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Multi-objective Optimization of Thermal and Sound Insulation Properties of Basalt and Carbon Fabric Reinforced Composites Using the Taguchi Grey Relations Analysis

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ABSTRACT

In this study, an experimental investigation was conducted to explore the thermal and acoustic insulation capabilities of basalt fabric and carbon fabric-reinforced composite materials. The relationship between fabric additive ratios and sound and thermal absorption qualities has been studied. The resin is mixed with two distinct mineral powder additions. Taguchi Grey Relations Analysis optimization approach was utilized to discover the composite material with the optimum sound and thermal insulation qualities. The Taguchi Method Experimental Design L18 (mixed 3–6 levels) was chosen. Fabric (six levels), Al_2O_3 (alumina) filler (three levels), and SiC (silicon carbide) filler (three levels) were chosen as test parameters as input variables based on the experimental design. Sound Transmission Loss and Thermal Conduction Coefficient were chosen as the output parameters to be optimized as response variables. The study's findings led to the identification of optimal samples for thermal conductivity coefficient and sound transmission loss testing, as well as confirmation tests for these samples. Using the Taguchi Grey Relational Analysis, the best input parameters were discovered to be 30% carbon, 0% Al_2O_3, and 5% SiC for the best Thermal Conductivity Coefficients (W/mK) and Sound Transmission Loss (dB). As a result of the confirmation test, an improvement of 0.15 was found.

摘要

在本研究中，对玄武岩织物和碳织物增强复合材料的隔热和隔音性能进行了实验研究. 研究了织物添加剂比例与吸声和热吸收质量之间的关系. 树脂与两种不同的矿粉添加剂混合. 利用田口灰色关联分析优化方法，发现具有最佳隔音和隔热性能的复合材料. 选择田口方法实验设计L18（混合3-6级）。基于实验设计，选择织物（6级）、Al2O3（氧化铝）填料（3级）和SiC（碳化硅）填料（三级）作为测试参数作为输入变量. 选择声传输损耗和热传导系数作为输出参数，作为响应变量进行优化. 该研究的结果导致确定了导热系数和声音传输损失测试的最佳样本，以及这些样本的确认测试. 使用田口灰色关联分析，发现最佳输入参数为30%碳、0%Al2O3和5% SiC，以获得最佳导热系数（W/mK）和声音传输损耗（dB）. 作为确认测试的结果，发现改进为0.15.

KEYWORDS

Basalt; carbon, Al_2O_3 and SiC filler; composite; thermal and sound insulation; the Taguchi Grey analysis method

关键词

玄武岩; 碳; Al2O3和SiC填料; 混合成的; 隔热和隔音; 田口灰色分析法

Introduction

The manufacture of composite materials has increased significantly in recent years. This type of composite is employed in a variety of sectors and technologies. This substance has taken the role of old-style manufacturing. Glass and carbon fibers are the most commonly utilized materials in composite technology. However, today's glass fiber production requires elements that are

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difficult to come by in nature, and carbon fiber is extremely expensive. People begin to examine new products as a result of this. Basalt fiber is one of these materials. Basalt has no hazardous reactions with air or water, is readily available in nature, and has a strong resistance to acid and alkali, as well as a high strength and the ability to function at extremely high temperatures. Basalt fiber-reinforced composites are becoming more popular these days. Basalt fibers can also be utilized to insulate and protect against heat and sound. Basalt fibers can also be employed as fire-resistant materials due to their characteristics (Van de Velde, Kiekens, and Van Langenhove 2003). Basalt fibers are better than other fibers in terms of thermal stability, thermal and acoustic insulation qualities, vibration resistance, and durability since they are made from a single-ingredient raw material melt (Singha 2012). A recent study has shown that when aluminized, they have strong thermal resistance (Gilewicz et al. 2013), and epoxy basaltoplastics have substantially better alkali resistance and thermal/humidity resistance than epoxy composites generated from E- and S-glass fibers (Dalinkevich et al. 2009). Mıstık and Merdan (2012) found that basalt composites containing hazelnut shell and polyester resin have better thermal characteristics than those of e-glass composites. Basalt has a high elastic modulus, thermal stability, chemical resistance, and sound insulating characteristics (Chuvashov et al. 2020). Kim, Rhee, and Park (2020) were study on to introduce ozone/TEPA-functionalized NDs within the epoxy matrix to improve its thermal conductivity and fracture resistance by enhancing interfacial interactions. Furthermore, due to their outstanding thermal and mechanical qualities, flax and basalt can replace asbestos in strengthening friction pad composites (Kumar, Kumar, and Prakash 2021). In the study by Kim and Park (2021), a simple and efficient method is proposed for the deep and stable penetration of graphene oxide/graphitic nanofiber nanohybrids (GO-GNFs) into an epoxy matrix as CFRPs. Liu et al. (2022) investigated how both basalt fibers and glass fibers can be used as reinforced materials in fiber-reinforced polymer (FRP) composites. In their study, the tensile strength, elastic modulus, and hardness of basalt fibers and E-glass fibers are studied by fiber tensile tester and nanoindentation.

