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Evaluation Study of Glass Fiber Reinforced Polyester and Kevlar Reinforced Polyester by Taguchi Method

Osama Sultan M.*   Majid Hmeed A.   Ishraq Abdul Razaq K.

Department of Materials Engineering/University of Technology

* Email: oalaamiri@yahoo.com

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Abstract

In the present investigation two different types of fiber reinforced polymer composites were prepared by hand lay-up method using three different parameters (curing temperature, pressing load and fiber volume fraction). These composites were prepared from the polyester resin as the matrix material reinforced with glass fibers as first group of samples and mat Kevlar fibers as the second group, both with different volume fractions (4%, 8%, and 12%) of fibers. They were then tested by tensile strength and impact strength. The main objective in this study is to use Taguchi method for predicting the better parameters that give the better tensile and impact strength to the composites, and then preparing composites at these parameters and comparing them with the randomly used once. The experimental and analytical results showed that the Taguchi method was successful in optimizing the parameters that give the highest properties and it can find the most influential parameter regardless of the material used. Also it showed that the volume fraction was the most influential parameter on the tensile and impact strength. The difference between these composites was in the properties values and that the Kevlar composites have higher tensile and impact strength.

Keywords: *Fiber reinforced composites, Taguchi method, Tensile strength, Impact strength.*

1. Introduction

Composite material is well known as an excellent structural material. It consists of two or more materials (i.e. fiber and matrix) combined to give superior performance compared to the properties of the individual components. Fiber reinforced plastic composites using resin such as epoxy, polyester and vinylester are extensively used as structural materials for many applications such as automotive industry, aerospace and civil engineering structures due to their high specific stiffness, strength, and cost and weight advantages. Manufacturing of structural materials made from fiber composites calls for an improved strength to weight ratio [1,2, 3].

Glass-fiber-reinforced polymers (GRPs) have received considerable attention as alternatives to steel and aluminum as structural materials; on the other hand, Kevlar fibers as reinforcement became more popular in specific applications such as parachute webbing, rocket motor casings, jet-engine containment, aircraft seats, and automobile tires due to their improved stiffness and density properties in relative to glass and their considerably lower cost than that of boron or even graphite fibers [4, 5].

The quality of any composite material is influenced by varying processing parameters. Among these parameters, there must be one or two that have the most influence. It has been realized that the full economic and technical potential of any manufacturing process can be achieved only while the process is run with the optimum parameters. One of the most important optimization processes is Taguchi method [6]. This technique helps to study effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined. Taguchi designs experiments using specially constructed tables known as “orthogonal array” (OA). The use of these tables makes the design of experiments very easy and consistent and it requires relatively lesser number of experimental trials to study the entire parameter space. As a result, time, cost, and labour saving can be achieved. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi technique recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) can be performed to analyze which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment may be needed to verify the optimal process parameters obtained from the parameter design [7,8]. Taguchi method provides a simple efficient and systematic approach to optimize design for performance, quality and cost. The methodology is valuable when design parameters are qualitative and discrete. Taguchi parameter design can optimize the performance characteristic through the setting of design parameters and reduce the sensitivity of the system performance to source variation [9,10]. The Taguchi approach reduces the experimental trials to a minimum number and it is a multi – step process which follow a certain sequence for the experiments to yield an improved understanding of product or process performance [11].

2. Materials and Methods

In this study, general purpose unsaturated polyester resin is used as the matrix and two types of reinforcing fibers (i.e. glass fibers and Kevlar fibers). Table (1) shows the mechanical properties of these materials.

