Studies on Acrylic Acid–Grafted Polyester Fabrics by Electron Beam Preirradiation Method. II. Novel Intelligent Immersion-Resistant and Moisture-Permeable Fabrics

Changcheng He, Zhenya Gu, Junying Tian

College of Material Science and Chemical Engineering, Tianjin Polytechnic University, Tianjin, 300160, China

Received 30 April 2002; accepted 14 January 2003

ABSTRACT: Moisture regain, water vapor permeability, and water-impermeable ability of polyester fabrics before and after grafting by acrylic acid (AA) were investigated. The results showed that the AA-grafted fabric presents novel properties. When it is dry it possesses a higher water vapor transmission rate. Once it comes into contact with water, the grafted poly(acrylic acid) layer on the fibers' surface begins to swell and seals the intervals between fibers and yarns to prevent water from penetrating, a phenomenon known as immersion resistance. This kind of immersion-resistant and moisture-permeable fabrics might be a suitable candidate for the immersion-resistant layer fabrics of Type B immersion-resistant suits. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 89: 3939–3943, 2003

Key words: immersion resistance; moisture-permeable; polyesters; fibers; intelligent fabrics

INTRODUCTION

The investigation of electron beam preirradiation-induced grafting of polyester fabrics by acrylic acid (AA) and the preparation and characterization of the grafted products were reported in a previous study.[1] In fact, our research work here is aimed at developing a new kind of intelligent fabric used for immersion-resistant suits.

The immersion-resistant suit is one kind of protective and lifesaving jacket that is absolutely needed by aviation and navigation personnel and others working in situations requiring exposure to sea water: it can keep the skin of drowning people from direct contact with cold water. In this way, the body temperature can be kept constant so that survival time might be prolonged and the survival probability might be increased.

The immersion-resistant layer of the original immersion-resistant suit is made of rubber-coated cloth that, although it is waterproof, is not moisture-permeable. This type of immersion-resistant suit is suitable for emergencies and is called Type A. Type B refers to a kind of professional garment with an immersion-resistant function. Its immersion-resistant layer is usually made of waterproof and moisture-permeable fabrics, such as high-density cotton fabrics, microporous membrane–laminated or coated fabrics (e.g., "Gore-tex "–laminated fabrics), and hydrophilic polyurethane-coated fabrics. However, all of them have some disadvantages: the former two cannot provide enough immersion resistance, whereas the latter is inadequate in water vapor permeability.

To improve the function of immersion-resistant suits, we propose a novel concept, that is, producing polyester fabrics grafted by hydrophilic monomer (AA), to develop a new kind of intelligent fabric with good immersion resistance and water vapor permeability in the light of shortcomings of current Type B immersion-resistant fabrics.

EXPERIMENTAL

Materials

We used the polyester fabrics, T21s/2 × T21s/2 × 69 × 44.5 × 48 in. (provided by Tianyi Textiles Group Co., Tianjin City, China), and the grafted fabrics obtained in our previous work with various graft ratios.

Moisture regain

Measurement of moisture regain was carried out according to Chinese National Standard GB9995-88.

$$\mathrm{MR} = \frac{M - M_0}{M_0} \times 100\%$$

where MR is the moisture regain (%) and M_0 and M are the original weight of the sample and the weight of

Correspondence to: C. He (herbert@pplas.icas.ac.cn).

Journal of Applied Polymer Science, Vol. 89, 3939–3943 (2003)

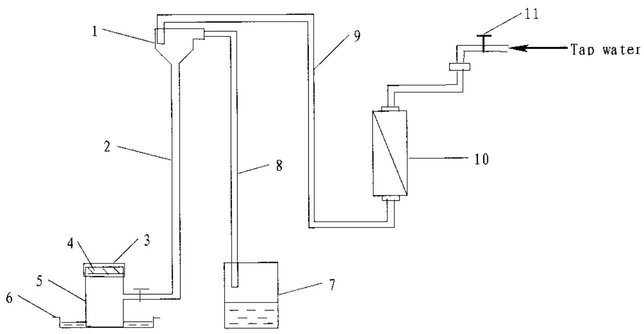

Figure 1 Schematic diagram of the water flow rate measuring device. 1, plastics hopper; 2, straight glass tube; 3, annular thread cap; 4, fabrics sample tested; 5, rustless steel cup; 6, tray for water collecting; 7, barrel for overflowing water collecting; 8 and 9, straight tubes for transmitting water; 10, hollow-fiber microfiltration membrane module; 11, water cock.

the sample after being in equilibrium in air, respectively.

