The Influence of Fiber Crimp on Acoustic Performance of Polypropylene Fibrous Batts

Mohsen Panahi, Hossein Tavanai and Mohammad Zarrebini

Abstract— **This paper reports on the effect of fiber crimp frequency on sound absorption capability of staple polypropylene nonwoven batts. Stuffer box was used to impart crimp to spun tow. Crimping of the tow renders the fibers the required textile applicability. In this work, polypropylene batts composed of staple fibers with linear densities of 9, 14, and 18 denier were employed. Three crimp frequency namely low, medium and high were imparted to fibers of each denier group. Impedance tube method with sound frequencies in the range of 250 – 4000 Hz was employed to measure the sound absorption coefficient of the batts. The results showed sound absorption properties of fibrous batts were affected by fiber crimp frequency, fiber fineness and web thickness. The highest sound absorption coefficient for the 9, 14 and 18 denier batts was 78.90, 77.14 and 71.18, respectively. The crimp frequency of the fibers making these batts was 1.9, 2.3 and 3.6 crimp per cm, respectively. It was found that higher crimp frequency along the fibers of the batts lead to higher sound absorption capacity. Finally, the highest sound absorption coefficient was recorded for the web with finest fibers and highest crimp frequency.**

Keywords: Crimp, sound absorption, polypropylene staple fiber, fibrous batt, fiber fineness.

I. INTRODUCTION

Synthetic fibers usually suffer from very low moisture absorption and low heat insulation ability. Imparting crimp to the fibers, improves these properties through entrapping air in voids made available by crimping. Crimping is carried out by stuffer box for almost all types of synthetic fiber tows before being converted to staple fibers. Crimp frequency affects the properties of the final product greatly. As loose non-woven fibrous batts are finding increasing application as sound and heat insulation in industries like car making and civil engineering, the aim of this project was to investigate the effect of crimp frequency of staple polypropylene fibers on the sound absorption of batts produced from them.

Sound absorption by fiber assemblies is not only important from noise pollution control point of view, but also from the viewpoint of controlling sound reflection in closed spaces. Apart from the social aspects, the hazards of noise pollution are well-documented [1]. As the interactions between sound waves and materials is similar to that of light waves, phenomena like reflection, refraction, diffraction, interference and absorption also occur when sound waves impinge materials. Sound absorption by materials can be measured by methods such as impedance tube, reverberant field, and steady state methods [2]. The impedance tube is fast and enjoys good repeatability [3]. This method can operate with either, one movable microphone (standing wave) or two fixed microphones. The sound absorbing performance of materials can be expressed by absorption coefficient, reflection coefficients, as well as acoustic impedance or propagation constant [2]. In this research, impedance tube was used to measure the sound absorption coefficient of the samples. Factors like fiber fineness, fiber cross-sectional shape, fiber tortuosity in web, web porosity, web compression and web thickness are reported to be significant in sound absorption of fibrous batts. Koizumi et al. [4] have reported that finer bamboo natural fibers exhibit higher sound absorption coefficient. This has been related to the higher total area available to sound waves by the finer fibers. Narang et al. [5] obtained a good correlation between specific surface area of polyester fibers and sound absorption. They also showed the superiority of profile fibers over round cross-section fibers in sound absorption. Hur et al. [6] found that finer fiber with higher fiber-fiber friction improves sound absorption of fibrous assemblies. Shahani et al. [7] also found that sound absorption capability of fiber assemblies increases with increasing fiber fineness. Ebrahim et al. [8] showed that at low frequencies, increasing the thickness of fibrous material leads to higher sound absorption. Fahy and Walker [9] as well as Ver and Beranek [10] have reported that flow resistance, porosity, air permeability,

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and tortuosity have the greatest impact on the acoustic performance of textile materials.

Despite extensive research on the influence of nonwoven parameters such as fiber fineness, fiber cross-section geometry, thickness, punch density and needle penetration depth, to the best of authors' knowledge there is no published scientific work covering the scope of fiber crimp effect on sound absorption of fibrous assemblies. Therefore, this work investigated the sound absorption property of fibrous batts composed of polypropylene fibers with fineness of 9, 14, and18 denier in terms of crimp frequency of their constituent fibers.

