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Investigating the Effect of Fabric and Lamination-Foam Properties on the Air Permeability of Laminated Headrest Fabrics

Seray Aksoy[1] 0000-0001-6792-6156
Semih Ertürk[1] 0000-0002-0002-4075
Cemil Işılak[1] 0000-0003-3677-4027
Diren Mecit[2] 0000-0002-3760-3417
Semih Oylar[2] 0000-0002-5052-7463

[1]Tofaş / Yeni Yalova Yolu Cad. No:574 Bursa / Türkiye
[2]Martur / Nilüfer Organize Sanayi Bölgesi 302. Sok. No.1 Bursa / Türkiye

Corresponding Author: Seray Aksoy, seray.aksoy@tofas.com.tr

ABSTRACT

In the automotive industry, the interior component, which the customer first encounters is the seat. Customers have many expectations in terms of aesthetics, functionality, and comfort from the seats of the vehicle. When considering comfort in car seats, it is the backrest, cushion, headrest foam, and upholstery which are placed at the top the list. The seat upholstery in the vehicle has a composite structure including fabric, lamination foam, and backing scrim. This composite structure is combined with seat foam by using techniques such as traditional method or in-situ technology. In the traditional method, the upholstery is trimmed on the product's foam. In in-situ technology, polyurethane (PU) is injected into ready-placed upholstery. The advantage of in-situ technology is to make perfect trimming for curved foam designs. Concave shapes are more achieveable with in-situ production techniques, which adds to the safety and comfort of the headrest. In this in-situ process, an overflow failure may occur on the surface of the upholstery, when foam is injected (PU) with high pressure during the process. Overflow failure is not desired by the main automobile producers, from both aesthetical and quality aspects. In this study, the effect of lamination-foam and fabric on the air permeability of composite structures used in in-situ headrests was investigated. The surface structure of the in-situ headrest was also analyzed via stereo microscope. In order to evaluate the overflow behavior of PU injected foam, the weight, peeling strength, and air permeability of fabric and lamination foam types were tested. As a result of this study, it was observed that the air permeability of the laminated fabrics has an effect on the overflow failure on the headrest.

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KEYWORDS

Lamination process, in-situ method, air permeability, stereo microscope, car headrest

1. INTRODUCTION

Automotive textiles have a large share in the global technical textiles market, which is comprised of seat upholstery, floor covering, headliners, door coverings, pillar coverings, safety belts, side panel coverings, airbags, tires, sound, and thermal insulators [1,2]. Automotive interior textiles are usually made of woven, warp knitted, weft knitted, laminated and nonwoven fabrics [3,4]. The seat upholsteries are of great importance, due to their effect on the driver and passenger comfort, and also the aesthetic appeal of the interior scheme. A summary of the properties required from car seat upholsteries was shown in Table 1.

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Car seat upholstery is generally made of different structures. The one layer of seat upholstery is the lamination foam, mostly made of PU due to the comfort and protection level served by PUs which is not achieved by any other single structure [5]. Lamination foams made of PU are generally obtained by reacting an isocyanate with polyols in the existence of blowing agents [6]. The second part is the face fabric, which is mainly a woven or knitted polyester fabric. Another part of seat upholstery is the backing scrim that is generally produced of polyester or polyamide [7,8]. Seat upholstery fabrics used as trilaminar structures were shown in Figure 1.

Table 1. Requirements on upholstery materials for car seat [4].

