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Taguchi optimization of impact, tensile and bending properties of carbon and basalt fabric reinforced epoxy composite

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Abstract: In this study, epoxy composites with different reinforcement ratios of basalt and carbon fabric were produced. Al_2O_3 and SiC powders were added to the resin at different ratios. Reinforcements were not used in hybrid form. Each composite contains basalt or carbon fabric as fabric. Fabric reinforcement was determined as 30%, 40% and 50% by weight and powder addition was determined as 0%, 2% and 4% for Al_2O_3 and 0%, 5% and 10% for SiC. Izod pendulum impact strength test, tensile strength test and three-point bending test, which have different importance in different areas of use for composite materials and are the most researched mechanical properties, were selected. Taguchi experimental design (Mixed 3-6 Level) optimization technique was selected for the optimization of mechanical properties. The optimum Izod Pendulum Impact strength was obtained from the composite with 50% basalt reinforcement and 4% Al_2O_3 and 5% SiC. In the matrix, the optimum tensile strength was obtained from the composite with 50% basalt reinforcement and no Al_2O_3 and SiC in the matrix and the optimum Three Point Bending value was obtained from the composite with 30% carbon reinforcement and 2% Al_2O_3 and 5% SiC in the matrix. Comparison tests were carried out for this result and these results support the Taguchi analysis.

Key words: Basalt and Carbon fabric; Textile Composites; Mechanical Properties; Optimization; Taguchi Method

1. Introduction

The composite industry is progressing rapidly with new reinforcements, resins and innovations in production methods every day. Traditional composite materials (such as glass fiber reinforced polyester composites, GRP) are being replaced by lighter, more functional and more durable composite materials. Today, the natural resource requirements of glass fiber production and the cost of carbon fiber manufacturing are increasing the interest in new products. One of these new materials is basalt fiber and fabrics made from it. Basalt fiber is a material made from volcanic rocks found in nature into fibers. Due to its very high resistance to acid and alkali, it may have the potential to expand the boundaries of the areas of use of composites. Basalt fibers also can be used as a thermal and sound insulation/protection material. And because of these properties, basalt fibers can be used as fire protection materials [1]. Basalt fiber reinforced composites show much better properties in tensile, bending and impact tests than e-glass reinforced composites [2]. Recent research showed that they have a good thermal resistance when it is aluminised [3] and the alkali resistance and heat/humidity resistance of epoxy basal to plastics are much greater than those of epoxy composites derived from E- and S-glass fibers [4]. In a study, it was concluded that basalt fiber showed better tensile strength than glass fiber, and the brittleness and brittleness of basalt fiber could be eliminated by adding more flexible fibers to basalt fiber (Fragassa et al. 2013). The results obtained in a recent study pointed out that by Ovalı et al. using of pumice stone as filling material improve thermal and sound properties of basalt composites [5]. Basalt has high elastic modulus, the thermal stability, the resistance to chemical attacks, the sound insulation properties [6].

Today, with the development of technology and increasing consumption, expectations from composite materials have increased. In order to match with these expectation, nano and micro particles start to be added to the composites such as Al_2O_3, TiO_2, SiC, SiO_2. Nayak et al. [7] showed that SiO_2 increased flexural strength and flexural modulus more than Al_2O_3, TiO_2. Agarwal

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et al. [8] added different ratio of SiC and found the best rate of SiC to have the best mechanical properties such as Bulut [9] and Prasanna [10]. Vaidya et al [11] tried to find the best filler among Al_2O_3, SiC, B_4C, $Mg(OH)_2$ and various chemical additives. Kaybal et al. [12] investigated the effect of adding nano Al_2O_3 to the composites' tensile properties. In this experimental study, the Taguchi analysis which was developed by Genichi Taguchi is used. In the method, the analyses can be made with less experiments. In this way, both the cost of the experiment and the saving of time are provided [13].

