Investigation of Acoustic Properties of Satin 7/1 Woven Fabrics Containing Hollow and Micro-porous Yarns

Asal Lolaki and Mohsen Shanbeh*

Abstract- **To control noise pollution, the sound intensity should be reduced to a level comfortable for humans. The use of textile products especially with porous structures for noise absorption applications is one of the most widely used methods of noise reduction. Therefore, in this study the acoustical properties of porous woven fabrics based on noise reduction coefficient (NRC) and noise absorption coefficient (NAC) were evaluated. Effects of weft density and type of porous yarns, namely hollow and micro-porous yarns and also hollow yarns hole size at different frequencies were studied. Analysis of variance and Duncan test at 95% confidence level were performed to evaluate the difference between the acoustical properties of samples statistically. The results determined that weft density and yarn type had a significant effect on acoustical properties of woven fabrics. In addition, fabrics woven by micro-porous yarns showed a better noise reduction procedure.**

***Keywords*: hollow yarn, micro-porous yarn, acoustic properties, woven fabric**

I. INTRODUCTION

Noise means any unwanted sounds composed of tones at random frequencies. Noise pollution is a loud or unpleasant sound that is caused by automobiles, airplanes, etc. and is harmful or annoying to the people who can hear it [1]. Therefore, noise control is one of the paramount problems of our age and this process could be successful only when the intensity of sound is reduced to a level that is comfortable for humans. In order to reduce the noise level, we need to employ proper techniques and scientifically designed materials. The use of textile structures is one of the most widely methods used for noise absorption application both technically and economically [2, 3]. The porous textile products are the most commonly used as noise absorption textiles and usually have some degree of absorption at all frequencies. They act by trapping the sound waves and then converting their energy into heat. The typical characteristics of porous materials often depend on the thickness of the material [4].

Aso and Kinoshita investigated the influence of porosity and total surface area of fiber assembly on noise absorption characteristics [5]. In another research, they examined the variation of noise absorption characteristics of cotton woven fabrics with flow resistance using the tube method [6, 7]. They defined two mechanisms for noise absorption by fabrics. In the first one, which was viscosity-resistance type, absorption occurs because the sound wave at the time of passing through fabric produces energy-loss to overcome the frictional resistance between the fiber and the air in it. In the second one, which is resonance type, absorption occurs because the sound wave vibrates the system composed of the fabric and the elastic air space behind the fabric. Na *et al.* showed that noise absorption characteristics of fabrics made of microfiber in comparison with fabrics made of conventional fibers were improved [8]. Lee and Joo studied the influence of fiber and web properties of recycled polyester nonwoven on noise absorption coefficient (NAC) [9]. Soltani and Zarrebini studied the effect of structural parameters of woven fabrics including wave type, weft yarn linear density, fabric thickness, spinning system and the extent of air space at the back of the fabrics on noise absorption characteristics by the tube method [10]. However, they emphasized that woven fabrics have a less NAC in comparison with nonwoven fabrics.

Hassanzadeh *et al.* investigated the effect of an Estabragh fiber component on NAC of nonwoven fabrics using the Taguchi method [2]. In other research work, Hasani *et al.* studied acoustical properties of light needle-punched nonwovens made of Estabragh/hollow-polyester fibers blends [11]. Porous materials have some properties that impact on transmission characteristics of fabrics [12]. Lately, manufacture of hollow and micro-porous yarns

Asal Lolaki and Mohsen Shanbeh
Department of Textile Engineering, Isfahan University of Technology, Isfahan8415683111, Iran.

Correspondence should be addressed to M. Shanbeh
e-mail: mshanbeh@cc.iut.ac.ir

and their applications in fabrics get increased [13-16]. These kinds of yarns have some enhanced properties such as the increase of yarn bulkiness without increase of its weight, the increase of yarn diameter and yarn elliptically ratio [17], higher compressibility and better compression recovery [12], better thermal resistance and better moisture vapor transmission [18] and etc.

