

A study on the effects of laminating temperature on the polymeric nanofiber web

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Abstract—The purpose of this study is to consider the influence of laminating temperature on nanofiber/laminate properties. Hot-press laminating was carried out at five different temperatures and nanofiber web morphology was observed under an optical microscope. Also, air permeability experiments were performed to examine the effect of laminating temperature on breathability of multilayer fabric. Optical microscope images showed that the nanofiber web began to damage when laminating temperature was selected above the melting point of adhesive layer. Air permeability decreased with increasing laminating temperature. It is also observed that the adhesive force between layers was increased by increasing laminating temperature.

Key words: Nanoscaled Polymeric Fiber, Laminating, Protective Clothing

INTRODUCTION

Nowadays, there are different types of protective clothing, some of which are disposable and non-disposable. The simplest and most preliminary of this equipment is made from rubber or plastic that is completely impervious to hazardous substances. Unfortunately, these materials are also impervious to air and water vapor, and thus retain body heat, exposing their wearer to heat stress which can build quite rapidly to a dangerous level. Another approach to protective clothing is incorporating activated carbon into multilayer fabric in order to absorb toxic vapors from the environment and prevent penetration to the skin. The use of activated carbon is considered only a short-term solution because it loses its effectiveness upon exposure to sweat and moisture. The use of semi-permeable membranes as a constituent of the protective material is another approach. In this way, reactive chemical decontaminants encapsulate in microparticles or fills in microporous hollow fibers and then coat onto fabric. The microparticle or fiber walls are permeable to toxic vapors, but impermeable to decontaminants, so that the toxic agents diffuse selectively into them and neutralize [1-3].

Generally, a negative relationship always exists between thermal comfort and protection performance for currently available protective clothing. Thus there still exists a very real demand for improved protective clothing that can offer acceptable levels of impermeability to highly toxic pollutions of low molecular weight, while minimizing wearer discomfort and heat stress.

Electrospinning provides an ultrathin membrane-like web of extremely fine fibers with very small pore size and high porosity, which makes them excellent candidates for use in filtration, membrane, and possibly protective clothing applications. Preliminary investigations have indicated that the use of nanofiber web in protective clothing structure could present minimal impedance to air permeability and extreme efficiency in trapping dust and aerosol particles. Meanwhile, it is found that the electrospun webs of nylon 6,6,

polybenzimidazole, polyacrylonitrile, and polyurethane provided good aerosol particle protection, without a considerable change in moisture vapor transport or breathability of the system. While nanofiber webs suggest exciting characteristics, it has been reported that they have limited mechanical properties. To provide suitable mechanical properties for use as cloth, nanofiber webs must be laminated via an adhesive into a fabric system. This system could protect ultrathin nanofiber web versus mechanical stresses over an extended period of time [4-6].

The adhesives could be as melt adhesive or solvent-based adhesive. When a melt adhesive is used, the hot-press laminating is carried out at temperatures above the softening or melting point of adhesive. If a solvent-based adhesive is used, laminating process could be performed at room temperature. In addition, the solvent-based adhesive is generally environmentally unfriendly, more expensive and usually flammable, whereas the hot-melt adhesive is environmentally friendly, inexpensive requires less heat, and so is now more preferred. However, without disclosure of laminating details, the hot-press method is more suitable for nanofiber web lamination. In this method, laminating temperature is one of the most important parameters. Incorrect selection of this parameter may lead to change or damage nanofiber web. Thus, it is necessary to find a laminating temperature which has the least effect on the nanofiber web.

It has been found that morphology such as fiber diameter and its uniformity of the electrospun polymer fibers are dependent on many processing parameters. These parameters can be divided into three groups as shown in Table 1. Under certain conditions, not only uniform fibers but also beads-like formed fibers can be produced by electrospinning. Although the parameters of the electrospinning process have been well analyzed in each of the polymers, this information has been inadequate enough to support the electrospinning of ultra-fine nanometer scale polymer fibers. A more systematic parametric study is hence required.

