Statistical Analysis of Effects of Production Parameters of Sound Insulation Materials Produced From Chicken Feather Fibers on Acoustic Properties

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Abstract

In recent years, noise, which is one of the negative effects of modern life and developing technology, has become a common problem. For this reason, the issue of struggle against the noise has become increasingly important, so sound-absorbing materials are being developed to provide acoustic comfort in closed areas. Among these materials, materials developed from natural materials have a special place. In this study, nonwoven surfaces produced from chicken feather fibers which emerged as a by-product in chicken meat production via thermal binding were developed in order to provide acoustic comfort. In the study, nonwoven surface samples were obtained at different densities using different binding materials. A multi-factor experimental design was designed in the Design Exper program to determine how the produced samples affected the acoustic performance of the production parameters and the samples were produced according this plan. The acoustic parameters of the produced samples were measured in the impedance tube. Statistical analysis was applied the data obtained from the measurement. In the sample production, the binder polymer type, the thickness of the sample, the amount of fiber, the amount of binding agent and the frequency of sound were taken as independent changing parameters. The sound absorption coefficient and the sound transmission values from the acoustic values of samples were chosen as the dependent parameters. The change intervals for each of these values were determined and experiments were performed. Mathematical models expressing the relation between sound absorption coefficient and sound transmission loss values with production parameters have been obtained and interpreted.

Keywords: chicken feather fibers, sound absorption materials, nonwoven, sound insulation

1. Introduction

One of the negative aspects of modern life and technology is noise. There are increasingly ways to combat noise, which affects living standards as well as many health problems. An important groups of these methods are methods based on the use of sound absorbans or sound absorbing materials. Sound absorbing materials are commonly used to reduce noise in enclosed areas.

Among the various sound absorbing materials in market, porous sound absorbing materials produced from fibers have a special place. Nonwoven surface type textile materials which are advantageous economically and lightly as well as ecologically are also widely used. Literature studies have shown that materials made from natural fibers have better in terms of sound absorption properties [1]. In this study, chicken feather fibers which is a natural material, were used.

Research has shown that the porous internal structure of the chicken feather fibers gives a insulating properties to the fibers. In this study, it is aimed to investigate the acoustic parameters of nonwoven surfaces type insulating materials which are produced by thermal binding method based on dry-laying from chicken feather fibers.

When look the literature studies, it is seen that there are many parameters affecting the sound insulation properties of fibrous materials which has a porous. It is clear that these parameters do not affect the acoustic properties of the material at the same level. Material thickness, fiber size of the material, porosity, volumetric density, surface treatments etc. are the main parameters affecting sound insulation [2], [3], [4]. Among these parameters, as well as the importance of parameters such as material thickness and porosity in terms of material structure is, the sound frequency parameter is important in terms of parameters of emitted sound.

This study is deal with that the statistical evaluation of the acoustic properties of sound insulation materials which are produced from chicken feather. For this purpose, a multi-factorial experiment was designed and the effects of indusial factors in terms of acoustic properties were investigated.

2. Material and Method

2.1. Material

Chicken feather fibers: Chicken feather used in this study was obtained from Tad Piliç (Gaziantep), then fibers were obtained from that feather after washing, disinfection and drying process [5], [6].

Binding Materials: Powder form polyethylene and ethylene vinyl acetate and low melt bicomponent fiber (PES/PP) were used.

2.2.Method

2.2.1. Designing of experimental plan

Production of nonwoven surface samples by thermal binding was performed according to a multi-factorial experimental design in the Design Expert program. Based on the preliminary investigations, the type and amount of binding material, the sample size, the amount of fiber in sample and the sound frequency were used as independent changing parameters in the sample production. The change levels of the parameters are given in Table 1. Sound absorption coefficient and sound transmission loss are seen dependent variables from acoustic parameters of the material.

A factorial experimental design which is designed with 4 numerical, 1 categorical factor, is given in Table 2. The test plan includes 720 experiments.

Table 1. Experimental factors, change intervals and levels

			Change levels of factors	**Factor levels**	
Factors	**Sign**	**Factor type**		**Chance levels**	
				-1	**+1**
Type of binding material	A	Categorical		EVA, LDP, PE-PP(LM)	
Layer number of sample	B	Numerical	1…3	1	3
Fiber amount in sample	C	Numerical	10…20	10	20
Amount of binding material in sample	D	Numerical	30…50	30	50
Frequency of sound wave	E	Numerical	63…6300	63	6300

Table 2. Experimental design plan

No	Factors					
	A: BM	B: Layer	C:F.A	D:BM.A	E: Frequency	Y_i
1	-1	-1	-1	-1	63	
2	-1	-1	-1	1	63	
3	-1	-1	1	-1	63	
4	-1	-1	1	1	63	
5	-1	0	-1	-1	63	
6	-1	0	-1	1	63	
7	-1	0	1	-1	63	
8	-1	0	1	1	63	
9	-1	1	-1	-1	63	
10	-1	1	-1	1	63	
11	-1	1	1	-1	63	
12	-1	1	1	1	63	
13	0	-1	-1	-1	63	
…	…	…	…	…	…	

2.2.2. Production of nonwoven surface samples

At specified rations, the fiber and binding polymer material were mixed homogeneously and laid in to 16x16cm metal molds and placed in a hot press machine. Sample thickness and press pressure were fixed by means of the molds, with different volumetric density and porosity are obtained [7] (Figure 1).