Since the sound wave collides with the material vertically, the evaluated NAC is known as the normal incidence NAC [2, 10]. In some cases, in addition to NAC, the mean of absorption coefficient values at all frequencies known as noise reduction coefficient (NRC) is also considered [10]. Since there is a lack of literature on acoustical properties of woven fabrics andespecially on acoustical properties of woven fabrics containing hollow or micro-porous yarns, in this study the noise absorption characteristics of woven fabricswith different weft densities containing hollow and micro-porous yarns were evaluated. In addition, the effect of hole size of hollow yarn was also studied.

II. MATERIALS AND METHODS

To study the acoustic properties of woven fabrics with a porous structure, two kinds of porous yarns namely hollow and micro-porous yarns were considered. In order to produce woven fabrics containing hollow yarns, at the first step, core-spun yarns with water-soluble multifilament PVA as a core part were prepared at dissolving temperature of 60 °C. These yarns were used as a weft yarn in woven fabric structure. After that, by washing the fabrics in hot water and dissolving a water-soluble component and removing it from fabric structure, woven fabrics containing hollow yarns in the weft were prepared. In order to produce woven fabrics containing a micro-porous yarn, a two-component yarn named wrap yarn containing water-soluble PVA filament at dissolving temperature of 90 °C was supplied and used as a weft yarn in the woven fabric structure. Then by boiling the fabrics, a water-soluble component was removed from fabric structures and woven fabrics containing micro-porous yarn in the weft were formed.

A two-component yarn that was containing the water-soluble PVA was made up by doubling the twist-less cotton yarn and PVA multifilament yarn. The final count of this yarn after removing the PVA multifilament was 39.36 tex. Since the yarn count of porous yarn was an effective parameter on fabric properties, we intended to produce all of the porous yarns with an equal linear density. Therefore, the count of 39.36 tex was considered as a desired nominal yarn count.

In fabrics containing hollow yarn, we aimed to change hole size. Therefore, the core-spun yarns were produced with the five different counts of core part namely 50, 100, 150, 200, and 250 denier. Core-spun yarns were produced based on Siro core-spun yarn method [19]. Therefore, the two ravings of cotton fiber together were used as a sheath part. The count of each cotton roving was 0.98 hank. The cotton fiber fineness was 4.1 μg/in and the effective length was 28.4 mm. The spinning of core-spun yarns was carried out at a speed of 17 m/min. The total draft of the spinning process was set in a way that after removing the core parts the count of hollow yarn was reached the value of 39.36 tex. The twist was 460 TPM, and the spindle speed was 7800 rpm.

To simplify, the fabrics containing micro-porous yarn were entitled Micro-Porous Yarn or M.P.Y fabrics and the fabrics containing hollow yarns were entitled Hollow Yarn or in a special manner H.Y(1), H.Y(2), H.Y(3), H.Y(4) and H.Y(5) fabrics. To clarify, the H.Y(1), H.Y(2), H.Y(3), H.Y(4) and H.Y(5) fabrics refer to the fabrics that at the first place were woven by the core-spun yarns with the core part of 50, 100, 150, 200 and 250 deniers, respectively.

To compare acoustical properties of produced porous woven fabrics with conventional woven fabrics, a reference yarn, i.e. 100% cotton conventional yarn, with the same count (39.36 tex, without PVA multifilament core feeding) was produced based on Siro spinning method and used as a weft yarn in woven fabric structure. The fabrics containing this yarn were entitled Reference Yarn after Boiling or R.Y.B fabrics. The diameter of produced yarns is presented in Table.1. To measure the yarn diameter, the cross-section of yarns was obtained using microtometechnique and the image was captured by a stereo microscope with 100× magnification.

Finally, seven different yarns were produced. These yarns were used as a weft in three levels weft densities i.e. 30, 40, and 50 per centimeter, and therefore, 21 satins (7/1) fabrics were woven on a Smit (Model: TP400, Italy) machine. In all samples, the warp yarn and warp density

TABLE I
YARN DIAMETER AFTER BOILING PROCESS.

