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ENVIRONMENTALLY FRIENDLY ACOUSTIC PANEL DESIGN FROM CURTAIN WASTE

PERDE ATIKLARINDAN ÇEVRE DOSTU AKUSTİK PANEL TASARIMI

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ABSTRACT: Using leftover industrial curtain fabrics, this study aims to develop environmentally friendly acoustic panels. In this context, two forms of curtain fabric waste, blackout and dimout, which are segregated as waste from post-production process within Oba Perdesan, are transformed into fiber utilizing mini shredder. The hot press method is used to produce composite samples made of 100% blackout and 50% blackout/ 50% dimout fabric waste in two different thicknesses (0.5 and 1 cm). The thickness, density, basis weight, FTIR, sound absorption coefficient, and sound transmission loss of the manufactured panels are measured. The FTIR analysis reveals the distinctive peaks of the raw materials of the structures, while the acoustic test results show that the sound absorption coefficient and sound transmission loss increase along with the thickness and basis weight of the structures, respectively. While the 1 cm blackout/dimout blend sample has a superior sound absorption coefficient for 2000 Hz with 0.81, the 1 cm 100% blackout sample performs highest with 10dB sound transmission loss. The produced panels aid in solid waste management while consuming minimal raw materials, and an essential step is taken toward the development of sustainable, practical, and decorative panels.

Keywords: Recycling, Acoustic Panel, Curtain Waste, Composite

PERDE ATIKLARINDAN ÇEVRE DOSTU AKUSTİK PANEL TASARIMI

ÖZ: Bu çalışma, atık endüstriyel perde kumaşlarını kullanarak çevre dostu akustik paneller geliştirmeyi amaçlamaktadır. Bu kapsamda Oba Perdesan bünyesinde üretim sonrası süreçte atık olarak ayrıştırılan iki farklı perdelik kumaş telefi (blackout ve dimout) mini parçalayıcı ile elyaf haline dönüştürülmüştür. %100 blackout ve %50 blackout/ %50 dimout kumaş telefinden oluşan iki farklı kalınlığa sahip (0,5 ve 1 cm) kompozit numuneler sıcak pres yöntemi ile üretilmiştir. Üretilen panellerin kalınlık, yoğunluk, gramaj, ses yutum katsayısı, ses iletim kaybı ölçülmüş, FTIR analizi gerçekleştirilmiştir. FTIR analizi, yapıların hammaddelerinin ayırt edici piklerini ortaya koyarken, akustik test sonuçları, yapıların kalınlığı ve gramajı ile birlikte sırasıyla ses emme katsayısının ve ses iletim kaybının arttığını göstermektedir. 1 cm'lik blackout/dimout karışımı numunesi 2000 Hz için 0,81 ile üstün bir ses yutum katsayısına sahipken, 1 cm'lik %100 blackout numunesi 10dB ses iletim kaybıyla en yüksek performansı gösterir. Üretilen panellerle, minimum hammadde tüketimi ile katı atık yönetimine yardımcı olunurken ve sürdürülebilir, pratik ve dekoratif panellerin geliştirilmesi yönünde önemli bir adım atılmaktadır.

Anahtar Kelimeler: Geri dönüşüm, Akustik Panel, Perde Atığı, Kompozit

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1. INTRODUCTION

The rapid expansion of today's industries has seriously disturbed the environment. Noise pollution has become a major health and ecological concern as a result of urbanization, industrial growth, and increased use of vehicles, electrical and mechanical devices. Noise pollution is defined by the World Health Organization (WHO) as noise above 65 decibels (dB). It causes a variety of health problems, such as sensory impairment, stress, high blood pressure, coronary heart disease, and stroke [1-4]. Noise control materials used in the construction industry are primarily inorganic and synthetic composites, such as glass wool, stone wool, and polystyrene. Typically, porous materials have significant sound-absorbing qualities. These substances have pore-producing cavities, channels, or interstices that result in open, interconnected pores. Despite having high sound absorption coefficients, these materials have a significant environmental impact [5-7].

Global textile consumption has risen gradually over the last two decades. The rising rate of consumption has had a huge effect on both manufacturing amounts and generation of waste [8]. Every year, approximately 150 million tons of textile waste are produced globally [9]. According to a briefing from the European Environment Agency, textiles rank as the fifth largest source of CO_2 emissions from private consumption [10]. Textile wastes are mostly incinerated or ends up in landfills in the lack of adequate waste management strategies, posing environmental and social risks. Since synthetic textiles are non-biodegradable, they cause higher environmental and social problems [8]. Polyester accounts for roughly 60% of all man-made fibers [11].