Two types of composites were prepared by the hand lay-up method (i.e. glass fiber reinforce polyester GFRP and Kevlar reinforced polyester KFRP). At first a glass mold of the dimensions (30*30*5 cm) was used with clean and regular inner surfaces, and then the resin was mixed with 2% methyl-ethyl-ketone peroxide (MEKP) as a hardener. After a short time, the mixture became as a gel which is then poured into the mold. The fibers in a mat shape were put between two layers of the matrix. The layered structure was put under different loads for about 24 hours for proper curing at room temperature and allowed to harden on cure. It was cured at room temperature for 24 hours and followed by oven cure at different temperatures so that the matrix completely seeps in and become dry. Three volume fractions (4%, 8% and 12%) of reinforcements were used for each type of composites. The resulted composites were then cut into appropriate specimens for the tensile and impact tests. After some preliminary tests, the experimental conditions shown in Table (2) were chosen to study the effects of processing parameters (Curing temperature, pressing load and volume fraction) on the tensile and impact strength of the composites.

Table 1,
General Properties of the Used Materials.

Property	**U-Polyester**	**E-Glass fibers**	**Kevlar fibers (49)**
Tensile strength (MPa)	40-90	1500	2800
Modulus of elasticity (GPa)	2- 4.5	76	125
Density (gm/cm^3)	1.2-1.5	2.59	1.44
Elongation (%)	2	3.8	2.1
Linear coefficient of thermal expansion (*10^{-6} K^{-1})	75	5	-2

Table 2,
Control Factors and Their Levels.

Factor	Control factor	Level 1	Level 2	Level 3
A	Curing Temperature (ºC)	20	40	60
B	Pressing load (gm)	100	150	200
C	Volume Fraction (%)	4	8	12

3. Application of Taguchi Method

The Taguchi method of design of experiments is a statistical tool based on the systematic approach of conducting minimal number of experiments using a mathematical instrument called orthogonal arrays. Traditionally, the method has been used to predict the significance of contribution of each design variables and their level to achieve optimum combination by conducting a real time experiment.

In our work, an orthogonal array of the type (L_9 3^3) was chosen since we have three factors (variables) and three levels. Table (3) represents the standard orthogonal array of type (L_9 3^3). During the composites preparation method, three process parameters for each type of composites were considered. These are: (1) curing temperature; (2) pressing load, and (3) fibers volume fraction. Each is at three levels as listed in Table (2). The degree of freedom for three parameters in each of the three levels is calculated as follows [6]:

Degree Of Freedom (DOF) = number of levels -1 …(1)

For each factor, DOF equals to:
For (A); DOF = 3 – 1 = 2
For (B); DOF = 3 – 1 = 2
For (C); DOF = 3 – 1 = 2

Table 3,
The Standard (L_9 3^3) Orthogonal Array [9].

Experiment number	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

* (P) represents factors.

In this research nine experimental trails were conducted at different parameters, for each type of composites and they were cut and tested by tensile and impact tests. Figure (1) shows some of the specimens. The tensile tests were performed by using the Time testing machine according to (ASTM D638- 87) standard in which the gage length is (60mm). The impact tests were performed by Time testing machine (Izod) type XJU-22 according to (D256- 87) standard with the dimensions (55 * 10 * 4mm).

Tables (4) and (5) indicate the used parameters and the result values of tensile and impact strength for (GFRP) and (KFRP) respectively.

A standard three level (L_9 3^3) orthogonal array with nine experimental runs was selected. The total degree of freedom is calculated from the following [6]:

Total DOF = no. of experiments – 1 …(2)

