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Effects of Gamma Irradiation on Some Mechanical Properties of Novoloid Fibers

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Abstract: Novoloid fibers have high chemical, flame and thermal resistance; however they have low tensile properties. Effects of gamma irradiation on the tensile properties of novoloid fibers have been investigated. Loop and knot resistance have also been examined. Maximum tenacity of the single fiber increased with an increase of the radiation dose applied. According to the loop and knot tenacity results it is found that brittleness has been also affected by the amount of radiation dose.

Keywords: Gamma radiation, Novoloid fibers, Tensile properties, Co 60, Novolac resins

Introduction

High performance fibers are used in a wide area because of their unique properties. One of those fibers is Novoloid fibers. Definition of Novoloid fiber according to U.S. Federal Trade Commission is that: Novoloid is a manufactured fiber containing at least 85 percent by weight of a cross-linked novolac [1]. Novoloid fibers are generally recognized by their high thermal and flame resistances. They also have high chemical and solvent resistances [2,3]. Some typical properties of novoloid fibers are shown in Table 1 [2,3]. The producer of novoloid fiber Kynol^{TM}, Nippon Kynol Inc of Japan, declares that "These properties vary slightly with the fiber diameter (denier) and may be further adjusted by varying with the conditions of production". Novoloid fibers are produced by melt-spun novolac resin which is cross-linked by acid-catalyzing [3]. These fibers have amorphous, fully cross-linked and three dimensional network structure. The chemical formula of polymer structure of novoloid fibers is shown in Figure 1.

Table 1. Some typical properties of novoloid fiber

Yarn count	0.22-1.11 tex
Specific gravity	1.27 g/cm^3
Tensile strength	12-16 cN/tex
Elongation	30-60 %
Modulus	260-350 cN/tex
Loop strength	19-27 cN/tex
Knot strength	10-13 cN/tex
Moisture regain	6 %
LOI (Limit Oxygen Index)	30-34
Melting point	Does not melt

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The fiber which is used in the experimental work contains approximately 76 % carbon, 18 % oxygen, and 6 % hydrogen.

Some typical end-uses of novoloid fibers are protective apparels, safety accessories and flame barriers. Composites such as clutch and brake pads, soft packings are also important application areas for novoloid fibers.

Radiation technology yields many achievements in polymer processing [4,5]. Some application areas of high-energy radiation in polymers are radiation induced polymerization, producing graft copolymers, curing of coatings and paints, vulcanization of rubber mixtures, producing composite materials and sterilization of medical materials [5-9].

When polymers are exposed to ionizing radiation, their basic molecular structure and associated macroscopic properties can be changed [10]. The main effects of irradiation in polymers are cross-linking and chain scission. While the chain scission reduces material strength, the crosslinking can improve tensile and shear strength [11].

The aim of the study is to investigate the effects of gamma irradiation on mechanical properties of novoloid fibers such as tensile strength and loop tenacities. Loop and knot tenacity are good indicators to show their limits to the fiber processing and their end-use applications. The brittleness can be estimated from the ratio of tenacity measured in loop or knot tests.

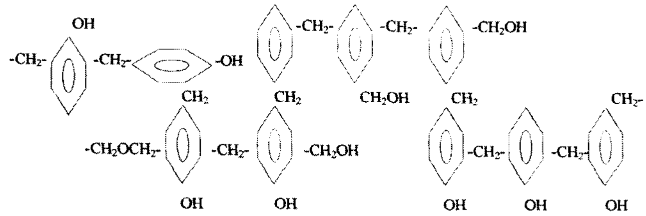

Figure 1. Polymer structure of novoloid fibers.

Experimental

Materials and Methods

Material

Kynol™ Novoloid fibers having fiber count of 0.241 tex were used in the study.

Irradiation

Irradiations were performed with Co-60 Gammacell. Dose rate was 0.387 Mrad/h with doses of 0, 10 kGy, 20 kGy, 30 kGy, 80 kGy, 130 kGy, and 180 kGy.

Mechanical Tests

Instron 4301 machine was used for the mechanical tests.

Maximum tenacity, breaking tenacity and maximum elongation have been measured according to ASTM D2101-82 test method to observe single fiber tensile properties. 10 N load cell was applied through all experiments with 2.5 cm gauge length. 30 measurements were tested for each specimen.

ASTM D3217-79 test was employed for knot tenacity and loop tenacity measurements. Elongation value in the loop or knot tests has no known significance and is usually not recorded.

Knot tenacity sample shape is shown in Figure 2. The two ends of the knot has been clapped by the jaws of the test machine and the knot has been placed in the middle of the clamps without stretching.