Expectations from composite materials have risen in recent years as technology has progressed and demand has climbed. Nano and micro particles, such as Al_2O_3, TiO_2, SiC, and SiO_2, have begun to be added to composites in order to meet these expectations. SiO_2 increased flexural strength and flexural modulus greater than Al_2O_3, TiO_2, according to Nayak, Dasha, and Ray (2014). Bulut (2018) Prasath and Krishnan (2013) introduced varied ratios of SiC and identified the optimal rate of SiC to have the best mechanical properties. Vaidya and Rangaswamy (2017) investigated Al_2O_3, SiC, B4C, $Mg(OH)_2$, and other chemical additions to discover the optimum filler. Kaybal, Ulus, and Avcı (2016) studied the influence of nano Al2O3 on the tensile characteristics of composites. Agarwal, Patnaik, and Sharma (2013) investigated the effect of the use of silicon carbide fillers on the thermo-mechanical properties of discontinuous glass fiber/epoxy composites. Zeng et al. (2012) investigated the effect of adding nanoparticles to the carbon fiber/epoxy composite on the mechanical properties of the composite. Ovalı (2015) produced polypropylene matrix composites using basalt fabric as reinforcement material and pumice stone of different sizes as filling material and examined the heat and sound insulation properties of these composites. At the end of the study, it was observed that the use of pumice stone improved the thermal and sound insulation properties of the composite, but negatively affected the tensile strength, modulus of elasticity and elongation properties. When these studies are examined, it is seen that the particles added to the composite are in general effective on the mechanical, sound, and thermal properties of the composite.

In this experimental study, the Taguchi Method (Grey Taguchi) based on Grey Relationships, which has become widespread in engineering studies in recent years, was used. With this method, which was developed by Genichi Taguchi, detailed analyses can be made with fewer experiments. In this way, both the cost of the experiment and the saving of time are provided (Savaşkan, Taptık, and Ürgen 2004).

Materials and methods

Material

Plain-woven basalt and carbon textiles weighing 200 g/m^2 were employed as composite reinforcing material in the investigation. Because basalt is a very strong material, its use has increased in recent years. These two materials were chosen in order to compare this material with carbon, which is the strongest material used in this field. Basalt is also used as a thermal insulation material. Gümülcine et al. (2013) suggested that basalt fibers are generally used as reinforcing material for composite materials with their excellent mechanical properties, in the fire protection sector due to their non-flammability and ability to retain their properties at high temperatures, as an insulator with their heat and sound insulation properties, and in corrosive environment applications due to their excellent chemical resistance.

Reinforcement fabrics were used at three different percentages: 30, 40, and 50 in composite. Figure 1 shows reinforcement materials and selected composite plates. Mineral powder components, SiC (micro powder, 3μ) and Al_2O_3 (nano powder, 28ηm), are used as particle additives. The matrix was epoxy resin (Propox 300 L-laminating epoxy set-LR 300/LH300–15 kg), and the accelerator was cobalt. The resin accelerator percent ratio is 75:25.

SiC (micro powder) was employed in three different proportions (0, 5, and 10) and Al_2O_3 (nano powder) in three different proportions (0, 2, and 4). These ratios are decided according to the literature and blended manually. The composite samples are produced using hand lay-up technique. It is known that composite materials are based on the weight ratio of the reinforcing resin. The porosity of the reinforcing fabrics was not evaluated in this study, but the m^2 weights of the carbon and basalt fabrics were chosen the same (200 g/m^2) to ensure the weight equality of the reinforcing fabrics in the composite.

Method

The Taguchi Grey Relations Analysis method was used as a multi-objective optimization method in the study. With this method, the composite sheet that will provide the optimization of both sound and thermal absorption properties (equal weight) has been investigated. MINITAB 16® package program was used in the application of the method. Experimental Design was chosen Taguchi L18-mixed 3–6 levels (Minitab Inc 2000). This design was chosen because of our test parameters and their levels. The Taguchi method states that instead of trying all combinations of the experiments, using orthogonal arrays, the factor levels that give the best performance characteristics can be found. Orthogonal arrays are expressed as a number of matrix. Each row represents the levels of the selected factors, and each column represents the factors considered. Generally, two- and three-level orthogonal arrays are used according to the experimental design. The most commonly used 2-level orthogonal arrays are L4, L8, L12, and L32. The most used three-level are L9, L18, L27. There are also orthogonal arrays, such as L18, L36, and L54, where both levels can be mixed. In our study, since the fabric factor is six levels, Al_2O_3 filler is three levels and the SiC filler is three levels, the L18 experiment plan was chosen in the mixed design suggested by the Taguchi experimental plan.

The test parameters (Input Variables) were determined as fabric (six levels), Al_2O_3 filler (three levels), and SiC filler (three levels) according to the experimental design. As a result of the experiments made according to the experimental design, the output parameters (response variables) to be optimized were decided as sound transmission loss and thermal conductivity coefficient. The input parameters and their levels are shown in Table 1. According to Table 1, if a full factorial experiment design is used, the number of experiments will be 54.

