RADIATION VULCANIZATION OF NATURAL RUBBER LATEX (NRL) USING LOW ENERGY ELECTRON BEAM ACCELERATOR

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Abstract

The electron beam induced vulcanization of natural rubber latex has been studied using low energy Electron Beam (EB) accelerators of 300, 250 and 175 keV. The latex was irradiated in a special type stainless steel reaction reactor with a stirrer at the bottom of the reactor. From the results it was found that 300 and 250 keV accelerators could effectively vulcanize NRL. But accelerator of 175 keV is too low energy to vulcanize the latex. At the same time a drum type irradiator where thin layer of NRL was irradiated by accelerator, was used for vulcanization of NRL. This type of irradiator also showed good physical properties of vulcanized latex. The effects of beam current and stirrer speed on vulcanization were studied

INTRODUCTION

Radiation has been used as a tool to vulcanize NRL for many years. So far Cobalt-60 isotope has been successfully utilized for vulcanization of NRL[1-4]. But in a number of recently works it was tried to vulcanize NRL using low energy electron beam accelerators[5-8]. The use of electron beam (EB) radiation is more economical compared to gamma rays, because vulcanization time is shorter than γ-rays and there is no need to use any radiation sensitizer. The only disadvantage of electron beam for vulcanization is their very low penetration capacity.

In the present work NRL has been vulcanized by low energy accelerators of different powers and various beam currents. Stirrer speed was changed to see the effect of stirring on vulcanization. The effect of type of reaction vessels on properties of irradiated latex was also studied.
After irradiation physical properties such as tensile strength, elongation at break and swelling ratio of irradiated films has been measured to establish the optimum conditions of vulcanization of NRL by low energy EB.

EXPERIMENTAL

Materials

The latex used in this work was high ammonia centrifuged natural rubber latex concentrate (60%) of Malaysia. To prevent formation of foams during irradiation 0.25 phr BYK-022 manufactured by BYK-Chemie, Japan was used. The main component of BYK-022 is a mixture of silicone resin and polyglycol, density 0.99g/cm^3 at 20° C. During experiment it is used as received. Antioxidants tris(nonylated phenyl) phosphite (TNPP) and (NS-5) were supplied by Ouchi Shinko Chemical Co., Ltd., Japan and used as received.

Electron beam accelerator

For irradiation of latex self-shielded electron beam accelerator of 300 kV manufactured by Nissan High Voltage company was used. Self shielded electron beam accelerators of 175 and 250 kV were manufactured by Iwasaki electric company Ltd. Japan.

The reaction vessels

The stainless steel reactor, diameter of 205 mm and height of 180 mm and a stirrer at the bottom has a holding capacity of 1450 ml latex. A water jacket was used to take off the heat produced during EB exposure to latex. The dimension of the reactor was shown in Figure 1.

The drum type reactor can continuously irradiate latex in a thin layer of 90 μm. The drum moved with a speed of 7 r.p.m. It has a diameter of 165.2 mm and length of 200 mm. The distance between beam window and surface of latex is 55 mm.

Radiation vulcanization of natural rubber latex

For vulcanization by EB natural rubber concentrate(60%) was diluted with 1% aqueous ammonia solution to 50% total solid content (TSC) and prior irradiation defoamer BYK-022 was added to latex.

Irradiated natural rubber latex was cast on leveled glass molds and dried at room temperature until they became transparent. Then the films were immersed in 1% ammonia solution for 24 hours to leach out water soluble components from the films. After drying of the films at room temperature, they finally dried in a oven at 80° C for one hour.

Measurement of physical properties

The tensile properties of the prepared latex films were measured using Strograph RI tension meter (Toyoseki Co. Ltd., Japan). For determination of weight Swelling ratio 20 mm diameter circular sample pieces of rubber films (W1) were weighed and then they were dipped in toluene for 24 hours. The weight of the swollen samples (W_2) was determined by blotting the excess solvent. Weight swelling ratio was calculated as follows:

$$S_{w,\%} = W_2/W_1 * 100$$

RESULTS AND DISCUSSION

Effect of accelerator power and type of irradiation vessel on properties of irradiated latex