2. Materials and Methods

In this study, composite plates were produced by reinforcing carbon and basalt fabrics with plain texture and 200 g/m^2 weight to epoxy resin. Impact, tensile and bending strength mechanical properties of composite plates were investigated. Fabric reinforcements were used at 30%, 40% and 50% by weight. Each fabric was used as a single layer in the composite. In this study, the effects of adding additives such as Al_2O_3 and SiC in powder form to the resin at different rates were also investigated in order to examine the effects on mechanical and other properties in composite materials. The resin type was epoxy and the accelerator was cobalt material and was used at a ratio of 75:25 in the composite structure.

In this study, Taguchi Method was used instead of full factorial experimental plan, which gives optimum results by reducing the number of experiments. In the experimental design, single layer basalt and carbon fabric reinforced composite plates produced. It is seen that fabric reinforcements are commonly used between 30% and 50% by weight in the literature. It was wanted to add 40% as an intermediate value to these two ratios. Thus, when 3 reinforcement ratios were selected for basalt and 3 reinforcement ratios for carbon were selected at the same rates, the fabric reinforcement level was determined as 6. SiC and Al_2O_3 ratios, which are frequently used in the literature, were also selected at 3 levels for these composite plates. Taguchi suggests different experimental setups according to the levels of inputs in the experimental design. For the inputs and levels selected in the study, the experimental design corresponding to 6, 3 and 3 levels of 3 different inputs is in the form of Taguchi Experimental Design L18 (Mixed 3-6 Level) L18 mix. MINITAB15® package program was used in the application of Taguchi method. Experimental Design L18 (Mixed 3-6 Level) was chosen (MINITAB Inc., 2000). Input parameters and their levels are shown in ▶Table 1. According to the ▶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. 18 different experimental samples determined with Taguchi method were produced as 30x30 cm composites by hand lay-up method.

Table 1. Selected Experimental Design L18 (Mixed 3-6 Level) [14]

Factors (Code)	Factor's Name	Level Number	Level's Name (B: Basalt, C: Carbon)
1 (A)	Reinforced 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

The mechanical properties to be optimized in the study are Impact, tensile and bending strength properties. ▶Table 2 shows test name and test standard. Different mechanical properties can come to the fore in different areas of use in composites. The optimization of each of these properties was done separately, unlike the study [18] which found a single composite that optimized all three of the selected mechanical properties. Verification experiments of the optimum samples were also performed. Verification experiments are essential since the theoretical result given by the Taguchi plan may have a composite composition that is not included in the experimental plan. In this study, with the verification experiments for all three properties, the composites that provide optimum impact strength, optimum tensile strength and optimum flexural strength were determined.

Table 2. Test Name and Test Standard [14]

Test Name	Test Standard
Izod Pendulum Impact Resistance Test (kJ/m^2)	ASTM D 256, 2005
Tensile Strength Test	DIN EN ISO 527-1
Three Point Bending Test	DIN EN ISO 178

3. Results and Discussions

The 18 different composite samples produced with the input parameters shown in ▶Table 1 and the experimental results are given collectively in ▶Table 3.

Experiment no. 1-18 is given in the 1st column, the combination formed according to Taguchi experimental planning is given in the 2nd-4th columns and the experimental results are given in the 5th-7th columns for three mechanical properties. According to the 1st row; In the 1st experiment, Basalt fabric was reinforced by 30% in the composite, no alumina or silica filler was added to the resin, and the impact strength of this composite plate was found to be 13.94, tensile strength was 201.05 and bending strength was 34.20. Therefore, each mechanical test was evaluated separately. The optimum results determined as a result of these evaluations are the optimum composite recommendations for each mechanical test separately. In this study, verification tests of the composite plate determined in the separate Taguchi optimization were also performed and the obtained improvements were given in the last part of the evaluations.

