doi: 10.56761/EFRE2024.R5-P-042102

Study of the influence of X-ray radiation on the structure and elastic strength properties of elastomers based on nitrile butadiene rubber

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Abstract. The results of a study of the effect of X-rays of 100 kR/h on the structure and elastic-strength properties of elastomers based on nitrile-butadiene rubber with degrees of vulcanization of t_{70}, t_{80}, t_{90} are presented. It is found that irradiation of rubbers with an exposure dose up to 50 kR leads to an increase in a the elongation at break and tensile strength due decreasing the degree of crystallinity and increasing of the number of cross-links between macromolecules. It is obtained that the X-ray irradiation of rubber with exposure doses in the range from 50 kR to 100 kR leads to an increase in a degree of crystallinity and to a deterioration in rubber elastic-strength properties. It is suggested that the cross-links of elastomers based on nitrile-butadiene rubber under the X-rays effect with dose in the range from 50 kR to 100 kR are destructed. The established nonlinear dependences of the elastic-strength properties of nitrile butadiene rubber with degrees of vulcanization t_{70}, t_{80} and t_{90} from an exposure dose point to greatly depending of the number of rubber intermolecular cross-links from an exposure dose of the X-rays.

Keywords: X-ray radiation, exposure dose, density, degree of vulcanization, elastic-strength properties.

1. Introduction

One of the priority areas of scientific and technological progress is the development and search for new technologies processing polymer materials in order to give them the required performance characteristics and unique properties. Radiation technologies based on the effect of ionizing radiation on materials are actively developing as a means of modification material properties in our days [1–3]. In the direction problems related to radiation vulcanization of polymers including rubbers, elastomers and various paints, varnishes are being solved simultaneously [4–9]. The relevance of the problems is that polymer materials during operation are subjected to several influences leading to destructive processes that negatively effect on the properties of polymers [10–14]. In connection with the above it is relevant to study the possibility to control operational properties of polymer composite materials by modifying them with ionizing radiation.

The paper presents results of a study of the effect of X-ray radiation on the performance characteristics of rubbers based on nitrile butadiene rubber (NBR) which are resistant to aggressive environments, water, greases and mineral oils.

2. Experimental methodology

The objects of the study were NBR elastomers with degrees of vulcanization of t_{70}, t_{80} and t_{90} from a rubber mixture of type 7-B-14. The choice of the degrees of vulcanization was made due to the fact that the cross-links structure of the rubber vulcanized up to t_{70} is not fully formed and is characterized with an additional opportunity for cross-linking of macromolecules under the X-rays. At the same time the structure of the cross-links of the rubber vulcanized up to t_{90} is already formed.

The X-ray installation at the X-ray tube with the operating voltage of 55 kV and the current of 15 mA for irradiating the NBR-elastomers with wavelength X-rays of 0.07 nm was used. The X-rays exposure dose rate at the distance of 10 cm from the X-ray tube window was 100 kR/h. The X-rays exposure dose was varied by adjusting the exposure time.

The rubber degree of crystallinity was carried out using X-ray diffraction analysis with help of a diffractometer DRON–3M in the CuKα radiation.

The elastic-strength properties of NBR elastomers were studied using a Kason WDW-1 testing machine in accordance with GOST 270-7 [10, 11].

3. Results and discussion

The analysis of a structure of NBR elastomers after X-ray irradiation with exposure dose not exceeding of 50 kR shows the decreasing crystallinity. In particular the degree of crystallinity of the control (non-irradiated sample) with the degree of vulcanization of t_{90} is equal 61%. In the same time the degree of crystallinity of the irradiated with the X-ray exposure dose of 50 kR samples is 45%. It is obtained that the degree of crystallinity of NBR elastomers decreases with increasing degree of vulcanization. How it can be seen from the Fig. 1 the degree of crystallinity of elastomers with the degree of vulcanization of t_{70} is 46%. This is approximately 33% less compare with the rubber vulcanized up to t_{90} [7].

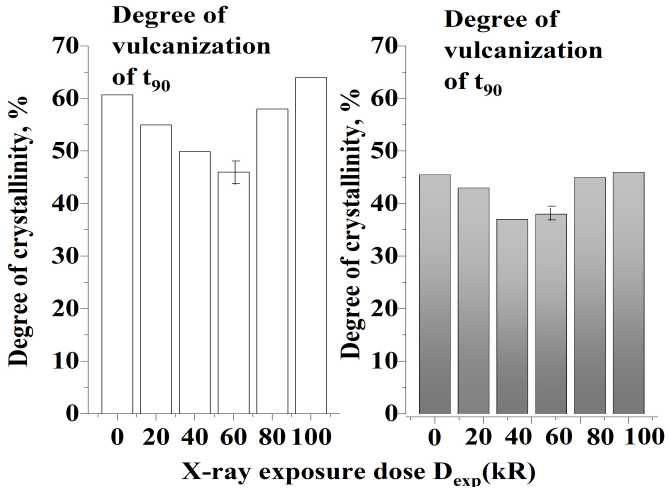

Fig. 1. Degree of crystallinity NBR elastomers vulcanized up to t_{90} and t_{70} and irradiated the X-rays.