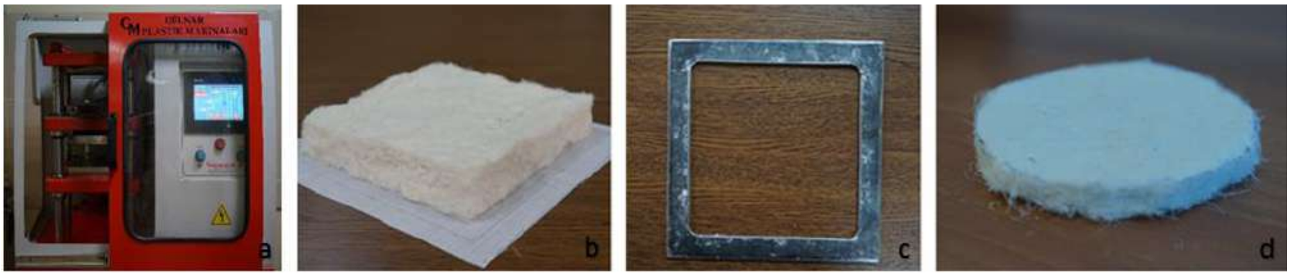


Figure 1. Production steps of nonwoven surface samples

(a-press machine, b-laid surface, metal mold, nonwoven sample)

2.2.3. Acoustic analyses of produced nonwoven surface samples

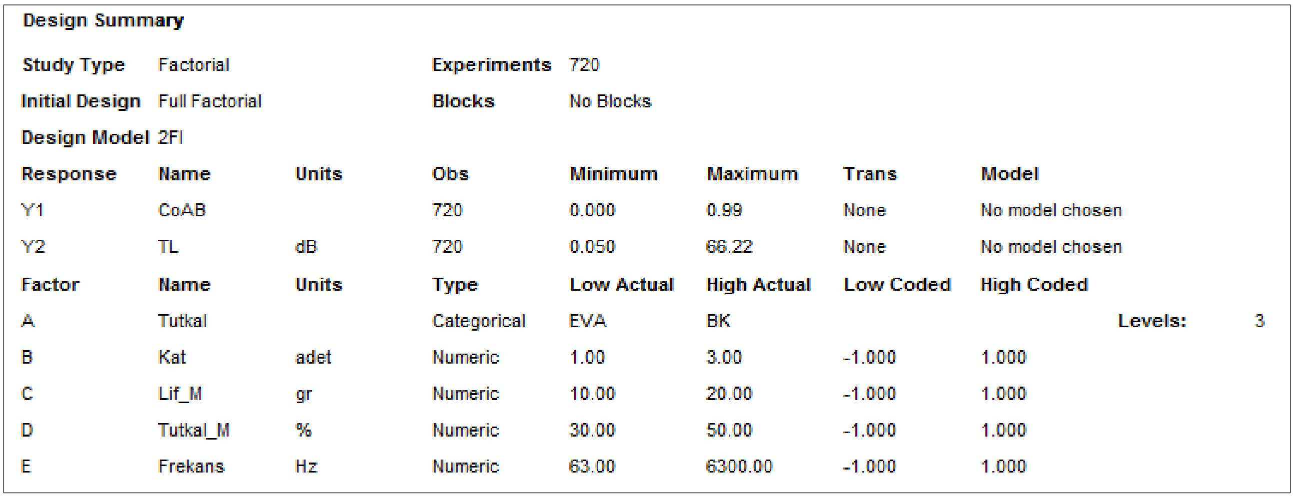
The sound absorption coefficient and the sound transmission loss values of the samples cut from the nonwoven surface samples were measured in the BSWA TECH branded impedance tube.

Figure 2. Impedance tube

3. Findings and Discussion

The acoustic properties of the samples, which were produced according to specified parameters, were measured and written to table. The summary of the experimental plan is given in Table 3.