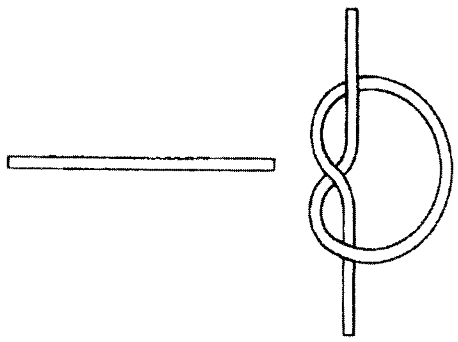

Figure 2. Knot tenacity sample shape.

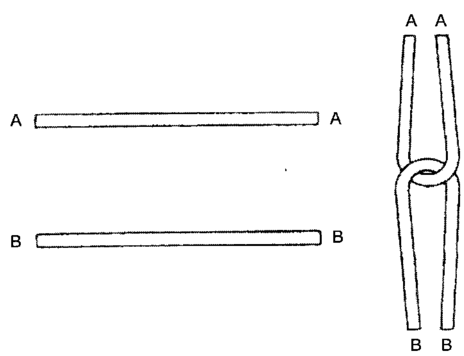

Figure 3. Loop tenacity sample shape.

The knot tenacity was calculated according to equation (1).

$$\text{Knot tenacity (N/tex)} = \frac{M}{L} \quad (1)$$

M = Breaking load (N)
L = Linear density of fiber, tex

Loop tenacity sample shape is illustrated in Figure 3. The two ends of loop A and B were clapped closely by the jaws of the test machine. The intersection of two fibers should be in the middle of the clamps.

Loop tenacity was calculated according to equation (2).

$$\text{Loop tenacity (N/tex)} = \frac{M}{2L} \quad (2)$$

Where, M = Breaking load (N)
L = Linear density of fiber, tex

Statistics

The results have been evaluated using one-way ANOVA having factor of radiation dose for the variables of maximum tenacity, maximum elongation, loop tenacity and knot tenacity. The rejected hypotheses have been tested by using SNK (Student Newman Keul) test. All results have been evaluated at 5 % significance level. In some cases, regression analysis was conducted.

Results and Discussion

Mechanical Test Results in Single Fiber

Maximum Tenacity

Figure 4 shows dose dependencies of the maximum tenacity for the novoloid fibers. According to one-way ANOVA procedure, radiation dose has an effect on the maximum tenacity for 5 % significance level. From the SNK statistical comparison, it can be concluded that, the doses of 0, 10, and 20 kGy have almost similar effect, the doses of 30 and 80 kGy have almost similar effect and the doses of 130 and 180 kGy have almost similar effect on maximum tenacity. However,

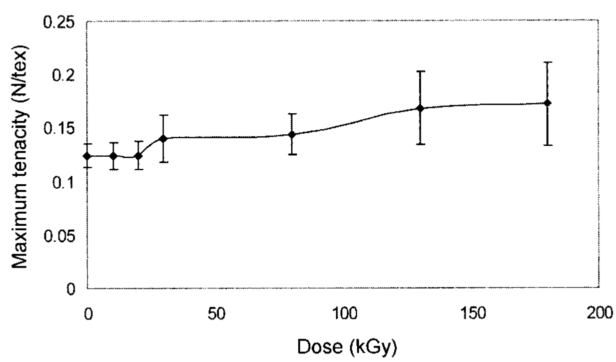

Figure 4. Radiation dose versus maximum tenacity of Kynol™ novoloid fiber.

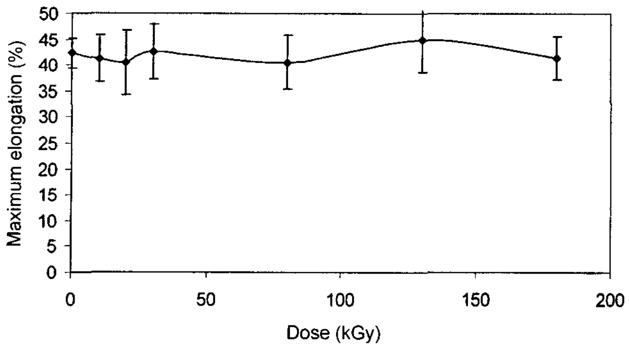

Figure 5. Radiation dose versus maximum elongation of Kynol™ novoloid fiber.

these three groups are different from each other at 5 % significance level. The comparison of the data displays a cause-result relationship between radiation doses and maximum tenacity. The results show that maximum tenacity increased with an increase of radiation dose. From regression analysis of the maximum tenacity values of the fiber for given doses, following equation is obtained:

$$y = 0.124 + 2.92x \quad (3)$$
$$R^2 = 0.94$$

Where, y = Maximum tenacity (N/tex)
x = Dose (kGy)

Breaking tenacity results have similar to the maximum tenacity results.