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Table 3. Results of the mechanical tests of the composite samples

No	Taguchi Experimental Design L18 (Mixed 3-6 Level)			Results of Mechanical tests		
	A (Fabric)	B (Al2O3)	C (SiC)	Impact Resist. (kJ/m2)	Tensile Strength (MPa)	Three Point Bending Strength (MPa)
1	1 (B30)	1 (0)	1 (0)	13,94	201,05	34,20
2	1 (B30)	2 (2)	2 (5)	19,35	152,57	48,40
3	1 (B30)	3 (4)	3 (10)	22,85	102,05	41,90
4	2 (B40)	1 (0)	1(0)	24,08	214,25	33,20
5	2 (B40)	2 (2)	2 (5)	24,17	177,19	42,00
6	2 (B40)	3 (4)	3 (10)	33,07	169,21	46,40
7	3 (B50)	1 (0)	2 (5)	22,28	191,03	35,60
8	3 (B50)	2 (2)	3 (10)	34,85	190,88	36,60
9	3 (B50)	3 (4)	1(0)	28,92	257,09	31,80
10	4 (K30)	1 (0)	3 (10)	19,19	174,34	65,60
11	4 (K30)	2 (2)	1 (0)	28,67	172,94	81,20
12	4 (K30)	3 (4)	2 (5)	41,22	181,68	77,70
13	5 (K40)	1 (0)	2 (5)	21,80	199,16	61,00
14	5 (K40)	2 (2)	3 (10)	26,69	201,88	67,80
15	5 (K40)	3 (4)	1(0)	37,31	216,50	71,60
16	6 (K50)	1 (0)	3 (10)	18,75	189,26	70,00
17	6 (K50)	2 (2)	1(0)	18,23	211,45	70,00
18	6 (K50)	3 (4)	2 (5)	40,62	193,72	62,00

3.1. Izod Pendulum Impact Resistance

Izod Pendulum Impact Resistance Test values obtained as a result of tests performed on 18 samples in accordance with ASTM D 256, 2005 standards in Kahramanmaraş Sütçü İmam University Faculty of Forestry Industry laboratories (Kahramanmaraş/TÜRKİYE). The results were given in ▶**Table 3**. Then, the test results obtained were loaded into the MINITAB15® program, and the analyses were made by running "*the larger is better*" method. The S-N Ratio graph obtained as a result of the analyses is shown in ▶**Figure 1**. When the drawn S-N Ratio graph is examined, it is understood that the sample containing B50 (containing 50% basalt), 4% Al_2O_3 and 5% SiC will have the highest Izod pendulum impact resistance. It has been observed that as the basalt ratio in the basalt composite increases, the Izod pendulum impact resistance of the composite increases, but as the carbon ratio in the carbon composite increases, Izod pendulum impact resistance decreases. In addition, it was concluded that the impact resistance of basalt composites is better than carbon composites. Izod pendulum impact resistance value increases with increasing Al_2O_3 (Alumina) ratio. This situation does not show a similar situation for SiC (Silicon carbide). When the SiC ratio is increased up to 5%, the Izod pendulum impact resistance increases, and when it is increased above 5%, the Izod pendulum impact resistance decreases.

This situation also supports the studies in the literature. Gümülcine et al. [16] investigated the mechanical properties of isophthalic polyester matrix continuous e-glass and basalt fiber reinforced composites, and as a result, basalt composites were found to have very good impact test results. When evaluated together with this thesis, it is concluded that basalt composites have better impact resistance properties than both glass composites and carbon composites.

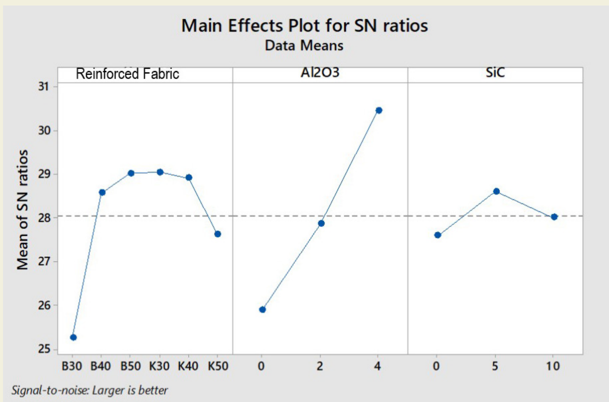

Figure 1. S-N Ratio Graph Drawn for Determination of Izod Pendulum Impact Resistance of Basalt and Carbon Composite Samples Test Results

