TEKSTİL VE KONFEKSİYON

VOL: 34, NO. 3
DOI: 10.32710/tekstilvekonfeksiyon.1260944

Multi-Objective Optimization of Selected Mechanical Properties of Basalt, Carbon Fabric Reinforced Particle Additive Composites

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ABSTRACT

In this study, some of the mechanical properties of basalt fabric and carbon fabric reinforced particle additive composite materials were investigated. The effect of fabric additive ratios on tensile strength, Izod pendulum impact resistance, and three point bending properties has been tried to be revealed. In order to determine the composite material that gives the optimum mechanical properties, Taguchi Grey Relational Analysis (Taguchi based GRA) method was chosen as multi-objective optimization method and used L18 (Mixed 3-6 Level) experimental design. Input variables-factors were determined as fabric (6 levels), Al_2O_3 additive (3 levels) and SiC additive (3 levels) according to the design. Tensile strength, impact resistance, and three point bending were selected as response variables. These three tests were optimized. The optimum composite combination was determined and found 30% carbon fabric, 4% Al_2O_3 and 0% SiC. The improvement by using confirmation test was seen as 0,07 when the 3rd experiment plan was selected as the initial process parameter.

ARTICLE HISTORY
Received: 06.03.2023
Accepted: 20.08.2023

KEYWORDS
Basalt and carbon fabric, Al_2O_3 and SiC additives, composite, mechanical properties, multi-objective optimization

1. INTRODUCTION

Today, with the developing technology, materials that are difficult to produce, high cost and high volume have been replaced by materials with greatly increased mechanical properties, lower cost, less volume and lighter. The materials that best meet these properties are composites. The most used materials in composites technology are glass and carbon fibers. Due to their disadvantages people start to investigate new product. One of these materials is basalt fiber. Basalt has no toxic reaction with air and water, it can be found easily in the nature and has a very high resistance against acid and alkali, has a very high strength and can be operated in very high temperature ranges. Basalt fiber-reinforced composites have an increasing utilization rate nowadays. 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 aluminized [3] and the alkali resistance and heat/humidity resistance of epoxy composites from basalt fibers 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 [5]. The results obtained in a recent study pointed out that by Ovalı using of pumice stone as filling material improve thermal and sound properties of basalt composites [6]. Basalt has high elastic modulus, the thermal stability, the resistance to chemical attacks, the sound insulation properties [7]. Liu et al. (2022) were investigated both basalt fibers and glass fibers can be used as reinforced

To cite this article: Sarpkaya Ç, Özgür E, Ceyhun Sabır E. 2024. Multi-objective optimization of selected mechanical properties of basalt, carbon fabric reinforced particle additive composites. *Tekstil ve Konfeksiyon,* 34(3), 211-221.

material in fiber-reinforced polymer composites [8]. In the study, the advantages of basalt fiber over glass fiber were revealed. In a study made by Gumulcine et al (2012) showed that basalt fiber reinforced composites have much better properties in tensile, bending and impact tests than e-glass reinforced composites [9].

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. (2014) showed that SiO_2 increased flexural strength and flexural modulus more than Al_2O_3, TiO_2 [10]. Agarwal et al. (2013) added different ratio of SiC and found the best rate of SiC to have the best mechanical properties such as Bulut (2018) and Prasanna et al. (2016) [11, 12, 13]. Ramesh et al. (2014) investigated the effect of modification with Al_2O_3 / SiO_2 / TiO_2 on the mechanical properties of glass fiber/epoxy composite [14]. Gün et al. (2017) investigated the effect of the addition of ceramic powder particles (Al_2O_3- TiO_2) on the mechanical properties of glass fiber reinforced epoxy matrix composites [15]. Vaidya and Rangaswamy (2017) tried to find the best additive among Al_2O_3, SiC, B_4C, $Mg(OH)_2$ and various chemical additives [16]. Kaybal et al. (2016) investigated the effect of adding nano Al_2O_3 to the composites' tensile properties [17]. Krzyzak et al. (2022) studied on the impact of the introduction of powder modifier into composite reinforced with carbon fabric on selected mechanical properties. Test results indicated that the increase of alumina content by weight caused the decrease of strength of polymer composites in most tests [18]. Akatsu et al. (2022) examined the mechanical properties, alumina matrix composite reinforced using homogeneously distributed carbon nanofiber [19]. In the study made by Sanusi (2020), the effectiveness of sintered alumina, developed from corundum, as a laminate component of ceramic-steel was investigated [20]. Lin (2020) was studied on the thermal conductivity, Young's modulus and hardness of the composites [21]. In the study by Kim and Park (2021), graphene oxide/graphitic nanofiber nanohybrids (GO-GNFs) were added into an epoxy matrix as a carbon fiber reinforced composite and found promising results [22]. Kim et al. (2020) studied ozone/TEPA-functionalized NDs were added to composite to improve its thermal conductivity and fracture resistance [23]. Ozgur et al (2023) added SiC and Al_2O_3 materials to carbon and basalt composites and to improve their thermal and sound insulation properties [24].