The total DOF for the experiments is: Total DOF = 9 – 1 = 8

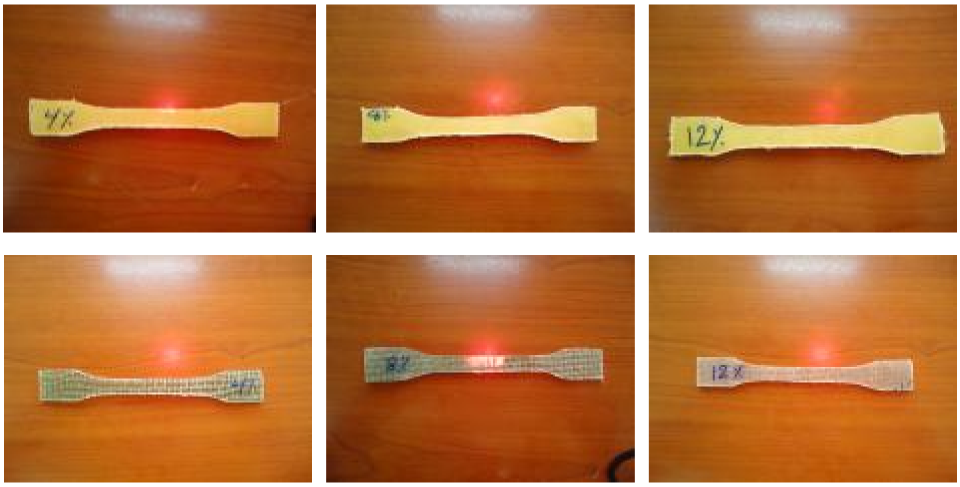

Fig. 1. Some of the Prepared Specimens (upper: GFRP, lower: KFRP).

Table 4,
Experimental Runs of the OA ($L_9\ 3^3$) for the GFRP.

Experiment number	Control factor			Response factor	
	A	B	C	Tensile strength (MPa)	Impact strength (MPa)
1	20	100	4	56	49.7
2	20	150	8	62	61.9
3	20	200	12	78	76.4
4	40	100	12	74	71.4
5	40	150	4	58	53.3
6	40	200	8	65	63.2
7	60	100	8	69	67.1
8	60	150	12	91	78.4
9	60	200	4	60	56.1

GFRP: Glass Fiber Reinforced Polyester.
A: Curing Temperature (ºC); B: Pressing Load (gm); C: Volume Fraction (%) and E: Error.

Table 5,
Experimental runs of the OA ($L_9\ 3^3$) for the KFRP.

Experiment number	Control factor			Response factor	
	A	B	C	Tensile strength (MPa)	Impact strength (MPa)
1	20	100	4	59	68.6
2	20	150	8	81	87.4
3	20	200	12	107	101.4
4	40	100	12	101	98.7
5	40	150	4	64	70.5
6	40	200	8	92	89.8
7	60	100	8	93	90.2
8	60	150	12	119	105.1
9	60	200	4	77	73.9

KFRP: Kevlar Fiber Reinforced Polyester.

Taguchi method stresses the importance of studying the response variation using the signal – to – noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. Since the tensile and impact strength were required to be high, the concept of "the larger the better" is considered. The S/N ratio used for this type of response is given by [6]:

$$SN_i = -10 \log \left[\frac{1}{N_i} \sum_{u=1}^{N_i} \frac{1}{y_u^2} \right] \quad \ldots(3)$$

Where
i: experiment number.
u: trail number.
Ni: number of trails for experiment *i*.
y_u: the response (property) value for a trial condition repeated (u) times.

The composite preparation parameters, namely: (A) curing temperature, (B) pressing load and (C) particles volume fraction were assigned to the 1st , 2nd and 3rd column of the ($L_9\ 3^4$) array, respectively. The 4th column was assigned as error (E). The S/N ratios were computed for tensile strength and impact strength in each of the nine trial conditions for each type of composites and their values are given in Tables (6) and (7). Computation scheme of pareto ANOVA (Analysis Of Variance) for three level factors is shown in Table (8).

In order to study the contribution ratio of the process parameters, pareto ANOVA was performed for tensile and impact strengths. The details are given in Tables (9) and (10) respectively for the GFRP and Tables (11) and (12) for the KFRP.

Table 6,
S/N Ratio of Tensile and Impact Strengths for the GFRP.