Seat Requirement	Important	Very Important
Optic / Aesthetic		
- Touch		⊗
- Color		⊗
- Brightness /		⊗
Dullness		⊗
- Price		
Resistant to wear and load		⊗
- Light fastness		⊗
- Abrasion resistance		⊗
- Pilling resistance		⊗
- Color fastness	⊗	
- Tenacity /		
Elongation		⊗
- Dimensional		
stability		⊗
Resistant to ageing	⊗	⊗
- Light resistant		
- Temperature		
resistant	⊗	
- Industrial	⊗	
production		
(Flexibility)	⊗	
Soil resistant – easy to	⊗	
clean	⊗	
- Soil resistance		
- Cleaning ability	⊗	
Seat comfort		⊗
- Surface softness		
- Humidity absorption		
- Humidity transport		
- Static charge		
Recycling		

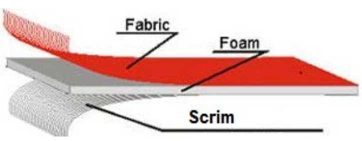

Figure 1. Trilaminar seat upholstery structure [9]

In the lamination process, PU-based lamination foams are laminated to the fabric by different methods. This process provides functionality and additional technical performance to the final composite products, which can not be achieved by using a single layer [10-12]. There are three types of lamination processes such as flame lamination, hot-melt lamination, and powder laminating. However, the most used method in the automotive sector is flame lamination process as it has lower costs and large production volumes compared to other methods [13]. In the flame lamination process, a foam layer is exposed to an open flame around 950°C, which causes its top surface to melt. While the foam is molten, it is fed into lamination machine, and as a result, layers are combined. Thanks to this method, flexible laminated fabrics are produced [3]. Hot-melt lamination can be operated by means of an engraving roller or a nozzle in the form of slots. The hot-melt of the polymer binder (commonly copolyamides, copolyesters, PUs, and polyethylene) is fed from the extruder by means of squeegees into the grooves of the engraving cylinder [14]. In powder laminating, the foam is applied as a binder powder over the entire width by means of a sieve template or by spreading. Textiles or the foam travels to the dryer, where the powder is gelled and it combines with other textiles. This is followed by compressing and cooling processes [15, 16].

Automotive seat commonly consists of three components such as cushion, backrest and headrest. The seat upholstery (consisting of fabric, laminated foam and scrim), whose lamination process has been completed as described above, must be combined with seat foams (cushion, backrest and headrest) in order to become the final product. For combining seat headrest foam and seat upholstery either traditional methods or in-situ technology can be used. The traditional method is widely used, and it is formed by combining the seat upholstery on seat headrest foam by methods such as sewing and trimming. Unlike the traditional method in the in-situ (pour-in-place) technology the upholstery is firstly formed, afterwards the PU liquid is poured into the upholstery and the final product is produced. As in-situ technology allows production of complex shaped headrests, it is expected that this technology will replace the traditional methods [17].

The main factors effecting the properties of final in-situ headrest are the components and their characteristics used in the process and in-situ process parameters. The upholstery and poured foam are the major two components. The properties of upholstery such as permeability, porosity, elongation and trimmability influence the in-situ process performance and as a result final headrest quality.

Air permeability is one of the most important property of textile materials that ensure their comfort. The air permeability of textile fabrics depends on many parameters of fabric structure [18]. The structure of a textile contains pores between the fibers. Airflow through textiles is mainly effected by the pore characteristics of the fabrics. It is quite clear that pore dimension and distribution is a function of the fabric geometry. The yarn diameter, surface formation techniques, number of yarn for woven fabrics (yarn density), and number of loop count for knitted fabrics per unit area are the main factors affecting the porosity of textiles. The porosity of a fabric is connected with certain important features of it, such as air permeability, water permeability, etc [19-21].

In this study, it was aimed to investigate the effect of lamination foam and fabric on the air permeability and surface structure (by evaluating the overflow) of in-situ headrests. In the first step of the study, the weight and air permeability of the seat fabric and lamination foam have been measured before and after lamination process. The peeling strength of laminated fabrics also have been measured. Afterwards PU injection has been realized. Images of final headrests have been taken by stereo microscope to compare overflow failure behaviour of headrest and its relation with the air permeability test results.