Innovative optimization techniques can be used to reduce test time, number and cost in the engineering experimental design of composite materials. Among these techniques, the Taguchi Method is a widely used technique [25]. In this study, Multi-Objective Optimization Based on Gray Relationship Analysis of this technique was applied.

2. MATERIAL AND METHOD

2.1 Material

The composite material of the study consists of epoxy resin, basalt and carbon fabric reinforcement and Al_2O_3 and SiC particle additives. Basalt and carbon fabrics used for reinforcement in the study are in plain pattern and weight 200 g/m^2. Three different ratios as %30,40,50 are used in fabric reinforcement. These two materials were chosen in order to compare basalt with carbon, which is the strongest material used in this field. Resin type is epoxy and accelerator is cobalt material. The resin accelerator percent ratio is 75:25. Mineral additive materials reinforced to the resin are in the form of SiC (micro powder, 3µm) and Al_2O_3 (nano powder, 28nm). SiC material was used in three different proportions as 0, 5, 10 and Al_2O_3 material was also used in three different proportions as 0, 2, 4. These ratios were decided according to the literature. The additives and the the resin were blended manually. The composite samples were produced with hand lay-up technique. It is known that composite materials are based on the weight ratio of the reinforcing resin.

2.2 Method

In this study, the Taguchi Method based on Grey Relational Analysis was applied as design of experiment (DOE). MINITAB 15 ® package program was used in the application of Taguchi method based on Grey Relational Analysis [26]. Experimental Design L18 (Mixed 3-6 Level) was chosen. Generally, 2- level (L4, L8, L12 and L32) and 3-level (L9, L18, L27) orthogonal arrays are used according to the experimental design. Also, some mixed orthogonal arrays used such as L18, L36, L54. In this study, 3 factors (Input Variables) were selected as fabric, additives (Al_2O_3 and SiC). The fabric factor is 6 levels, Al_2O_3 Additive is 3 levels and SiC Additive is 3 levels. Therefore, the L18 (Mixed 3-6 Level) experiment design was selected suggested by the Taguchi experimental plan. The output parameters (Response Variables) to be optimized were decided as tensile strength, Izod pendulum impact resistance and three point bending properties. Table 1 shows input parameters (factors) and their levels for L18 orthogonal layout (Mixed 3-6 Level). The factor A (Fabric) is 6 level (B30, B40, B50, C30, C40, C50). In the codes in Factor A, B refers to basalt fabric and C refers to carbon fabric. The numbers (30,40,50) next to these letters show the fabric ratio in the composite. Accordingly, for example, B30 refers to 30% basalt fabric reinforcement. The factor B (Al_2O_3 additive) is 3 level (0, 2, 4). The factor C (SiC additive) is 3 level (0, 5, 10). The number of experiments was reduced to 18 with the Taguchi Method used in the study. Table 2 shows experimental plan suggested by Taguchi method. Table 2 contains the codes of experimental plan and the factor levels. For example, experiment 5 means a combination of B40 fabric, 2% Al_2O_3 additive and 2% SiC additive.

Table 1. Factors and their levels for design L18 (mixed 3-6 level)

Factor	Factor Code	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Fabric	**A**	B30	B40	B50	C30	C40	C50
Al_2O_3 Additive, %	**B**	0	2	4	-	-	-
SiC Additive, %	**C**	0	5	10	-	-	-

Table 2. Selected experimental design L18 (mixed 3-6 level, coded)

Experiment No	A (Fabric)	B (Al_2O_3 Additive)	C (SiC Additive)
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 (C30)	1 (0)	3 (10)
11	4 (C30)	2 (2)	1 (0)
12	4 (C30)	3 (4)	2 (5)
13	5 (C40)	1 (0)	2 (5)
14	5 (C40)	2 (2)	3 (10)
15	5 (C40)	3 (4)	1(0)
16	6 (C50)	1 (0)	3 (10)
17	6 (C50)	2 (2)	1(0)
18	6 (C50)	3 (4)	2 (5)

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 fibres/fabrics placed in a mold with resin with a roller or brush.

After samples were produced according to test plan in Table 2, output parameters were tested. For Tensile Strength Test (MPa), test standard of DIN EN ISO 527-1was used. For Izod Pendulum Impact Resistance Test (kJ/m^2), test standard of ASTM D 256, 2005 was used. For Three Point Bending Test (MPa), test standard of DIN EN ISO 178 was used. Tensile Strength Test was made by the Zwick Roell Z010 test device with 5 mm/min device speed and 0,1 MPa preload, Izod Pendulum Impact Resistance Test was made by Zwick Roell Hit5.5P test device with 5 joule energy, Three Point Bending Test was made by the Zwick Roell Z010 test device with an 8 mm/min device speed. All tests were made in Kahramanmaraş Sütçü İmam University Forest Industry Engineering Department Laboratories (Kahramanmaraş/Türkiye).

