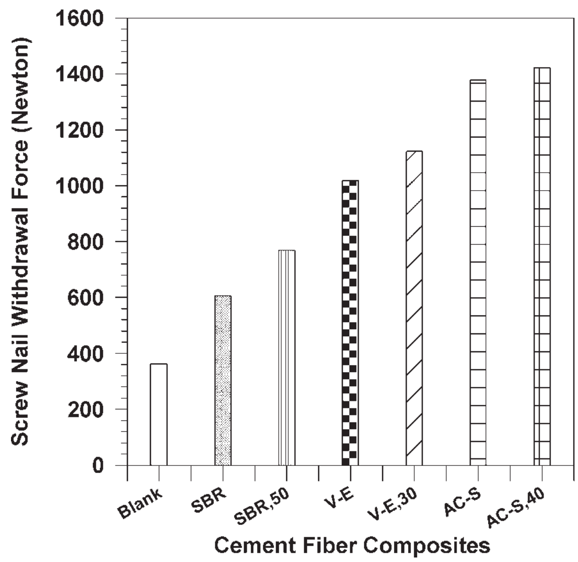


**Figure 12** Screw-nail withdrawal of bagasse fiber–cement composites prepared without adding latex (blank), and those prepared using polymer lateces with and without electron beem irradiation.

drive out the screw-nails when compared with the other unirradiated or irradiated bagasse-polymer cement composite specimens. These are due to the reasons mentioned earlier.

## Static and dynamic friction coefficients

A comparative study of the static coefficient of friction of different bagasse-polymer cement composites is shown in Figure 13. The results showed that the bagasse-vinyl-esters cement composite irradiated at 30 kGy, EB-irradiation dose, has the lower average value of static coefficient of friction than that of the other bagasse-polymer cement composite and control specimens. The average values of static coefficient of friction of irradiated bagasse-polymer composites were lower when compared with the average values of static coefficient of friction of the unirradiated bagasse-polymer cement composites and control specimens. This can largely be attributed to the strong adhesion between the composite components under effect of the irradiation process. The average values of dynamic coefficient of friction different bagasse fiber–polymer cement composites when compared with the average values of dynamic coefficient of friction of the control specimens are shown in Figure 14. The comparative studies gave some interesting results. The average values of dynamic coefficient of friction of the bagasse-polymer cement composite were lower than that of the control specimens.

The average values of dynamic coefficient of friction of the irradiated bagasse-polymer composites were low when compared with the friction of the unirradiated specimens. Also, the lowest average values of the dynamic coefficient of friction were attributed to the bagasse-vinyl-esters cement composite irradiated at 30 kGy of EB-irradiation dose. These observations confirmed the physicochemical and mechanical properties mentioned earlier.

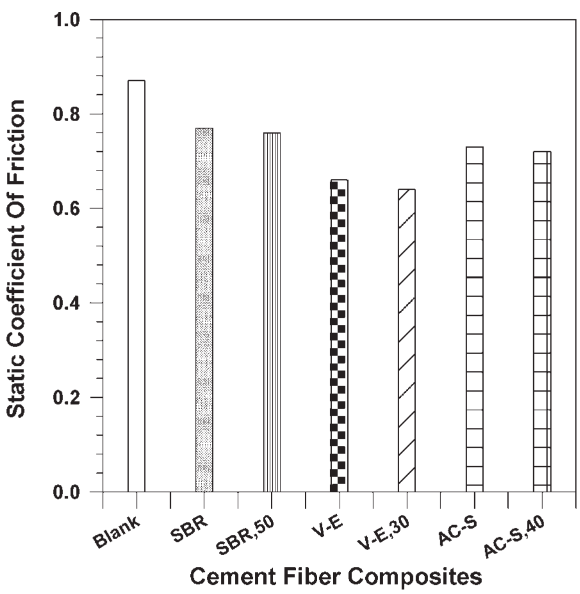


**Figure 13** Static coefficients of friction of bagasse fiber–cement compsoites prepared without adding latex compared to those prepared using lateces with and without electron beem irradiation.