Maximum Elongation

Figure 5 shows dose dependencies of the maximum elongation for Kynol™ Novoloid fibers. According to one-way ANOVA procedure, there is no difference between applied radiation doses for maximum elongation at 5 % significance level. 30 measurements were executed for every radiation dose. The data have been scattered in a wide range. Therefore, standard deviations of the results are high.

Maximum Knot Tenacity

Figure 6 shows the cause-result relationship between

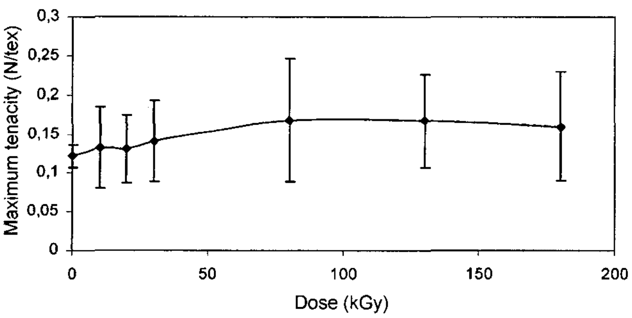

Figure 6. Radiation dose versus maximum knot tenacity of Kynol™ novoloid fiber.

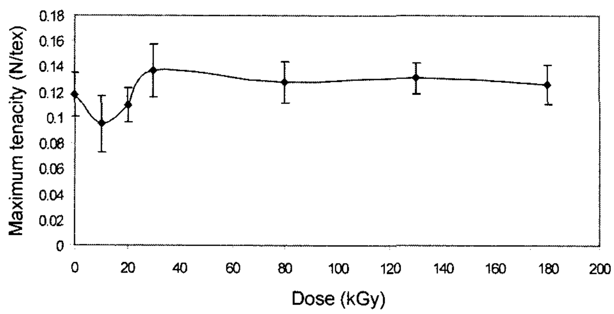

Figure 7. Radiation dose versus maximum loop tenacity of Kynol™ novoloid fiber.

maximum knot tenacity and radiation dose. According to one-way ANOVA procedure the factor of dose has a significant effect on maximum tenacity of the knot at 5 % level. SNK test indicates that there are three different groups among dose levels. These groups consist of doses of 0, 10, 20, and 30 kGy in one group, 80 kGy in one group and 130 and 180 kGy in another group respectively. Maximum knot tenacity has been increased up to 80 kGy, and then, knot tenacity has been started to decrease.

As a result of regression analysis of the maximum knot tenacity values of the fiber for given doses, following formula has been obtained:

$$y = 0.121 + 7.88.10^{-4}x - 3.19.10^{-6}x^2 \quad (4)$$
$$R^2 = 0.97$$

Where, y = Maximum knot tenacity (N/tex)
x = Dose (kGy)

Maximum Loop Tenacity

Figure 7 shows that loop maximum tenacity results are related to radiation dose. According to one-way ANOVA results, there is an effect of factor of dose on the maximum loop tenacity. SNK results indicate that there are four different groups based on maximum loop tenacity measurements. There is a significant decrease at 10 kGy, and then tenacity has increased.

From regression analysis of the maximum loop tenacity values for given doses, following equation is obtained:

$$y = 0.118 - 52.10^{-4}x + 3.6.10^{-4}x^2 - 0.68.10^{-4}x^3 \quad (5)$$
$$R^2 = 0.99$$

Where, y = Maximum knot tenacity (N/tex)
x = Dose (kGy)

The effect of radiation is influenced by some factors such as the presence of oxygen, additives, degree of polymer crystallinity, non-localization of absorbed energy and type of radiation used [6]. A change in irradiation conditions can affect the predominant process, i.e. crosslinking over chain scission or the reverse. The test results should be evaluated according to the statement.

Conclusion

It can be concluded that there is statistically no significant change in tenacity of the single fiber up to 30 kGy at 5 % significance level due to protection action of benzene rings in radiation chemical process as indicated in the literature [12,13]. So it can be stated that the fiber shows high irradiation resistance because of benzene rings at low doses. On the other side, the tenacity has been started to increase because of crosslinking over 30 kGy. An increase in the molecular weight due to crosslinking and crosslinking itself are responsible for some improvements in mechanical properties of the fiber. However, crosslinking can cause over-hardened state beside these improvements [9]. Decreases in loop and knot tenacity, which are estimation methods for material brittleness, can be explained by crosslinking process.

These results indicate that the radiation method applied here can be employed to increase the strength of the materials where it is necessary. This behavior of the fiber under radiation process is a unique property of the fiber. It can be advised that change in material properties should be tested before usage under irradiation, such as irradiation curing of fiber reinforced polymer composites, because of different responses of different materials.

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