2.3 Grey relational analysis method

Grey Relational Analysis allows the optimization of more than one performance characteristics (Output Parameters). In this study, three mechanical performance parameters were optimized. These are tensile strength, Izod pendulum impact resistance and three-point bending. After application of the method, the method suggests optimum combination for the best three performance characteristics. While applying the Grey Relational Analysis method, the steps are followed respectively and the equations in the table 3 are used.

The steps are

1. Experimental Design and its application
2. Determination of the Reference Series
3. Normalization of data
4. Calculation of the distance matrix of the normalized series to the reference series
5. Obtaining the grey relations coefficient matrix of the series with the distance matrix calculated.
6. Weighting of Normalized Data (W) and Determination of the degree of Grey Relations
7. Determination of new levels of experimental factors,
8. ANOVA test
9. The application of Taguchi Method [27-34].

Table 3. Equations used in grey relational analysis

Steps	Symbols	Equations	
1	Experimental Design and its application		
2	n: experiment number n:1,2....n	$x_0 = (x_0(1), x_0(2), x_0(3), \ldots\ldots, x_0(n))$	(1)
3	For The Larger-The Better $x_i(k)$: After Normalization i. series k. value $x_i^0(k)$: i series k. original value $min\ x_i^0(k)$: Minimum value in i series $max\ x_i^0(k)$: Maximum value in i series k: k. rank in n length of series k=1,2,...,n j=1,2,…m	$x_i(k) = \frac{x_i^0(k) - min\ x_i^0(k)}{max\ x_i^0(k) - min\ x_i^0(k)}$	(2)
4	$x_0(k)$: the k. value in reference series $x_j(k)$: k. value in j. value $\Delta_{0i}(k)$: k. value in the series	$\Delta_{0i}(k) = \lvert x_0(k) - x_j(k) \rvert$	(3)
5	$\varepsilon(x_0(k), x_i(k))$: Grey relational coefficient at point k ξ: a coefficient between (0,1) Δ_{min}: Minimum value in the series Δ_{max}: Maximum value in the series $\Delta_{0i}(k)$: k. value in the series	$\varepsilon(x_0(k), x_i(k)) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}}$	(4)
6	$\sum_1^n w_k = 1$ $x_i(k)$: After Normalization i. series k. value x^0: Desired ideal value x_i: m series with comparing x^0series $\gamma(x_0, x_i)$: Grey relations degree in i. rank w_k: Total weight must be 1	If the effects of the response variables on performance are equal; $\gamma(x_0,x_i) = \frac{1}{n}\sum_{k=1}^{n} \varepsilon(x_0(k), x_i(k))$	(5)
		If the effects of the response variables on performance are not equal; $\gamma(x_0,x_i) = \frac{1}{n}\sum_{k=1}^{n} w_k\varepsilon(x_0(k), x_i(k))$	(6)
7	Determination of new levels of experimental factors		
8	ANOVA test		
9	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	"The Larger-The Better" $s/N = -10log \frac{\sum_{i=1}^{n} \frac{1}{y^2}}{n}$	(7)
		$\eta = \eta_m + \sum_{i=1}^{j} \eta_{i-}\ \eta_m$	(8)

3. RESULTS AND DISCUSSION

3.1. Grey relational analysis method for the study

Composite plates were produced according to Table 2. Mechanical tests were carried out in accordance with the standards. The results of the mechanical tests were given as Figure 1a,b,c **(Step 1)** [35]. It was seen that the combination with the best tensile strength test value was the 9th Experiment, and the worst combination was the 3rd Experiment. It was seen that the combination with the best Izod Pendulum Impact Resistance Test value was the 12th Experiment, and the worst combination was the 1st Experiment. The combination with the best Three Point Bending Test value was the 11th Experiment, and the worst combination was the 9th Experiment. As can be seen, when the tests are considered separately, the best combination differs.

Step 2. Using Equation 1, determination of the reference series is determined in Table 4, The reference series for three performance output variables are identified as maximum and minimum values.

Step 3. The normalization matrix for outputs is calculated using Equation 2 and calculated values are seen in Table 4.