The number of experiments was reduced to 18 with the Taguchi Method used in the study. Table 1 shows L18 orthogonal layout in Taguchi experimental design and Table 2 shows the experimental plan. Table 2 contains the codes of experimental plan and the factor levels corresponding to the codes. According to the experimental design given in Table 2, the production of composite plates was carried

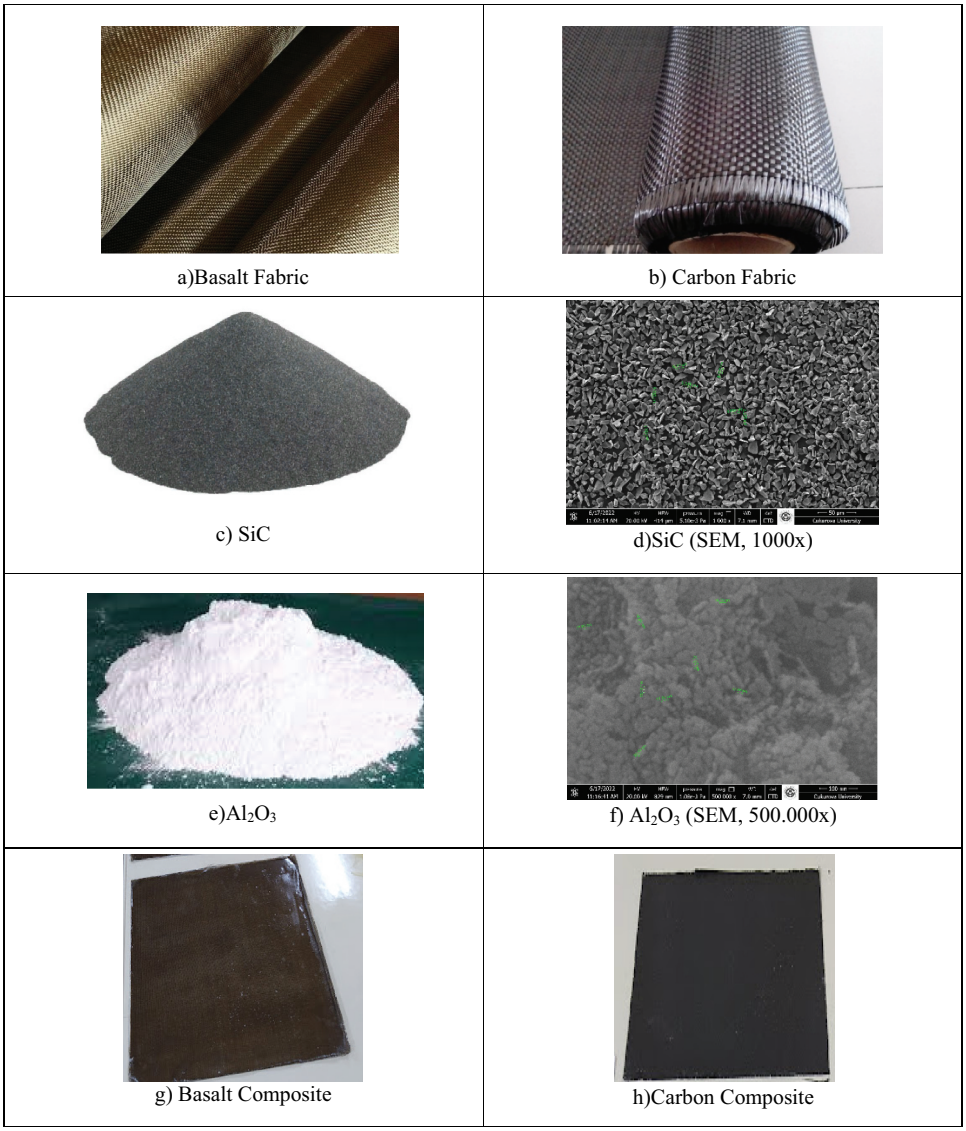


Figure 1. The materials for the study.

out using the hand lay-up method. The hand lay-up method used for composite production has been one of the production methods that has been widely used in low production quantities. This method is the process of giving the shape of the mold for fibers/fabrics placed in a mold with resin with a roller or brush (Figure 2).

After sample production, the samples were cut in the laser cutting device in the dimensions specified in the test standards. Thermal and sound absorption tests were applied to the produced composite samples. These were the outputs for the study. Sound transmission loss is the result of materials with sound absorbing properties. It is the value in decibels (dB) of the insulation level of sound waves coming on it. Determination of Heat Conduction Coefficient is the value that shows how much a material transmits heat, and this value is different for each material.

Sound transmission loss tests (ASTM E-2611:2009) was used for sound absorption (a four-microphone impedance tube). The larger the measured value in these tests, the higher the sound