MATERIAL AND METHOD

2.1 Material

Within the scope of the study, 3 types of laminated automotive upholstery fabrics were produced from 100% PET (Polyethylene-terephthalate) yarns. Two of the fabrics produced are woven and one is warp knitted fabric. Three types of laminated automotive upholstery fabric were laminated with two different PU lamination foams. Six fabric variants were obtained in the study. Information of fabric variants was shown in Table 2.

Table 2. Fabric variations produced in the study

Fabric Type	Lamination Foam
woven fabric 1	laminated foam 1
woven fabric 1	laminated foam 2
woven fabric 2	laminated foam 1
woven fabric 2	laminated foam 2
warp knitted	laminated foam 1
warp knitted	laminated foam 2

2.1.1 Production of fabrics

In the study, woven fabric 1 and woven fabric 2 samples were produced on dobby weaving machines, and the warp knitted fabric sample was produced on tricot warp knitting machine. All of the yarns used in the production phase are obtained from 100% PET polymer in accordance with automotive standards. Some construction information of woven and knitted fabrics were shown in Table 3 and Table 4.

2.1.2 Finishing processes applied to the produced fabrics

The same finishing processes were applied to all fabrics produced. A washing process was applied to remove the dust, oil and oligomers that occur during the production phase of the yarns and fabrics. Then, a process using temperature and chemical/mechanical ordering was carried out in a Stenter machine, which achieves width-length stabilization of the fabrics, followed by flame lamination. The gas pressure, machine speed, distance between the cylinders and the thicknesses at the entrance/exit of the machine were constant for all flame-lamination processes. 2 different lamination foams were used in the study. The fabrics produced were cut in the cutting machine and stitched in the sewing machine to be turned into an automotive headrest upholstery cover. As a result of these productions, finally 6 different laminated foam structures as upholstery cover were produced from six different laminated fabrics.

2.1.3 In-situ process

After the cutting and sewing processes, the final laminated headrest upholstery covers were injected with foam through the in-situ process. In the in-situ process, the polyol and isocyanate materials were fed from separate feeding units. In the meantime, previously sewn and prepared headrest upholstery covers were placed in the closed mold that will form the shape of the final product. The mouth of the mold is designed to contain an opening for foam feeding inlet. After the foam was poured into the mold in the determined weight, it expands among the mold and fills the inside of the fabric cover. Injected foam, which expands to the size allowed by the closed mold, formed as the final form of the headrests. Parameters such as foam hardness and density were determined by the ratio of polyol and isocyanate in the formulation. There are two different method for the in-situ process. The vertical method is applied for complex geometries whereas the horizontal method is used for basic geometries. In this study, the horizontal production method was applied for the in-situ process of all samples due to the basic shape of the headrest. All variables in the in-situ process were kept constant for the production of all samples. The components of headrests are shown in Figure 2.

Table 3. Woven fabrics' construction information

b	Yarn Type	Weave unit	Weft Yarn Type (denier)	Warp Yarn Type (denier)	Number of Filament	Warp Density (yarn/cm)	Weft Density (yarn/cm)
Woven fabric 1	Friction Texturised	2x2 twill	PET 450	PET 450	144	24	18
Woven fabric 2	Friction Texturised	2x2 twill	PET 300	PET 450	144	28	19

Table 4. Warp knitted fabric construction informations

Yarn Type	Number of Filament	Machine Fineness (F/inch)	Course Density (C/cm)
PET 100 denier	36	28 fein	20-22

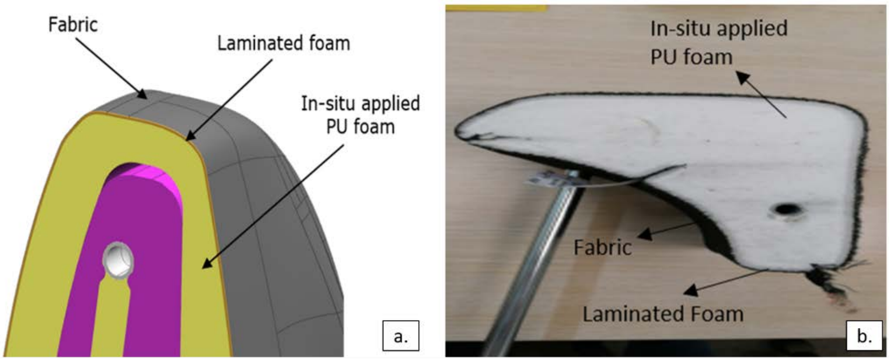

Figure 2. Headrest components a. Schematic image of headrest b. Real image of headrest