II. Experimental

Polypropylene tows were produced on an industrial scale melt spinning line (P.F.E, England) with deniers of 9, 14, and 18. Each tow was crimped at three frequencies of low, medium and high by the stuffer box positioned at the end of the spinning line just before the Lumus cutter. Crimp frequencies were obtained adjusting the pressure inside the stuffer at minimum, half and maximum levels of allowable setting. Nine lots of staple fibers as shown in Table I were prepared at staple length of 10 cm on the Lumus rotary cutter. Analysis of variance (ANOVA, P= 0.01) confirmed the statistical significance of the difference between the three crimp frequency levels of the samples of 9, 14 and 18 denier. Crimp frequency of the fibers was measured prior to carding. Considering the thermoplasticity of polypropylene, it was assumed that fiber crimp remained unaltered due to carding operation.

TABLE I
CRIMP FREQUENCY (CRIMP/CM) OF POLYPROPYLENE FIBERS

Denier = 9			Denier = 14			Denier = 18		
LF	MF	HF	LF	MF	HF	LF	MF	HF
1.2 (5.2)	1.5 (4.8)	1.9 (4.9)	1.3 (14.7)	1.8 (8.4)	2.3 (6.1)	2.5 (11.4)	2.9 (4.6)	3.6 (12.7)

Number in the brackets shows the coefficient of the variation
HF = high frequency
MF = medium frequency
LF = low frequency

A laboratory-carding machine (Autefa MAK, Poland) was employed to produce the primary carded web. The primary batts were put on top of each other carefully to produce thicker batts of 500 g/m^2. Weight wise similar Samples of 10cm × 10cm with a thickness of 10 mm were cut from the layered carded batt. Figure 1 shows typical samples of crimped polypropylene tows (HF = High frequency, MF = Medium frequency, LF = Low frequency).

HF MF LF

Fig. 1. Typical samples of crimped polypropylene tows
(HF = high frequency, MF = medium frequency, LF = low frequency)

Sound absorption ability of the samples were tested using a single moveable impedance tube method based on ASTM C384 [11] shown in Figure 2.

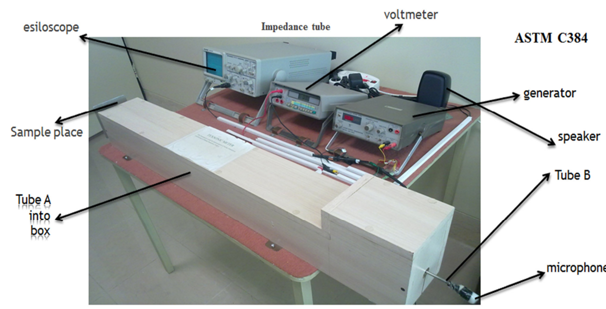

Fig. 2. Impedance tube apparatus.

The sound absorption coefficients were measured over the frequency range of 250 Hz to 4000 Hz in a still room (23 °C and relative humidity of 55%). In this method, the sample is positioned on one end of the tube, and the loud speaker is attached to the other end. The loud speaker emits sound waves at selected frequencies. Upon impingement of the emitted waves on the sample, a part of the incident sound is reflected back and is received by the microphone of the set up. Sound absorption coefficient of the samples was calculated according to reference [7]. For more details on the mechanism of impedance tube method readers are referred to [12]. It must be noted that all data reported for the sound absorption coefficient of all the samples with the exception of Figure10 are the average of sound absorption coefficients calculated for sound frequencies of 250, 500, 1000, 2000 and 4000 Hz. The replica for the measurements made at each frequency was 10.

Porosity of fibrous batts was determined using the following formula:

$$P (\%) = (1- \rho/\rho_0)\ 100 \qquad (3)$$

where ρ and ρ_0 show the apparent density of the web and the density of polypropylene fibers (0.92 g/cm^3), respectively. P was calculated by dividing the weight of fibrous webs into their volume.