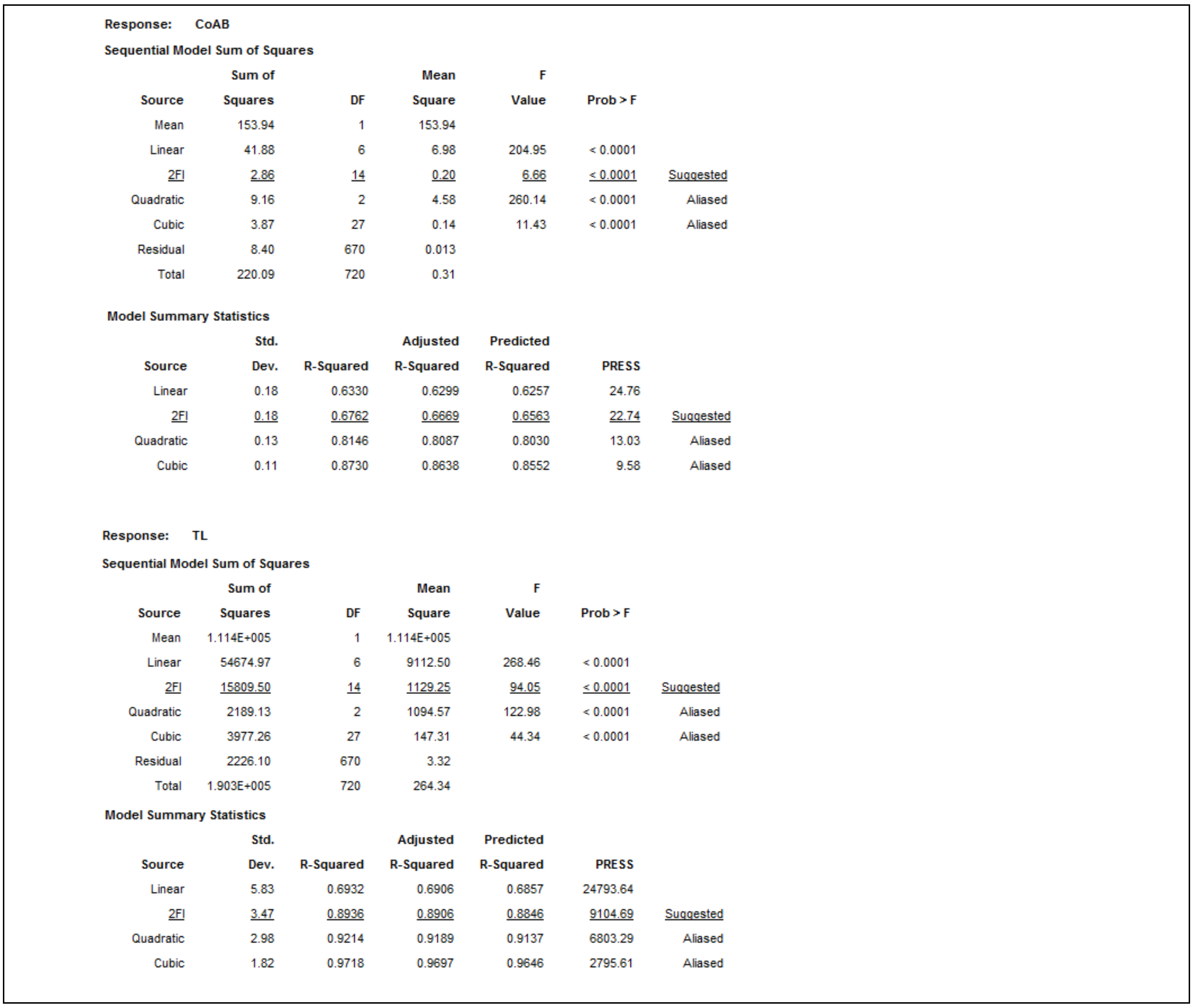
Table 3. The summary of multi-factorial experimental plan



Design Summary									
Study Type	Factorial		**Experiments**	720					
Initial Design	Full Factorial		**Blocks**	No Blocks					
Design Model	2FI								
Response	**Name**	**Units**	**Obs**	**Minimum**	**Maximum**	**Trans**	**Model**		
Y1	CoAB		720	0.000	0.99	None	No model chosen		
Y2	TL	dB	720	0.050	66.22	None	No model chosen		
Factor	**Name**	**Units**	**Type**	**Low Actual**	**High Actual**	**Low Coded**	**High Coded**		
A	Tutkal		Categorical	EVA	BK			**Levels:**	3
B	Kat	adet	Numeric	1.00	3.00	-1.000	1.000		
C	Lif_M	gr	Numeric	10.00	20.00	-1.000	1.000		
D	Tutkal_M	%	Numeric	30.00	50.00	-1.000	1.000		
E	Frekans	Hz	Numeric	63.00	6300.00	-1.000	1.000		

The model choice for both outcome parameters (sound absorption coefficient, sound transmission loss) is given in Table 4.

Table 4. Selection of model in multi-factorial experiment plan analysis



Response: CoAB

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	153.94	1	153.94			
Linear	41.88	6	6.98	204.95	< 0.0001	
2FI	2.86	14	0.20	6.66	< 0.0001	Suggested
Quadratic	9.16	2	4.58	260.14	< 0.0001	Aliased
Cubic	3.87	27	0.14	11.43	< 0.0001	Aliased
Residual	8.40	670	0.013			
Total	220.09	720	0.31			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.18	0.6330	0.6299	0.6257	24.76	
2FI	0.18	0.6762	0.6669	0.6563	22.74	Suggested
Quadratic	0.13	0.8146	0.8087	0.8030	13.03	Aliased
Cubic	0.11	0.8730	0.8638	0.8552	9.58	Aliased

Response: TL

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	1.114E+005	1	1.114E+005			
Linear	54674.97	6	9112.50	268.46	< 0.0001	
2FI	15809.50	14	1129.25	94.05	< 0.0001	Suggested
Quadratic	2189.13	2	1094.57	122.98	< 0.0001	Aliased
Cubic	3977.26	27	147.31	44.34	< 0.0001	Aliased
Residual	2226.10	670	3.32			
Total	1.903E+005	720	264.34			