3.2. Tensile Strength

Tensile strength test values obtained as a result of tests performed on 18 samples in accordance with DIN EN ISO 527-1 standards in Kahramanmaraş Sütçü İmam University Faculty of Forestry Industry laboratories (Kahramanmaraş/TÜRKİYE). The results were given in ▶**Table 3**. Afterwards, the obtained test results were loaded into the MINITAB15® program, and analyses were made by running "*the larger is better*" method. The S-N Ratio graph obtained as a result of the analyses is shown in ▶**Figure 2**. When the drawn S-N Ratio graph is examined, it is understood that the sample containing B50 (containing 50% basalt), 0% Al_2O_3 and 0% SiC will have the highest tensile strength. It has been observed that as the basalt ratio in the basalt composite increases, the tensile strength of the composite increases. But the tensile strength increases when the carbon ratio in the carbon composite is 40%, but decreases when the carbon fabric ratio exceeds 40%. In the drawn S-N Ratio graph, it was observed that the tensile strength decreased with the addition of Al_2O_3 and SiC fillers. It is thought that with the addition of filler materials, the resistance of the composite against the tensile force decreases and therefore the tensile strength decreases. With the addition of filling materials, the filling materials were homogeneously distributed on the surface of the fabric and between the fibers, and this caused a decrease in the resistance of the fibers against the tensile force.

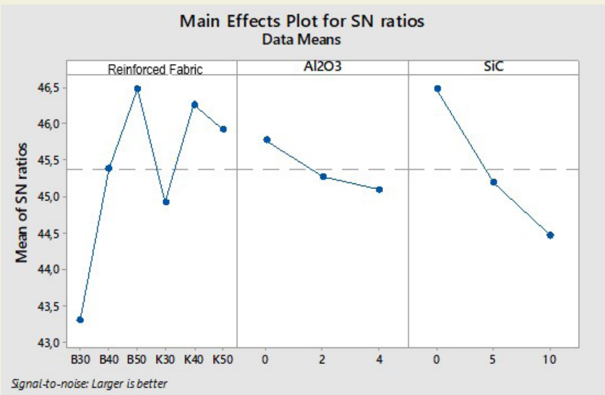

Figure 2. S-N Ratio Graph Drawn for Tensile Strength Test Results Applied to Basalt and Carbon Composite Samples

3.3. Three Point Bending

Three Point Bending Test values obtained as a result of tests performed on 18 samples in accordance with DIN EN ISO 178 standards in Faculty of Forestry Industry laboratories of Kahramanmaraş Sütçü İmam University (Kahramanmaraş/TÜRKİYE). The results were given in ▶**Table 3**. Afterwards, the obtained test results were loaded into the MINITAB15® program, and analyses were made by running "*the larger is better*" method. The S-N Ratio graph obtained as a result of the analyses is shown in ▶**Figure 3**. When the drawn S-N Ratio graph is examined, it is understood that the sample containing K30 (containing 30% carbon), 2% Al_2O_3 and 5% SiC will have the highest bending strength value. It has been observed that as the basalt ratio in the basalt composite increases, the bending resistance value decreases, with the increase of the carbon ratio in the carbon composite up to 40%, the bending resistance decreases, but then the bending resistance value increases slowly. In the drawn S-N Ratio graph, it is seen that the bending strength increased with the increase of Al_2O_3 filling material up to 2%, but then the bending resistance decreased. It was observed that the bending strength value increased with the addition of SiC filler material up to 5%, but then there was no significant change. Seydibeyoğlu et al. [17] tried to increase the flexural strength properties of basalt fiber reinforced epoxy composites with the help of graphene nanoparticle and carbon nanotube composites.