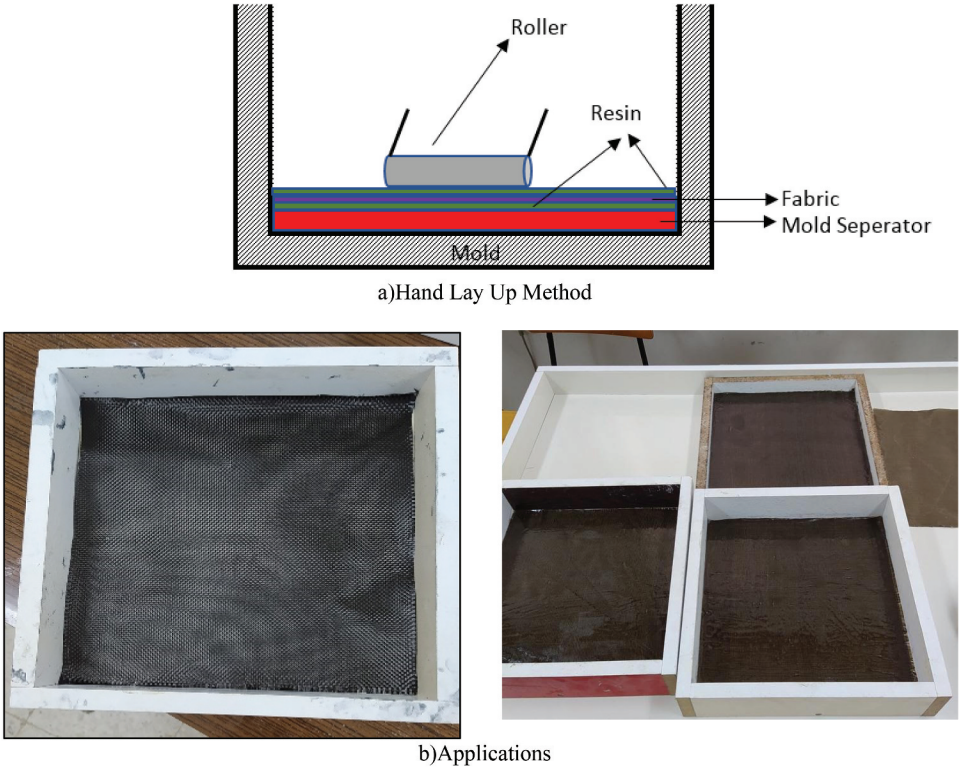


Figure 2. Hand lay-up method.

Table 1. Selected experimental design L18 (mixed 3–6 levels).

Factor No (Code)	Factor's Name	Level Number	Level's Name
1(A)	Fabric	6	B30, B40, B50, K30, K40, K50
2(B)	Al_2O_3 Filler	3	0, 2, 4
3(C)	SiC Filler	3	0, 5, 10

absorption value. The standard of "Thermal Performance of Building Materials and Products - Determination of Thermal Resistance by Means of Guarded Hot Plate and Thermal Flow Meter Methods (TS EN 12667)" was used for thermal absorption property of the composite plates. The determination of the thermal transfer coefficient of the composite plates was made by the Thermtest device at Erciyes University (Kayseri/Türkiye). The lower the measured value, the better the thermal insulation.

The Taguchi Grey Relations Analysis method

Grey Relations Analysis method based on Taguchi Method is applied to cases where more than one performance characteristics need to be optimized together (multi-objective optimization). Steps and formulas used in this method;

1. Experimental Design and Its Application
2. Determination of the Reference Series

Table 2. Experimental plan for selected experimental design L18 (mixed 3–6 levels).

Experiment No	A (Fabric)	B (Al_2O_3 Filler)	C (SiC Filler)
1	1 (B30)	1 (0)	1 (0)
2	1 (B30)	2 (2)	2 (5)
3	1 (B30)	3 (4)	3 (10)
4	2 (B40)	1 (0)	1(0)
5	2 (B40)	2 (2)	2 (5)
6	2 (B40)	3 (4)	3 (10)
7	3 (B50)	1 (0)	2 (5)
8	3 (B50)	2 (2)	3 (10)
9	3 (B50)	3 (4)	1(0)
10	4 (K30)	1 (0)	3 (10)
11	4 (K30)	2 (2)	1 (0)
12	4 (K30)	3 (4)	2 (5)
13	5 (K40)	1 (0)	2 (5)
14	5 (K40)	2 (2)	3 (10)
15	5 (K40)	3 (4)	1(0)
16	6 (K50)	1 (0)	3 (10)
17	6 (K50)	2 (2)	1(0)
18	6 (K50)	3 (4)	2 (5)

$$x_0 = (x_0(1), x_0(2), x_0(3), \ldots., x_0(n)) \tag{1}$$

n: experiment number 1,2. . ..n

3. Normalization of data: In the case of "the larger-the better," normalization is as follows.

$$x_i(k) = \frac{x_i^o(k) - \min\ x_i^o\ (k)}{\max\ x_i^o(k) - \min\ x_i^o(k)} \tag{2}$$

$x_i(k)$: After normalization i. series and k. value
$x_i^o(k)$: i. series and k. original value
$\min x_i^o(k)$: Minimum value in i series
$\max x_i^o(k)$Maximum value in i series
k: k. rank in n length of series
k = 1,2,. . .,n
j = 1,2, . . . m

4. Calculation of the distance matrix of the normalized series to the reference series

$$\Delta_{oi}(k)\ = |\ x_o(k)\ - x_j(k)| \tag{3}$$

$x_0(k)$: the k. value in reference series
$x_j(k)$: k. value in j. value
$\Delta_{oi}(k)$: k. value in the series

5. Obtaining the Grey Relations coefficient matrix of the series with the distance matrix is calculated as follows:

$$\varepsilon(x_o\ (k),\ x_i\ (k))\ =\ \frac{\Delta_{\min}\ +\xi\ \Delta_{\max}}{\Delta_{oi}\ (k)+\ \xi\Delta_{\max}} \tag{4}$$

$\varepsilon(x_0(k), x_i(k))$: Grey relational coefficient at point k
ξ: a coefficient between (0,1)
$\Delta_{\min}$: Minimum value in the series
$\Delta_{\max}$: Maximum value in the series
$\Delta_{oi}(k)$: k. value in the series