The purpose of this study is to consider the influence of laminating temperature on nanofiber/laminate properties. Multilayer fabrics were made by electrospinning polyacrylonitrile nanofibers onto nonwoven substrate and incorporating into fabric system via hot-

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Table 1. Processing parameters in electrospinning

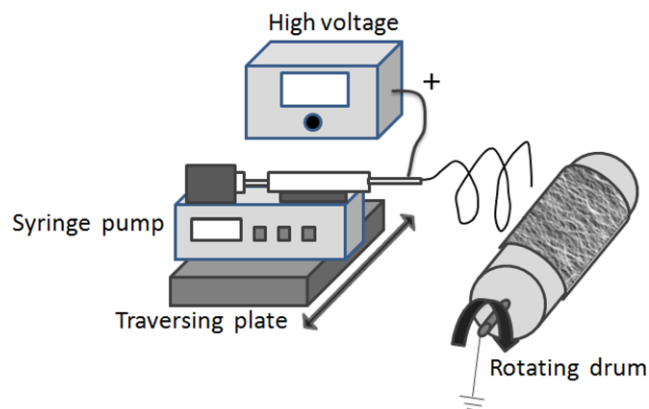
Solution properties	Viscosity
	Polymer concentration
	Molecular weight of polymer
	Electrical conductivity
	Elasticity
Processing conditions	Applied voltage
	Distance from needle to collector
	Volume feed rate
	Needle diameter
Ambient conditions	Temperature
	Humidity
	Atmospheric pressure

press method at different temperatures.

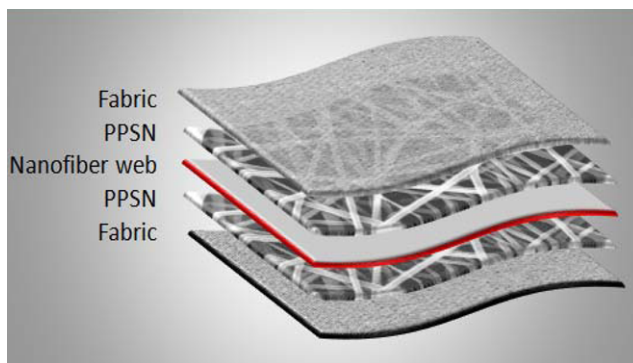
EXPERIMENTAL

1. Electrospinning and Laminating Process

Polyacrylonitrile (PAN) of 70,000 g/mol molecular weight from Polyacryl Co. (Isfahan, Iran) has been used with Dimethylformamide (DMF) from Merck, to form a polymer solution 12% w/w after stirring for 5 h and exposing for 24 h at ambient temperature. The yellow and ripened solution was inserted into a plastic syringe with a stainless steel nozzle 0.4 mm in inner diameter and then it was placed in a metering pump from WORLD PRECISION INSTRUMENTS (Florida, USA). Next, this set was installed on a plate which it could traverse to left-right along drum (Fig. 1). The flow rate 1 $\mu\text{l/h}$ for solution was selected and the fibers were collected on an aluminum-covered rotating drum (with speed 9 m/min) which was previously covered with a polypropylene spun-bond nonwoven (PPSN) substrate of 28cm 28cm dimensions; 0.19 mm thickness; 25 g/m² weight; 824 cm³/s/cm² air permeability and 140 °C melting point. The distance between the nozzle and the drum was 7 cm and an electric voltage of approximately 11 kV was applied between them. Electrospinning process was carried out for 8 h at room temperature to reach approximately web thickness 3.82 g/m². Then nanofiber webs were laminated into cotton weft-warp fabric with a thickness 0.24 mm and density of 25 \times 25 (warp-weft) per centimeter to

**Fig. 1. Electrospinning setup.**

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**Fig. 2. Multilayer fabric components.**

form a multilayer fabric (Fig. 2). Laminating was performed at temperatures 85, 110, 120, 140, 150 °C for 1 min under a pressure of 9 gf/cm².