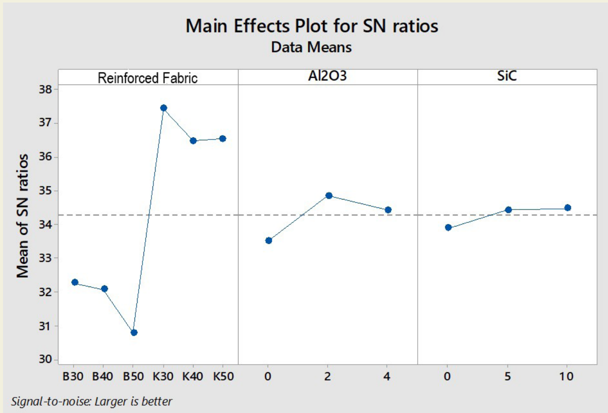

Figure 3. S-N Ratio Graph Drawn for Three Point Bending Test Result Results Applied to Basalt and Carbon Composite Samples

For this, epoxy composites containing 0.1% and 0.5% doped graphene nanotubes and carbon nanotubes were permeated onto basalt woven fiber by hand lay-up method. At the end of the study, it was concluded that the flexural strength of basalt fiber reinforced composites increased. However, in this study, basalt fiber addition caused a decrease in bending strength values. It is thought that this may be due to the different materials used as filling material.

3.4. Confirmation Tests

The following equation is used for the confirmation tests [14];

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

In this equation, η is the S/N ratio value of the optimum sample, ηm_m is the arithmetic mean of the calculated S/N ratio value, and η_i is the factor values of the calculated optimum sample.

Izod Pendulum Impact Resistance: The average of the S/N ratio value calculated for the Izod impact resistor

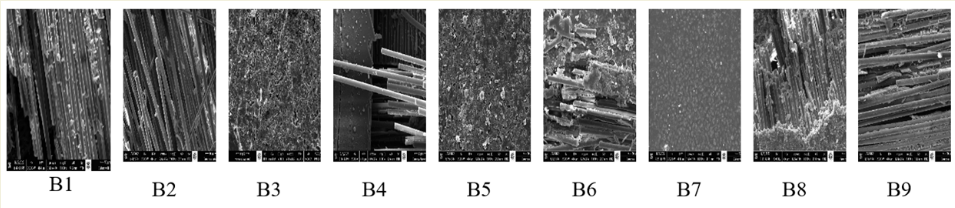

Figure 4. SEM Images of the Fracture Regions of Basalt Composites Tensile Test (1000X)

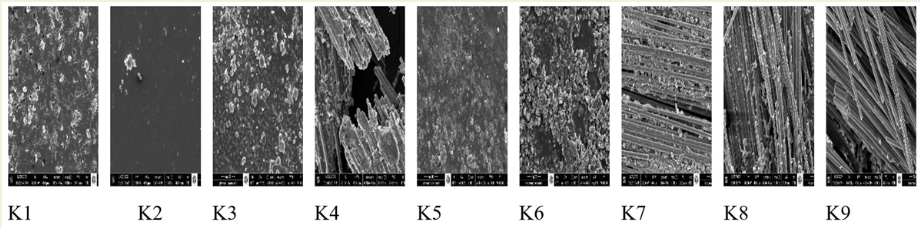

Figure 5. SEM Images of the Fracture Regions of Carbon Composites Tensile Test (1000X)

is 28.07. As a result of the Taguchi analyses made, it is aimed to improve the optimum sample by 9% for the determination of the Izod impact resistance values. When the results obtained from the Taguchi analyses were examined, it was understood that the sample with the highest Izod Pendulum Impact Resistance value is the sample containing B50 (containing 50% basalt), 4% Al_2O_3 and 5% SiC. Since this sample is not included in the Taguchi L18 design, this sample was produced later and the Izod Pendulum Impact Resistance value was determined as 96,92 kJ/m^2 and this result supports the Taguchi analysis that has been done.