Yarn Type	H.Y(1)	H.Y(2)	H.Y(3)	H.Y(4)	H.Y(5)	M.P.Y	R.Y.B
Yarn Diameter (μm)	314.07	327.91	337.13	358.83	453.23	273.08	298.17
Coefficient of Variation (CV %)	4.29	2.78	1.43	2.58	5.07	2.91	3.17

TABLE II
CHARACTERISTICS OF PRODUCED WOVEN FABRICS AFTER PVA DISSOLVING

Fabric Thickness (mm)	Fabric Mass (g/m$^{2)}$	Weft Density (1/cm)		Count of PVA Yarn (denier)	Fabric Code	Type of Weft Yarn	Sample number
		After Boiling	Nominal				
0.73(1.57)	240.08	34.6	30	50	H.Y(1)	core-spun	1
0.82(2.20)	281.64	43.0	40	50	H.Y(1)	core-spun	2
0.93(2.94)	347.60	54.0	50	50	H.Y(1)	core-spun	3
0.72(2.11)	239.76	34.0	30	100	H.Y(2)	core-spun	4
0.85(1.66)	287.40	44.0	40	100	H.Y(2)	core-spun	5
1.01(4.30)	342.92	54.0	50	100	H.Y(2)	core-spun	6
0.86(2.79)	234.13	34.0	30	150	H.Y(3)	core-spun	7
0.93(7.63)	298.69	44.0	40	150	H.Y(3)	core-spun	8
1.08(4.52)	372.13	56.0	50	150	H.Y(3)	core-spun	9
0.84(4.31)	237.19	35.0	30	200	H.Y(4)	core-spun	10
0.91(7.82)	269.88	43.0	40	200	H.Y(4)	core-spun	11
1.12(2.44)	339.81	55.0	50	200	H.Y(4)	core-spun	12
0.79(2.75)	236.38	34.5	30	250	H.Y(5)	core-spun	13
0.93(1.55)	292.31	46.0	40	250	H.Y(5)	core-spun	14
1.08 (3.61)	334.88	54.5	50	250	H.Y(5)	core-spun	15
0.89(5.10)	318.00	34.0	30	50	M.P.Y	Wrap	16
1.12(3.80)	366.25	44.0	40	50	M.P.Y	Wrap	17
1.21(0.89)	388.50	54.0	50	50	M.P.Y	Wrap	18
0.73(3.41)	246.40	35.0	30	-	R.Y.B	Cotton	19
0.84(3.14)	279.80	43.5	40	-	R.Y.B	Cotton	20
0.96(3.01)	340.08	53.0	50	-	R.Y.B	Cotton	21

*: Data in parenthesis is coefficient of variation (CV %).

were the same (polyester/viscose, 40 tex, 18 threads per centimeter). The width and speed of weaving machine was 168 cm and 220 picks per minute, respectively. All fabric samples were treated with boiling water for 90 min. All three reference fabrics, in which the weft yarn was 100% cotton, was also treated with the same condition to normalize the effect of boiling water shrinkage. To promote the extraction efficiency of PVA from yarn structure, the samples need to be shaken in the water. Finally, the samples were rinsed under running water and then dried in open space in daylight. In Table II the properties of woven fabrics after PVA dissolving that were evaluated in this study are shown.

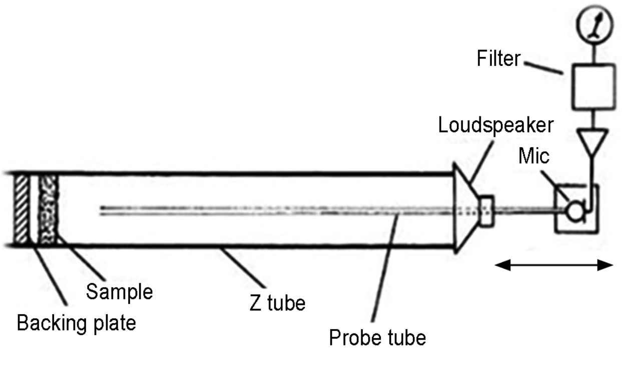

Fig. 1. Schematic of impedance tube [2].