2.2 Method

2.2.1 Performed tests on laminated upholstery fabrics

Unit mass

Unit mass of face fabrics, foams and final laminated fabrics were tested according to the TS EN 12127 standard. Total weight was measured, then the laminated layers were seperated and measured seperately. Five samples having 100 cm² area were taken from each type of materials and their weights were measured. The mean value per square meter weight was calculated.

Peeling Strength

After the flame lamination process, the peeling strength of the upper surface fabric to the lamination materials was tested in the Zwick test machine for length and width directions of the fabric according to FIAT 50441/05 standard. According to the FIAT 9.55441 specification, the adhesion strength of the upper surface fabric and the lamination material to each other must be equal to or greater than 0.8 daN. If peeling strength between the two layers is intense, manual separation cannot be performed at the beginning of the test and the test result is stated as "no separation" (NS).

Air permeability

In this study air permeability of non-laminated face fabrics, foams, and laminated fabrics were measured. The air permeability property has been measured according to the TS 391 EN ISO 9237. This method is being used for all types of fabrics, including industrial fabrics, nonwovens, and textiles [22, 23]. The basic principle of the air permeability test is that the velocity of the airflow in the vertical direction through a given area of the fabric is measured at the pressure difference within the test area of the fabric in a given time range. The air permeability is defined as the speed of the air passing in the vertical direction through a part of the test with determined conditions such as test area, pressure drop, and time in the vertical direction. During the test, pressure of 200 Pa was applied on to the area of 20 cm^2. Ten measurements were done for each group. The arithmetic means and % CV (Coefficient of variation) of the measurements taken were calculated and reported.

2.2.2 Performed tests on final products after the in-situ process

Observing samples with Stereo Microscope

The ZEISS / Stemi 508 Zoom Microscope device used in this study, which is used to observe metal, plastic, and textile materials, provides a wide range of images between 40X and 100X. In this study, the area where the driver's head touches the headrest during driving was observed.

3. RESULTS AND DISCUSSION

3.1 Unit mass results

The weights of the face fabrics (unlaminated) and foams (Sample W1-W2-WK-F1-F2) before lamination and the weights of the laminated foams and fabrics (Sample L1-L2-L3-L4-L5-L6) after the lamination process were shown in Table 5.

According to the unit mass measurements, it was seen that warp knitted fabric had the lightest weight, whereas woven fabric 2 had the heaviest weight. It was also determined that lamination foam 1 was lighter than lamination foam 2. Laminated fabric test results showed that lamination foam 2 lost some weight after lamination process while lamination foam 1 did not lose weight.

3.2 Peeling strength results

The peeling strength between the fabrics and the foams were measured. As can be seen in Figure 3, no separation was observed from any of the samples. During the adhesion test of these materials, crumbling is observed in the foams after the attraction force applied for separation. No separation means that there is good adhesion between the fabric and foam for all samples.

Table 5. Unit mass of samples

Fabric Type	Laminated Foam	Total Weight (g/m^2)	Fabric (g/m^2)	Foam (g/m^2)	Samples Codes
woven fabric 1	-	-	268	-	W1
woven fabric 2	-	-	275	-	W2
warp knitted	-	-	216	-	WK
laminated foam 1	-	-	-	177	F1
laminated foam 2	-	-	-	185	F2
woven fabric 1	laminated foam 1	444	265	179	L1
woven fabric 1	laminated foam 2	438	270	168	L2
woven fabric 2	laminated foam 1	451	272	179	L3
woven fabric 2	laminated foam 2	450	272	178	L4
warp knitted	laminated foam 1	393	210	183	L5
warp knitted	laminated foam 2	375	215	160	L6

Figure 3. The samples subjected to tensile force during the adhesion test

3.3 Air permeability test results

The air permeability results of fabrics were shown in Table 6.