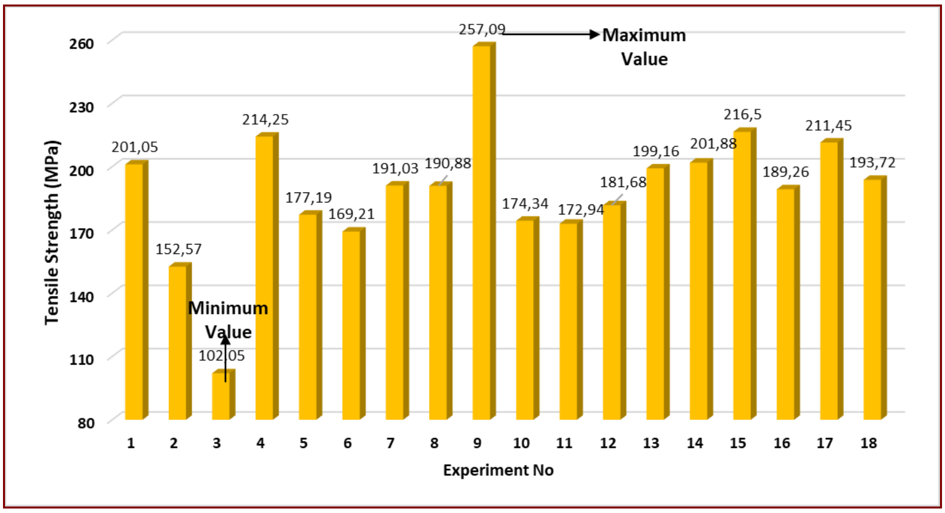
Step 4. Distance matrix is seen in Table 4 and calculated using Equation 3.

Step 5. Grey relational coefficient matrix is seen in Table 5 and determined with Equation 4.

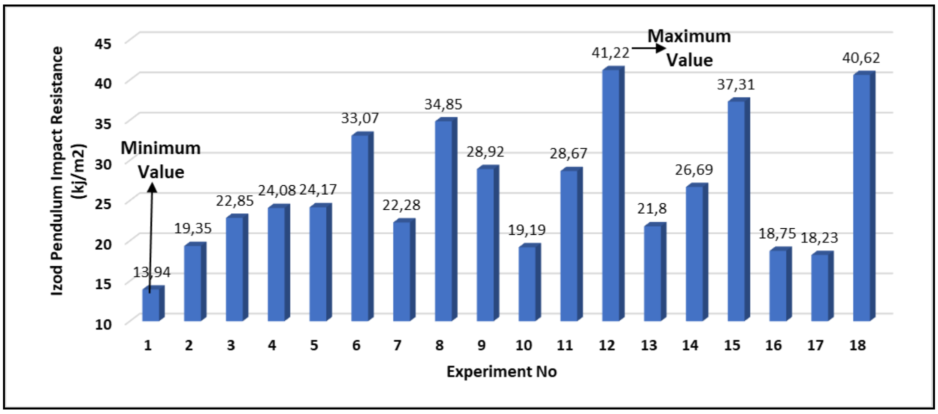
Step 6: Grey Relational Degree for Outputs were calculated with Equation 5 (Respectively weighted 0,35-0,35-0,30). Grey relational degree and ranking are seen in Table 5. In the table, 12th experiment has the highest grey relational degree.

The Graph of Grey Relational Degree is seen in Figure 2. Grey relation degree of Experiment No. 12 is the highest.

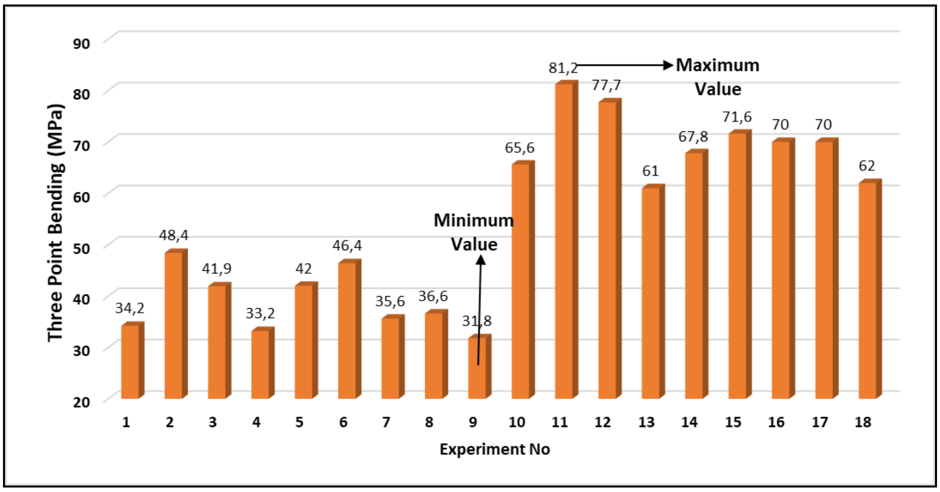
Step 7. New levels of experimental factors are calculated and calculated new factor levels are seen in Table 6. As seen from the table, because differences between levels are biggest, the most effective parameter is factor A (Fabric). Second effective parameter is factor B (Al_2O_3 Additive) and third effective parameter is factor C (SiC Additive)



(a)



(b)



(c)

Figure 1. Results of experiments for L18 (mixed 3-6 level)