Since waste generation is directly associated with carbon emissions, the current EU goal is to cut carbon emissions by 55% by 2030. In recent years, the use of recycled materials in the field of acoustics has gained importance [6]. Sound pollution can be significantly reduced by using acoustic insulation materials made from recycled textile waste, which also contributes to a decrease in municipal solid waste [12]. Textile waste has been one of the most important innovative raw materials used in the development of sound insulation materials in recent years since they can improve the porosity of construction materials [13]. When the literature is examined, it is discovered that there are studies in which sound insulation materials are designed and manufactured using a variety of textile wastes [9,11,14-16]. In this study, it is aimed to develop an environmentally friendly, sustainable, value-added acoustic panel from the fabric wastes generated in an interior window covering factory (Oba Perdesan). In this way, it is aimed to recover approximately 4 tons of fabric waste generated every month.

2.EXPERIMENTAL STUDY

2.1. Materials

Within the scope of this study, two types of curtain wastes (Figure 1) generated within Oba Perdesan are utilized:

i. Blackout curtains are tightly woven fabrics including 100% polyester fibers with a polyacrylate based foam coating that provides 100% blackout effect. The foam ratio is 60%.

ii. Dimout curtains are tightly woven fabrics including 100% polyester fibers without foam coating thus these curtains provide semi-blackout effect.

Warp x weft density of both blackout and dimout waste woven fabrics is 51x 35, basis weight and fabric thickness value ranges are 315-365g/m² and 0.35-0.49mm, respectively.

Figure 1. Backout (maroon color) and dimout (green color) curtain fabric wastes

Blackout fabrics are utilized on their own while dimout fabrics are blended with blackout fabrics at a weight ratio of 50% for the manufacturing of composite panels. The blackout fabric's polyacrylate-based foam coating which can be seen in Figure 1 as white color coating in the inside of the sample, made it easy to process the panels using the hot press method without the use of an additional binder.

2.2 Methods

2.2.1 Waste Collection

Waste collection bins (Figure 2) are placed throughout Oba Perdesan and employees are trained to properly collect the waste in the relevant bins.

Figure 2. Waste collection bins

2.2.2 Production of Composite Structures

Both blackout and dimout curtain fabric wastes collected throughout Oba Perdesan are opened into fiber form using a mini-shredder (Mapishredder-s40, Figure 3).

For the manufacture of composite samples, a casting mold suitable for the production of test samples in suitable sizes for specifically acoustic performance tests and a general rectangular form for other performance analysis is used. Teflon paper is placed in the mold, and the sample is prevented from sticking to the mold surface when it melted (Figure 4a). The mold is placed in the hot press, the samples are placed while the press is cold, the temperature is increased to 160 °C and after 15 minutes, the heating is turned off and the samples are left to cool down in hot press to avoid curling (Figure 4b). The molds are separate for both small and large tube acoustic sample sizes, allowing simultaneous production of samples of 0.5 and 1 cm thickness. For small tube samples with a thickness of 0.5 cm, the total weight is determined to be 2.30±0.05g, and for large tube samples, the total weight is determined to be 23±0.5g. These values are doubled when producing samples that are 1 cm-thick. Produced composite samples can be seen in Figure 4c. Sample codes and the explanations of the composite samples can be seen in Table 1.

Figure 3. a. Mini-shredder **b.** shredded blackout (maroon color) and dimout (green color) curtain fabric wastes

Figure 4. a. the sample placement in a casting mold, **b.** hot press, **c.** produced composite samples

Table 1. Sample codes and the explanations of the composite structures produced within this study.

Sample Codes	**Explanations**
100B_0.5	Composites composed of 100% blackout curtain wastes with a thickness of 0.5cm
100B_1	Composites composed of 100% blackout curtain wastes with a thickness of 1cm
50B-50D_0.5	Composites composed of 50% blackout and 50% dimout curtain wastes with a thickness of 0.5cm
50B-50D_1	Composites composed of 50% blackout and 50% dimout curtain wastes with a thickness of 1cm

2.2.3 Performance Analysis of Composite Structures

2.2.3.1. Physical Analysis

The thickness of the samples are measured by a digital microgage (Hexagon Metrology) while the weight of the samples are measured using a precision balance. Densities are calculated using these experimental data. Results are given as means and standard deviations.

2.2.3.2. FTIR Analysis

Fourier-transform infrared (FTIR) spectroscopy (UATR Two, Perkin Elmer) is used to perform a chemical analysis on the blackout and dimout fabrics in order to demonstrate the origin of the fabrics and the presence of coating materials.