Tensile Strength Test: The average of the S/N ratio value calculated for the tensile strength test is 45,38. As a result of the Taguchi analyses made, it is aimed to improve the optimum sample by 5 % for the determination of the tensile strength test. It also was understood that the highest tensile strength test value is the sample B50 (containing 50% basalt), 0% Al_2O_3 and 0% SiC. Since this sample is eighter not included in the Taguchi L18 design (in ▶**Table 3**), this sample was produced later and the tensile strength value was determined as 260 MPa.

Three Point Bending Test: The average of the S/N ratio value calculated for the three point bending test is 34,27. As a result of the Taguchi analyses made, it is aimed to improve the optimum sample by 0,2 % for the determination of the tensile strength test. Finally, it was understood that the sample with the highest Three Point Bending value is the sample containing K30 (containing 30% carbon), 2% Al_2O_3 and 10% SiC. Since this sample is not included in the Taguchi L18 design, this sample was produced later and the Three Point Bending Test value was determined as 81,98 MPa and this result supports the Taguchi analysis that has been done.

3.5. SEM Analysis of the Composites

The images taken with 250X and 1000X magnification as a result of SEM analysis of the fracture regions of the tensile test specimens produced are shown in the ▶**Figure 4** and ▶**Figure 5**.

4. Conclusion

In this study, carbon fabric and basalt fabric reinforced epoxy composite plates were produced according to Taguchi L18 mix design and the optimization of selected mechanical properties was investigated. The results in the study should be examined separately for each mechanical property in 18 composite plates. Accordingly, it was seen that the sample with the best, highest Izod Pendulum Impact Resistance value (96.92 kJ/m2) in terms of impact resistance was obtained by using 50% basalt fabric and adding 4% Al_2O_3 and 5% SiC into the epoxy. The sample with the best, highest tensile strength value (260 MPa) among the composite plates was the sample with 50% basalt fabric and no Al_2O_3 and SiC added into the epoxy. It was determined that the sample with the highest Three Point Bending value (81.98 MPa) was the sample with 30% carbon fabric reinforcement and 2% Al_2O_3 and 5% SiC added into the resin. Confirmation tests were performed for these results and it was observed that the optimum results obtained were also supported by Taguchi analysis. This study showed that Taguchi method can be used in composite manufacturing studies with less experiments, separate optimizations can be made and the reliability of the results can be increased with the verification method. When the results obtained from this study are examined, composites in which 50% basalt fabric is used for impact and tensile strength and 30% carbon fabric is used for bending strength should be selected. It is not desired to add Al_2O_3 and SiC powders for tensile strength. However, it was observed that SiC has a positive contribution in impact and bending strength. Mechanical properties are the determining factor in the selection of engineering materials in industrial applications. Since this study shows the results in which each mechanical property is optimized separately, it can be said that the composites in the study can be evaluated in the construction sector where bending and impact resistance is desired and earthquake-like loads are effective, in the defence industry, and in the transportation sector such as aviation and automotive.

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Research Ethics

Ethical approval not required.

Artificial Intelligence Use

The author(s) declare that no generative artificial intelligence (e.g., ChatGPT, Gemini, Copilot, etc.) was used in any part of this study.

Author Contributions

Conceptualization: [Ertan Özgür, Emel Ceyhun Sabır], Data curation: [Ertan Özgür, Emel Ceyhun Sabır], Formal analysis: [Ertan Özgür, Emel Ceyhun Sabır], Funding acquisition: [Emel Ceyhun Sabır, Ertan Özgür], Investigation: [Ertan Özgür, Emel Ceyhun Sabır], Methodology: [Ertan Özgür, Emel Ceyhun Sabır], Project administration: [Ertan Özgür, Emel Ceyhun Sabır], Resources: [Ertan Özgür, Emel Ceyhun Sabır], Supervision: [Emel Ceyhun Sabır], Validation: [Ertan Özgür, Emel Ceyhun Sabır], Visualization: [Ertan Özgür, Emel Ceyhun Sabır], Writing – original draft: [Ertan Özgür, Emel Ceyhun Sabır], Writing – review & editing: [Ertan Özgür, Emel Ceyhun Sabır]

Competing Interests

The author(s) declare that there are no competing interests.

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Data Availability

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