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ORIGINAL ARTICLE

An investigation into sound transmission loss by polypropylene needle-punched nonwovens

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Taguchi method

Abstract In this work, the effects of variables such as initial carded web mass, needle penetration depth, punch density, and the frequency of incident sound wave on transmission of sound through polypropylene needle-punched nonwovens were investigated. Fibrous carded webs using commercially available 17 dtex, 90 mm staple length polypropylene fibers were prepared with different mass per unit area using carding machine. Samples were needled at various punch-densities and needle penetration depths were produced. Design points of experiments were set up using Taguchi experimental design method. Sound transmission loss (STL) of needled samples was measured using an impedance tube equipped with four microphones. Minitab software was used to analyze the sound transmission ability of the samples. Results indicated that all of the considered controllable factor have significant effects on STL values determined for the needled nonwovens. Also, initial carded web mass was found to be the most influential factor affecting sound transmission through the samples. It was concluded that an increase in thickness of the samples as well as mass per unit area of nonwovens results in higher sound transmission loss by the samples.

1. Introduction

Use of sound insulation in automobiles is of particular importance even in low cost vehicles. Sound insulation in vehicles can be measured by active and passive techniques. The former is based on wave interference phenomenon and the latter uses acoustic materials to dampen the incident sound waves [1]. Textile materials due to their inherent porosity and low-cost are ideal candidate for sound insulation. Nonwoven structures due to their technical and economical merits are currently used to make over 40 various parts of vehicles that include trunk liners, carpets and filters [2,3]. Good performance and safety, engineered nonwovens incorporating inherent essential properties, performance and safety provide advanced insulation.

Acoustic properties of nonwoven structures are related to geometry of constituent fibers and their orientation within the fibrous structure [4]. Like other surfaces upon incident of sound wave on surfaces of nonwovens, the incident wave is partly reflected, absorbed and transmitted [5].

Measurement of sound absorption by porous materials can be achieved by following methods [3,4]:

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(1) Reverberant field
(2) Free field
(3) Impedance tube

The impedance tube method equipped with two microphones is an effective and inexpensive means which is commonly used to measure both sound absorption and sound reflection coefficients of the barrier material [6–11].

Most of studies conducted so far have focused on absorption of sound by nonwoven materials using two microphone impedance tube. Research on transmission as well as insulation of sound by nonwovens is scarce. In case of highly porous material with low flow resistivity, four microphone systems are preferred over two microphone system which usually is used for determination of absorbed component of sound wave. The sound insulation ability of materials is generally determined in terms of transmitted component of sound wave. Sound Transmission Loss (STL) represents the amount of sound, in decibels (dB) that is isolated by a material or partition in a particular octave band. It can be measured using impedance tube equipped with four microphones.

Lee and Kim [12] studied sound absorption behavior and sound transmission loss (STL) of composite structures. A composite sheet was fabricated by hot-pressing the sandwiched polypropylene and polyethylene terephthalate nonwovens. The sound transmission loss of a nonwoven composite containing the activated carbon fiber and cotton was studied in another investigation [13]. Sengupta [14] predicted sound transmission loss of jute needle-punched nonwovens in terms of punch density, depth of needle penetration and mass per unit area by developing a statistical model, based on central composite rotatable experimental design.

This study undertakes the effect of different processing parameters such as carded web mass, needle penetration depth, punch density and also sound frequency on the sound transmission loss of needled polypropylene nonwovens, using Taguchi method. Sound transmission loss through the nonwoven samples was measured using impedance tube equipped with four microphones. Using Taguchi experimental design, the effect of the particular controllable parameters on sound transmission loss of the samples was determined.

2. Materials and methods

2.1. Samples preparation

Processing parameters such as initial carded web mass, needle penetration depth and punch density were selected for consideration. Staple 17 dtex, 90 mm melt-spun polypropylene fibers at a crimp frequency of 3 crimp/cm were used to produce the needled samples of nonwovens. Initial carded webs of 200, 300 and 400 g/m^2 were prepared using a laboratory carding machine. The laboratory carding specification is listed in Table 1. The carded batts were needled using a laboratory needling machine equipped with 60×10 cm needle board and Groz-Backert felting needles type: G, $15 \times 18 \times 32 \times 3$. The needle-punched samples were produced at punch densities of 30, 60 and 90 ($punch/cm^2$) at 5, 10 and 15 (mm) needle penetration depth. Nine circular needle-punched samples (Diameter = 113 mm) prepared using Taguchi experimental design are shown in Table 2.

Table 1 Laboratory carding machine specification.

Parameters	Value
Machine width	100 cm
Feeding roller diameter	5 cm
Cylinder diameter	40 cm
Doffer roller diameter	27 cm
Feeding roller linear speed	0.28 cm/s
Take up roller linear speed	3.97 cm/s

Table 2 Taguchi experimental design and details of variation levels for each controllable parameter.

Trial	Carded web mass (g/m^2)	Punch density ($punch/cm^2$)	Needle depth (mm)	Frequency (Hz)	Measured STL
1	200	30	5	500	0.47
2	200	30	5	1000	0.48
3	200	30	5	1600	0.6
4	200	60	10	500	0.5
5	200	60	10	1000	0.51
6	200	60	10	1600	0.62
7	200	90	15	500	0.4
8	200	90	15	1000	0.39
9	200	90	15	1600	0.51
10	300	30	10	500	0.59
11	300	30	10	1000	0.63
12	300	30	10	1600	0.81
13	300	60	15	500	0.67
14	300	60	15	1000	0.71
15	300	60	15	1600	0.88
16	300	90	5	500	0.49
17	300	90	5	1000	0.5
18	300	90	5	1600	0.62
19	400	30	15	500	0.71
20	400	30	15	1000	0.76
21	400	30	15	1600	0.96
22	400	60	5	500	0.66
23	400	60	5	1000	0.71
24	400	60	5	1600	0.89
25	400	90	10	500	0.72
26	400	90	10	1000	0.78
27	400	90	10	1600	0.98

2.2. Experimental design

Design points of experiments were set up using Taguchi experimental design method [10]. In this method a target value for measuring the process response based on the loss function concepts should be defined. This is followed by selection of design parameters that affect process objective and their specified number of variation levels. According to the number of selected parameters and their variation levels, a proper orthogonal array is determined. The trials as indicated in Taguchi orthogonal array table are performed and data of the process response are collected. Eventually, the effect of the different parameters on the process response is analyzed.

Analysis is based upon ratio of signal to noise (SN), which in fact compares the level of a desired signal with the level of background noise. This ratio refers to the amount of noise in