2.2.3.3. Acoustic Analysis

The acoustic performance of composite samples in terms of sound absorption coefficient (ISO 10534-2 standard) and sound transmission loss (ASTM E2611-09) is carried out using the TestSens Sound tube. For sound absorption coefficient measurement, TestSens Two Microphone Impedance Measurement Tubes in the frequency range from 50 Hz to 6400 Hz is used while the sound transmission loss is measured using the TestSens Four Microphone Impedance Measurement Tube.

2.2.3.4. Statistical Analysis

Minitab 16 software program is used to perform the statistical analysis of sound absorption results. 2*2 full-factorial experimental design is used and the factors and their levels are given in Table 2. The statistical significance of the findings is determined using ANOVA. Tests are run three times for each factor and level combination, the experimental design layout has 12 runs.

Table 2. Factors and levels

Factors	Levels	
Material Type	100B	50B50D
Thickness	0.5	1

3. RESULTS

3.1 Physical Analysis Test Results

Table 3 lists the physical analysis test results. When the measurement findings are assessed, the basis weight values are 5592.15 g/m^2 and 5264.00 g/m^2 for 1 cm thick samples, and these values are roughly twice that of samples with 0.5cm thickness at 2826.47 g/m^2 and 2877.94 g/m^2. Although it is assumed that the thickness values are kept constant because of the fixed mold dimensions employed, the Teflon paper thickness that was utilized to prevent the material from sticking to the mold caused a variance of 1.5–2 mm in all samples (independent of thickness). The sample densities are altered, as a result. The thickness values of the samples containing blackout fabric waste, on the other hand, are slightly lower than the thickness of the samples containing blackout-dimout fabric waste. This can be explained by the wastes sticking together as a result of the melting of the acrylic foam coating used on blackout fabrics.

3.2. FTIR Analysis Test Results

Figure 5 represents the FTIR spectra obtained for the dimout and blackout fabrics (both from the backside/frontside). The dimout and blackout/frontside spectra are very similar to each other, indicating that they belong to polyester fabrics. Characteristic absorption bands are observed at 2924 and 2848 cm^{-1} for $\nu_{s,as}$(C–H) bonds from alkyl chains, the stretching vibration of the carbonyl group ν(C=O) from acid is noticed at a band of 1710 cm^{-1}, CH_2 vibrations can be seen at 1460 cm^{-1}, bands at 1338 and 1239 cm^{-1} show ν(O–C) from acid, while 1093 and 1012 cm^{-1} peaks represent ester ν(O–C) [17].

The FTIR spectrum of backside of the blackout fabric totally differs from the frontside which proves the acrylic based coating including the absorption peaks of stretching vibrations at 1736 cm^{-1} for (C=O) carboxyl groups and at 2931 cm^{-1} and 2859 cm^{-1} for -CH_2 in the molecular chain [18, 19].

Table 3. Means of thickness, weight and the density of the samples with standard deviations (SD).

Sample Codes	Thickness±SD [cm]	Basis weight±SD [g/m^2]	Density±SD [g/cm^3]
100B_0.5	3.27±0.07	2874.72±110.85	0.88±0.03
100B_1	8.08±0.26	5766.26±518.68	0.71±0.05
50B-50D_0.5	3.47±0.08	2832.50±206.83	0.82±0.05
50B-50D_1	8.38±0.08	5263.83±187.18	0.63±0.02