6. Weighting of normalized data (w) and determination of the degree of Grey relations

If the effects of the response variables on performance are equal, the Grey relations degree is calculated as Equation 5:

$$\gamma(x_{o,}\, x_i) = \frac{1}{n}\sum_{k=1}^{n} \varepsilon(x_o\,(k),\ x_i\,(k)) \tag{5}$$

If the effects of the response variables on performance are not equal, the Grey relations degree is calculated as Equation 6:

$$\gamma(x_o, x_i)\ = \frac{1}{n}\sum_{k=1}^{n} W_k \varepsilon(x_o\,(k),\ x_i\,(k)) \tag{6}$$

$$\sum_{1}^{n} W_k = 1$$

$x_i(k)$: After Normalization i. series k. value
x^o: Desired ideal value
x_i: m series with comparing x^oseries
$\gamma(x_0, x_i)$: Grey relations degree in i. rank
W_k: Total weight must be 1

7. Determination of new levels of experimental factors.
8. Performing te ANOVA test
9. The last step is the application of the Taguchi Method, estimate for optimal values and verification experiments for optimal values. The formulas to be used are given in Equation 7 and Equation 8 (Sarpkaya 2014; Khan, Siddiquee, and Kamaruddin 2012; Kuo, Yang, and Huang 2008; Pawade and Joshi 2011; Sarpkaya and Sabır 2016; Özgür, and Sabır 2015).

$$''\mathit{The\ Larger} - \mathit{The\ Better}''\, S/N = -10\log\ \frac{\sum_{i=1}^{n}\frac{1}{y_i^2}}{n} \tag{7}$$

$$\eta = \eta_m + \sum_{i=1}^{j}(\eta_i - \eta_m) \tag{8}$$

y_i: Experimental results,
n: Experiment number
η : Grey relations degree predicted by optimum design
η_m: Mean Grey relations degree
η_i: The value of calculated new factor levels in optimum combination

Results and discussion

The results of the Taguchi Grey R analysis method

In this study, Grey Relations Analysis method based on Taguchi Method was applied. Experimental Design L18 (mixed 3–6 levels) was chosen, and results are given in Table 3. The first row is factors affecting the process (A, B, and C) and the response variables are sound transmission loss and heat conduction coefficient. The first column in Table 4 is the number of experiments. The last two columns are the experimental results for L18 (mixed 3–6 levels) Taguchi Experimental Design **(Step 1)**.

Table 3. Results of experiments for L18 (mixed 3–6 levels) Taguchi experimental design (Özgür 2022).

	Experiment Parameters (Input Factors)			Response Variables (Outputs)	
Experiment No	A (Fabric)	B (Al_2O_3 Filler)	C (SiC Filler)	Sound Transmission Loss (dB)	Heat Conduction Coefficient (W/mK)
1	1 (B30)	1 (0)	1 (0)	29,3322	0,0362
2	1 (B30)	2 (2)	2 (5)	29,9524	0,0305
3	1 (B30)	3 (4)	3 (10)	26,3147	0,0333
4	2 (B40)	1 (0)	1(0)	22,8541	0,0311
5	2 (B40)	2 (2)	2 (5)	23,9550	0,0330
6	2 (B40)	3 (4)	3 (10)	23,0685	0,0313
7	3 (B50)	1 (0)	2 (5)	21,3560	0,0313
8	3 (B50)	2 (2)	3 (10)	22,3237	0,0294
9	3 (B50)	3 (4)	1(0)	21,5871	0,0302
10	4 (K30)	1 (0)	3 (10)	27,9643	0,0391
11	4 (K30)	2 (2)	1 (0)	25,9352	0,0348
12	4 (K30)	3 (4)	2 (5)	28,2670	0,0373
13	5 (K40)	1 (0)	2 (5)	27,0351	0,0318
14	5 (K40)	2 (2)	3 (10)	27,7120	0,0319
15	5 (K40)	3 (4)	1(0)	26,8678	0,0330
16	6 (K50)	1 (0)	3 (10)	25,2448	0,0302
17	6 (K50)	2 (2)	1(0)	23,5680	0,0308
18	6 (K50)	3 (4)	2 (5)	23,2088	0,0306

Table 4. Grey relational analysis method (steps 2–4).

	Reference Series for Outputs		Normalization Matrix for Outputs		Distance Matrix for Outputs	
	Sound Transmission Loss (dB)	Heat Conduction Coefficient (W/mK)	Sound Transmission Loss (dB)	Heat Conduction Coefficient (W/mK)	Sound Transmission Loss (dB)	Heat Conduction Coefficient (W/mK)
Reference Series	29,9524	0,0391	1,00	1,00	1,00	1,00
1	29,3322	0,0362	0,93	0,70	0,07	0,30
2	**29,9524**	0,0305	1,00	0,11	0,00	0,89
3	26,3147	0,0333	0,58	0,40	0,42	0,60
4	22,8541	0,0311	0,17	0,18	0,83	0,82
5	23,9550	0,0330	0,30	0,37	0,70	0,63
6	23,0685	0,0313	0,20	0,20	0,80	0,80
7	**21,3560**	0,0313	0,00	0,20	1,00	0,80
8	22,3237	**0,0294**	0,11	0,00	0,89	1,00
9	21,5871	0,0302	0,03	0,08	0,97	0,92
10	27,9643	**0,0391**	0,77	1,00	0,23	0,00
11	25,9352	0,0348	0,53	0,56	0,47	0,44
12	28,2670	0,0373	0,80	0,82	0,20	0,18
13	27,0351	0,0318	0,66	0,25	0,34	0,75
14	27,7120	0,0319	0,74	0,26	0,26	0,74
15	26,8678	0,0330	0,64	0,37	0,36	0,63
16	25,2448	0,0302	0,45	0,08	0,55	0,92
17	23,5680	0,0308	0,26	0,15	0,74	0,85
18	23,2088	0,0306	0,22	0,12	0,78	0,88

Step 2. Determination of the Reference series. Using Equation 1, the reference series for the two performance output variables are determined in Table 4.