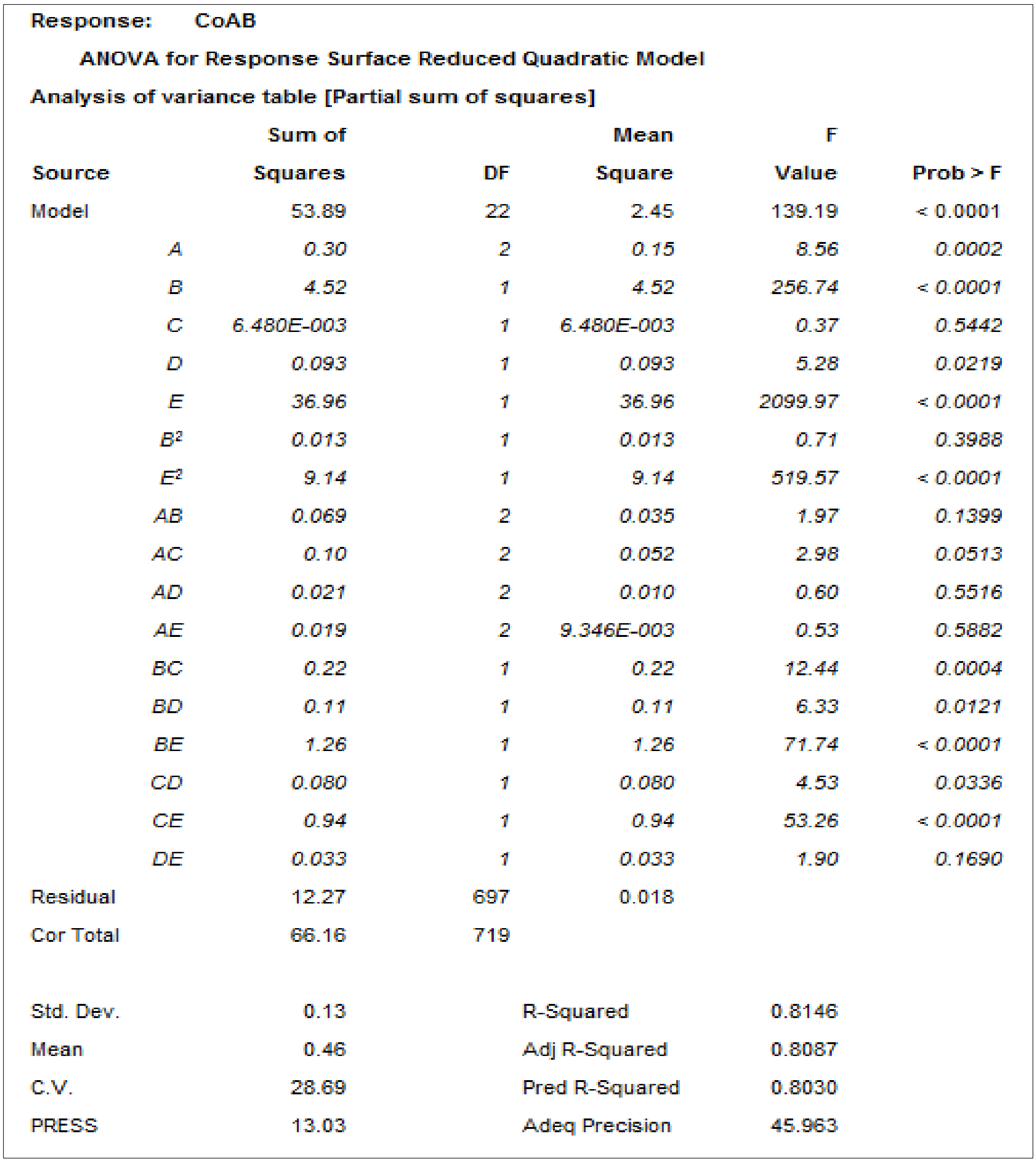
Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	5.83	0.6932	0.6906	0.6857	24793.64	
2FI	3.47	0.8936	0.8906	0.8846	9104.69	Suggested
Quadratic	2.98	0.9214	0.9189	0.9137	6803.29	Aliased
Cubic	1.82	0.9718	0.9697	0.9646	2795.61	Aliased

For the value of sound absorption coefficient, it suggests an incomplete quadratic model. Although the F and S² values of the model are higher than the quadratic model, incomplete quadratic model was selected. For the sound transmission loss, it is also suggested the incomplete quadratic model.

The summary of ANOVA table for sound absorption is given in Table 5. The summary of ANOVA table 6 for sound transmission loss is given in Table.