The properties of irradiated latex with reaction vessel of 1450 ml capacity are shown in Figure 2 & 3. From Figure 2 it can be seen that with the increase of reaction time tensile strength increases, reaching to maximum value and for beam current 40 mA the tensile strength is maximum. Figure 4 shows that for EB accelerator of 175 keV energy there is only small change of tensile strength with irradiation time. In this case the electrons do not have sufficient energy to vulcanize latex. Where as for accelerators of 300 and 250 keV energy (Figure 2 & 4) an increase of tensile strength with irradiation time was observed. This change is due to radiation induced crosslinking (vulcanization) of NRL which increases with radiation dose. Accelerators of 175 and 250 keV use drum type reaction vessel for irradiation of latex. Figure 3 &5 shows the effect of beam current on elongation at breake and swelling ratio of latex, when the the latex is irradiated with accelerator of 300 keV. Effect of beam current on tensile and swelling ratio for accelerators of 175 and 250 keV is shown in Figure 6. With EB accelerator of 175 keV tensile strength increases slowly and at 8 mA of beam current the tensile strength is 27.1 MPa. But for 250 keV EB accelerator the tensile strength increases more rapidly. From these results it can be concluded that the drum type irradiator with beam current above 8 mA, is usful even when low energy EB accelerator of energy 175 keV, was used for irradiation of latex.

Effect of beam current on tensile properties

Beam current of electron beam accelerator corresponds to the dose of irradiation of latex. From the Figure 2 it can be seen that tensile strength of the irradiated films increases with the increasing irradiation time. Maximum tensile strengths at 20,30, 40, 50 and 60 mA beam currents correspond to 25.1, 22.6, 14.2, 12.7 and 9.2 minutes of irradiation times respectively and the tensile strength values are 23.3, 25.5, 28.9, 24.4 and 24.3 MPa respectively. It can be seen that for higher beam current it takes less time to irradiate the latex.

Elongation at break of irradiated latex films at 20, 30, 40, 50, 60 mA beam currents is shown in Figure 3. From the Figure 3 it can be seen that with the increase of beam current the elongation at break for the same period of exposure to radiation is decreasing. With the increase of exposure time of radiation elongation at break decreases for all samples. For beam currents 20, 30, 40, 50 and 60 mA at 30 minutes of exposure time, elongation at break corresponds to 990, 970, 750, 610 and 505% respectively.

According to Figure 5 percent swelling ratio value decreases with increasing radiation time. The same trend is observed for all samples. The swelling ratio drops quickly for irradiated film of higher beam current (60 mA) than film of lower beam current (20 mA) (Figure 5).

Effect of speed of mixing of latex on proprties of irradiated latex

Effect of stirrer speed on tensile properties and on swelling ratio are shown in Figure 6, 7 & 8. During irradiation the latex was continuously stirred with a stirrer fitted at the bottom, at speeds 100, 150 and 200 r.p.m. From Figure 6 it can be observed that at speed of 150 r.p.m. the maximum tensile strength is obtained (28.9 Mpa), whereas for 100 and 200 r.p.m. these values are 24.2 ,25.2 MPa respectively. It is expected that at higher stiring speed (200 r.p.m.) vulcanization process would take less time and tensile strength would be higher. But it is observed that vigorous stirring cause displacement of some drops of latex on to the aluminium film which absorbs a greater part of energy of electron. As a result partially carbonized latex are formed on the aluminium film and the latex in the reactor at stirring speed 200 r.p.m. gets energy to absorb. Consequently the tensile strength at 200 r.p.m. (25.2 MPa) is less than at 150 r.p.m. (28.9 MPa).

Energy utilization efficiency for vulcanization using low energy electron beam accelerator

For vulcanization of NRL without sensitizer the required dose is 250 kGy (Makuuchi et al.). It was found that using beam current 40 mA it takes 15 minutes to vulcanize 1.45 kg of latex. So the energy used for vulcanization is

$$1.45 \text{ kg} * 250 \text{ kJ/kg} = 362.5 \text{ kJ}$$

While, Electron beam energy to the latex is

$$300 \text{ kV} * 40 \text{ mA} * 10 \text{ cm}/60 \text{ cm} * 15 \text{ min} * 60 \text{ sec} = 1800 \text{ kJ}$$

Therefore the energy utilization efficiency for vulcanization is

$$362.5 / 1800 * 100 \% = 20.13 \%$$

CONCLUSION

Reaction vessel with stirrer can be used for vulcanization of natural rubber latex using EB accelerator of power above 250 keV. But when vulcanization was carried out in thin layers even lower power accelerator (175 keV) can be used. Properties of electron beam irradiated latex are comparable with those of gamma ray irradiated latex..