In this research, the method of measuring NAC was based on impedance tube method. The schematic of this tube is shown in Fig. 1. In this method, there is a tube equipped with a moveable microphone. A loudspeaker which supplied a required sound wave was connected to one end of the tube and a test sample was set on the other end of the tube. Produced sound waves were restricted within the tube. It should be noted the test sample was cut in a circular shape with a diameter large enough to cover the cross-section area of the tube. Sound waves after striking a sample were reflected. The traces of reflected sound waves were appeared on the screen of the oscilloscope. Finally, NAC was calculated using Eq. (1) as follow:

$$\mathrm{NAC}=\frac{I_i}{I_r}=\frac{|P_i|^2-|P_r|^2}{|P_i|^2}=1-|R|^2=1-\left(\frac{n-1}{n+1}\right)^2=\frac{4n}{(1+n)^2}=\frac{4(P_{max}/P_{min})}{(1+P_{max}/P_{min})^2}$$

In Eq. (1), Iiand I_r are the intensities of the incident and reflected waves, respectively. P_i and P_r are the pressure of the incident and reflected waves, respectively; R is the reflected factor; n is the standing wave ratio, and P_{max} and P_{min} are the maximum and minimum values of sound wave

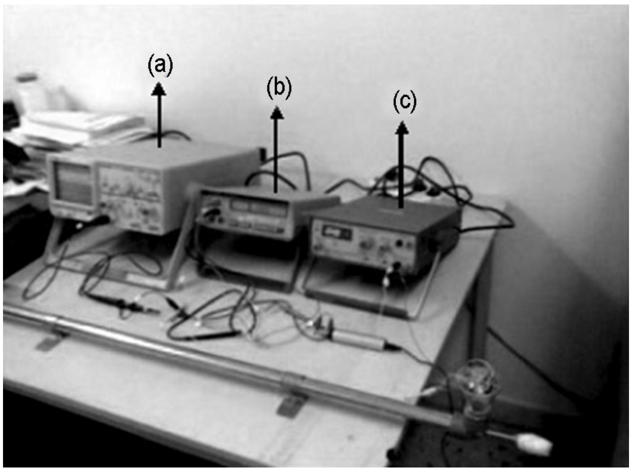

Fig. 2. Texonicmeter®: (a) Oscilloscope Screen, (b) Digital Voltmeter, and (c) Signal Generator [10].

pressure, respectively. Fig. 2 shows the Texsonicmeter® set up.

Values of sound wave pressure were shown on oscilloscope screen(a). So, a digital voltmeter(b) in parallel was connected to the oscilloscope and maximum and minimum values of reading voltage corresponding to maximum and minimum values of sound wave pressure were noted. Therefore, in the calculation of NAC, the value of V_{max}/V_{min} instead of P_{max}/P_{min} was used.

Each sample was tested 5 times at 250, 500, 1000 and 2000 Hz frequencies, and the average of these five measurements was considered as the NAC of each sample. In our experiments there was no air space behind the fabric samples, so only the first noise absorption mechanism, defined by Aso and Kinoshita; i.e. viscosity-resistance type, was considered.

As mentioned before, the method of measuring NAC in this device was based on measuring are flected sound wave. So, if the incident sound wave after collision with sample surface someway was dissipated, the reflected sound wave was decreased, and therefore, the sound wave absorption coefficient was increased. Hence, every factor that increases sound dissipation can increase NAC. Furthermore, yarn diameter, yarn density, yarn or fabric surface porosity and weave type were considered as effective factors. Statistical evaluation of results based on analysis of variance at 95% confidence level and also Duncan test was managed by SPSS17 software.

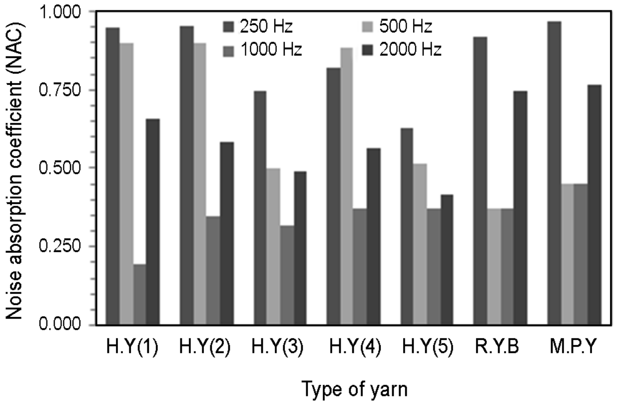

Fig. 3. Noise absorption coefficient (NAC) of woven fabrics with 30 wefts per cm.