III. RESULTS AND DISCUSSION

Figures 3, 4 and 5 show the variation of the sound absorption coefficient of samples versus the crimp frequency of 9, 14 and 18 denier polypropylene fibers, respectively.

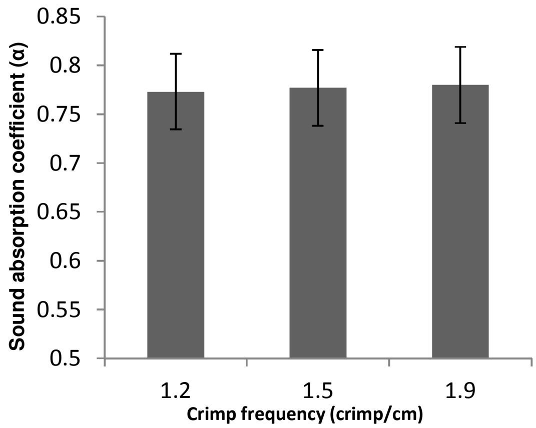

Fig. 3. Variation of the sound absorption coefficient of non-woven batts versus the crimp frequency of 9 denier polypropylene fibers.

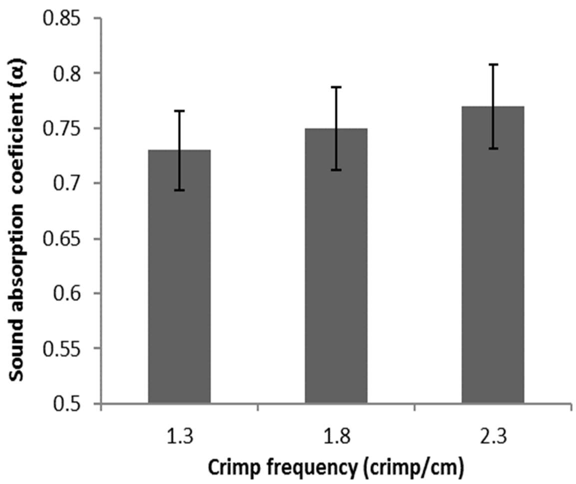

Fig. 4. Variation of the sound absorption coefficient of non-woven batts versus the crimp frequency of 14 denier polypropylene fibers.

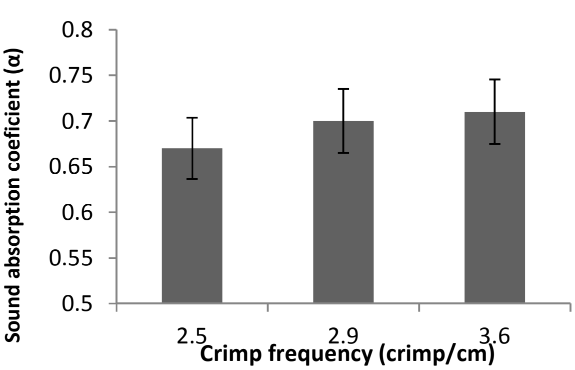

Fig. 5. Variation of the sound absorption coefficient of non-woven batts versus the crimp frequency of 18 denier polypropylene fibers.