Table 5. ANOVA summary for sound absorption coefficient



Response: CoAB

ANOVA for Response Surface Reduced Quadratic Model

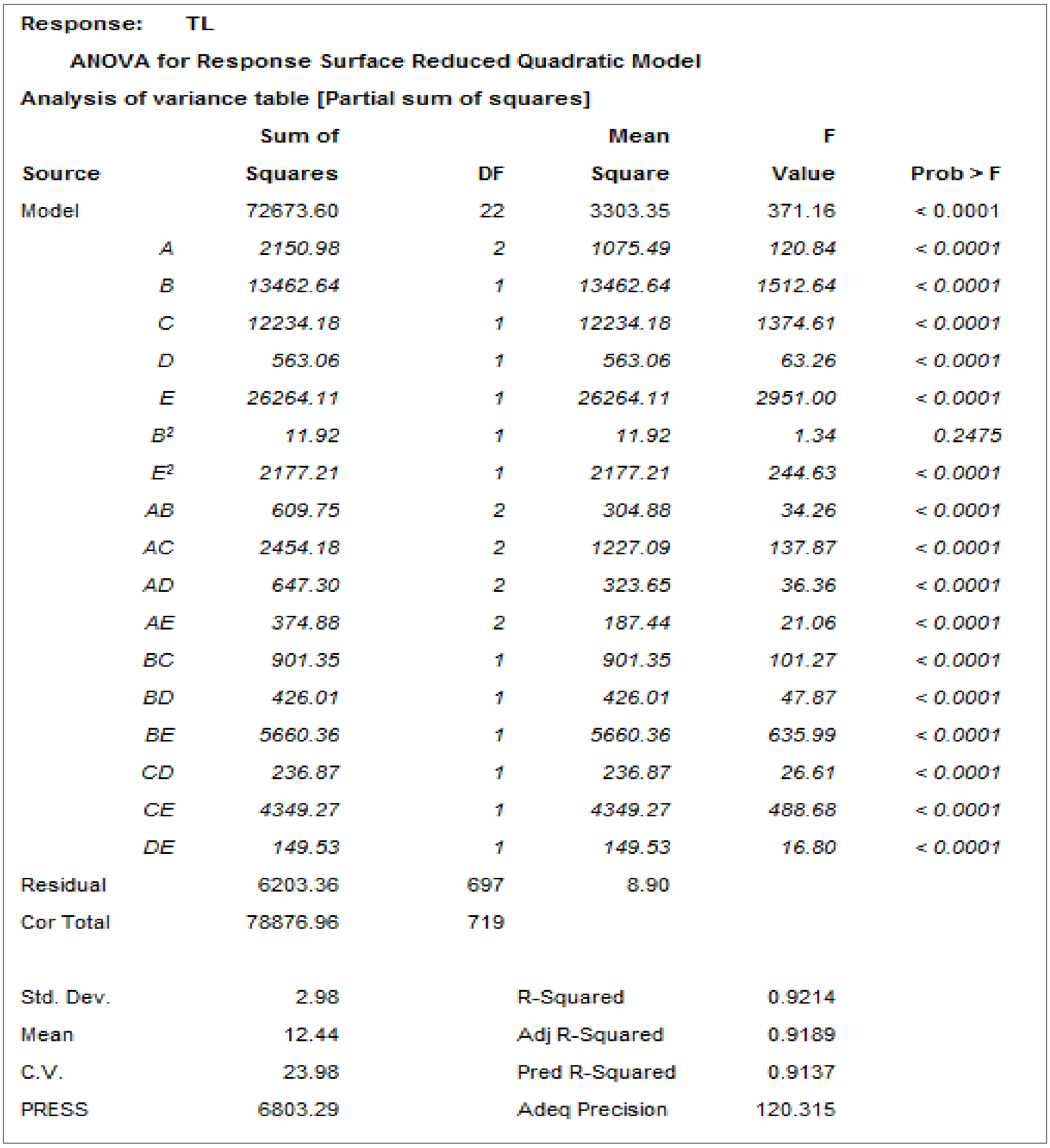
Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	53.89	22	2.45	139.19	< 0.0001
A	0.30	2	0.15	8.56	0.0002
B	4.52	1	4.52	256.74	< 0.0001
C	6.480E-003	1	6.480E-003	0.37	0.5442
D	0.093	1	0.093	5.28	0.0219
E	36.96	1	36.96	2099.97	< 0.0001
B^2	0.013	1	0.013	0.71	0.3988
E^2	9.14	1	9.14	519.57	< 0.0001
AB	0.069	2	0.035	1.97	0.1399
AC	0.10	2	0.052	2.98	0.0513
AD	0.021	2	0.010	0.60	0.5516
AE	0.019	2	9.346E-003	0.53	0.5882
BC	0.22	1	0.22	12.44	0.0004
BD	0.11	1	0.11	6.33	0.0121
BE	1.26	1	1.26	71.74	< 0.0001
CD	0.080	1	0.080	4.53	0.0336
CE	0.94	1	0.94	53.26	< 0.0001
DE	0.033	1	0.033	1.90	0.1690
Residual	12.27	697	0.018		
Cor Total	66.16	719			

Std. Dev.	0.13	R-Squared	0.8146
Mean	0.46	Adj R-Squared	0.8087
C.V.	28.69	Pred R-Squared	0.8030
PRESS	13.03	Adeq Precision	45.963

When look at the Table 5, it is seen that the selected model is meaningful. However, some terms of the model are meaningless in the chosen experiment space. The terms ″Prob>F″ value above 0,05 are meaningless. In this respect, the values of A, B, D, E, E², BC, CD, DE are meaningful value. The S² values of the individual model terms are investigated to see which Factor is more likely to affect the value of the sound absorption coefficient. In this respect, E (sound frequency) and B (number of sample layers) are more effective as factors.

Table 6. ANOVA summary for sound transmission loss



Response: TL

ANOVA for Response Surface Reduced Quadratic Model

Analysis of variance table [Partial sum of squares]

Source		**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**
Model		72673.60	22	3303.35	371.16	< 0.0001
	A	2150.98	2	1075.49	120.84	< 0.0001
	B	13462.64	1	13462.64	1512.64	< 0.0001
	C	12234.18	1	12234.18	1374.61	< 0.0001
	D	563.06	1	563.06	63.26	< 0.0001
	E	26264.11	1	26264.11	2951.00	< 0.0001
	B^2	11.92	1	11.92	1.34	0.2475
	E^2	2177.21	1	2177.21	244.63	< 0.0001
	AB	609.75	2	304.88	34.26	< 0.0001
	AC	2454.18	2	1227.09	137.87	< 0.0001
	AD	647.30	2	323.65	36.36	< 0.0001
	AE	374.88	2	187.44	21.06	< 0.0001
	BC	901.35	1	901.35	101.27	< 0.0001
	BD	426.01	1	426.01	47.87	< 0.0001
	BE	5660.36	1	5660.36	635.99	< 0.0001
	CD	236.87	1	236.87	26.61	< 0.0001
	CE	4349.27	1	4349.27	488.68	< 0.0001
	DE	149.53	1	149.53	16.80	< 0.0001
Residual		6203.36	697	8.90		
Cor Total		78876.96	719			

Std. Dev.	2.98	R-Squared	0.9214
Mean	12.44	Adj R-Squared	0.9189
C.V.	23.98	Pred R-Squared	0.9137
PRESS	6803.29	Adeq Precision	120.315

As shown in Table 6, the selected model is meaningful. In here all terms of the model are meaningful except for B^2. It can be said that the factors of E (sound frequency), B (layer number of sample), C (fiber amount in sample) are more effective.