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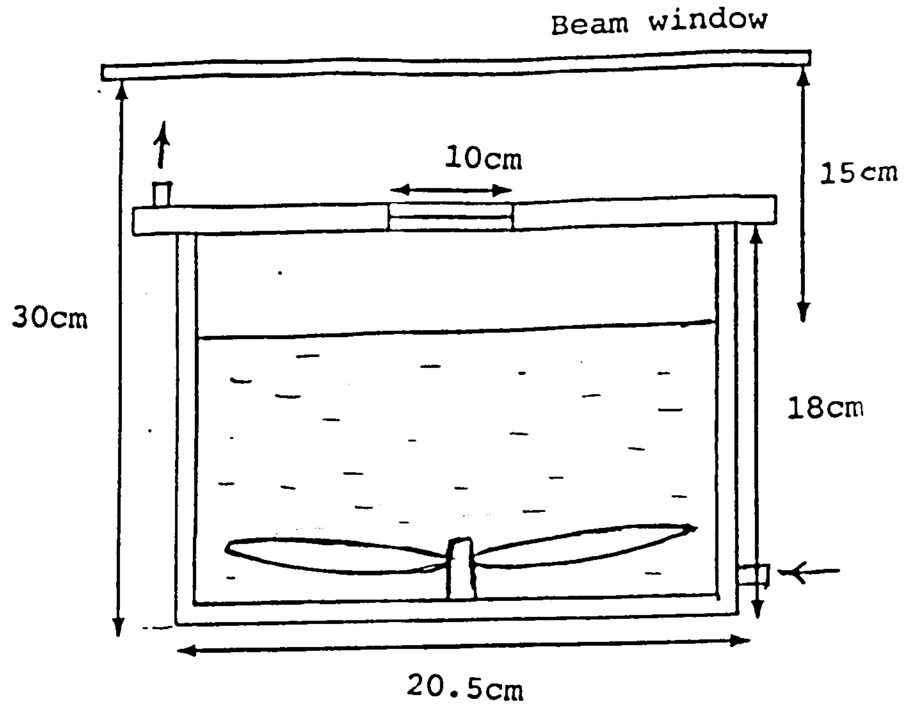

Figure 1: Diagram of reaction vessel.