Table 4. Grey relational analysis method for step 2-4

	Reference Series for Outputs			**Normalization Matrix for Outputs**			**Distance Matrix for Outputs**		
	Tensile Strength Test (MPa)	**Izod Pendulum Impact Resistance (kJ/m²)**	**Three Point Bending Test Result (MPa)**	**Tensile Strength Test (MPa)**	**Izod Pendulum Impact Resistance (kJ/m²)**	**Three Point Bending Test Result (MPa)**	**Tensile Strength Test (MPa)**	**Izod Pendulum Impact Resistance (kJ/m²)**	**Three Point Bending Test Result (MPa)**
Reference Series	257,09	41,22	81,2	1,00	1,00	1,00	1,00	1,00	1,00
1	201,05	**13,94**	34,2	0,64	0,00	0,05	0,36	1,00	0,95
2	152,57	19,35	48,4	0,33	0,20	0,34	0,67	0,80	0,66
3	**102,05**	22,85	41,9	0,00	0,33	0,20	1,00	0,67	0,80
4	214,25	24,08	33,2	0,72	0,37	0,03	0,28	0,63	0,97
5	177,19	24,17	42	0,48	0,38	0,21	0,52	0,63	0,79
6	169,21	33,07	46,4	0,43	0,70	0,30	0,57	0,30	0,70
7	191,03	22,28	35,6	0,57	0,31	0,08	0,43	0,69	0,92
8	190,88	34,85	36,6	0,57	0,77	0,10	0,43	0,23	0,90
9	**257,09**	28,92	**31,8**	1,00	0,55	0,00	0,00	0,45	1,00
10	174,34	19,19	65,6	0,47	0,19	0,68	0,53	0,81	0,32
11	172,94	28,67	**81,2**	0,46	0,54	1,00	0,54	0,46	0,00
12	181,68	**41,22**	77,7	0,51	1,00	0,93	0,49	0,00	0,07
13	199,16	21,8	61	0,63	0,29	0,59	0,37	0,71	0,41
14	201,88	26,69	67,8	0,64	0,47	0,73	0,36	0,53	0,27
15	216,5	37,31	71,6	0,74	0,86	0,81	0,26	0,14	0,19
16	189,26	18,75	70	0,56	0,18	0,77	0,44	0,82	0,23
17	211,45	18,23	70	0,71	0,16	0,77	0,29	0,84	0,23
18	193,72	40,62	62	0,59	0,98	0,61	0,41	0,02	0,39

Table 5. Grey relational analysis method for step 5-6

No	**Tensile Strength Test (MPa)**	**Izod Pendulum Impact Resistance Test (kJ/m²)**	**Three Point Bending Test (MPa)**	**Grey Relational Degree**	**Ranking**
1	0,73	0,50	0,51	0,59	16
2	0,60	0,56	0,60	0,59	17
3	0,50	0,60	0,56	0,55	18
4	0,78	0,61	0,51	0,64	13
5	0,66	0,62	0,56	0,61	14
6	0,64	0,77	0,59	0,66	12
7	0,70	0,59	0,52	0,60	15
8	0,70	0,81	0,53	0,67	10
9	1,00	0,69	0,50	0,73	5
10	0,65	0,55	0,76	0,66	11
11	0,65	0,68	1,00	0,78	4
12	0,67	1,00	0,93	**0,86**	**1**
13	0,73	0,58	0,71	0,68	9
14	0,74	0,65	0,79	0,73	6
15	0,79	0,87	0,84	0,83	2
16	0,70	0,55	0,82	0,69	8
17	0,77	0,54	0,82	0,72	7
18	0,71	0,98	0,72	0,79	3
		Mean Grey Relational Degree		**0,69**	

Table 6. New factor levels of inputs

Factors	**Levels**						**Max-Min**	**Rank**
	1	**2**	**3**	**4**	**5**	**6**		
A	0,5739	0,6355	0,6696	**0,7683**	0,7468	0,7353	0,1944	1
B	0,6431	0,6832	**0,7383**				0,0952	2
C	**0,7146**	0,6893	0,6607				0,0540	3