The distribution of the data is normal. The model has 0,81 value for sound absorption coefficient, has a R^2 value equal to 0,92 for sound transmission loss. This indicates that the model is sufficiently descriptive.

We can interpret from the graphs of the obtained models that how individual factors affect the acoustic parameters (Figure 3-6). When look at the graphs in Figure 3, for each binding material type, the sound absorption coefficient increases in the low and medium frequency regions as the sound frequency value increases, but decreases in the high frequency regions (Fig.3, left). As can be seen from graphs, the acoustical parameters are not affected much by the binding material type.

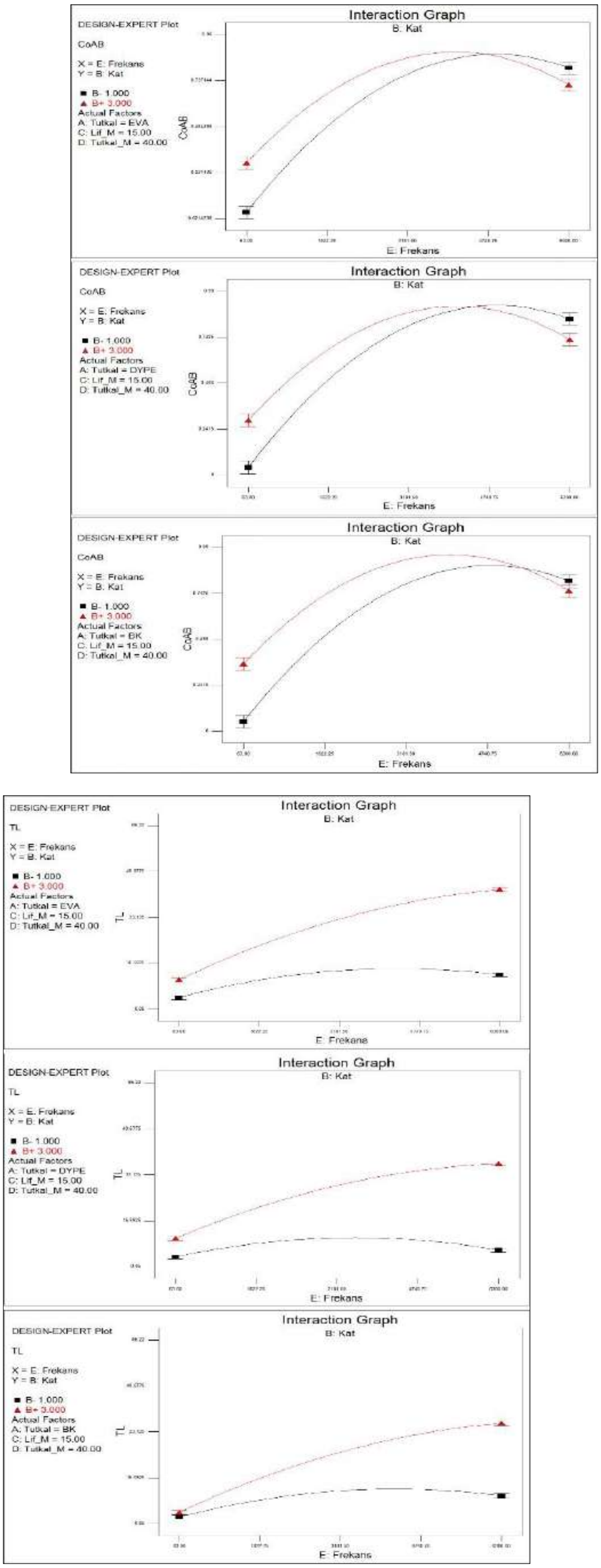


Figure 3. Effetc of binding material type on acoustic parameters

As the sample thickness increases the sound absorption coefficient increases and this shifts towards the low frequency (Fig.4, left). The same situation was seen in the curves of sound tranmission loss (Fig.4, rigt). As the thickness increases, the sound tranmission loss increases along the all frequency scale.