Experiment number	A	B	C	E	S/N Ratio (Tensile strength)	S/N Ratio (Impact strength)
1	1	1	1	1	34.96	33.93
2	1	2	2	2	35.85	35.83
3	1	3	3	3	37.84	37.66
4	2	1	3	2	37.38	37.07
5	2	2	1	3	35.27	34.53
6	2	3	2	1	36.26	36.01
7	3	1	2	3	36.78	36.53
8	3	2	3	1	39.19	37.89
9	3	3	1	2	35.56	34.98

Table 7,
S/N Ratio of Tensile And Impact Strengths for the KFRP.

Experiment number	A	B	C	E	S/N Ratio (Tensile strength)	S/N Ratio (Impact strength)
1	1	1	1	1	35.42	36.73
2	1	2	2	2	38.17	38.83
3	1	3	3	3	40.59	40.12
4	2	1	3	2	40.09	39.89
5	2	2	1	3	36.12	36.96
6	2	3	2	1	39.28	39.07
7	3	1	2	3	39.37	39.1
8	3	2	3	1	41.51	40.43
9	3	3	1	2	37.73	37.37

Table 8,
Pareto ANOVA for Three Level Factors [6].

Factors	**A**	**B**	**C**	**E**	**Total**
Sum. at factor level	A_1	B_1	C_1	E_1	T
	A_2	B_2	C_2	E_2	
	A_3	B_3	C_3	E_3	
Sum. of squares of differences	S_A	S_B	S_C	S_E	S_T
Degree of freedom					
(Contribution ratio)/100	S_A/ S_T	S_B/ S_T	S_C/ S_T	S_E/ S_T	1

$T = A_1 + A_2 + A_3$

$S_A = (A_1 - A_2)^2 + (A_1 - A_3)^2 + (A_2 - A_3)^2$

$S_B = (B_1 - B_2)^2 + (B_1 - B_3)^2 + (B_2 - B_3)^2$

$S_C = (C_1 - C_2)^2 + (C_1 - C_3)^2 + (C_2 - C_3)^2$

$S_E = (E_1 - E_2)^2 + (E_1 - E_3)^2 + (E_2 - E_3)^2$

$S_T = S_A + S_B + S_C + S_E$

Table 9,
Pareto ANOVA of Tensile Strength for the GFRP.

Factors	**A**	**B**	**C**	**E**	**Total**
Sum. at factor level	108.65	109.12	105.79	110.41	329.09
	108.91	110.31	108.89	108.79	
	111.53	109.66	114.41	109.89	
Sum. of squares of differences	15.226	2.13	114.385	4.105	135.846
Degree of freedom	2	2	2	2	8
(Contribution ratio)/100	11.208	1.568	84.202	3.022	1
Optimum level	2 A_3 60	3 B_2 150	1 C_3 12		

Table 10,
Pareto ANOVA of Impact Strength for the GFRP.

Factors	**A**	**B**	**C**	**E**	**Total**
Sum. at factor level	107.42	107.53	103.44	107.83	324.43
	107.61	108.25	108.37	107.88	
	109.4	108.65	112.62	108.72	
Sum. of squares of differences	7.161	1.933	126.64	1.5	137.234
Degree of freedom	2	2	2	2	8
(Contribution ratio)/100	5.218	1.409	92.28	1.093	1
Optimum level	2 A_3 60	3 B_3 200	1 C_3 12		

Table 11,
Pareto ANOVA of Tensile Strength for the KFRP.

Factors	A	B	C	E	Total
Sum. at factor level	114.18	114.88	109.27	116.21	348.28
	115.49	115.8	116.82	115.99	
	118.61	117.6	122.19	116.08	
Sum. of squares of differences	31.075	11.485	252.766	0.0734	295.4
Degree of freedom	2	2	2	2	8
(Contribution ratio)/100	10.52	3.888	85.567	0.025	1
Optimum level	2 A_3 60	3 B_3 200	1 C_3 12		

Table 12,
Pareto ANOVA of Impact Strength for the KFRP.