Table 6. Air permeability test results of structures

Samples	Mean (mm/s)	% CV (mm/s)
W1	178.2	2.6
W2	129.5	2.8
WK	1353	1.6
F1	95.4	9.6
F2	63.2	16.6
L1	69.1	8.5
L2	77.6	7
L3	64.4	16
L4	74.9	16.7
L5	107.8	15.4
L6	151.6	15.2

In Table 6 the highest air permeability result belongs to WK, as warp knitted fabric have more porosity in the structure than the woven fabrics. When woven fabrics are compared, it is observed that the air permeability of W1 is higher than that of W2 due to the lower warp density of W1 than W2. Comparison of lamination foams showed that F1 is more permeable than F2. When the air permeability of laminated fabrics compared, it was observed that laminated warp knitted fabrics (L5, L6) have higher air permeability than that of laminated woven fabrics (L1, L2, L3, L4). This result showed that the porosity structure of warp knitted fabric caused to a more permeable final product. When the results of woven fabrics compared, there was not seen any difference between the results of fabrics laminated with W1 (L1, L2) and that of fabrics laminated with W2 (L3, L4). These results mean although there is a small difference between the air permeability of woven fabrics (W1, W2), it was not observed in final laminated fabrics (L1, L2, L3, L4).

3.4 Stereo Microscope Results

The 40X images taken with stereo microscope from the final product headrests injected with PU by in-situ technology was shown in Figure 4. Although it has a wide imaging range of stereo microscope, the value at which PU overflow failures can be observed was determined as 40X. Therefore this magnification was used in the measurements.

It was seen from Figure 4 that there is no PU overflow failure was observed in L1 (a.), L2 (b.), L3 (c.) and L4 (d.), whereas there are PU overflow failures at observed samples L5 (e.) and L6 (f.). The observation of overflow failures on L5 and L6 can be a result of the higher permeability and porosity of the warp knitted fabrics as both L5 and L6 samples were produced with warp knitted fabric.