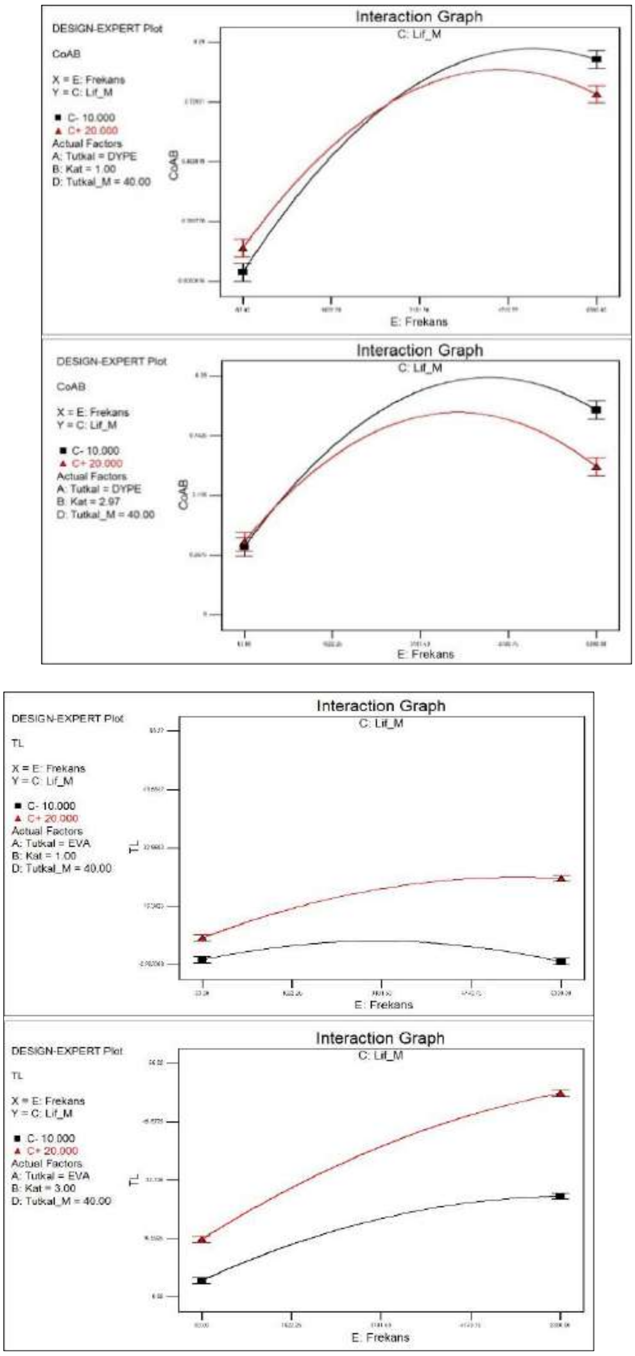


Figure 4. Effect of sample thickness on acoustic parameters

The increase of fiber amount in the sample leads to a decrease in the value of the sound absorption coefficient when the sound frequency increase (Fig., left). In fact, an increase in fiber amount means an increase in material density. This leads to a decrease in the value of the sound absorption coefficient ah high frequencies. For the values of sound transmission loss, this situation is different from it (Fig.5, right).

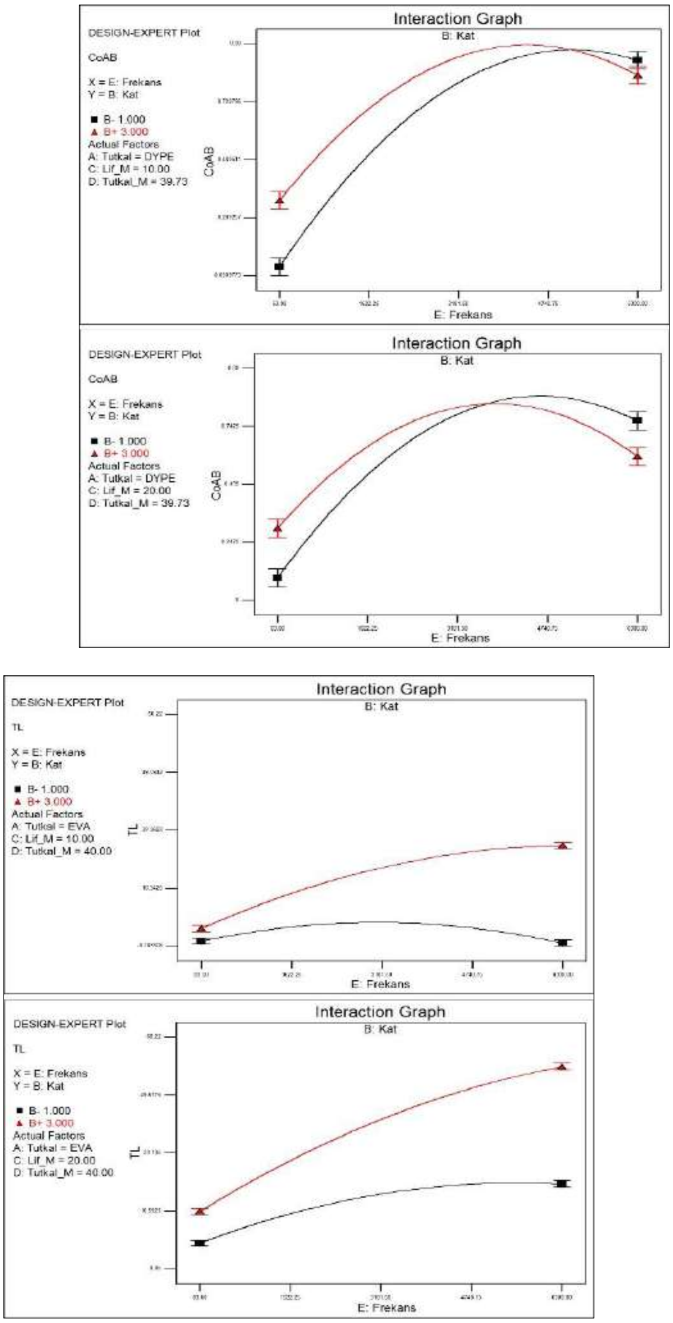


Figure 5. Effect of the fiber amount on acoustic parameters

Since the amount of binding material in samples directly affected the density of the material, fiber amount affect similarly to the values of sound absorption and sound transmission loss (Fig 6).