Factors	A	B	C	E	Total
Sum. at factor level	115.68	115.72	111.06	116.23	348.5
	115.92	116.22	117	116.09	
	116.9	116.56	120.44	116.18	
Sum. of squares of differences	2.506	1.071	135.102	0.03	138.71
Degree of freedom	2	2	2	2	8
(Contribution ratio)/100	1.81	0.77	97.4	0.02	1
Optimum level	2 A_3 60	3 B_3 200	1 C_3 12		

4. Results and Discussion

Tables (4) and (5) represents the values of tensile and impact strengths for both types of composites and it shows that Kevlar composites gave higher tensile and impact than the glass fiber composites. This is true since the Kevlar fibers have more toughness.

From Table (9), it can be seen that the third level of factor (A) give the highest summation (i.e. A_3, which is 60ºC curing temperature). The highest summation for factor (B) is at the second level (i.e. B_2, which is 150 gm) and the highest summation for factor (C) is at the third level (i.e. C_3, which is 12% volume fraction). These predicted parameters are already used in the GFRP composite preparation as indicated in Table (4).

It can be seen from Table (10) for the impact results of GFRP that the optimum levels were A_3, B_3 and C_3 (i.e. 60ºC, 200 gm and 12%). These parameters were not used in the composite trails as indicated in Table (4). An experiment was conducted at the predicted parameters (A = 60ºC, B = 200 gm, and C = 12 % volume fraction), and the resulted specimen was tested by impact. The resulted impact strength was (82 MPa) which is greater than the impact strength values in Table (4).

The optimum levels of Kevlar composites parameters for the tensile and impact strengths are similar to the results of impact of the glass fiber composites in which A_3, B_3 and C_3 (i.e. 60ºC, 200 gm and 12%) had gave the highest contribution ratio. These parameters were also not used in the composite trails as indicated in Table (5). Two additional specimens of Kevlar fiber reinforced polyester were prepared at the predicted parameters (A = 60ºC, B = 200 gm, and C = 12 % volume fraction), and were tested by tensile and impact. The resulted tensile strength was (121 MPa) while the impact strength was (109 MPa) which are greater than the strength values in Table (5).

These results proved the success of Taguchi method in the prediction of the optimum parameters for higher tensile and impact strengths. In Tables (9, 10, 11 and 12), it was found that the fiber volume fraction contributes a larger impact on tensile and impact strength of the composites followed by curing temperature and then finally pressing load.

5. Conclusions

In this research Taguchi's off – line quality control method was applied to determine the optimal process parameters by which a glass fiber reinforced polyester and Kevlar fiber reinforced polyester were prepared. For this purpose, concepts like orthogonal array, S/N ratio and ANOVA were employed. After determining the optimum process parameters, a confirmation experiments were conducted. In light of our analysis the following conclusions were drawn:

1. The optimum level of process parameters to obtain good tensile and impact strengths for the composites prepared by the hand lay-up method are 12% volume fraction of fibers, 60ºC curing temperature, and 150 gm pressing load for tensile strength and 200 gm for impact strength for the glass fiber reinforced polyester. While it is 12% volume fraction of fibers, 60ºC curing temperature, and 200 gm for tensile and impact strengths for the kevlar fiber reinforced polyester.
2. Taguchi method was successful in predicting the parameters that give the highest properties and it can find the most influential parameter regardless of the material used.
3. From the Pareto analysis it was evident that the volume fraction is a major contributing factor for improving tensile and impact strengths.
4. Taguchi method proved its success in predicting the optimum parameters to reach the best properties.

6. References

[1] Zulkifli R., "Surface Fracture Analysis of Glass Fiber Reinforced Epoxy Composites Treated with Different Type of Coupling Agent", European Journal of Scientific Research, Vol.29, No.1, (2009), pp.55-65.

[2] Iwaya T. et. al., "Recycling of fiber reinforced plastics using depolymerization by solvothermal reaction with catalyst", J Mat. Sci., Vol.43, (2008), pp.2452–2456.

