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Study on the production of a new generation of electrospun nanofiber webs

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Electrospun nanofiber web has many potential applications due to its large specific area, very small pore size and high porosity. Despite such potentials, the mechanical properties of nanofiber web are very poor for use in textile application. To remedy this defect, a lamination process could be accomplished in order to protect nanofiber web *versus* mechanical stress. However, nanofiber properties may change during the process. The purpose of this study is to consider the influence of lamination temperature on nanofiber/laminate properties. Hot-press lamination 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 lamination temperature on the breathability of a multilayer fabric. Optical microscope images showed that the nanofiber web began to damage at lamination temperatures above the melting point of the adhesive layer. Air permeability decreased with increasing the lamination temperature. The adhesive force between layers increased by increasing the lamination temperature.

Keywords: Nanofiber, lamination, protective clothing

INTRODUCTION

Clothing is a person's second skin, since it covers large parts of the body and has a large surface area in contact with the environment. Therefore clothing is a proper interface between environment and the human body, and could act as an ideal tool to enhance personal protection. Over the years, growing concern regarding health and safety of persons in various sectors, such as industries, hospitals, research institutions, battlefields and other hazardous conditions, has led to intensive research and development in the field of personal protective clothing. Today, there are different types of protective clothing, both disposable and non-disposable. The simplest and earliest specimens of this equipment have been made of 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 to incorporate activated carbon into a multilayer fabric in order to absorb toxic vapors from the environment and prevent penetration to the skin [1]. 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 are encapsulated in microparticles [2] or filled in microporous hollow fibers [3] and coated 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.

Generally, a negative relationship always exists between thermal comfort and protection performance for currently available protective clothing. Thus there still exists a 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 using of nanofiber web in protective clothing structure could present minimal impedance to air permeability and extreme efficiency in trapping dust and aerosol particles [4-6]. Many researchers have shown an enhancement of aerosol protection by a thin layer of electrospun

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fibers. They found that the electrospun webs of nylon, 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 offer exciting characteristics, it has been reported that they have limited mechanical properties. In order to provide suitable mechanical properties for use as a cloth, nanofiber webs must be laminated using an adhesive into the fabric system [7,8]. This system could protect ultrathin nanofiber web *versus* mechanical stress over an extended period of time.

The adhesives could be in the form of melt adhesive or solvent-based adhesive. When a melt adhesive is used, hot-press lamination is carried out at temperatures above the softening or melting point of the adhesive. If a solvent-based adhesive is used, the lamination 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 is now preferred. Lee *et al.* [9], without disclosure of lamination details, reported that the hot-press method is more suitable for nanofiber web lamination. In this method, lamination temperature is one of the most important parameters. Incorrect selection of this parameter may lead to change or damage of the nanofiber web. Thus, it is necessary to find out a lamination temperature which has the least effect on the nanofiber web.

The purpose of this study was to consider the influence of the lamination temperature on nanofiber/laminate properties. Multilayer fabrics were made by electrospinnig polyacrylonitrile nanofibers onto nonwoven substrate and incorporating into fabric system *via* hot-press method at different temperatures.

EXPERIMENTAL

Electrospining and Laminating process

Polyacrylonitrile (PAN) of 70,000 g/mol molecular weight from Polyacryl Co. (Isfehan, Iran) was used with dimethylformamide (DMF) from Merck, to form a 12% w/w polymer solution after stirring for 5 h and exposing for 24 h at ambient temperature. The yellow 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).

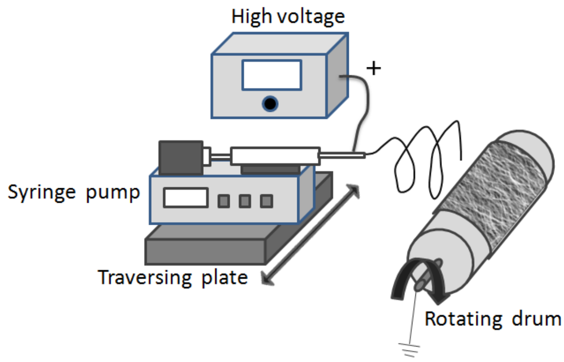

Fig.1. Electrospinning setup

A flow rate of 1 µl/h for the solution was selected and the fibers were collected on an aluminum-covered rotating drum (with speed of 9 m/min) previously covered with a polypropylene spun-bond nonwoven (PPSN) substrate of 28cm×28cm dimensions; 0.19 mm thickness; 25 g/m^2 weight; 824 cm^3/s/cm^2 air permeability and 140ºC melting point. The distance between the nozzle and the drum was 7 cm and an electric voltage of approximately 11kV was applied between them. The electrospinning process was carried out for 8 h at room temperature to reach an approximate web thickness of 3.82 g/m². Then the nanofiber webs were laminated into cotton weft-warp fabric with a thickness of 0.24 mm and density of 25×25 (warp-weft) per centimeter to form a multilayer fabric (Fig.2).