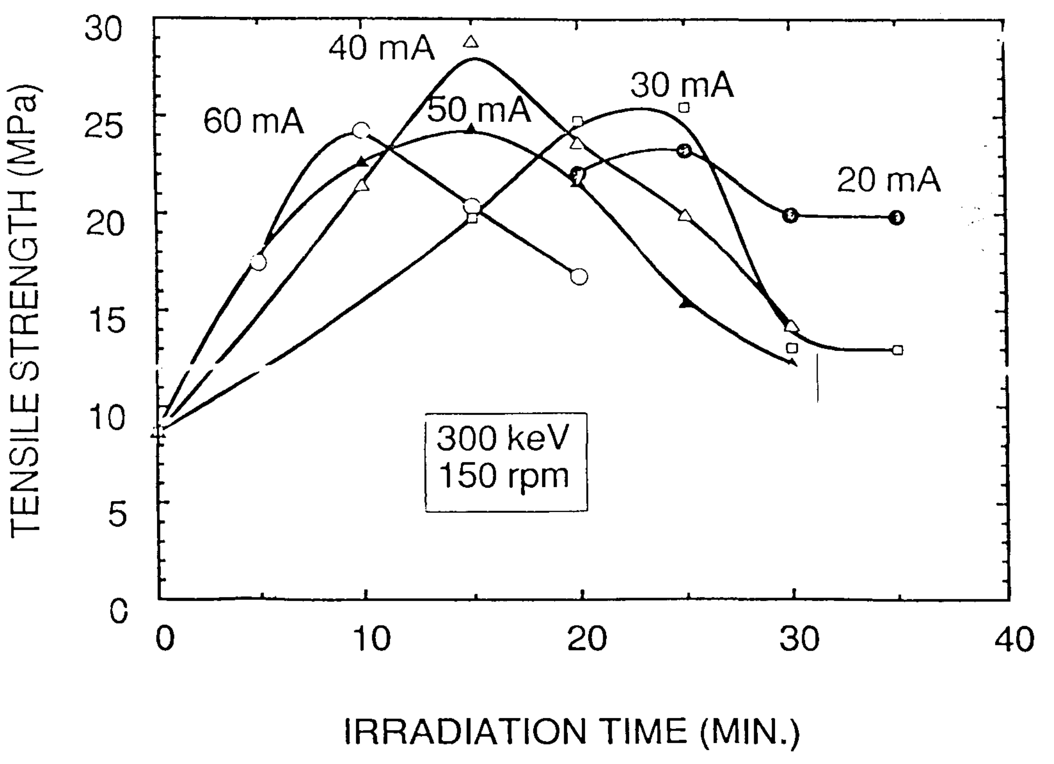

Figure 2: Effect of irradiation time on tensile strength.

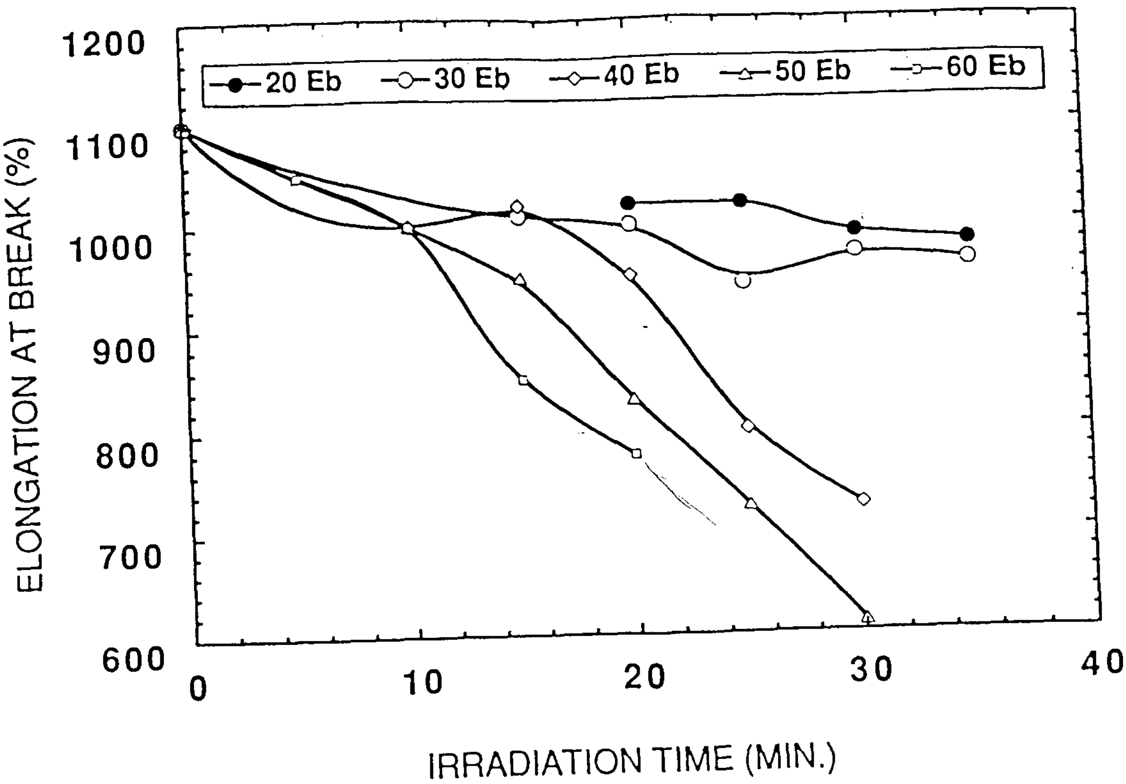

Figure 3: Change of tensile properties of latex film with irradiation time.