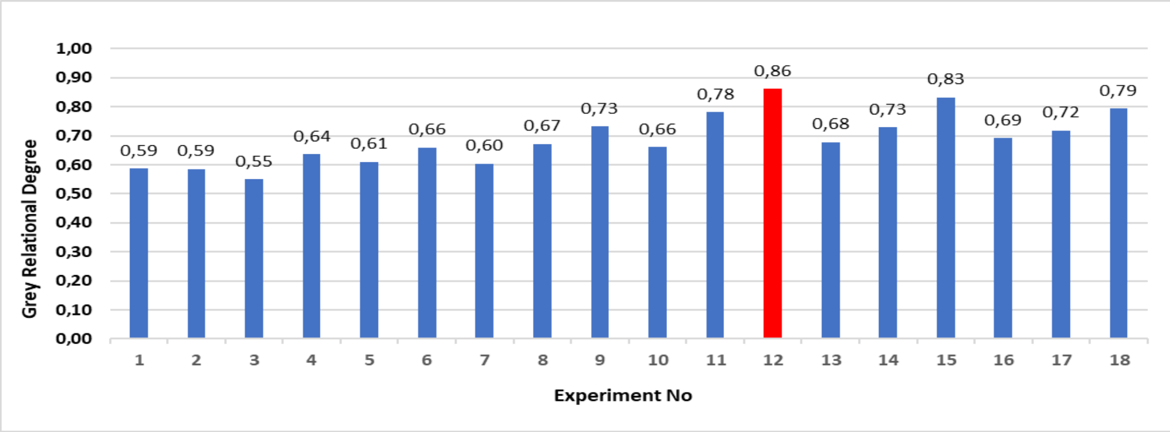


Figure 2. The graph of grey relational degree for outputs

The graph of the parameters levels is shown in Figure 3. It is understood that optimal parameter levels are combination of A4B3C1. (The experimental plan has not this combination.)

Step 8. ANOVA test results are given in Table 7. In the table, Factor A (Fabric) has the highest F value. Factor B (Al_2O_3 Additive) has Second F value and Factor C (SiC Additive) has third F value. The highest F value means that the most effective factor is Factor A (Fabric). This value shows that when input parameter values are evaluated together, the most influential factor on output parameters is Factor A (Fabric). Figure 4 shows contribution (%) of factors in the grey relational grade.

Step 9: Finally, last step is the Taguchi Method using Grey relation degree values from Table 5 and confirmation test. In Table 8, S/N Ratio of Grey Relational Degree is seen (Equation 7 and using MINITAB 15® package program). As seen in Table 8, the lowest S/N value is in 12th experiment. This means that the most optimum sample is sample number 12 when tensile strength, Izod pendulum impact resistance, and three point bending values are evaluated together.

Figure 5 also shows the S/N ratio graph obtained from the MINITAB 15® package program.

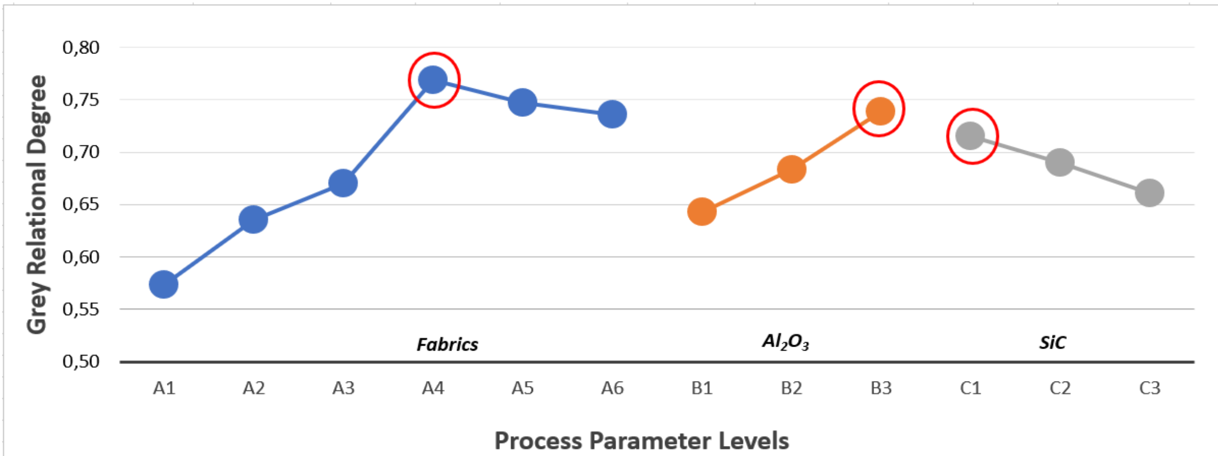


Figure 3. The graph of process parameter levels

Table 7. ANOVA of grey relational degree

Source	DF	Seq SS	Adj SS	Adj MS	F	Contribution (%)
A	5	0,081511	0,081511	0,016302	**10,34**	**62,94**
B	2	0,026311	0,026311	0,013156	8,35	20,32
C	2	0,009078	0,009078	0,004539	2,88	7,01
Residual Error	8	0,012611	0,012611	0,001576		9,74
Total	17	0,129511				