Step 3. Data Normalization. The normalization matrix for outputs can be seen in Table 4 (Eq. 2)

Step 4. Using equation, Distance matrix is calculated in Table 4.

Step 5. Grey relational coefficient matrix of the Distance matrix calculated is obtained with Eq. 4 (Table 5)

Table 5. Application step 5–7 of grey relational analysis method.

Experiment No	Sound Transmission Loss (dB)	Heat Conduction Coefficient (W/mK)	Grey Relational Degree	Ranking
1	0,93	0,77	0,85	2
2	1,00	0,53	0,77	4
3	0,70	0,62	0,66	8
4	0,55	0,55	0,55	14
5	0,59	0,61	0,60	10
6	0,56	0,55	0,55	13
7	0,50	0,55	0,53	16
8	0,53	0,50	0,51	17
9	0,51	0,52	0,51	9
10	0,81	1,00	**0,90**	**1**
11	0,68	0,69	0,69	5
12	0,84	0,85	0,84	3
13	0,75	0,57	0,66	9
14	0,79	0,58	0,68	6
15	0,74	0,61	0,67	7
16	0,65	0,52	0,58	11
17	0,57	0,54	0,56	12
18	0,56	0,53	0,55	15
Mean Grey Relational Degree	**0,65**			

Step 6: Performance outcomes were calculated as equally (0,5–0,5) weighted. Applying Equation 5, Grey Relational Degree is calculated. In Table 5, Grey relational degree and ranking are seen. In the table, the experiment with the highest Grey relational degree is 10th experiment.

Figure 3 shows Grey relational degree graph. Grey relation degree of Experiment No. 10 is the highest.

Step 7. After steps 1–6, new levels of experimental factors are calculated. Table 6 shows Calculated new Factor levels. As seen from the table, the difference between the levels of factor A (Fabric) is the biggest, and this factor is understood as the most influential parameter.

Figure 4 shows the graph of the parameter levels. Optimal parameter levels are seen as A4B1C2. (This combination is not included in the experimental plan.)

Step 8. ANOVA test. The ANOVA test results are given in Table 7. As seen in the table, the highest F value is Factor A (Fabric). The second F value is Factor B (Al_2O_3 Filler), and the third F value is Factor C (SiC Filler). Factor A (Fabric), which has the highest F value, is the most effective factor. Contribution (%) values also support that. The highest contribution (%) value, respectively, is Factor A (Fabric), Factor B (Al_2O_3 Filler), and Factor C (SiC Filler). This value shows that when the thermal and sound insulation values are evaluated together, the most effective factor is Factor A (Fabric).

Step 9: The final step is applying the Taguchi Method and confirmation test. In Table 8, S/N Ratio of Grey Relational Degree is seen (Equation 7 and was calculated by using MINITAB 16® package program). When Table 8 is examined, it is seen that the lowest S/N value is in sample 10. It means that when the heat transmission coefficient and sound transmission loss values are evaluated together, the most optimum sample is sample number 10.

Confirmation Test:

According to the Grey Relation Taguchi test results, when the heat and sound insulation properties were examined together, it was concluded that the most optimum sample is the sample containing 30% carbon, 0% Al_2O_3 and 5% SiC.

When the analyzes are examined, it is seen that the sample moves away from the optimum situation with the increase in the amount of fabric in the composite, and the most optimal samples are the samples containing 30% fabric (basalt and carbon).

In addition, it was concluded that adding Al_2O_3 (alumina) as a filling material into the composite negatively affects the thermal and sound insulation properties of the composite. It is thought that the reason for this situation may be that the nano Al_2O_3 material creates gaps in the composite and the

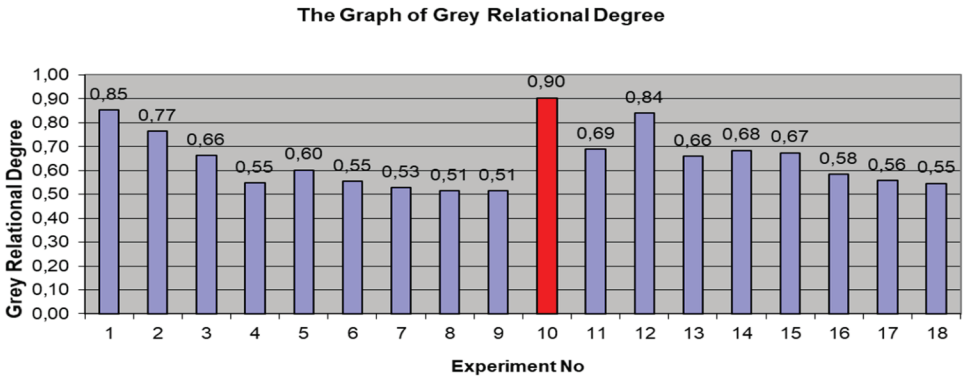


Figure 3. Grey relational degree graph for outputs.