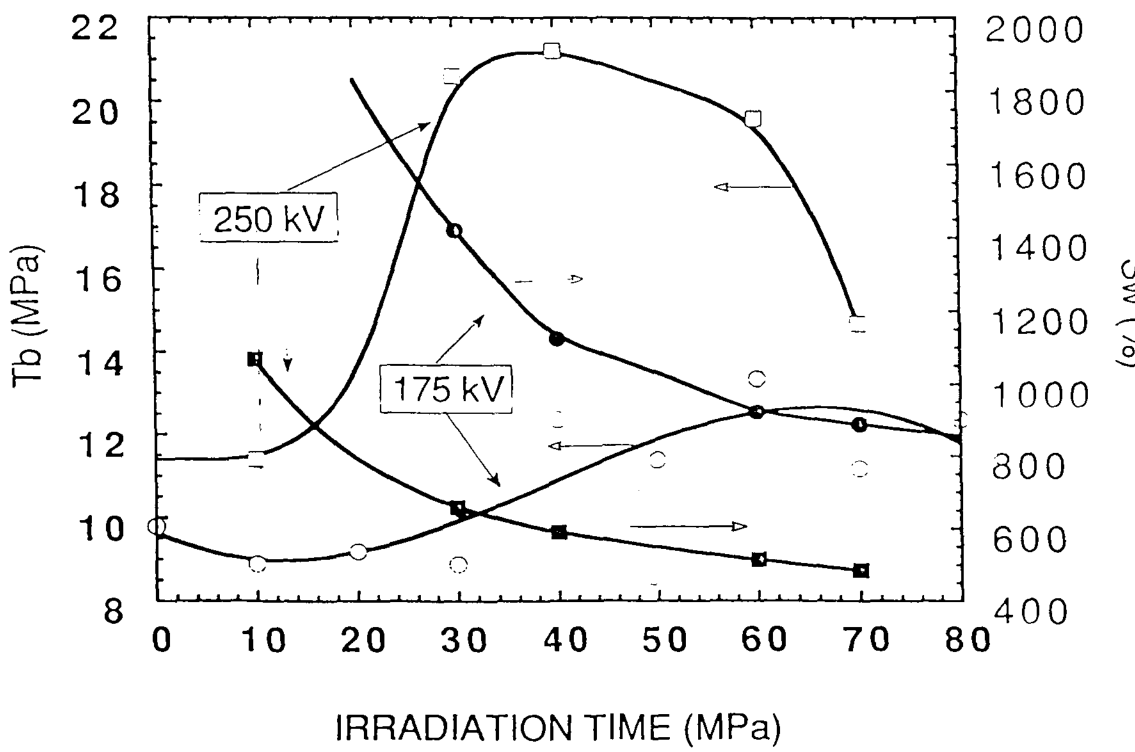

Figure 4 : Dependance of elongation at break on beam current.