III. RESULTS AND DISCUSSION

A. Effect of sound wave frequency on NAC

The variation of the NAC values versus wave frequency at different weft densities are shown in Figs. 3, 4 and 5. From these figures, we found that at constant weft density, by increasing the sound frequency, in most cases the NAC values were decreased. This was probably due to the decrease of sound wave dissipation from the sample surface and the increase of sound wave passage through the fabric. The greater sound wave frequency had smaller wave amplitude and wavelength, so by increasing the sound wave frequency the sound wave amplitude got smaller, and therefore, the sound wave dissipation from sample surface got lower and the sound wavepassage through the fabric void space got easier.

It is necessary to point that the coefficient of the noise absorption at the sound frequency of 1000 Hz showed an obvious decline. In other words, the minimum value of NAC occurred at the frequency of 1000 Hz. Based on the research done by Soltani *et al.* [10], the reduction of the NAC values at some frequencies could be due to the coincidence dip phenomenon that is known as a critical frequency which can restrict the absorption ability of sample. This phenomenon occurs when the incident and

TABLE III
ANOVA TEST RESULTS AT 95% CONFIDENCE LEVEL

Parameter	Significant Value			
	250 Hz	500 Hz	1000 Hz	2000 Hz
Weft Density	0.000	0.000	0.144	0.000
Yarn Type	0.000	0.000	0.001	0.000
Weft Density* Yarn Type	0.000	0.000	0.000	0.000

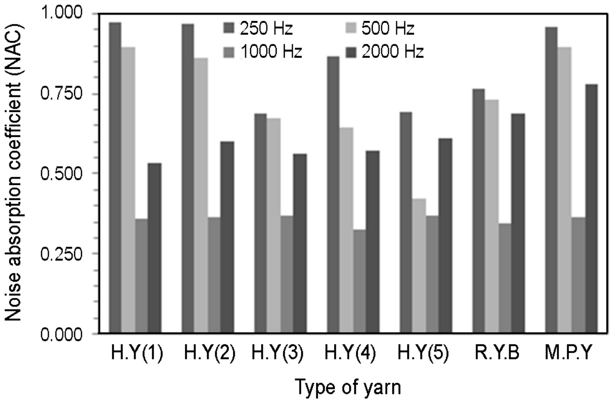

Fig. 4. Noise absorption coefficient (NAC) of woven fabrics with 40 wefts per cm.

reflected sound waves have the same phase.

ANOVA test results at 95% confidence level are shown in Table III. According to Table III, weft density inall frequencies except at the frequency of 1000 Hzhada significant effect on the NAC values. In addition, the yarn type and interaction effect of the yarn type and weft density showed a significant effect on the NAC values of the fabrics.

B. Effect of weft density on NRC

The NRC values of samples at different weft densities are shown in Fig. 6. We found that in woven fabrics containing reference and micro-porous yarns, by increasing the weft density the NRC values were increased, But, in the case of woven fabrics containing hollow yarns by increasing the weft density, the NRC values at first, were increased and then were decreased.

An increase in the weft density caused some opposite effects. First of all, void spaces between yarns were decreased that couldlead to decrease in sound passage through the sample, and therefore, decrease in NRC value, based on the viscosity-resistance mechanism. Second, the number of interlacing points surface unit was increased that could lead to increase in sound dissipation from the sample surface, and therefore, increase in NRC values. In addition, as shown in Table II, by increasing the weft density the thickness of the fabrics was increased that could lead to increase in NRC values [4]. So, an increase in the NRC values of hollow yarn samples by increasing the weft density from 30/cm to 40/cm could be because of dominant effect of increasing of collision points and fabric thickness compare with decreasing of void space. Also, decrease in NRC values at 50/cm weft density could be as the result of a dominant effect of reduction of void space between yarns.