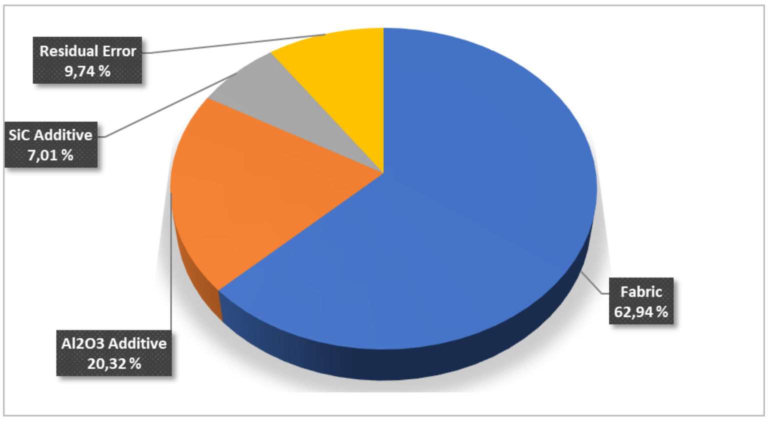


Figure 4. Contribution (%) of factors in the grey relational grade

Table 8. Determination S/N ratio

Experiment No	A (Fabric)	B (Al_2O_3 Additive)	C (SiC Additive)	S/N (dB)
1	1 (B30)	1 (0)	1 (0)	-4,58296
2	1 (B30)	2 (2)	2 (5)	-4,58296
3	1 (B30)	3 (4)	3 (10)	-5,19275
4	2 (B40)	1 (0)	1(0)	-3,87640
5	2 (B40)	2 (2)	2 (5)	-4,29340
6	2 (B40)	3 (4)	3 (10)	-3,60912
7	3 (B50)	1 (0)	2 (5)	-4,43697
8	3 (B50)	2 (2)	3 (10)	-3,47850
9	3 (B50)	3 (4)	1(0)	-2,73354
10	4 (K30)	1 (0)	3 (10)	-3,60912
11	4 (K30)	2 (2)	1 (0)	-2,15811
12	4 (K30)	3 (4)	2 (5)	**-1,31003**
13	5 (K40)	1 (0)	2 (5)	-3,34982
14	5 (K40)	2 (2)	3 (10)	-2,73354
15	5 (K40)	3 (4)	1(0)	-1,61844
16	6 (K50)	1 (0)	3 (10)	-3,22302
17	6 (K50)	2 (2)	1(0)	-2,85335
18	6 (K50)	3 (4)	2 (5)	-2,04746

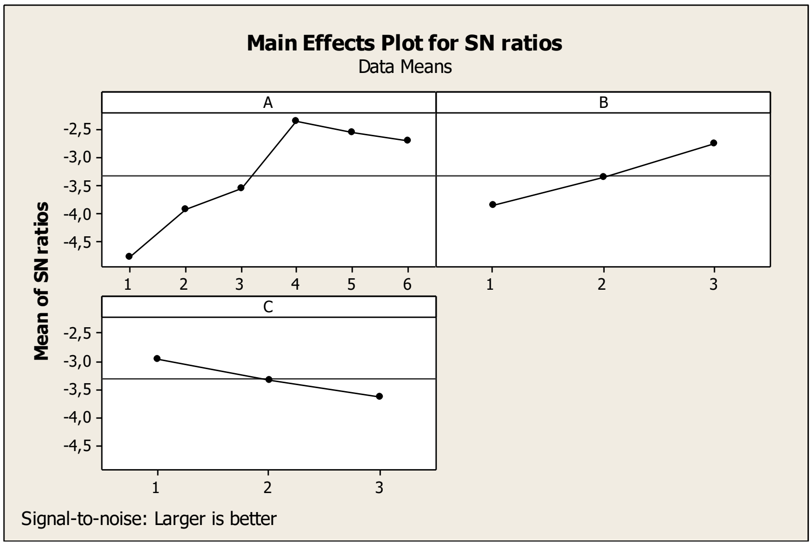


Figure 5. The S/N Ratio Graph Obtained from The MINITAB 15® Package Program

3.2 Confirmation test

As seen in Grey Relational Taguchi test results (Figure 3), optimum sample is the sample containing, 30% carbon fabric, 4% Al_2O_3 and 0% SiC when tensile strength, Izod pendulum impact resistance and three point bending values are evaluated together.

It is an expected result that the mechanical properties of composites containing carbon fabric are better. The reason for this is that the mechanical properties of carbon fabric are better than basalt fabric.

Since the optimum combination sample suggested by the Grey Relational Taguchi Method was not included in the experimental plan, it was reproduced. After that, tensile strength test, Izod pendulum impact resistance test and three point bending test were done on the optimum combination sample. The Grey Relational Degree was calculated for the estimation and the experiment. Improvement in Grey Relational Grade was also found. These findings are seen collectively in Table 9. In this table, the initial process parameter was chosen as the first experiment and the degree of improvement in Grey Relational Grade was calculated accordingly. Likewise, the improvement in Grey Relational Grade for the values below the Grey Relational Degree obtained in the calculations for the experimental result of the optimum process parameter are calculated and given in Table 10 collectively. The highest recovery rate is seen as 0,07 when the 3rd experiment plan is selected as the initial process parameter.