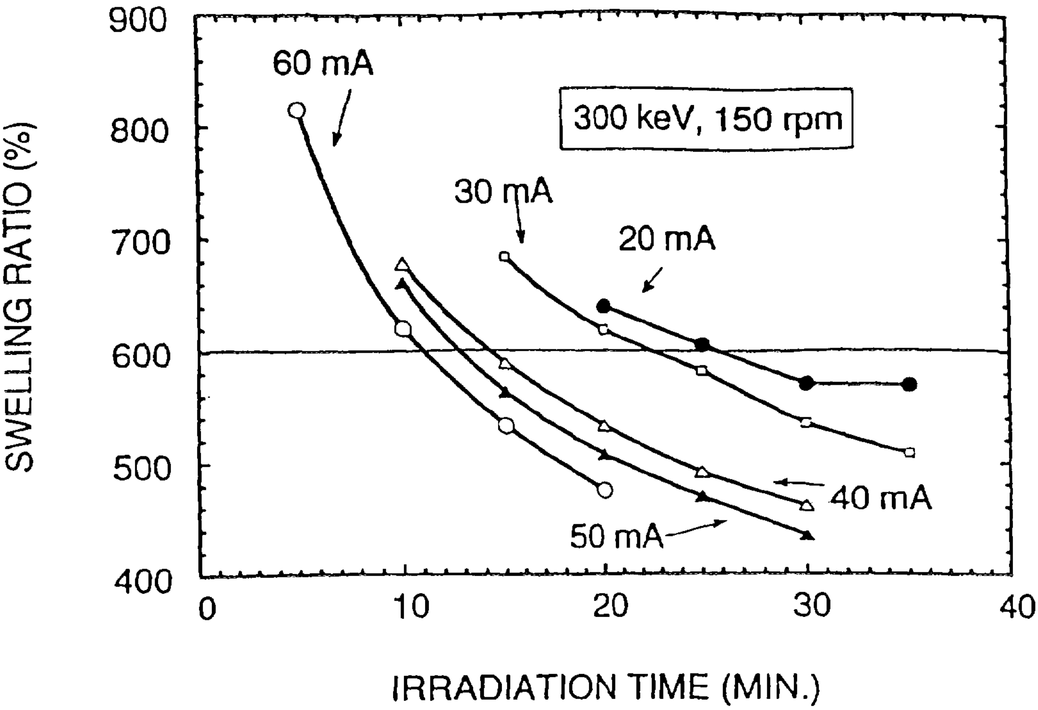

Figure 5 : Effect of beam current on swelling ratio.

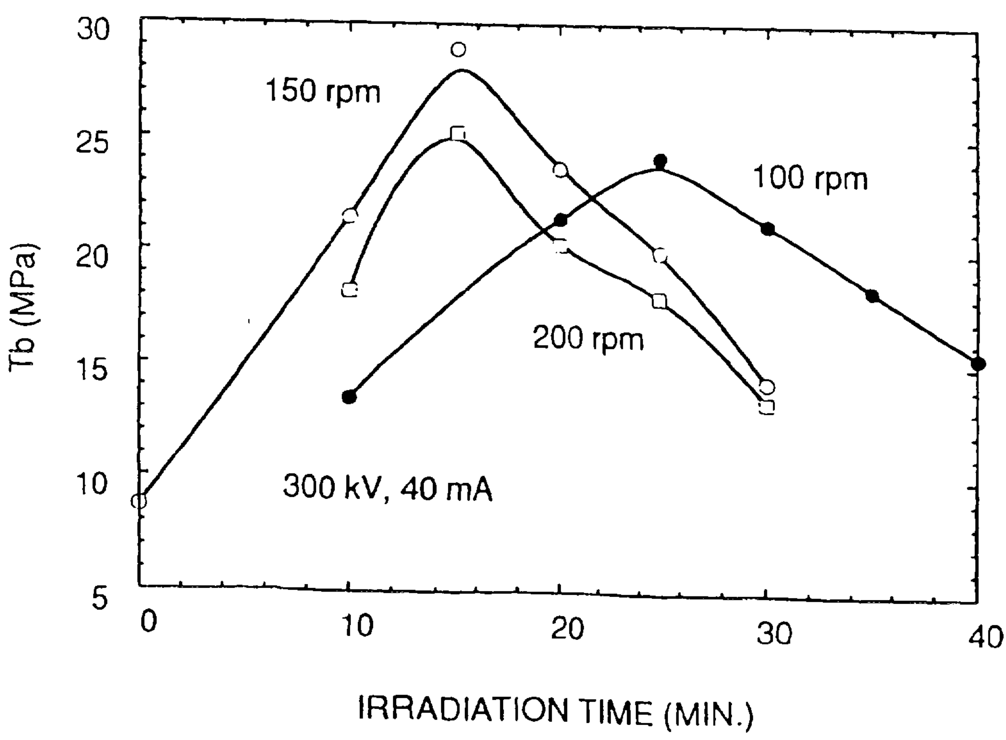

Figure 6: Effect of stirrer speed on tensile strength.