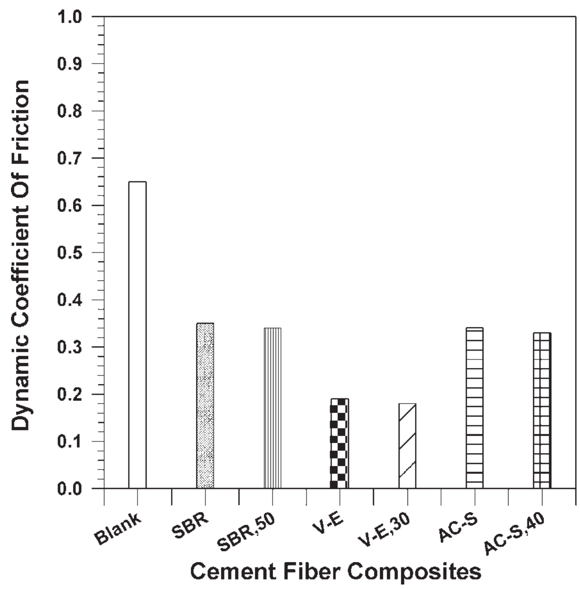


**Figure 14** Dynamic coefficients of friction of bagasse fiber–cement composites prepared without adding latex compared to those prepared using lateces with and wihtout electron beem irradiation.

## Scanning electron microscopy

The micrograph obtained for the bagasse fiber vinyl-esters-cement composite [Figs. 15(a,b)] (30% bagasse fibers and 9% vinyl-esters polymer emulsion) showed agglomerated vinyl-esters emulsion latex precipitated in the hollows and on the surface of the bagasse fibers. The large quantities of CSH gel formed from the hydration fill the interfaces thin layer between the fiber and the matrix. When the fiber and the matrix combine, organic composition and hydration products in the matrix diffuse each other. These cause a solid and dense the materials formed in this layer, and this leads to improve the mechanical properties when compared with the fiber–cement composite [Fig. 15(b)]. Some pores and micrographic characteristics of the bagasse fiber vinyl-esters composites have the same above-mentioned mix composition and irradiated at 30 kGy using EB.

It was clearly observed that the formation of polymer clusters deposited in the interface layer between the fibers and cement matrix, and the hydrated products of cement also appear in this layer. The presence of these materials together leads to a formation of a network structure as a result of the reaction between the hydrated products and the polymeric materials

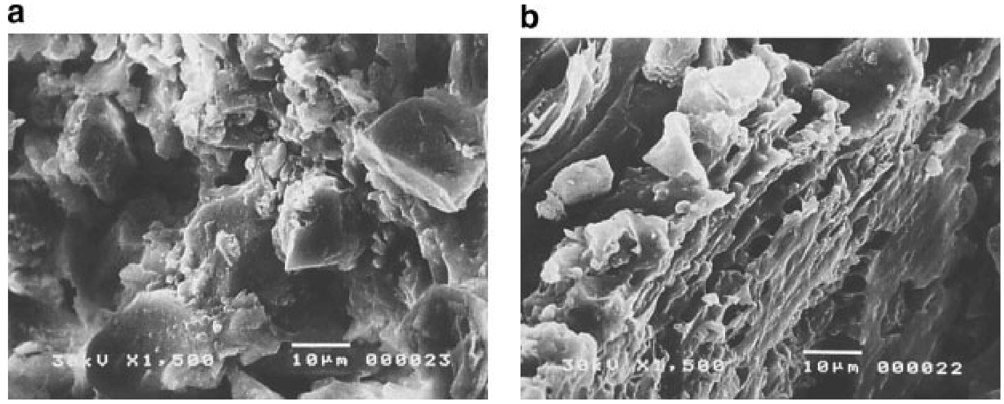


**Figure 15** Scanning Electron Microscope pictures (×1500) of (a) fracture surface of cement fiber composites containing 30% bagasse fibers and 9% vinyl-esters polymer emulsion. (b) Fracture surface of cement fiber composites containing 30% bagasse fibers and 9% vinyl-esters polymer emulsion, after treatment at 30 kGy electron beam irradiation.

during the irradiation process. This is accompanied by a development in the mechanical properties of these composites more than that of the unirradiated bagasse-polymer/cement composite specimens.