Water vapor permeability

Measurement of water vapor permeability was carried out according to Chinese National Standard GB/T12704-91.

$$\mathrm{WVT} = 24[\Delta m/(St)]$$

where WVT is the water vapor transmission rate (g m^{-2} 24 h^{-1}), Δm is the weight loss of the sample during testing (g), S is the effective size of the tested sample (m^2), and t is the testing time (h).

Water-impermeable ability

Measurement of the water flow rate (WFR) was carried out using a WFR-measuring device, as presented in Figure 1.

The sample was placed on the top mouth of a specially devised rustless steel cup that was then covered with its cap with a thread screw whose internal hole had the same size as the inner diameter of the cup. The sample was fixed tightly between the top mouth and the cap of the cup through the thread fit. A pipe at the bottom of the cup was connected through a ball valve with a water-supplying system, which supplied water purified by a microfiltration membrane module. The water penetrating the sample was collected within a certain time interval. The WFR can be calculated from the volume of the collected water, according to the following relationship:

$$\mathrm{WFR} = V/(tS)$$

where WFR is the water flow rate (mL m^{-2} min^{-1}), V is the volume of the collected water (mL), t is the time taken for collection (min), and S is the effective size of the sample (0.00237 m^2).

A constant water pressure of 116-cm high water column was maintained during the test.

Environmental scanning electron microscopy (ESEM)

The *in situ* tracing examination of the AA-grafted fabric from dry to wet was carried out with the help of ESEM. The sample was fixed on a metal stage, which

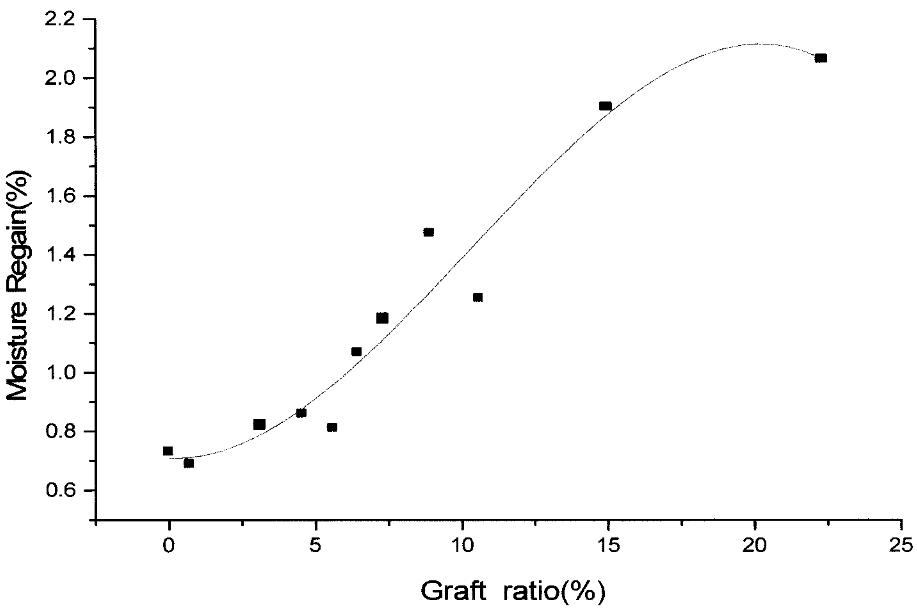

Figure 2 Effect of graft ratio on moisture regain.

