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Effect of concentration of polyfunctional monomers on physical properties of acrylonitrile–butadiene rubber under electron-beam irradiation

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Abstract

An investigation has been undertaken to find out the effect of concentration of different polyfunctional monomers (PFMs) on the physical properties of the acrylonitrile–butadiene rubber (NBR) crosslinked by electron beam (EB). The PFMs used were diethylene glycol dimethacrylate, trimethylol propane trimethacrylate and trimethylol propane triacrylate. The physical properties of EB-irradiated NBR sheets were evaluated by measuring the tensile strength, elongation percent at break, hardness and gel fraction. The results showed a remarkable increase in tensile strength, hardness and gel fraction as the concentration of PFMs was increased from 1 part per hundred (phr) to 5 phr in the NBR samples whereas elongation percent decreased in a steady manner. The improvement in physical properties of radiation crosslinked NBR in the presence of PFMs may be attributed to its increased crosslinking density as observed by the corresponding increase in gel content.

Keywords: Acrylonitrile–butadiene rubber; Radiation crosslinking; Polyfunctional monomers; Crosslinking; Electron beam irradiation

1. Introduction

Acrylonitrile–butadiene rubber (NBR) is an unsaturated copolymer of acrylonitrile and butadiene and commonly considered as the workhorse of the industrial and automotive rubber products. NBR with appropriate acrylonitrile content in balance with other desired properties have wide variety of applications where oil, fuel and chemical resistance are required (Brydson, 1988; Yasin et al., 2002).

For commercial applications, NBR requires additional ingredients, which include reinforcement fillers, plasticizers, antioxidants, processing aids and crosslinking agents (Tan et al., 1993). Generally, commercially available NBR products are crosslinked by chemical package, the radiation crosslinking of NBR is still in the infancy stage (Yasin et al., 2002, 2003), although, it was found in 1940s that polymer can be crosslinked by radiation (Charlesby, 1960). The major obstacle in radiation crosslinking of NBR is the requirement of high irradiation doses, which are prerequisite to achieve the desired crosslink density in NBR. Appropriate polyfunctional monomers (PFMs) in polymer matrix can be used to obtain the desired

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crosslinking density at lower irradiation doses (Tabata et al., 1991; Makuuchi and Hagiwara, 1984; Youssef et al., 1993; Ahmed and Ruimin, 1999). Our earlier work on radiation crosslinking of NBR showed that the irradiation doses can be lowered by incorporating suitable PFMs such as diethylene glycol dimethacrylate (2G) and trimethylol propane trimethacrylate (TMPT). In this work, we have studied the effect of PFMs concentration on physical properties of electron beam (EB) crosslinked NBR. This is very important from the viewpoint of finding out optimum quantity of PFM required to obtain desired properties. This will help avoid the unnecessary addition of PFMs in NBR which will in turn reduce the cost. Establishing the optimum dose required for achieving the desired crosslinking will further help avoiding the exposure of the rubber to doses higher than what is necessary.

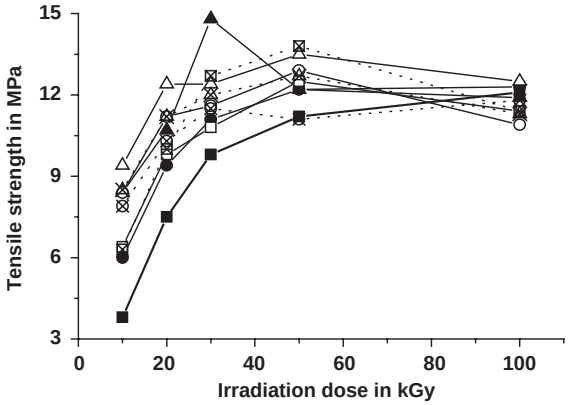

Fig. 1. Effect of irradiation dose on tensile strength of NBR containing 2G (−■−1 phr, −●−3 phr, −▲−5 phr), TMPT (−□−1 phr, −○−3 phr, −△−5 phr) and A-TMPT (−⊠−1 phr, −⊗−3 phr, −⧋−5 phr).

2. Experimental part

2.1. Materials

Commercial grade NBR (DN-206) with 33% acrylonitrile content was from Nipol Zeon, Japan and carbon black (SRF-50) was from Asahi Carbon Company Japan. Zinc oxide and stearic acid were commercial grade. The PFMS were obtained from Shin-Nakamura Co. Ltd. Japan. All the chemicals/reagents were used as such without further purification. The procedure describing the preparation of samples, irradiation and measurement of physical properties has already been published elsewhere (Yasin et al., 2002).

2.2. Physical Properties

The tensile strength (Tb) and elongation at break (Eb) were measured by using tension machine type strograph R1 from Toyoseiki Co. Ltd. Japan, according to the Japan Industry Standard JIS K-6301 using crosshead speed of 500 mm/min at ambient temperature (~25 °C). Hardness was measured according to ASTM D2240 using an ASKER DD2 durometer. The units of hardness are expressed in shore A. The gel content of the crosslinked NBR was determined by the extraction of samples in boiling xylene for 24 h using a Soxhlet apparatus. The extracted samples were dried in vacuum oven at 50 °C till constant weight.

3. Results and discussion

The present study was carried out by using two methacrylate-type PFMs, i.e., 2G (difunctional) and TMPT (trifunctional) and the results were compared with similar trifunctional acrylate, i.e., trimethylol propane triacrylate (A-TMPT) at 1, 3 and 5 phr. Each formulation was irradiated at five different doses up to a maximum of 100 kGy. Fig. 1 shows the effect of increasing the amount of different PFMs on Tb of EB crosslinked NBR. This figure shows that in the case of methacrylate type PFMs, Tb increases with increasing the amount of PFMs. A gradual improvement in Tb was observed as the concentration of 2G or TMPT was varied from 1 part per hundred (phr) to 5 phr. Similarly, Tb was increased as the irradiation dose was increased upto 50 kGy. In the range of 50 to 100 kGy, constancy in Tb values was observed in the case of 2G, while a decrease was observed in the case of TMPT. An interesting behavior in Tb was observed for A-TMPT in NBR as shown in Fig 1. A decrease in Tb was observed as the amount of A-TMPT was increased from 1 to 5 phr. The exact reasons for the unexpected behavior for A-TMPT are not clear. Generally, the reactivity of PFMs depends on a combination of factors including their ability to dissolve and diffuse into the polymer matrix, the reactivity of unsaturated bond and the influence by the aromatic ring (Xu et al., 1993). The different behavior of A-TMPT may be explained on the basis of the reactivity of its unsaturated bonds and its ability to dissolve and diffuse into the polymer matrix of the NBR compared to that of the TMPT. This behavior is obviously due to the difference in polarity of the two PFMs. It has already been observed that A-TMPT has slightly higher solubility in NBR than TMPT (Yasin et al., 2002). Moreover, it has already been observed that the sensitizing efficiency and rate of radical polymerization of acrylates is higher than that of the analogous methacrylates (Moor, 1977).

The Eb of 2G, TMPT and A-TMPT are shown in Fig. 2. This figure shows that at all doses a decrease in Eb is observed as the concentration of PFMs increases