The microstructural features [Fig. 16(a)] of bagasse styrene-acrylic cement composite displayed the polymeric clusters of styrene-acrylic coplyomer in the pores and a flattened bagasse fiber also appears. When the fibers and matrix (cement) are combined, styrene-acrylic emulsion on the interface and the hydration products of the matrix diffuse reciprocally, and the density of this area is relatively high. These lead to enhance the strength of the bagasse styrene-acrylic cement composite when compared with the strength of bagasse cement composite.

The scanning electron micrograph of bagasse styrene-acrylic cement composite, which irradiated at 40 kGy using EB are shown in Figure 16(b). It seems that the bagasse fibers and hydrated products of cement are diffused together and deposited the interface layer between the bagasse and the matrix. A small hole and microcrack also appear. During the irradiation process, the interaction between hydrated products and styrene-acrylic latex takes place to form a sort of chemical bonds between the composite constituents. Thus, it shows an improved mechanical strength than the unirradiated composites.

Figure 17(a) also shows the SEM examination of the bagasse SBR cement composite. The SEM image shows that the agglomerated SBR latex was precipitated in the interface layer between the fiber and the matrix and also on the surface of flattened bagasse fiber. The CSH gel and CH formed during the hydration reaction display in the interface layer between the bagasse fiber and cement matrix, and the voids between the particles are wide and predominated. These cause lower mechanical properties of the bagasse SBR cement composites when compared with the bagasse polymer cement composites prepared using vinyl-esters and styrene-acrylic emulsions.

The morphology characteristics of the bagasse SBR cement composite irradiated at 50 kGy using EB is shown in Figure 17(b). It was noted that a large quantity of agglomerated SBR latex was deposited on bagasse fiber surface and in the interface layer between the bagasse fibers and cement matrix, and cover the hy-

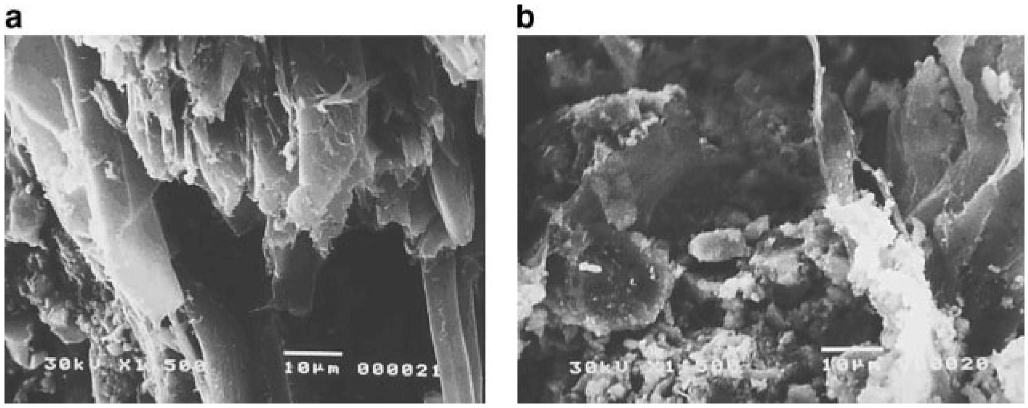


**Figure 16** Scanning electron microscopic picture (×1500) of (a) fracture surface of cement fiber composites containing 30% bagasse fibers and 15% acrylic-styrene polymer emulsion. (b) Fracture surface of cement fiber composites containing 30% bagasse fibers and 15% acrylic-styrene polymer emulsion, after treatment at 40 kGy electron beam irradiation.