Table 6. Calculated new factor levels.

	Levels							
Factors	1	2	3	4	5	6	Max-Min	Rank
A	0,7603	0,5682	0,5187	**0,8111**	0,6724	0,5623	0,2924	1
B	**0,6791**	0,6351	0,6323				0,0468	2
C	0,6390	**0,6566**	0,6509				0,0176	3

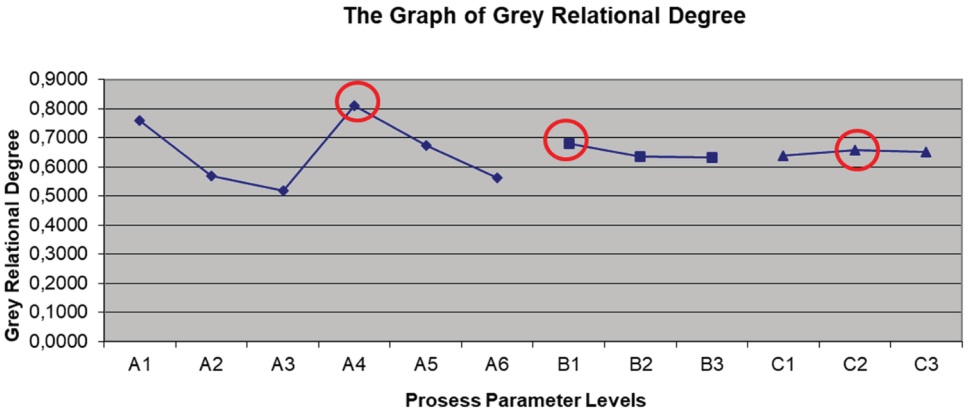


Figure 4. Parameter levels graph.

Table 7. ANOVA test of Grey relational degree.

Analysis of Variance for Means						
Source	DF	Seq SS	Adj SS	Adj MS	F	Contribution(%)
A	5	0,210688	0,210688	0,042138	**9,31**	**82,2527**
B	2	0,008267	0,008267	0,004134	0,91	3,2274
C	2	0,000966	0,000966	0,000483	0,11	0,3771
Residual Error	8	0,036226	0,036226	0,004528		14,1426
Total	17	0,256147				

passage of heat and sound through these gaps becomes easier. This situation also supports the literature. It is known that the heat conduction properties of Al_2O_3 material are not good.

For the confirmation test, a sample containing 30% carbon fiber, 0% Al_2O_3, and 5% SiC suggested by the method was produced, and measurements were made for the heat conductivity coefficient and

Table 8. Determination of the S/N ratio.

Experiment No	A (Fabric)	B (Al_2O_3 Filler)	C (SiC Filler)	S/N (dB)
1	1 (B30)	1 (0)	1 (0)	−2,21538
2	1 (B30)	2 (2)	2 (5)	−2,43901
3	1 (B30)	3 (4)	3 (10)	−2,62265
4	2 (B40)	1 (0)	1(0)	−4,70670
5	2 (B40)	2 (2)	2 (5)	−4,93033
6	2 (B40)	3 (4)	3 (10)	−5,11397
7	3 (B50)	1 (0)	2 (5)	−5,24920
8	3 (B50)	2 (2)	3 (10)	−5,81511
9	3 (B50)	3 (4)	1(0)	−6,04054
10	4 (K30)	1 (0)	3 (10)	−1,52278
11	4 (K30)	2 (2)	1 (0)	−2,13049
12	4 (K30)	3 (4)	2 (5)	−1,97185
13	5 (K40)	1 (0)	2 (5)	−2,99668
14	5 (K40)	2 (2)	3 (10)	−3,56259
15	5 (K40)	3 (4)	1(0)	−3,78802
16	6 (K50)	1 (0)	3 (10)	−4,65190
17	6 (K50)	2 (2)	1(0)	−5,25961
18	6 (K50)	3 (4)	2 (5)	−5,10097

Table 9. Heat and sound insulation properties of samples produced using initial and optimum composite components (for weighting coefficient 0.5 and sound conduction loss 0.5).

	Initial Process Parameter	Optimum Process Parameter	
		Prediction	*Experiment*
Level	A2B1C1	A4B1C2	A4B1C2
Heat Conduction Coefficient (W/mK)	0,031		0,033
Sound Transmission Loss (dB)	22,85		27,53
Grey Relationship Degree	0,55	0,85	0,70
Improvement in Grey Relationship Grade		0,15	

sound transmission loss values. The Grey Relationship Degree was calculated for the estimation and the experiment. Improvement in Grey Relationship Rating was also found. These findings are seen collectively in Table 9.