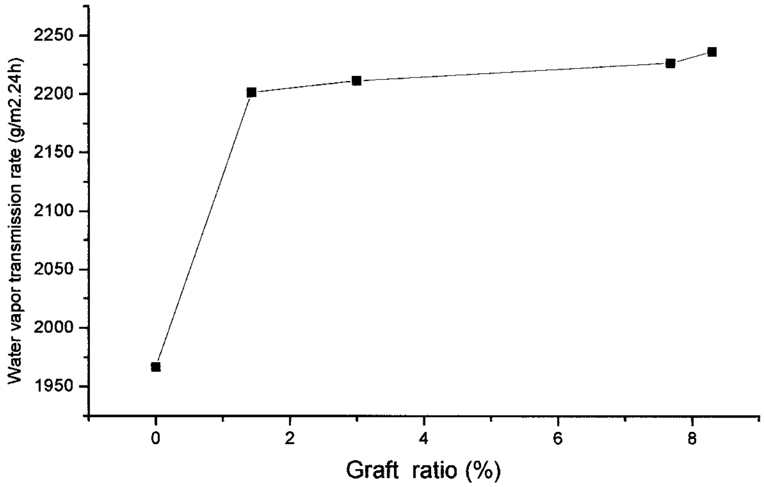

Figure 3 Effect of graft ratio on water vapor permeability.

is the so-called cooling stage with melting paraffin wax. After the metal stage was moved into the sample chamber, the chamber was closed immediately and deaerated to a desired vacuum and then water vapor was pumped into it. The saturated water vapor pressure can be adjusted according to the requirement. Temperature in the sample chamber was controlled by a temperature controller. ESEM images were obtained by scanning the sample surface with a special probe.

RESULTS AND DISCUSSION

Moisture regain

Moisture regain is a criterion evaluating the moisture-absorption ability of fibers or fabrics. Figure 2 shows the effects of graft ratio on moisture regain. It can be seen from the figure that moisture regain increases with increasing graft ratio. It is well known that the materials' moisture absorption mainly results from the interaction between the polar groups of material and water molecules in the air. The polarity of –COO$^-$ (or –COOH) in poly(acrylic acid) (PAA) is greater than that of –COO– in PET macromolecules. Thus the introduction of a PAA layer onto the fibers increases the polarity of the polyester fabrics; therefore, the AA-grafted fabrics can absorb many more water molecules. The increase of moisture regain of polyester fabrics will boost static elimination and thus improve wearing characteristics.

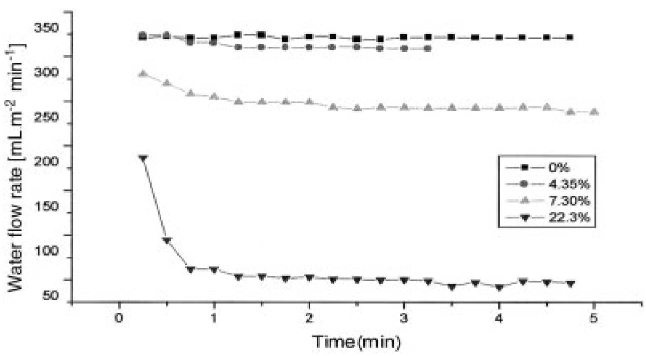

Figure 4 Effect of graft ratio on water-impermeable ability of fabrics. Water temperature, 25 ± 1°C; measurement interval, 0.25 min.

Water vapor permeability

The effect of graft ratio on water vapor permeability is illustrated in Figure 3. Water vapor permeability is an essential criterion reflecting comfort for dress fabrics. It can be seen from Figure 3 that it is improved after grafting and, the higher the graft ratio within the range of measurement, the better the water vapor permeability. Water vapor transmission is a procedure by which water vapor moves from one side of the fabric to the other, the driving force of which is the difference in humidity between the two sides of fabrics. This transmission procedure includes two components. One component is the direct transmission of vapor through the intervals between fibers and yarns. Another is an indirect component through the pickup and liberation of moisture by fibers. Thus, the fabric construction, yarn construction, and the feature of the fibers constitute essential factors that determine the water vapor permeability of fabrics. The introduction of a PAA grafting layer onto fibers decreases the size of the intervals, and thus the direct transmission of