2. Nanofiber Web Morphology

To consider nanofiber web morphology after hot-pressing, another laminating was performed by a non-stick sheet made of Teflon (0.25 mm thickness) instead one of the fabrics (fabric/pp web/nanofiber web/pp web/non-stick sheet). Finally, after removing of Teflon sheet, the nanofiber layer side was observed under an optical microscope (MICROPHOT-FXA, Nikon, Japan) connected to a digital camera.

3. Measurement of Air Permeability

Air permeability of multilayer fabric after lamination was tested by TEXTEST FX3300 instrument (Zürich, Switzerland). Five pieces of each sample were tested under air pressure 125 pa at ambient condition (16 °C, 70%RH) and average air permeability was obtained.

RESULTS AND DISCUSSION

PPSN was selected as melt adhesive layer for hot-press laminating (Fig. 2). This process was performed under different temperatures to find an optimum condition. Fig. 3 presents the optical microscope images of nanofiber web after lamination. It is obvious that by increasing of laminating temperature to melting point (samples a-c) the adhesive layer gradually melts and spreads on the web surface. But, when melting point was selected as the laminating temperature (sample d) the nanofiber web began to be damaged. In this case, the adhesive layer completely melted and penetrated into nanofiber web and occupied its pores. This procedure was intensified by increasing of laminating temperature above the melting point. As shown in Fig. 1 (sample e), perfect absorption of adhesive by nanofiber web creates a transparent film which leads to appear as fabric structure.

Also, to examine how laminating temperature affects the breathability of multilayer fabric, an air permeability experiment was performed. Fig. 4 indicates the effect of laminating temperature on air permeability. As might be expected, air permeability decreased with increasing laminating temperature. This behavior is attributed to the melting procedure of the adhesive layer. As mentioned above, before the melting point the adhesive gradually spreads on the web surface. This phenomenon causes the adhesive layer to act like an impervious barrier to air flow and reduces air permeability of a mul-