[3] Kang G. et. Al., "Uniaxial ratchetting of polymer and polymer matrix composites: Time-dependent experimental observations", Mat. Sci. Eng. A, Vol.523, (2009), pp.13–20.

[4] Bagherpour S. et. al., "Effects of concentrated HCl on the mechanical properties of storage aged fiber glass polyester composite", Materials and Design, Vol.30, (2009), pp.271–274.

[5] Wallace M. M., Bert C. W., "Experimental determination of dynamic young's modulus and damping of an Aramid-fabric/polyester composite material", Proc. Okla. Acad. Sci., Vol.59, (1979), pp.98-101.

[6] Muhammed O. S., Saleh H. R., Alwan H. L., "Using of Taguchi Method to Optimize the Casting of Al–Si /Al_2O_3 Composites", Eng. & Tech. J., Vol.27, No.6, (2009), pp. 1143 – 1150.

[7] Kamaruddin S., Khan Z. A., Foong S. H., "Application of Taguchi Method in the Optimization of Injection Moulding Parameters for Manufacturing Products from Plastic Blend", IACSIT International Journal of Engineering and Technology, Vol.2, No.6, (2010), pp. 574 – 580.

[8] Mehravar R. et. al., "Applying the Taguchi Method for Optimized Fabrication of Lactalbumin Nanoparticles as Carrier in Drug Delivery and Food Science", Iranica Journal of Energy & Environment, Vol.2, no.1, (2011), pp.87-91.

[9] Ross Phillips J., "Taguchi technique for quality engineering", New York: McGraw – Hill, (1988).

[10] Roy Ranjit K., "A primer on Taguchi method", New York: Van Nostrad Reinhold, (1990).

[11] Basavarajappa S., Chandramohan G., Paulo Davim J., "Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites", Materials and Design, Vol. 28, (2007), pp. 1393 – 1398.

دراسة تقييم ما بين البولي استر المقوى بالياف الزجاج والبولي استر المقوى بالياف الكفلر بواسطة طريقة تاكوجي

أسامة سلطان محمد*   ماجد حميد عبد المجيد   اشراق عبد الرزاق كاظم
قسم هندسة المواد/ الجامعة التكنولوجية
*البريد الالكتروني: oalaamiri@yahoo.com

الخلاصة

تم في هذا البحث تحضير مادتين متراكبتين مختلفتين من البوليمر المقوى بالالياف بواسطة طريقة التحضير اليدوي وباستخدام ثلاثة متغيرات هي (درجة حرارة المعالجة، حمل الكبس و الكسر الحجمي للالياف). تم تحضير المواد المتراكبة من راتنج البولي استر كمادة اساس مقوى بالياف الزجاج كمجموعة اولى من العينات والياف الكفلر كمجموعة ثانية من العينات وبكسور حجمية مختلفة لكل نوع من الالياف هي (٤%، ٨%، ١٢%). تم بعدها اجراء اختباري مقاومة الشد ومقاومة الصدمة على العينات. ان الهدف الاساسي من البحث هو استخدام طريقة تاكوجي للتكهن بافضل المتغيرات التي تعطي افضل مقاومة شد وصدمة للمواد المتراكبة ومن ثم تحضير مواد متراكبة عند هذه المتغيرات ومقارنتها مع المتغيرات المستخدمة المختارة عشوائيا. اظهرت النتائج التجريبية والتحليلية بان طريقة تاكوجي كانت ناجحة في التكهن وايجاد المتغيرات التي تعطي اعلى الخواص وكذلك يمكنها ايجاد المتغير الاكثر تاثيرا على الخواص بغض النظر عن المادة المستخدمة. اظهرت النتائج كذلك بان الكسر الحجمي كان المتغير الاكثر تاثيرا على مقاومة الشد والصدمة. كذلك ان الفرق بين المادتين المحضرتين كان في قيم الخواص وان المادة المتراكبة ذات الياف الكفلر اعطت مقاومة شد وصدمة اعلى.