TABLE I
The Original and Stable WFR of the AA-Grafted Fabrics with Different Graft Ratios

Graft ratio (%)	0	4.35	7.30	22.3
Original WFR (mL m^{-2} min^{-1})	320.7	324.1	280.2	186.5
Stable WFR (mL m^{-2} min^{-1})	320.7	308.9	238.0	47.9

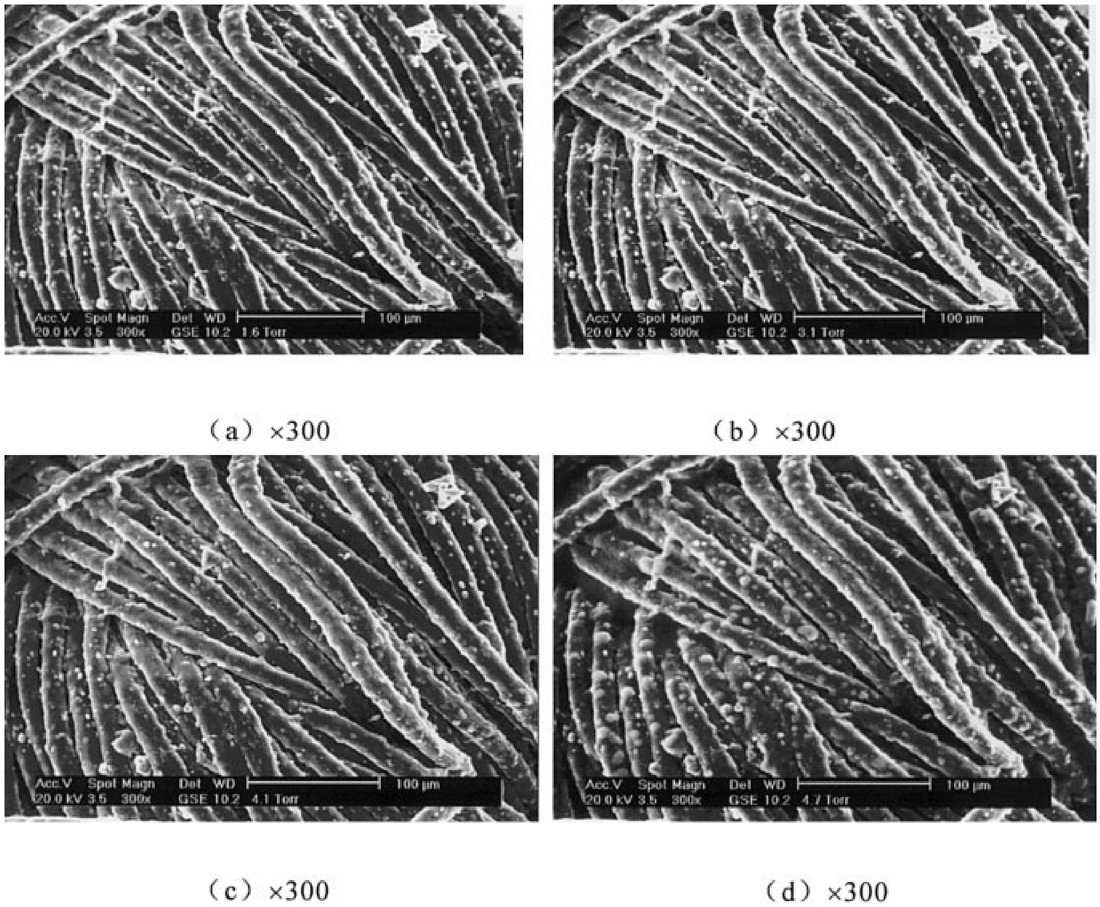

Figure 5 ESEM pictures of AA-grafted fabrics for *in situ* observation. Vapor pressure in the sample chamber: (a) 213.3 Pa; (b) 413.3 Pa; (c) 546.6 Pa; (d) 626.6 Pa. Time at which pictures were taken: (a) 0 min; (b) 0.5 min; (c) 1.5 min; (d) 2.5 min.

vapor is eliminated to some extent. However, the hydrophilic PAA layer can greatly improve the hydrophilicity of polyester fibers, such that the process of indirect transmission is accelerated and enhanced. The results of the balance of these two components are that the water vapor permeability of AA-grafted fabrics increases with increasing graft ratios.