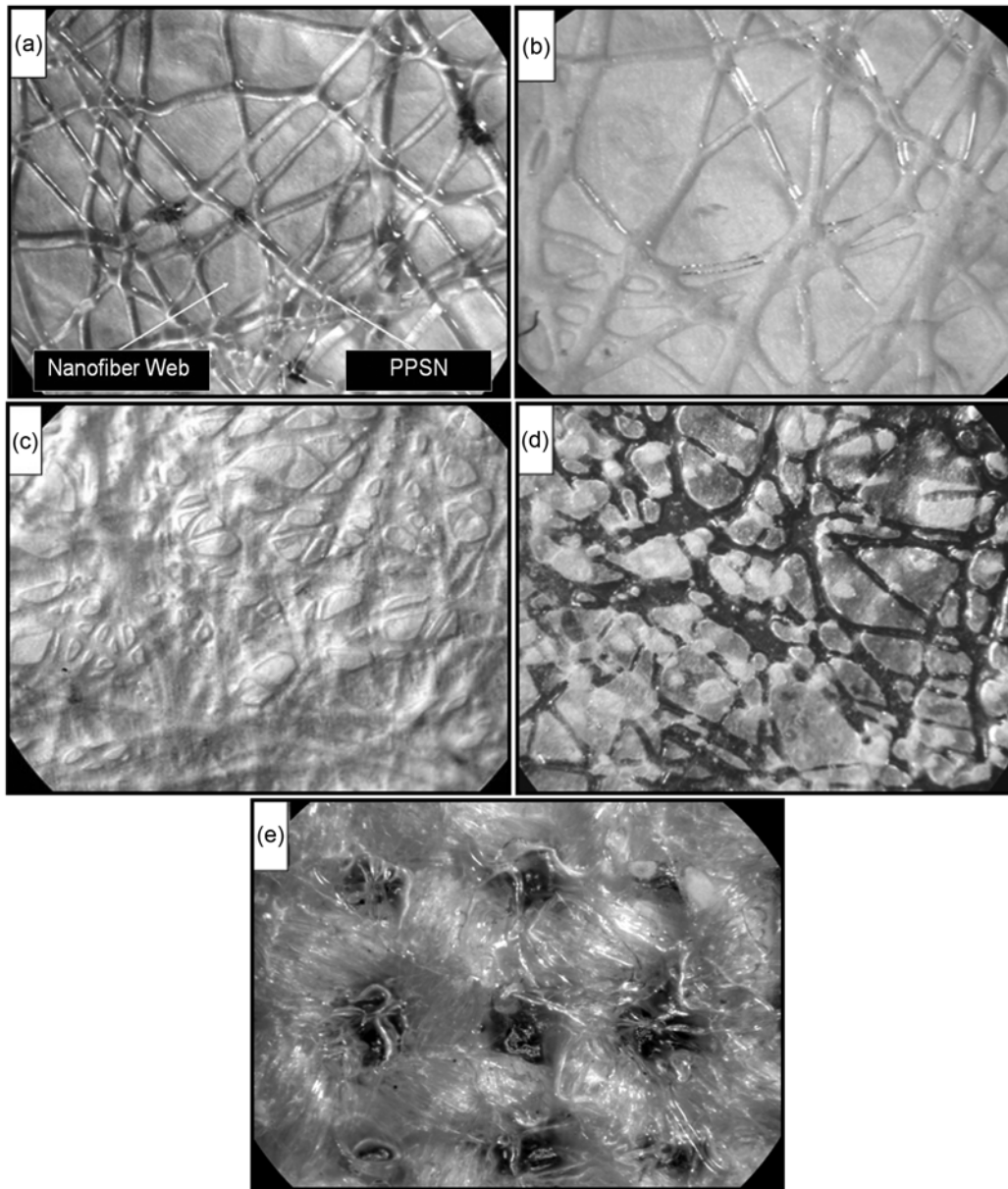


Fig. 3. The optical microscope images of nanofiber web (at 100 magnification) after laminating at (a) 85 °C, (b) 110 °C, (c) 120 °C, (d) 140 °C and (e) >140 °C.

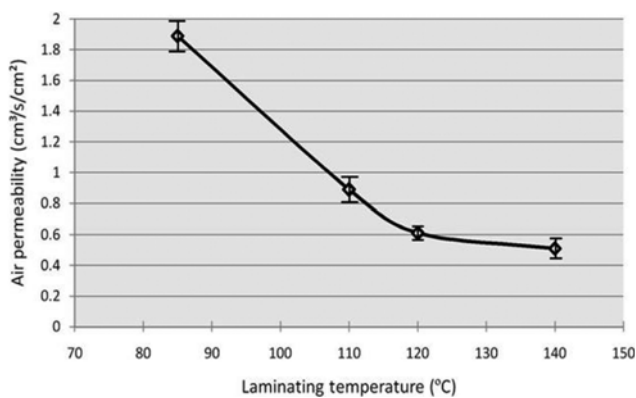


Fig. 4. Air permeability of multilayer fabric as a function of laminating temperature.

tilayer fabric. But at the melting point and above, the penetration of melt adhesive into nanofiber/fabric structure leads to filling its pores and finally a decrease in air permeability.

Furthermore, we only observed that the adhesive force between layers was increased according to temperature rise. Sample (a) exhibited very poor adhesion between nanofiber web and fabric and it could be separated by light abrasion of the thumb, while adhesion increased by increasing laminating temperature to melting point. It must be noted that after the melting point because of passing of melt PPSN across nanofiber web, adhesion between two layers of fabric will occur.

CONCLUSION

The effect of laminating temperature on nanofiber/laminate prop-

erties was investigated to make next-generation protective clothing. First, surface images of nanofiber web after lamination were taken using an optical microscope in order to consider morphology changes. It was observed that the nanofiber web remains unchanged as laminating temperature is below PPSN melting point. In addition, to compare breathability of laminates, air permeability was measured. It was found that by increasing laminating temperature, air permeability was decreased. Furthermore, it only was observed that the adhesive force between layers in laminate was increased with temperature rise.

These results indicate that laminating temperature is an effective parameter for lamination of nanofiber web into fabric structure. Thus, varying this parameter could lead to developing fabrics with different levels of thermal comfort and protection depending on our need and use.

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