Experiment (4) (A2B1C1) is chosen as the initial design. Grade of Grey Relations = 0.55 calculated for this experiment. The average Grey Relationship Grade for weighting coefficient of thermal conduction is 0.5 and the sound conduction loss 0.5 is η_m, 0,65 (Table 5) Optimum levels of factors are $\eta_{A4} = 0,8111$, $\eta_{B1} = 0,6791$ ve $\eta_{C2} = 0,6566$.

$$\eta = \eta_m + (\eta_{A4} - \eta_m) + (\eta_{B1} - \eta_m) + (\eta_{C2} - \eta_m)$$

$$\eta = 0,65 + (0,8111 - 0,65) + (0,6791 - 0,65) + (0,6566 - 0,65) = 0,85$$

$$\eta = 0,85$$

For the experiment performed at optimum process parameters (A4B1C2), the Grey Relationship Degree is calculated as follows by applying steps 1–6 in the method and is found to be 0,71.

	Heat Conduction Coefficient (W/mK)	Sound Transmission Loss (dB)
Step 1:	0,033	27,53
Step 2:	$\frac{0,033-0,0294}{0,0391-0,0294} = 0,37$	$\frac{27,53-21,36}{29,95-21,36} = 0,72$
Step 3:	$1 - 0,37 = 0,63$	$1 - 0,72 = 0,28$
Step 4:	$\frac{0+1}{0,63+1} = 0,61$	$\frac{0+1}{0,28+1} = 0,78$

(*Continued*)

	Heat Conduction Coefficient (W/mK)	Sound Transmission Loss (dB)
Step 5:	Weight Determination (It is calculated for 0,5–0,5)	
Step 6:	$(0,61 + 0,78)/2 = 0,70$	

The difference between the Grey Relationship Degree (0,70) calculated for the experiment performed at the optimum process parameters and the Grey Relationship Degree (0,55) calculated for the Initial process parameters gives the improvement in the Grey Relationship Degree. This value is seen as 0,15 in Table 9.

Since the optimum experimental plan (A4B1C2) suggested by the Grey Relationship Analysis for the confirmation test was not included in the experimental plan, the experiment of A4B1C2 was carried out under the recommended conditions under the operating conditions. As a result of the experiment, thermal conductivity coefficient output in the test for the confirmation test is 0,033 W/mK and the sound transmission loss is 2753 dB. In a study by Ovalı (2015), it was observed that the heat transmission coefficient value increased with the increase in filling materials above a certain level. The reason for this situation was thought to be related to the thermal permeability properties of the filling materials used.

Conclusion

In this study, 18 different composite containing basalt and carbon fabric at the rate of 30%, 40%, and 50%, Al_2O_3 (Alumina) at the rates of 0%, 2%, and 4% and SiC (Silicon carbide) at the rates of 0%, 5%, and 10% were produced in accordance with the Taguchi orthogonal experiment design. Thermal conductivity coefficient and sound absorption tests were performed on the basalt and carbon reinforcement epoxy composite samples. Obtained test results were analyzed with L18 (mixed 3–6 levels) orthogonal experiment design using the Taguchi Method Based on Grey Relationships. From the Grey Taguchi analysis, it was concluded that the most optimum sample in terms of thermal transmission coefficient and sound transmission loss values was the sample containing 30% carbon, 0% Al_2O_3 and 5% SiC. It is also concluded that when the heat conductivity coefficient is low and the sound transmission loss value is high, it is concluded that the optimum sample is the 30% carbon containing samples.

It can be thought that the reason for the high thermal and sound properties of the sample containing 0% Al_2O_3 is the change in the porous structure. It was thought that the reason for the optimum sample was that the sample containing 0% Al_2O_3 might be that the heat conduction properties of Al_2O_3 are not very good. In addition, it can be concluded that the rate of filling materials increases above a certain level as a result of inhomogeneously spreading of the filling materials on the composite surface, which facilitates the passage of heat through the composite surface. It was also shown that when the heat conductivity coefficient is low and the sound transmission loss value is high, the 30% carbon-containing samples are the best. As seen in Tables 6 and 7, as a result of the Grey relations analysis performed for the effect of the factors that will optimize the heat and sound insulation together in the study, Al_2O_3 Filler is the second most effective factor and SiC Filler is the third most effective factor. As a result of the confirmation test, after the combination suggested from Grey Taguchi was produced, heat and sound insulation tests were performed. An improvement degree was found of 0.15.

The density of the composites also is important data. Future studies that can be added to the model and the effect can be examined. Composite materials produced within the scope of the study can be used as heat and sound insulation materials in buildings, automotive, aerospace, defense, and construction industries and in areas where sound insulation is required, thanks to their heat and sound insulation properties and high mechanical properties.

Highlights

- This study is an experimental study examining the optimization of both sound and heat insulation properties of basalt and carbon fabric-reinforced composite plates, which are materials with superior physical and mechanical properties, using a multi-objective decision method.
- In this study, powder substances, such as Al_2O_3 and SiC, were added to the epoxy matrix, as well as basalt and carbon fabric reinforcements, to reveal the effect of these substances on the optimum heat and sound absorption properties.
- Taguchi Grey Relations Analysis method was used as a multi-objective optimization method and thus the optimum composite plate that could be analyzed statistically with fewer samples could be determined experimentally.
- By performing verification experiments based on Grey Relations, the accuracy and improvement of the optimum results obtained can be demonstrated.
- The study includes experiments in which optimum results named "Confirmation Test" are verified and also shows the proportional values of the improvements obtained.

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Ethical approval

We confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country. The research does not involve any human or animal welfare related issues.

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