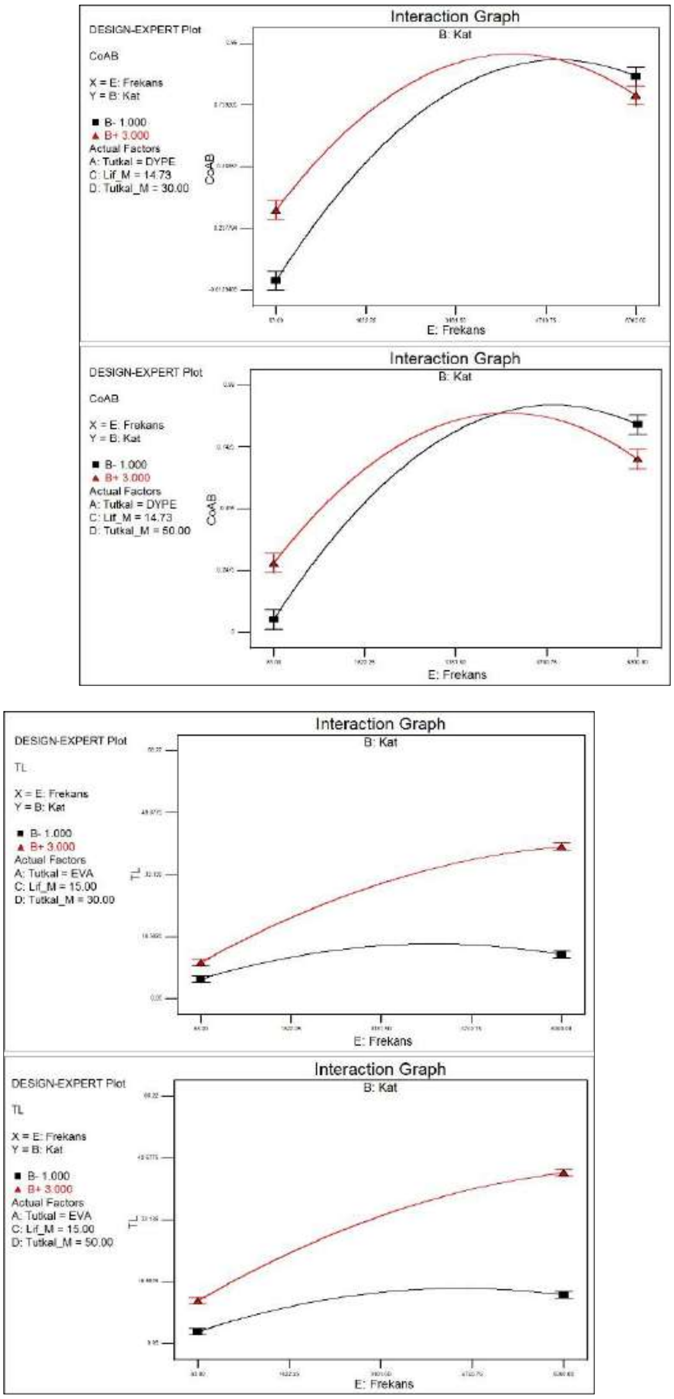


Figure 6. Effect of the amount of binding material in the sample on acoustic parameters

In the Design Expert program, the optimization issue has been resolved and study areas have been defined that allow to obtained evaluable results by determining the desired value range for each optimization criterion. In figure 7, the change range of the sample production parameters that the sound absorption coefficient is in the range of 0,4---1,0 and the sound transmission loss is in the range of 20…70Db is given. Yellow colored areas are study areas where we can obtain these values.

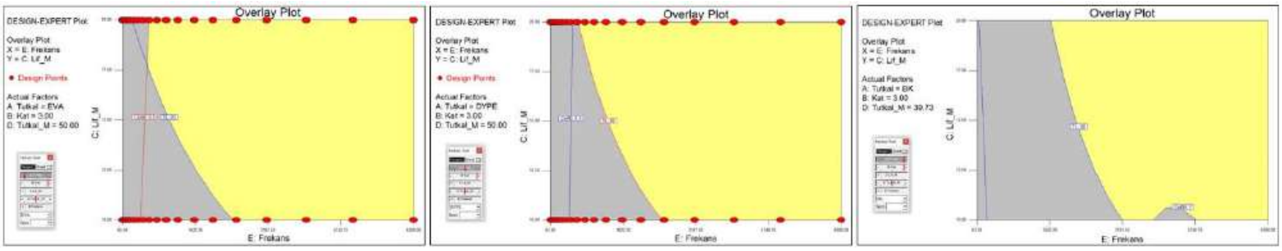


Figure 7. Study areas with factors to produce samples at acceptable quality

4. Conclusions and Recommendations

As a results of statistical analysis applied to the data obtained from the designed and realized multi-factorial experiments, parameters such as binding polymer type, sample thickness, fiber amount in sample, binding amount in sample and sound frequency, seriously affect the values of the sound absorption coefficient and sound transmission loss. According to experiment conditions, increase of fiber amount caused an increase of material density. When look at the results, it is seen that the increase of material density caused a decrease of sound transmission loss at high frequencies. In values of sound transmission, this effect caused increases. As the increases in the fiber amount effect the sample density, it decreased the value of sound absorption coefficient at high frequencies and increases the loss of sound transmission values.

It is seen from the study results, it is possible to develop acoustic materials with different sound absorption and transmission properties by changing the levels of factors.

For example, as the sample thickness increases, the values of the sound absorption coefficient increase and this increasing shift to low frequency regions. For the sound transmission loss, the increase of sample thickness caused an increase in the all frequency scales.

Acknowledgement

This study was supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK) with 115M725 numbered researching project.

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