Water-impermeable ability

The definition of water flow rate (WFR) was established earlier, that is, the volume of the water passing through fabrics with unit area in unit time (min). The definitions of original WFR and stable WFR are given here. With the continuous penetrating of the water through the fabric, the water flow rate decreases gradually and then tends to reach a constant value. This constant value is called stable WFR, and the first value obtained in each measurement is called original WFR.

Figure 4 shows the variation of WFR with time. These curves reflect obvious differences in water-impermeable ability. The curve of the original fabric is nearly a straight line, which indicates that its WFR remains almost constant. However, the situations are not the same for AA-grafted fabrics, in which WFR decreases with time. Moreover, the reduction tends to be sharp at the beginning and then lessens and levels off at the end. Especially, when the graft ratio is 22.3%, there is a sharp reduction within the first 0.75 min: the WFR decreases by 49.3% in 0.25 min and by 66.7% in 0.50 min. The WFR then varies gradually and 4.5 min later, it is close to the stable WFR, which decreases by 75.1% versus that of the original WFR. The experiments show that almost all the original WFR of AA-grafted fabrics decrease with increasing graft ratio, and the stable WFR of samples with higher graft ratios show major differences. The detailed data are listed in Table I.

The changing of WFR with time implies that the AA-grafted fabrics can interact with water and cause the microscopic construction to change. This kind of interaction occurs once the sample contacts water and reaches a balance after a certain time. The graft ratio has an essential effect on the rate and the extent of the response of the sample to water.

The changing of WFR with time can be attributed to the introduction of a grafted PAA layer onto the fibers. PAA is a kind of water-soluble polymer, so the grafted PAA layer can absorb water quickly and swell to some extent as soon as it contacts water, which reduces the intervals between fibers and yarns. That is why the WFR of the AA-grafted fabric decreases with time. The *in situ* tracing ESEM pictures (Fig. 5) directly and vividly demonstrate this mechanism. Differing from SEM, ESEM permits the presence of a low pressure of gas in the sample chamber. This means that a saturated water vapor atmosphere (up to $\sim$ 2666 Pa) can be maintained, which makes it possible to examine hydrated samples.[2] We obtained ESEM pictures of *in situ* examination that reflect how the AA-grafted fabric interacts with water. It can be seen clearly from the pictures that, with the increase of the water condensed onto the sample, both the size of the protrusions and the diameter of the fibers increase gradually; thus, the passages between fibers and yarns, for water penetration, narrow down.

CONCLUSIONS

Comparative research of the properties of original polyester fibers and AA-grafted products was carried out in this study. It was found that the moisture regain and the water vapor permeability of the fabrics increase after being grafted by AA, which could improve the comfort of cloth used for apparel. The water-impermeable ability was also greatly improved after being grafted. In particular, when the graft ratio is higher, the grafted PAA layer covering the fibers can respond to water on contact; that is, absorbing water and swelling immediately, which was demonstrated by ESEM pictures for *in situ* observation. In this way, the small intervals between fibers and yarns are instantly reduced. This kind of modified fabric has been called "intelligent fabric" because it can function the moment it encounters water and provides a novel water-impermeable ability. After this wet fabric is dried, the grafted PAA layer deswells and returns to its original condition and all of its properties remain unchanged. The perfect water vapor permeability in a dry state and a novel water-impermeable ability when in contact with water of AA-grafted fabrics make them suitable candidates for immersion-resistant layer fabrics of Type B immersion-resistant suits.

References

1. He, C.; Gu, Z. J Appl Polym Sci 2003, 89, 3931.
2. Jenkings, L.W.; Donald, A. M. Textile Res J 2000, 70, 269.