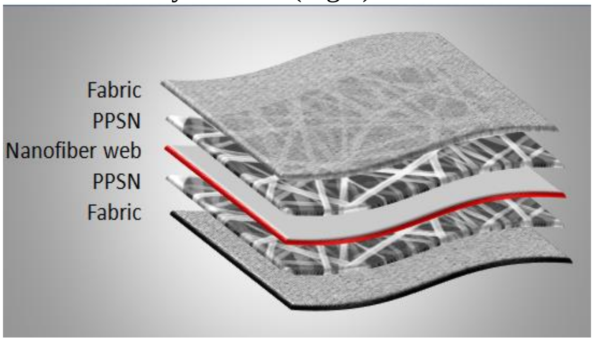

Fig. 2. Multilayer fabric components

Lamination was performed at temperatures of 85,110,120,140 and 150°C for 1 min under a pressure of 9 gf/cm^2.

Nanofiber Web Morphology

In order to consider nanofiber web morphology after hot-pressing, another lamination 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 the Teflon sheet, the nanofiber layer side was observed under an optical microscope (MICROPHOT-FXA, Nikon, Japan) connected to a digital camera.

Measurement of Air permeability

Air permeability of the multilayer fabric after lamination was tested on a TEXTEST FX3300 instrument (Zürich, Switzerland). Five pieces of each sample were tested under air pressure of 125pa at ambient conditions (16ºC, 70% RH).

RESULTS AND DISCUSSION

PPSN was selected as the melt adhesive layer for hot-press lamination (Fig.2). This process was performed at different temperatures in order to find the optimum conditions. Fig. 3 presents the optical microscope images of the nanofiber web after lamination.

It is obvious that on increasing the lamination temperature to the melting point (samples a-c), the adhesive layer gradually melts and spreads on the web surface. When the melting point was selected as lamination temperature (sample d), the nanofiber web began to damage. In this case, the adhesive layer completely melted, penetrated into the nanofiber web and occupied its pores. This procedure was intensified by increasing the lamination temperature above the melting point. As shown in Fig. 2 (sample e), perfect absorption of the adhesive by the nanofiber web creates a transparent film which leads to appear fabric structure.