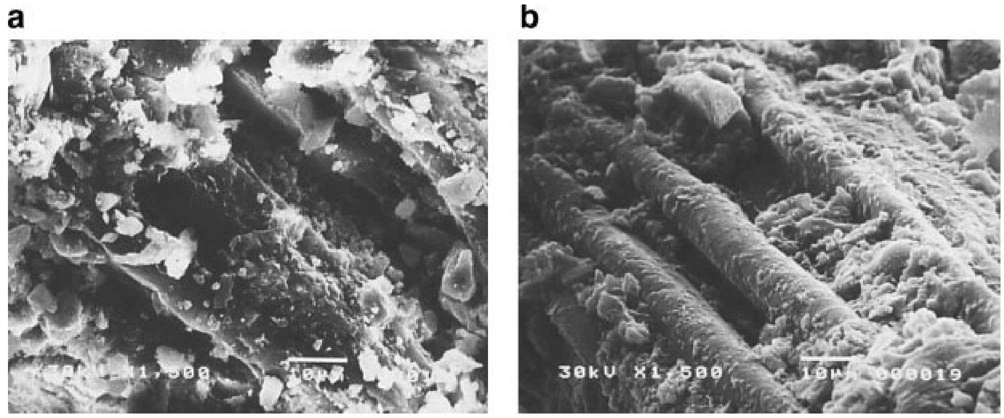

**Figure 17** Scanning electron microscope picture (×1500) of (a) fracture surface of cement fiber composites containing 30% bagasse fibers and 9% SBR polymer emulsion and (b) fracture surface of cement fiber composites containing 30% bagasse fibers and 9% SBR polymer emulsion, after treatment at 50 kGy electron beam irradiation.

drated products. The voids between the composite components are diminished, and this leads to the increase of solid materials in the interface layer, and consequently, the mechanical properties are also improved than the unirradiated bagasse SBR cement composite specimens. These observations are in good agreement with the physicomechanical properties such as flexural and impact strength.

## CONCLUSIONS

The flexural strength and modulus of rupture values of bagasse fibers–cement polymer latex increase with increasing the latex polymer content up to 9, 9, 15% of styrene butadiene (SBR), vinyl-esters, and acrylic-styrene lattices, respectively.

The results indicated that MOE and impact toughness values of the fiber–polymer cement composites increase with increasing polymer lattices ratio up to the previous values and then decrease. It is also noticed that SBR latex composites have the highest impact toughness values.

It was noticed that moisture content of the composites increase with increasing polymer lattices ratio. Also, SBR latex composites have the lowest moisture content.

The results showed that the flexural strength values of bagasse fibers–polymer cement composites increase with increasing EB irradiation dose up to 25, 40, and 45 kGy for vinyl-esters, acrylic-styrene, and styrene-butadiene lattices, respectively. The improvement in these properties of the three composites has the order vinyl-esters > acrylic-styrene > SBR.

The results showed that EB irradiation can effectively enhance the ball hardness of different composites. It was also observed that the average ball hardness of bagasse fiber-SBR, acrylic-styrene, and vinyl-esters cement composites irradiated at 45, 40, and 25 kGy was higher than the average values of ball hardness for the unirradiated composites and control composites.

The average abrasion values (weight loss) of the irradiated and unirradiated bagasse fiber–polymer cement composites are very low than that of the abrasion values of the control values.

It is observed that there is an improvement in nail force of the composites due to addition of polymer lattices. This improvement increases on using EB irradiation of the composites.

It is noticed that there is a decrease in the coefficient of friction of the fiber composites due to the addition of polymers. Also, there is a slight difference in the coefficient of friction between the irradiated and unirradiated fiber–polymer cement composites.

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