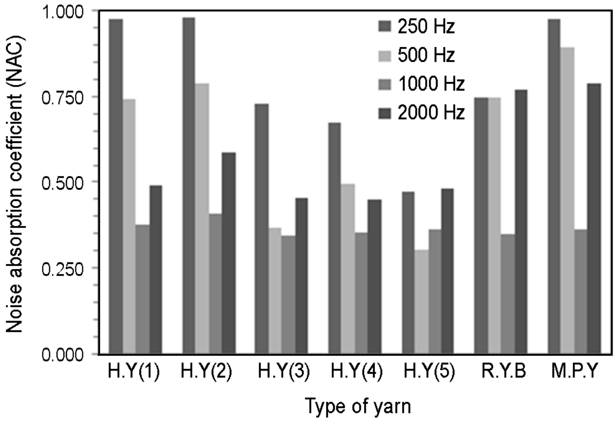

Fig. 5. Noise absorption coefficient (NAC) of woven fabrics with 50 wefts per cm.

TABLE IV
RESULTS OF DUNCAN TEST BASED ON WEFT DENSITY AT 95% CONFIDENCE LEVEL

Weft Density	N	Subset	
		1	2
50	35	.5896	
40	35		.6399
30	35		.6489
Sig.		1.000	.714

Samples woven by micro-porous and reference yarns, as shown in Table I, had a smaller diameter than hollow yarn samples; hence by increasing the weft density the void spaces between yarns in these samples did not decrease as much as in fabrics containing hollow yarns. Therefore, in these fabrics probably increase in collision points had a dominant effect on NRC trend.

The analysis of variance at 95% confidence level showed that the weft density hada significant effect on the NRC values of the fabrics. In addition, as shown in Table IV, Duncan test at 95% confidence level showed that samples woven with 30 and 40 wefts per centimeter did not have a significant difference and were in one subset.

C. Effect of porous yarn on NRC

As shown in Fig. 6, at the weft density of 30/cm the fabrics containing H.Y(1), H.Y(2), H.Y(3) and H.Y(4) had more NRC values and the H.Y(5) fabric hadless NRC valuethan the reference yarn fabric. Also, at the weft density of 40/cm the fabrics containing H.Y(1) and H.Y(2) had more NRC values and the fabrics containing H.Y(3), H.Y(4) and H.Y(5) had less NRC values than the reference yarn fabric. In addition, at the weft density of 50/cm, the fabric containing H.Y(2) had more NRC value than the reference yarn fabric and fabrics containing H.Y(1), H.Y(3), H.Y(4) and H.Y(5) had less NRC values than the reference yarn

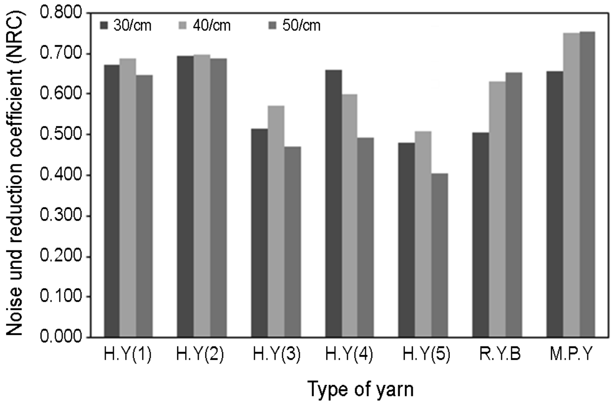

Fig. 6. Noise reduction coefficient (NRC) of woven fabrics at different weft densities.

fabric. It was obvious that at all weft densities, the H.Y(2) fabrics had the greatest NRC values and H.Y(5) fabrics had the less NRC values than the reference yarn fabrics. In addition, by increasing the weft density the NRC values of samples containing hollow yarns in comparison with reference yarn fabrics were descended more. As shown in Table I, reference yarn had a smaller diameter than hollow yarns that could present a bigger space for sound wave passage. In addition, the smaller diameter of reference yarn led to the less descent by increasing the weft density.