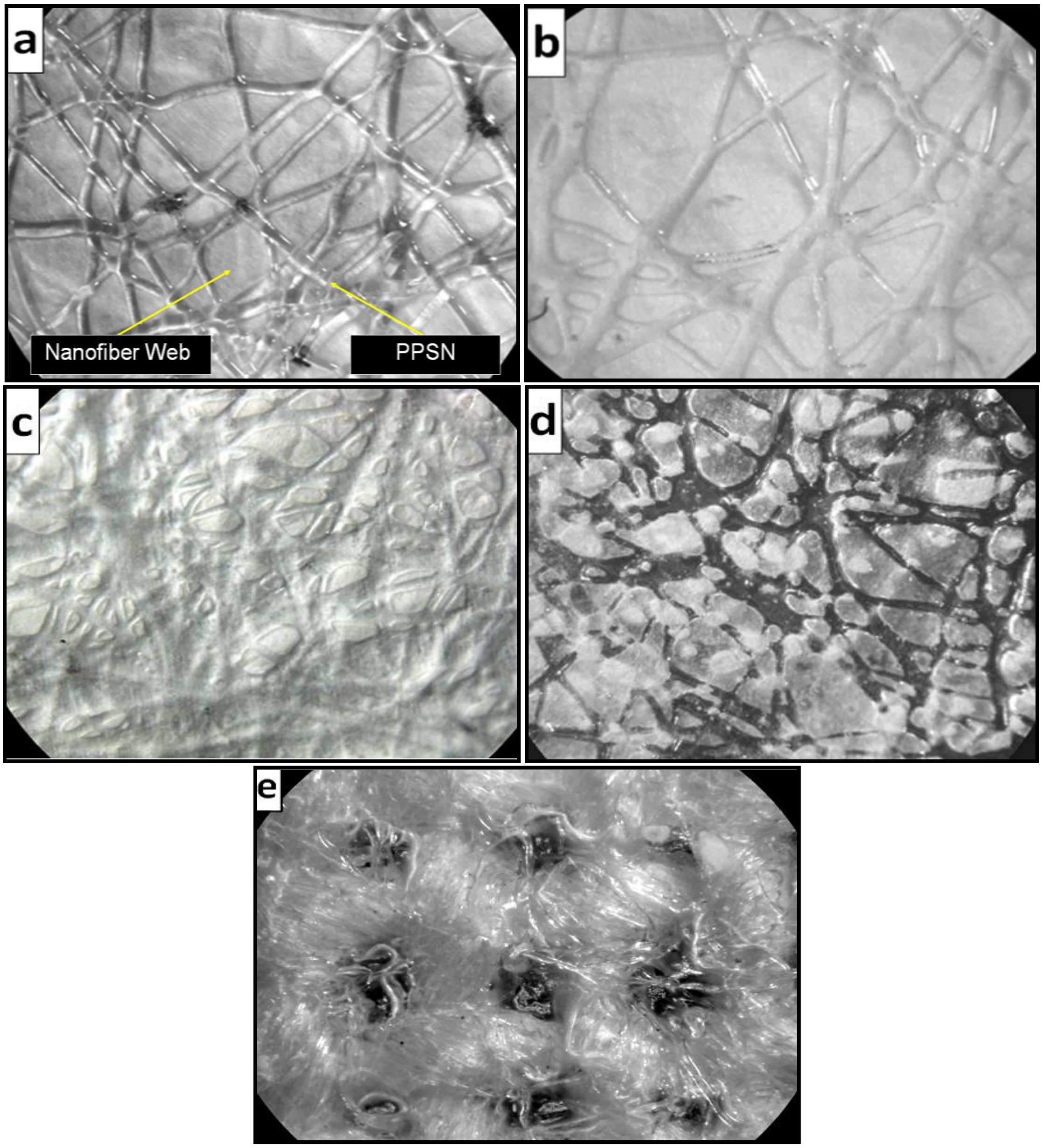

Fig. 3. Optical microscope images of nanofiber web (at 100× magnification) after lamination at (a) 85ºC, (b) 110ºC, (c) 120ºC, (d) 140ºC and (e) >140ºC.

Also, to examine how lamination temperature affects the breathability of a multilayer fabric, air permeability experiment was performed. Fig. 4 illustrates the effect of lamination temperature on air permeability. As might be expected, air permeability decreased with increasing lamination temperature.

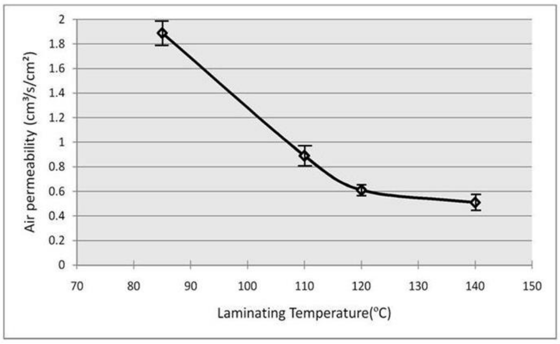

Fig. 4 . Air permeability of a multilayer fabric as a function of lamination temperature.

This behavior was attributed to the melting of the adhesive layer. As mentioned above, prior to the melting point, the adhesive gradually spreads on the web surface. This phenomenon causes that the adhesive layer acts like an impervious barrier to air flow and reduces air permeability of the multilayer fabric. At the melting point and above, the penetration of melt adhesive into the nanofiber/fabric structure fills its pores and finally decreases its air permeability.

Furthermore, we observed that the adhesive force between the layers increased according to the temperature rise. Sample (a) exhibited very poor adhesion between the nanofiber web and the fabric: it could be separated by slight abrasion with the thumb. Adhesion increased by increasing the lamination temperature to the melting point. It should be noted that above the melting point, because of melt PPSN passing across the nanofiber web, adhesion between two layers of fabric will occur.

CONCLUSION

In this study, the effect of lamination temperature on the nanofiber/laminate properties was investigated with a view to the elaboration of a new generation of protective clothing. First, surface images of nanofiber web after lamination were taken using optical microscope in order to consider morphology changes. It was observed that the nanofiber web remains unchanged when the lamination temperature is below the PPSN melting point. In addition, to compare breathability of laminates, air permeability was measured. It was found that by increasing the lamination temperature, air permeability decreased. Furthermore, it was observed that the adhesive force between layers in laminate increased with temperature rise.

These results indicated that lamination temperature is an effective parameter in the lamination of a nanofiber web into fabric structure. Thus, by varying this parameter fabrics with different levels of thermal comfort and protection could be developed depending on need and use.

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ИЗСЛЕДВАНЕ ВЪРХУ ПОЛУЧАВАНЕТО НА НОВО ПОКОЛЕНИЕ ТЪКАНИ ОТ ЕЛЕКТРОПРЕДЕНИ НАНОВЛАКНА

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(Резюме)

Електропредените нановлакна има много потенциални приложения поради голямата си специфична повърхност, малките размери на порите и голямата си порьозност. Въпреки тези възможности механичните им свойства са лоши за приложението им като текстил. За намаляването на този ефект и защитата на тъканите от нановлакна срещу механични напрежения може да се приложи ламинирането. Целта на тази работа е да се изследва влиянието на температурата на ламиниране върху свойствата на нановлакната. Извършено е ламиниране на при горещо пресуване и е наблюдавана морфологията на тъканите под оптичен микроскоп. Освен това са извършени експерименти по въздухопроницаемостта, за да се проучи ефекта на температурата на ламиниране върху проницаемостта на многослойни тъкани. Микроскопските образи показват, че тъканите от нановлакна започват да се повреждат, когато температурите на ламиниране са над точката на топене на адхезивния слой. Въздухопроницаемостта намалява с повишаването на температурата на ламиниране. Освен това бе наблюдавано, че адхезионната сила между слоевете нараства с повишаването на температурата на ламиниране.