As can be seen, sound absorption ability of the samples increases with increasing fiber crimp. Analysis of variance (ANOVA) confirmed the significance of the differences between fiber crimp frequencies for each of 9, 14 and 18 denier group. Considering the equal weight of the samples, this outcome is explained by the fact that higher crimp frequency leads to shorter straight fiber lengths and more creases along them. This reduces the available surface for reflection of sound. It can be said that for each denier group, increasing fiber crimp results in higher tortuosity and hence, a higher resistance is offered by the constituent fibers of the batts against the sound waves. The increased resistance is the main reason for the observed increase in sound absorption as fiber crimp is increased. Comparison of Figures 3, 4, and 5 also highlights the effect of the fiber fineness on the sound absorption ability of fibrous batts, bearing in mind that the crimp frequency of fibers has decreased with increasing fineness. Higher sound absorption ability, due to finer fibers is related to higher specific surface of finer fibers and as a result increased fiber surface for a given batt weight, which leads to a considerable increase of absorbed sound. As fiber fineness increases, for a given weight per unit area of the batts, higher number of fibers is required. This leads to both higher tortuosity and airflow resistance of the fibrous assembly. Probability of sound wave contacting fiber increases, as fibers become finer. This in turn results in increasing resistance to air flow. Moreover, fine fibers are more readily displaced within the batt in comparison to coarse fibers. The ease of displacement associated with finer fibers results in rapid conversion of acoustic energy to heat. Furthermore, the presence of fine fibers also decreases the probability of pore connectivity, which enhances the sound absorption behavior of fibrous samples. This agrees with the results already mentioned in the introduction part [7].

As the compression of the fibrous batts is likely to play a role in determining their sound absorption, the sound absorption coefficient of compressed fibrous batts was also measured. Prior to testing samples were compressed for 2h at a pressure of 30 Pascal and then allowed to be relaxed for 1h [13]. Figures 6, 7 and 8 show the variation of the sound absorption coefficient of batts versus crimp frequency of 9, 14 and 18 denier polypropylene fibers, respectively before and after compression. Figures 6, 7 and 8 show that sound absorption coefficient of batts increases to some extent after being compressed. The amount of increase is higher for coarser fibers. It is also observed that for a given fiber fineness, the increase in sound absorption coefficient due to compression is more for fibers with lower crimp frequencies. It can be concluded that in general, compression results in increase in sound absorption coefficient. This is due to the formation of smaller pores and the corresponding reduction in spaces for sound entry. In this context, the porosity of the fibrous batts is also important. Hence, the sound absorption coefficient was plotted against the porosity of the samples as shown in Figure 9 which depicts the fact that for a given fiber fineness, the sound absorption coefficient increases steadily to some extent with increasing porosity. The differences become more pronounced as fiber fineness is increased from 9 to 14 and then to 18.

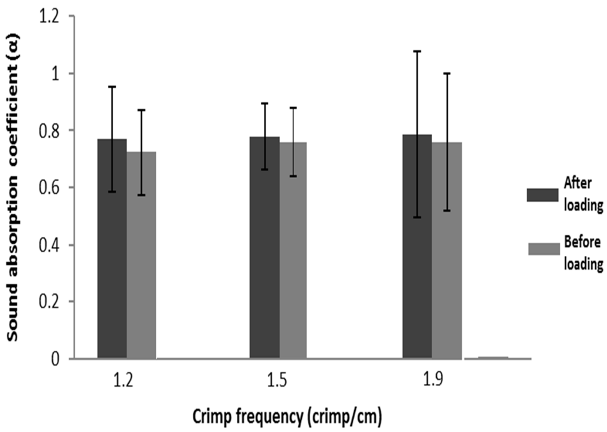

Fig. 6. Variation of the sound absorption coefficient of batts versus crimp frequency of 9 denier polypropylene fibers before and after compression.

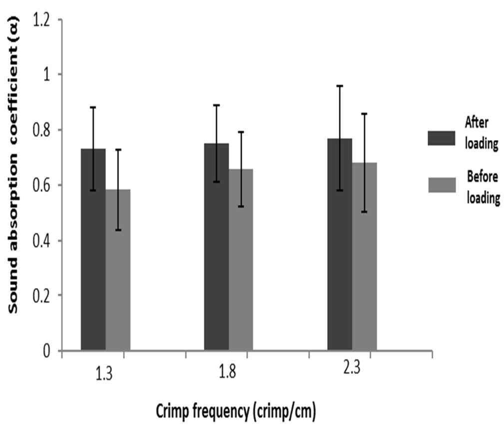

Fig. 7. Variation of the sound absorption coefficient of batts versus crimp frequency of 14 denier polypropylene fibers before and after compression