Experiment (1) (A1B1C1) is chosen as the initial design. Grade of Grey Relations = 0,59 calculated for this experiment. Average Grey Relationship Grade for weighting coefficient of Tensile Strength 0,35- Izod Pendulum Impact Resistance 0,35- Three Point Bending 0,30 is η_m, 0,69 (Table 5) Optimum levels of factors are $\eta_{A4} = 0{,}7683$, $\eta_{B3} = 0{,}7383$ ve $\eta_{C1} = 0{,}7146$.

For the experiment performed at optimum process parameters (A4B3C12), the Grey Relationship Degree is calculated as follows by applying the 1st Step, 2nd Step, 3rd Step, 4th Step, 5th Step and 6th Step in the method and is found as 0,62.

The difference between the Grey Relationship Degree (0,62) calculated for the experiment performed at the optimum process parameters and the Grey Relationship Degree (0,59) calculated for the Initial process parameters gives the improvement in the Grey Relationship Degree. This value is seen as 0,03 in the Table 9.

Table 9. Tensile strength, izod pendulum impact resistance and three point bending of samples produced using initial and optimum composite components (for weighting coefficient tensile strength 0,35- izod pendulum impact resistance 0,35- three point bending 0,30)

	Initial Process Parameter	Optimum Process Parameter	
		Prediction	*Experiment*
Level	A1B1C1	A4B3C1	A4B3C1
Tensile Strength (MPa)	201,05		178,98
Izod Pendulum Impact Resistance (kJ/m^2)	13,94		12,51
Three Point Bending (MPa)	34,2		60,06
Grey Relational Degree	0,59	0,84	0,62
Improvement in Grey Relational Grade		0,03	

$$\eta = \eta_m + (\eta_{A4} - \eta_m) + (\eta_{B3} - \eta_m) + (\eta_{C1} - \eta_m)$$

$$\eta = 0{,}69 + (0{,}7683 - 0{,}69) + (0{,}7383 - 0{,}69) + (0{,}7146 - 0{,}69 = 0{,}84$$

$$\eta = 0{,}8$$

Table 10. Improvement in Grey Relational Grade for The Values Below The Grey Relational Degree Obtained in The Calculations For The Experimental Result of The Optimum Process Parameter

Experiment No	Initial Process Parameter Grey Relational Degree	Optimum Process Parameter Grey Relational Degree (*for Experiment*) (A4B3C1)	Improvement in Grey Relational Grade
1	0,59	0,62	0,03
2	0,59	0,62	0,03
3	**0,55**	**0,62**	**0,07**
5	0,61	0,62	0,01
7	0,60	0,62	0,02

4. CONCLUSION

In this study, mechanical properties (Tensile strength, Izod pendulum impact resistance and three point bending) of basalt, carbon fabric reinforced particle additive composites were investigated using Grey Taguchi orthogonal experimental design. For this, 18 different composite containing basalt and carbon fabric (at the rate of 30, 40 and 50%), Al_2O_3 (Alumina) (at the rate of 0, 2 and 4%) and SiC (Silicon carbide) (at the rate of 0, 5 and 10%) were produced. Tensile strength, Izod pendulum impact resistance and three point bending tests were performed on the samples. According to the Grey Taguchi orthogonal experimental design, optimum combination for mechanical properties was 30% carbon fabric,4% Al_2O_3 and 0% SiC. The improvement was seen as 0,07 when the 3rd experiment plan was selected as the initial process parameter. In this designed experimental study, it was seen that the optimum composite in terms of selected mechanical properties is not basalt fabric, but carbon fabric, and at the same time, SiC has no effect. Thus, carbon and basalt fabric reinforced particle added composite plates could be compared in terms of mechanical properties. Although there is no similar study in the literature in which the reinforcement is basalt or carbon fabric and Al_2O_3 and SiC powders are added to the resin, there are studies to increase the mechanical properties of these powders. In the optimum composite combination obtained, Al_2O_3 was included with carbon fabric. In the study of Kaybal et al. (2016), it was concluded that adding Al_2O_3 to the epoxy composite significantly improved the tensile property of the composite [36]. It can be interpreted that SiC has no effect on optimum mechanical properties, this particle is micro-sized and has sharp corners due to its crystal structure, thus creating discontinuity in its contact with the fibers in the fabric and weakening the mechanical property. SiC can improve the mechanical properties of the composite if the reinforcement material is irregular fibers and not fabric. As a study supporting this in the literature, Özsoy et al. (2015) can be given. In the study conducted by Özsoy et al. (2015), it was seen that adding micro and nano ceramic particles to the epoxy resin composite improves the mechanical properties of the composite [37]. Investigation of these particle reinforcements in terms of properties such as tribological and hardness may be recommended in future studies.

This study can be developed with experimental studies in which carbon and basalt fabric are designed not as a single layer, but as a multi-layer. Again, using more than 4% Al_2O_3 particle ratio can be investigated. In the continuation of the study, instead of multi-objective optimization, studies in which each mechanical property is optimized separately can be done.

Acknowledgment

The study was supported by University of Çukurova Scientific Research Department (Project Number: FDK-2017-8490).

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