In contrast the degree of crystallinity of NBR elastomers irradiated with X-ray exposure dose in the range of 50 kR < D_{exp} ≤ 100 kR increases. The obtained data indicate the dependence of number of intermolecular cross-links and densities on X-ray exposure dose.

Fig. 2 presents the results of the study of the effect of X-ray radiation on the density of NBR elastomers [8]. As it can be seen on the Fig. 2 the density of elastomers with degree vulcanization of t_{70} after irradiation with X-ray exposure dose up to 50 kR increases and in the range from 50 to 100 kR noticeably decreases. So the density of elastomers with the degree of vulcanization of t_{70} irradiated with D_{exp} of 60 kR/h is equal to 1.263 g/cm^3, and the density of samples irradiated with D_{exp} of 100 kR is 1.225 g/cm^3. The obtained results correlate with the data of the degree of crystallinity and point to decreasing of the elasticity of NBR-elastomers due irradiation with X-ray exposure dose higher than 50 kR/h [8].

Table 1 presents the results of a study of the elastic-strength properties of NBR elastomers with degrees of vulcanization t_{70} and t_{90} irradiated with X-ray exposure doses in the range from 0 to 100 kR.

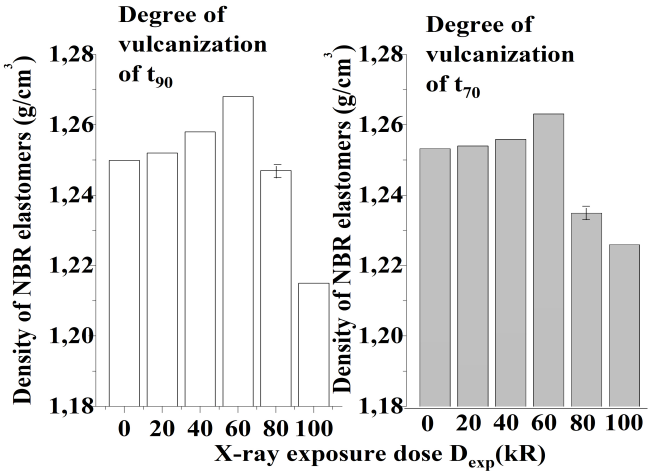

Fig. 2. Density of NBR elastomers vulcanized up to t_{90} and t_{70} and irradiated X-rays.

Table 1. Elastic-strength properties of NBR elastomers with degrees of vulcanization of t_{70} and t_{90} Results of a study of the effect of X-ray radiation.

Characteristics	X-ray exposure dose (kR)					
	0	20	40	60	80	100
	NBR elastomers with degree of vulcanization of t_{70}					
Tensile strength (MPa)	7.64	8.14	8.45	8.59	8.43	8.17
Elongation at break (%)	282.42	289.12	307.30	310.00	309.00	305.60
	NBR elastomers with degree of vulcanization of t_{90}					
Tensile strength (MPa)	7.95	8.00	8.35	8.48	6.98	6.79
Elongation at break (%)	270.85	277.37	285.40	301.07	244.37	242.07

It is established that the X-rays effect up to 60 kR contributes to an increase in an elongation at break and tensile strength. In particular elongation at break of the non-irradiated elastomer with degree of vulcanization of t_{90} is 282 %. After exposure with the X-ray radiation of 50 kR it increases up to 310% that is 10% bigger than control rubber sample. Tensile strength after irradiation with D_{exp} of 50 kR also increases in 15%. The increasing of the main strength indicators of irradiated rubbers with X-ray exposure dose up to 60 kR can be explained by increasing of the number of cross-links between macromolecules which determine the highly elastic properties and elastic-strength characteristics of rubbers. At higher irradiation doses promotes to noticeable decrease in their elastic-strength characteristics of NBR elastomers. So after irradiation of elastomers with D_{exp} of 100 kR the elongation at break is 306% which is 8% higher than control rubbers, but 2% lower than irradiated rubbers with D_{exp} of 50 kR [9, 12].

4. Conclusions

The results of a study of the effect of X-ray radiation of 100 kR/h on the degree of crystallinity and elastic-strength properties of elastomers based on nitrile-butadiene rubber with degrees of vulcanization of t_{70}, t_{80} and t_{90} are presented.

It is found that irradiation of rubbers with an exposure dose up to 50 kR leads to decrease in the degree of crystallinity of NBR elastomers, their densities and an increase in the elongation at break and tensile strength, which is associated with an increase in a number of cross-links between macromolecules.

It is obtained that the X-ray irradiation of rubber with exposure doses in the range of 50 kR to 100 kR leads to an increase in a degree of crystallinity and to a deterioration in elastic-strength properties. It is suggested that the destruction of rubber cross-links under the X-rays effect with doses in the range from 50 kR to 100 kR. The established nonlinear dependences of the elastic-

strength properties of NBR elastomers with degrees of vulcanization t_{70}, t_{80} and t_{90} from an exposure dose of radiation indicate that a number of intermolecular cross-links greatly varies from an exposure dose of X-rays.

Acknowledgement

This work was supported by Ministry of Education of Republic of Belarus and the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant № AP 19680121).

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