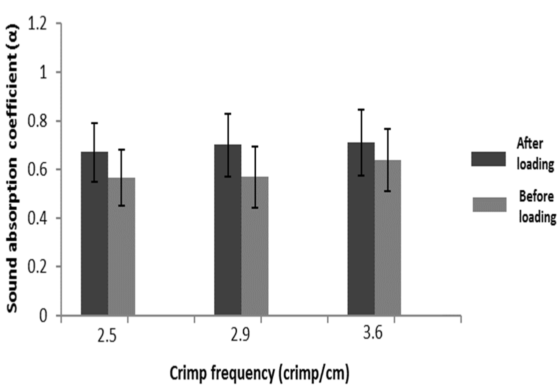

Fig. 8.Variation of the sound absorption coefficient of batts versus crimp frequency of 18 denier polypropylene fibers before and after compression

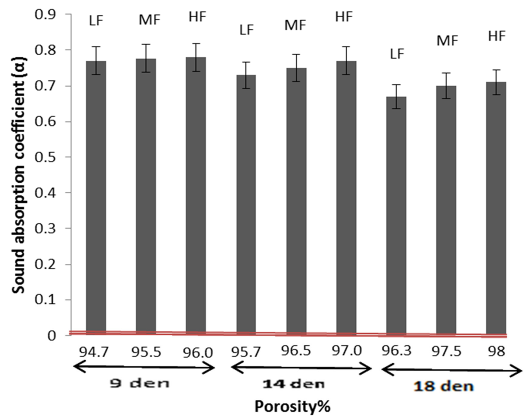

Fig. 9. Variation of the sound absorption coefficient versus the porosity of fibrous batts

Thickness of the fibrous batt is another parameter that can affect the sound absorption coefficient. Figure 10 shows the variation of sound absorption coefficient versus sound frequency for different number of layers of the batts composed of 14 denier polypropylene fibers with crimp frequency of 1.3 crimp per cm. It is concluded that sound absorption coefficient in all samples tends to increase up to frequency of 2000 Hz, beyond which it tends to remains rather unchanged while the frequency is increased to 4000 Hz. Figure 10 is a typical trend exhibited by the samples. This figure shows that up to 1000 Hz, sound absorption coefficient increases rather uniformly with increasing number of layers. At frequency of 2000 Hz, a steeper upward trend is observed for all the samples, but the rather uniform difference between sound absorption coefficients of different number of layers is diffused. The same is true for frequency of 3000 Hz. It is worth mentioning that for a given weight of batt, the highest sound absorption coefficient was recorded for the sample consisting of coarser but highly crimped fibers.

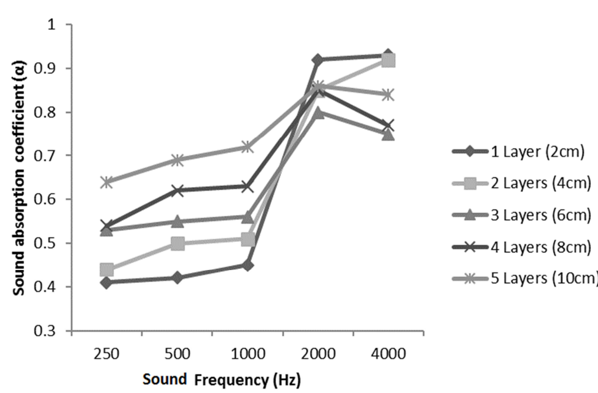

Fig. 10. Variation of sound absorption coefficient versus sound frequency of multi-layered batts (14 denier polypropylene fibers, crimp frequency=1.3/cm)

IV. CONCLUSIONS

It was established that, staple fiber crimp influences sound absorption coefficient of non-woven fabrics. Higher crimp frequencies resulted in higher sound absorption due to higher tortuosity of the fibers. The results also indicated that, fabrics produced from finer fibers absorbed sound wave more efficiently. Additionally, highest sound absorption was recorded for the batt composed of finest staple polypropylene fibers with highest crimp frequency. Finally, slight decrease in sound absorption due to increasing porosity was observed.

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