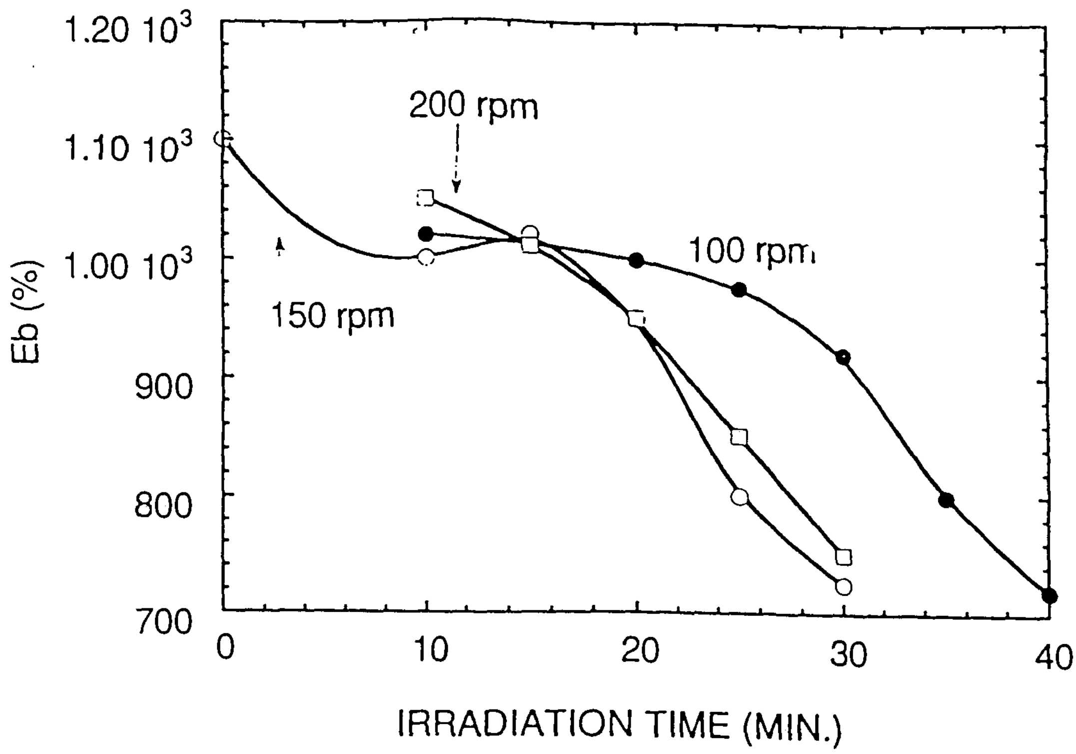

Figure 7: Change of elongation at break on stirrer speed.

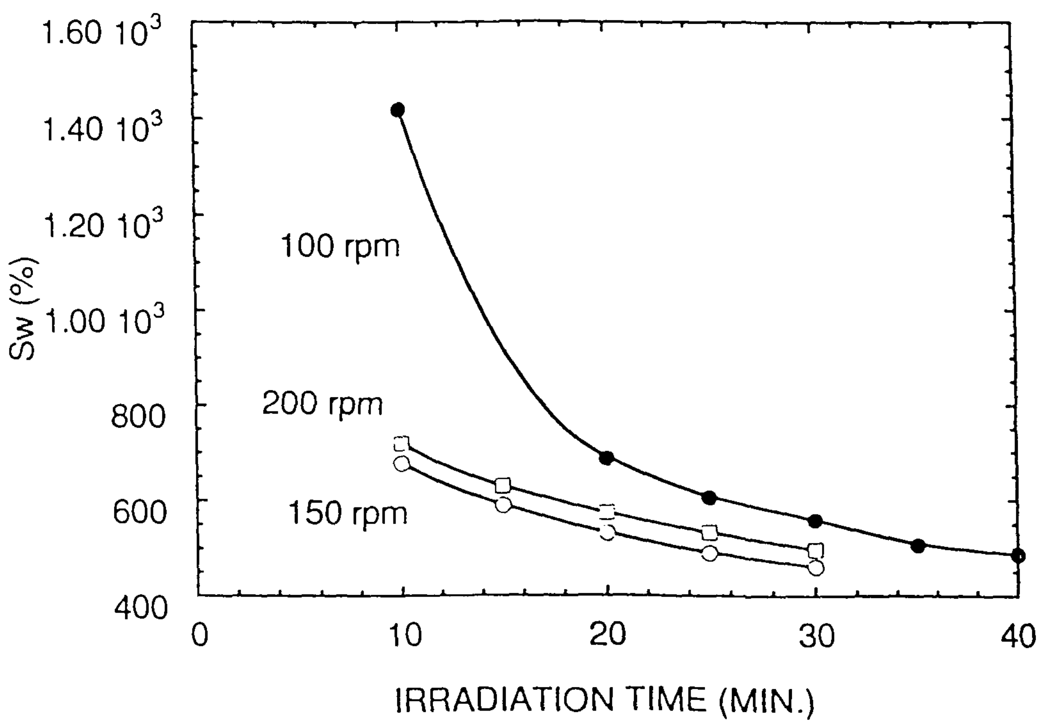

Figure 8: Effect of stirrer speed on wt. swelling ratio.