Greater values of NRC in some cases, especially in the H.Y(1) and H.Y(2) fabrics, could be in result of more porosity of hollow yarns than reference yarn which led to more sound wave dissipation. For clarifying, in hollow yarns the same amount of cotton fibers was put in the bigger area, therefore, there were bigger spaces between the fibers in yarn structure.

Based on Fig. 6, it was obvious that the fabrics containing micro-porous yarn, at all densities had greater values of NRC than the reference yarn fabrics. This trend could be due to fewer diameters of micro-porous yarns (M.P.Y) than the reference yarn and also microscale surface porosity of micro-porous yarns (M.P.Y).

The analysis of variance at 95% confidence level showed that yarn type had a significant effect on NRC values of fabrics. In addition, as shown in Table IV, Duncan test put H.Y (1), H.Y (2) and reference yarn fabrics in one subset. In most cases, the NRC values of micro-porous yarn fabrics at all densities were more than hollow yarn fabrics. This was probably because of microscale surface porosity of M.P.Y and also smaller diameter of micro-porous yarn in compare with hollow yarns that provide bigger space for sound wave passage. The results of Duncan test at 95% confidence level on yarn type are shown in Table V. According to this table, Duncan test did not put the woven fabrics by M.P.Y samples and woven fabrics by H.Y in the same subset. This showed that there was a significant difference between the NRC values of M.P.Y and H.Y fabrics.

D. Effect of hole size of hollow yarn on NRC

As shown in Fig. 6, in all weft densities, from H.Y (1) to H.Y (5) samples the sound reduction coefficient (NRC) was decreased. It was probably because of increase of yarn diameter, and therefore, reduction of yarn spaces between yarns. It should be noted that divergence of NCR variation from observed trend could be in result of the opposite effect of the increase of yarn diameter and the increase of surface porosity; as mentioned before all yarns hadanequal linear density therefore from H.Y(1) to H.Y(5) by increasing the yarn diameter, the fibers were placed in a bigger area, and therefore, there was a bigger space between fibers in yarn surface. This surface porosity could lead to more sound wave dissipation. So, while an increase in the yarn diameter acted as a negative factor for dissipating the sound waves, and therefore, reducing the NRC values, an increase in the yarn surface porosity acted as a positive factor. Duncan test

TABLE V
RESULTS OF DUNCAN TEST BASED ON YARN TYPE AT 95% CONFIDENCE LEVEL

Yarn Type	N	Subset				
		1	2	3	4	5
H.Y(5)	15	.4717				
H.Y(3)	15		.5217			
H.Y(4)	15			.5922		
R.Y.B	15				.6707	
H.Y(1)	15				.6715	
H.Y(2)	15				.6953	
M.P.Y	15					.7600
Sig.		1.000	1.000	1.000	.179	1.000

(as shown in Table IV) showed that the fabrics containing H.Y(1) and H.Y(2) belonged to the same category which meant there was no significant difference bet ween them, but each of fabrics containing H.Y(3), H.Y(4), and H.Y(5) samples belonged to the separate subsets.

V. CONCLUSION

We found that, by increasing the weft density from 30 to 40 per centimeter, the NRC of woven fabrics by hollow yarns was increased, but by increasing the weft density till 50 per centimeter, the reduction of NRC was observed. On the other hand, in samples woven by 100% cotton and also micro-porous yarns by increasing the weft density the increasein NRC was observed. Generally, fabrics woven by micro-porous yarns (M.P.Y) showed the highest value of NRC which could be because of their microscale surface porosity. Effect of weft density and yarn type was statistically significant at 95% confidence level on NRC of woven fabrics. By increasing the sound wave frequency, the NAC of samples was decreased, but the lowest values of NAC were obtained at the frequency of 1000 Hz that can be due to the coincidence dip phenomenon that is known as a critical frequency which can restrict absorption ability of sample. The hole size of hollow yarns showed a significant effect on NRC of woven fabrics statistically. Hence, based on the results, during designing a woven fabric with a concentration on its acoustical properties, the opposite effects of weft density, yarn diameter and structure should be considered. In future, we aim to investigate the effect of structural parameters of micro-porous yarns and weave pattern on acoustical properties of woven fabrics.

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