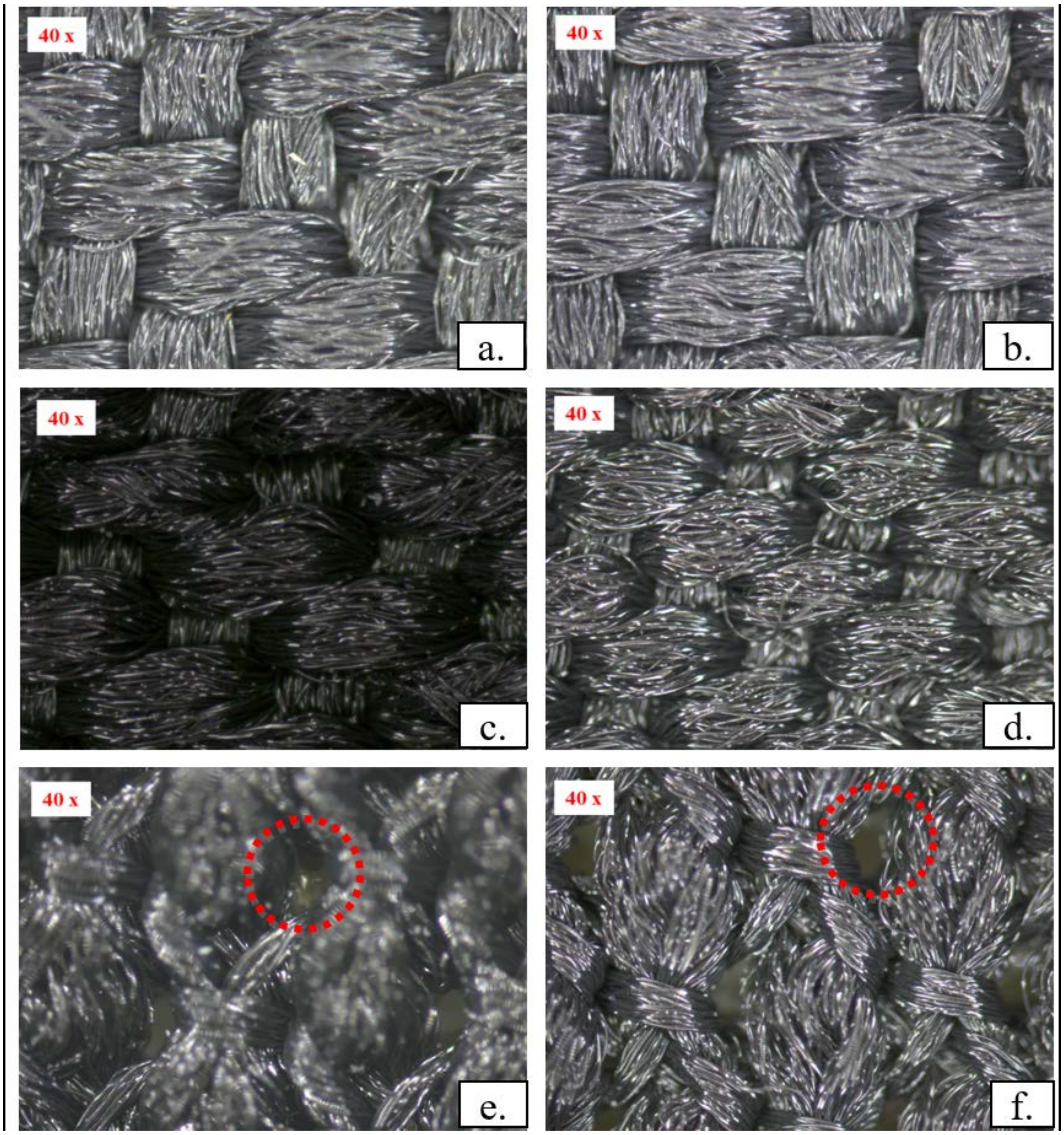

Figure 4. 40X zoom image of samples a. L1 sample b. L2 sample c. L3 sample d. L4 sample e. L5 sample f. L6 sample

4. CONCLUSION

In this study; the weight, air permeability and adhesion of laminated layers have been analyzed and evaluated in order to predict the over-flow behavior of foam during the in-stu process.

Comparison of air permeability and weight results of induvidual layers showed that the heavier fabric and foam has the less air permeability (see Table 5). However the comparison of air permeability and weight results after lamination showed the opposite result. The same fabrics, which were laminated with F2, showed more air permeability than that of laminated with F1, even though the F2 layer's weight was higher than the F1 layer's before lamination. The comparison of burned foam weights showed that F2 lost weight during the flame lamination process.

As a result, it can be concluded that the laminated fabrics, which have a higher weight, have lower air permeability.

No difference was observed between the peeling test results of all fabrics. Therefore any relation between peeling strength and the over-flow failure in the in-stu process was not found.

Analysis of stereo microscope images showed that over-flow failure was observed on the warp knitted fabrics, whereas none was observed on the surface of the woven fabrics. This may be a result of either fabric construction type or total fabric weight.

As a result of this study it can be concluded that air permeability and the weight of the fabric have a remarkable effect on the final quality of the in-stu process in respect of overflow existence. In conclusion, fabrics which have lower weights may cause more overflow failure due to a higher air permeability.

Air permeability of 100 mm/s should be set as a limit value for this process in order to avoid overflow failure.

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