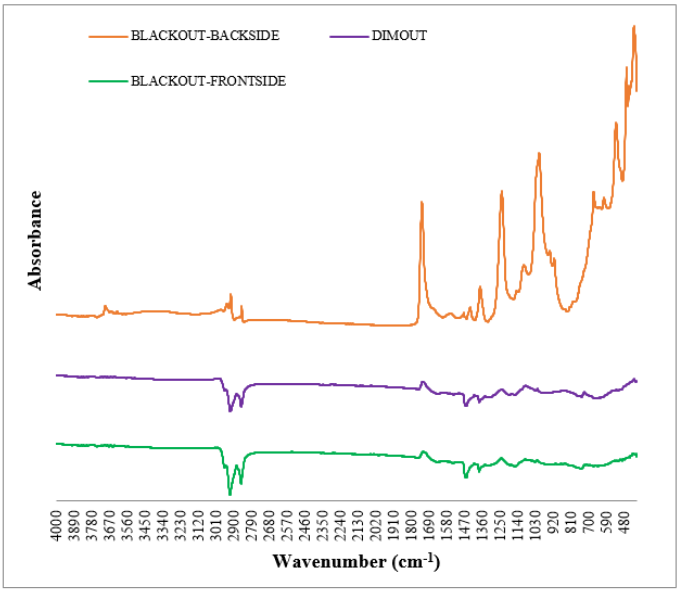

Figure 5. FTIR spectra of blackout and dimout curtain fabrics

3.3. Acoustic Analysis Test Results

3.3.1. Sound Absorption

Examining the sound absorption test results from Figure 6 reveals that the increase in sample thickness has a significant impact on sound absorption performance. The 100B_1 sample, which has a thickness of 1 cm, has a sound absorption coefficient of 0.64 at 2000Hz which is 83% higher than that of the 100B_0.5 sample (0.35). For sample groups that have dimouts, the same is valid. The sound absorption coefficient of the 50B-50D_1 sample is 93% higher at 2000 Hz (0.81) than that of the 50B-50D_0.5 sample (0.42).

Similarly, the samples containing 50% blackout - 50% dimout regardless of thickness provide better sound absorption than 100% blackout samples. This can be explained by the fact that the foam coating content in the blackout curtains melts under the effect of heat and pressure applied in the hot press, closing the structural gaps and consequently reducing the structural porosity.

3.3.1. Sound Transmission Loss

Sound transmission loss analysis test results can be seen in Figure 7. According to the literature, a material's mass per unit area is the most crucial physical characteristic that affects its sound transmission loss [20]. With an increase in mass per unit area, sound transmission loss rises. The sound transmission loss values of the 50B50D_0.5 and 100B_0.5 samples, whose basis weight values are relatively close to one another and less than the other samples, are lower than those of the other samples, but the sound transmission loss value of the 100B_1 sample with the highest basis weight value is the highest in all frequency values. In addition, it is thought that there may be the effect of foam coating in the blackout fabric, which melts under heat and makes the structure more compact.

3.4. Statistical Analysis Results

Table 4 shows the ANOVA response table of sound absorption values of samples at 2000Hz. When the main effects are examined, the p values of both are less than 0.05, indicating that they are statistically effective on sound absorption. When the two factors are compared, it is clear that the thickness factor ($p=0.000$) has a greater effect on sound absorption than the material factor ($p=0.023$). The main effect plot in Figure 8a clearly shows this situation. With the variation of the thickness between the levels, the absorption value changes at a higher rate.

