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Manufacturing process and property analysis of industrial flame retarded PET fiber and polyurethane composite

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Abstract

Nonwovens are manufactured with a fast and low-cost process and are used extensively for clothing, transportation, building, upholstery and medical applications. Thus, the issue of safety while using nonwovens becomes more and more significant. In this paper, we discuss the manufacturing process of flame retarded nonwovens by PET flame retarded hollow fiber and PET low melting point fiber. Polyurethane foam was coated between two nonwoven sheets to construct a sandwich structure. The weight ratio of the PET low melting point fiber in the nonwoven sheet was changed to evaluate its limit oxygen index (LOI). And the thermal conductivity of industrial flame retarded PET fiber and polyurethane composites was estimated by the Taguchi method. The parameters included in the Taguchi method were the needle punching density of the nonwoven sheets, the fineness of the flame retarded PET hollow fiber, the weight ratios of PET low melting point fiber and the thickness of polyurethane foam. Follow-up results of the Taguchi method were obtained in this research; extra specimens were prepared with varying thickness of the polyurethane foam to demonstrate the accuracy of the Taguchi method.

Keywords: Nonwoven; Polyester; Thermal insulation; Taguchi method

1. Introduction

The resources of the earth were exploited excessively for meeting the human requirements; thus result in the energy saving was valued as the one of the important problems of this century. Hence, seeking and providing a beneficial method for energy savings is a significant subject for safeguarding the human future. Thermal insulation is a major contributor for achieving energy efficiency and reducing energy cost. It retards the rate of heat flow by conduction, convection, and radiation and it also retards heat flow into or out of the thermal transfer mechanism due to its high thermal resistance [1]. Most thermal insulations in engineering applications were used for covering or capping the system to attain the energy conserved and maintain the temperature of the system. If early and accurate design decisions are made regarding the development and integration of the thermal insulation, a thermal engineer can contribute to solving the energy problem [4].

In other words, the secure subject of the material of thermal insulation application in operating process has gained importance today. Especially in the prevention of fire accident, because polymers were used for thermal insulations extensively and they did not flame retard and were usually inflammable. Therefore, in the developing process of thermal insulation materials, we should value the fire preventive aspects of in the material of applications.

2. Principle

2.1. The principle of needle punching

The principle of the needle punching process is based on subjecting a web to the needle punching machine in the effect of needles oscillating in vertical, slanting or both directions to the surface of the web. As the needles penetrate the web, their barbs or grooves catch the fibers and draw them in a vertical

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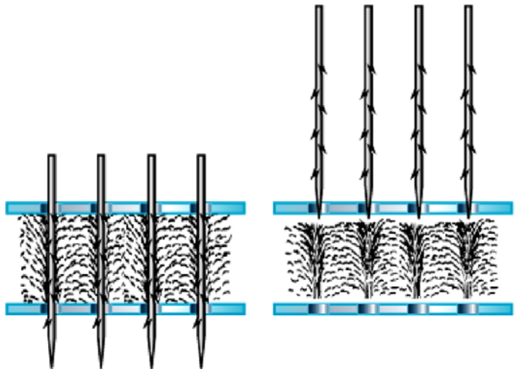

Fig. 1. Barbs of the needles catch the fiber and draw them in a vertical direction through the thickness of the web.

or slanting direction through the thickness of the web. Thus the areal strength of the web can be achieved. The diagram of the needle punching is showed in Fig. 1.

2.2. The principle of thermal bonding

Adhesives of solid thermoplastics through heating and/or pressure application were transformed into a viscous liquid phase immediately upon made contact with the fiber web. Thus when the temperature of the fiber web was reinstated, the thermoplastic would solidify and reinforce the structure of nonwovens. The diagram of the bonding structure is showed in Fig. 2.

2.3. Thermal conductivity

Thermal conductivity is the time rate of steady state heat flow (*W*) through a unit area of 1 m thick homogeneous material in a direction perpendicular to isothermal planes, induced by a unit (1K) temperature difference across the sample [2]. Thermal conductivity, *k*-value, is expressed in W/m-K (Btu/h-ft-F or Btu-in/hrft 2-F). It is a function of material mean temperature and moisture content. Thermal conductivity is a measure of the effectiveness of a material in conducting heat. Hence, knowledge of thermal conductivity values allows quantitative comparison to be made between the effectiveness of different thermal insulation materials.

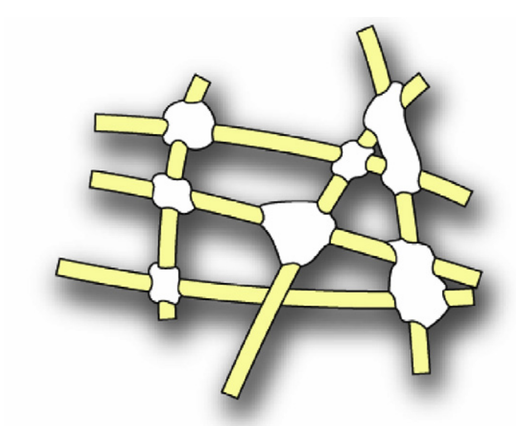

Fig. 2. Diagram of the bonding structure.

3. Taguchi analytical methodology

Taguchi method is a powerful tool in designing high-quality systems. It provides an efficient, systematic approach that optimizes designs for superior performance and quality. Additionally, the Taguchi parameter design can also optimize performance through establishing design parameters and reducing system performance sensitivity to variation sources.

A typical application of the Taguchi's method includes three parameter designation steps. The first step clarifies the dominant parameters within more than five factors, which are mutually interactive. Typically, this step requires 18 groups of samples to approach the Taguchi's criteria. However, the second step, based on recommendations from the first step, revises dominant parameter concentrations. This step is performed to ensure the precise concentration thereof, while retaining the characteristics of mixed factors. Thus, in the second step, fine-tuning of quantities for the various parameters is more vital than determining the dominant parameters of the sampling process. Moreover, in contrast to the 18 sample groups in the previous step, there are 9 sample groups in this step. The third step is the last step which verifies the sample process evaluation and produces a more accurate quantity of interested parameters than those produced if only the recommendations of the first step were adhered to.

3.1. Orthogonal arrays

Four conditions, fineness of the PET hollow fiber in the nonwoven sheets, needle punching density of the nonwoven sheets, the weight ratio of the PET low melting point fiber in the nonwoven sheets and thickness of the polyurethane foam layers, as declared previously as four dominant parameters in thermal insulation composites, and each condition in the thermal insulation as three distinct levels are shown in Table 1. Thus, a total of 81 ($3 \times 3 \times 3 \times 3$) combinations were formed. According to Taguchi's method, the samples could be organized into L_9 (3^4) orthogonal array. Table 2 displays the arrangement of the samples into the nine groups. The numbers indicate the experimental layout or concentrations of the distinct factors. Alternately, Table 2 displays the manipulation of samples, which exactly followed the Taguchi's suggestion. As indicated in the

Table 1
Details of factors A–D

A	Fineness of the PET hollow fiber (den)		
	1	2	3
	7	12	15
B	Needle punching density (needles/cm^2)		
	1	2	3
	75	150	225
C	PET low melting point fiber (wt%)		
	1	2	3
	10	30	50
D	Thickness of the polyurethane foam (mm)		
	1	2	3
	7	10	15