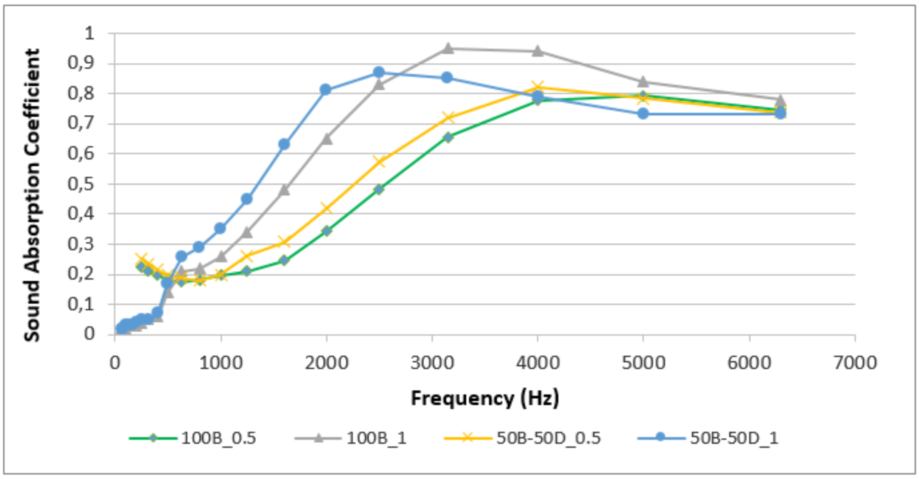

Figure 6. Sound absorption coefficient test results of the composites

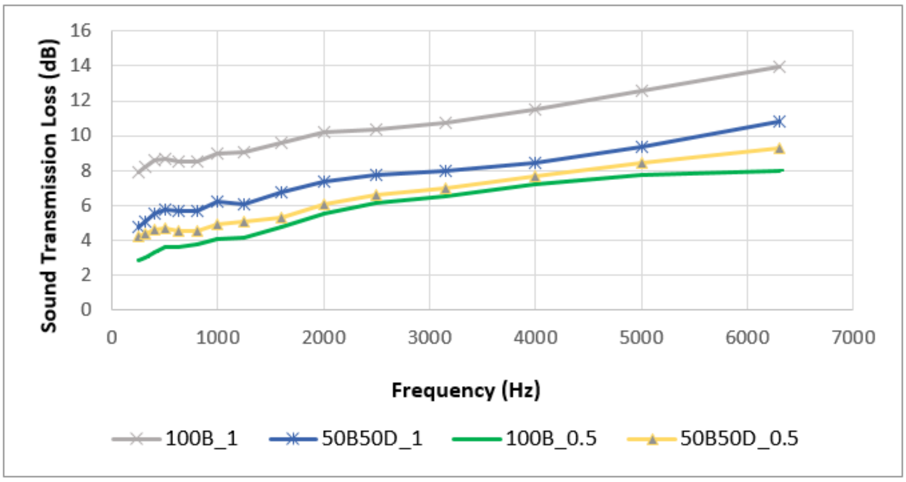

Figure 7. Sound transmission loss test results of the composites

Table 4. ANOVA response table of sound absorption values of samples at 2000Hz

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	0,341089	0,339049	0,169524	84,50	0,000
Material Type	1	0,034722	0,016783	0,016783	8,37	0,023
Thickness	1	0,306367	0,302252	0,302252	150,67	0,000
2-Way Interactions	1	0,000007	0,000007	0,000007	0,00	0,953
Material*Thickness	1	0,000007	0,000007	0,000007	0,00	0,953
Residual Error	7	0,014043	0,014043	0,002006		
Pure Error	7	0,014043	0,014043	0,002006		
Total	10	0,355139				

The interaction between the two factors is seen to have a p value of 0.953. This demonstrates that although these two factors have an impact on the outcome separately, their bilateral interactions have no statistically significant impact on the material's ability to absorb sound. It can be seen from the dual interaction graph that the two curves are parallel to one another. Two curves are known to intersect when there is a significant interaction. It is supported by the obtained parallel curves that the interaction is not statistically significant.

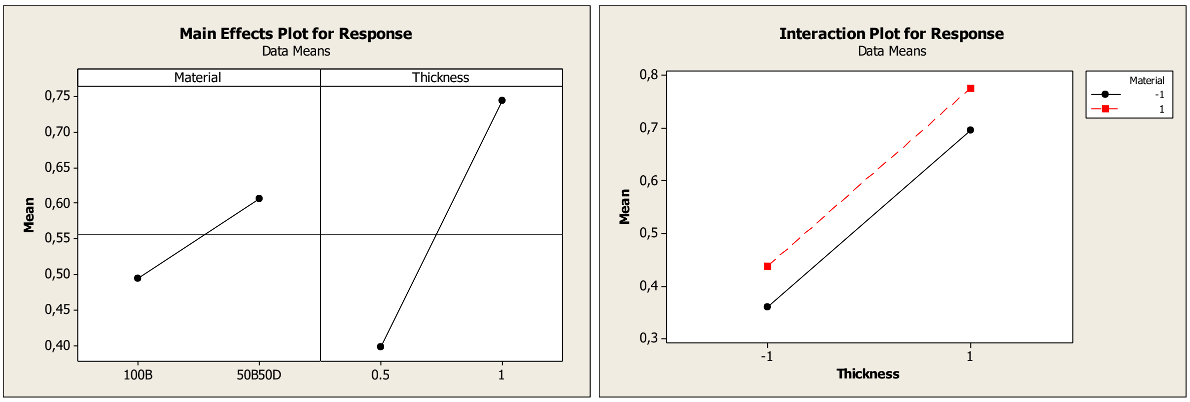

Figure 8. a. Main effects plot, **b.** interaction plot for response

4. CONCLUSION

Within the scope of this study, two different post-production curtain wastes (blackout and dimout) are recycled and acoustic panel production is carried out by hot press method. The physical and acoustic properties of the composite samples produced with different thicknesses (0.5 and 1 cm) and raw materials (100% blackout and 50% blackout/50% dimout are examined and the results show that sample thickness increase sound absorption performance, and that samples with 50% blackout and 50% dimout have enhanced sound absorption coefficients (0.81 at 2000 Hz) than samples with 100% blackout (0.64 at 2000Hz) due to their more porous structure. ANOVA analysis further supports the results' significance. When the sound transmission loss values are examined, the increase in the sound transmission loss value with the increasing weight value of the sample is apparent. The highest sound transmission loss value measured at 2000 Hz is 10 dB for 100B_1. Additionally, FTIR analyses of the produced samples are carried out, and the distinctive peaks of the materials are displayed indicating the presence of polyester fabric and foam coating. This work pioneered an important step towards the creation of sustainable and decorative panels while also assisting waste recycling and solid waste management.

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