Effect of reinforcing materials on mechanical properties of composite material using Taguchi method

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Abstract: The mechanical properties play an important role in the selection of suitable material in the manufacturing of boats. In this paper, the effect of glass fiber orientations and the fillers weight fraction on the mechanical properties of unsaturated polyester composite material were studied. The glass fibers were used with (0/0, 0/90, 45/45) angles. The carbon filler used with (2.5%, 5%, 7.5%), while the aluminium oxide nano was used with (0%, 1%, 3%) weight fraction respectively. The standard Taguchi’s array L9 (3³) was used. The signal to noise ratio and analysis of variance were introduced to analyze and estimate the optimal combination parameters. The results show that the mechanical properties improved with using the reinforcements. The glass fibers orientations angle presents the most parameter effect than the other parameters on the modulus of elasticity, tensile strength and impact strength with a contribution of 81.8%, 83.39% and 96.75% respectively. Followed by carbon and aluminium oxide nano. The optimum parameter with their levels for the highest modulus of elasticity was obtained at (0/90 fiber orientation, 5% carbon and 0% nano aluminium oxide). While the highest tensile strength and impact strength present with using (0/0 fiber orientation and 5% carbon). The experimental and expected results are very close, with an error ratio not exceeding 5%.

1. Introduction
A composite material consists of the combination of two or more materials with different physical or chemical properties that result in new properties completely different from the properties of the basic components. To prepare a composite material, two important components should be provided that the
matrix material and reinforcing material. The properties of a composite material are determined by
depending on these two elements, as well as the interaction occurring or overlapping between them.
Composite materials are classified into three types according to the base material contained in the
composite material, which are mineral, ceramic and polymeric composite materials. The polymer
molecule is a large molecule that consists of small chemical molecules linked together by chemical bonds,
and these molecules may be linked to each other in a linear fashion called the linear polymer [1]. The
polymeric molecule may be branched and it is called the branched polymer, and in sometimes these
branches are intertwined with each other and the polymer is called a cross linked polymer [2]. Polymers
can be divided into thermoplastic Polymer and thermosetting Polymer.

Where plastic polymers are known as linear molecular chains that are not linked to cross-linking, but there
are attractive forces between the chains, which are weak secondary bonding forces called Vander Waals
Forces, which transform from a solid state to molten material under the influence of heat. Examples
include polyethylene, nylon, and polystyrene [2]. The thermosetting polymers, they are transformed by the
effect of heat from the melted state to a solid that is not melting by the formation of covalent cross-linking
[3]. These materials are in liquid form, so they can be poured into any desired shape. Epoxy resins and
unsaturated polyester are examples of this type.

Many technological processes require an incorporation of properties that do not exist in metallic. These
properties can only be achieved by using composite materials [4]. Composite materials have been used in
many applications such as aircraft, automotive and marine vessels. Glass fiber reinforced unsaturated
polyester has been used in the manufacture of boats and large ships due to its light weight with high
strength, durability and ease of production.

Muhammed et al. [5], using Taguchi's method in studying the effect of stirring time, stirring speed and
volume fraction of reinforce materials on the mechanical properties of the composite material. The results
showed that the volume fraction is the most parameter influencing tensile strength and hardness of the
prepared composite materials.

Anter and Hasan [6], studied the effect of water absorption on the mechanical properties of epoxy
reinforced with glass fiber. Where epoxy composites are prepared as a base material reinforced with glass
fibers with 25% volume fraction. The samples are immersion in water. Samples were tested before and
after immersion in water at room temperature. The results showed that the hardness decreased with
increasing the time of immersion in the water. And the amount of water absorbed increases with the
increase in the time of immersion, especially in the first week.

Muhammad [7], studied the mechanical properties of composite materials under the influence of different
parameters by using the Taguchi method. The most effect parameters on the mechanical properties were
found using signal to noise ratio and analysis of variance. The results showed that the type of fiber most
influenced the mechanical properties, followed by the filler and the volume fraction of the fiber. Raju B. et
al. [8], studied the mechanical properties of a composite material of polyester reinforced with glass fiber
and ZnO nanoparticles with different weight fractions. It was found that the mechanical properties
improve in the composite material that contains 2% ZnO nanoparticles weight fraction and 50/50 glass
fiber.

Farag and Jamal [9], had an experimentally investigation of mechanical properties of unsaturated
polyester composite reinforced by natural fillers using Taguchi technique. Three samples of date palm
waste natural filler with particle size ≤ 400μm be selected. The results show that the date seeds filler has
the main influence on the tensile strength, while, the petiole has the dominate parameter for the yield
stress and impact strength. Farag and Jamal [10], using Taguchi method with a regression model to
investigate the honeycomb sandwich panel behavior under the effect of AL%-filler contents the
glass/polyester composite material subjected to impact load. The results show that, the mass has highest
contribution for deflection, followed by the AL% filler. While the AL% has the highest contribution for
the deformation, followed by the height and mass with close contribution for each other. Aa good with use the prediction regression model.

The main objective of this research is to investigate the effect of reinforcing on the mechanical properties of unsaturated polyester composite materials used in boats structure applications. The reinforcements consist of glass fibers, carbon filler and aluminum oxide Nano filler. The standard Taguchi’s array L9 (3\(^3\)) be used to present the optimal parameters combination.

2. Experimental work

The materials selected to prepare the experimental test specimens in this work are the matrix system used is unsaturated polyester resin known commercially as TOPAZ -1110 TP medium reactive unsaturated polyester resin based on Phthalic Anhydride (KSA made). The polyester resin is mixed with hardener (Methyl Ethyl Ketone Peroxide MEKP). The reinforcement materials in which consist of glass fibers at 30% weight fraction with different orientation angles. The glass properties as in references [7,11]. The carbon filler and aluminum oxide nano filler with different weight fraction.

Experimental design: Three parameters with three levels for each to investigate the mechanical properties of composite material used for boats structures. The glass fibers with three orientation angles of (0/0, 0/90, 45/45). The carbon filler with weight fraction of (2.5%, 5%, 7.5%) and the Aluminum oxide nano filler with weight fraction of (0%, 1%, 3%). Table 1 shows the parameters with their levels. Selection of control factors is the most important stage in the experiment design. To study the effect of parameters in this work, L9 (3\(^3\)) orthogonal design has been used as shown in table 2.

2.1 Specimens Preparation
The samples were manufactured by dry hand layup technique at room temperature. The filler materials be added in intermittently to the matrix material with a specified weight fraction and stir it for a period of (10-15) minutes to obtain homogeneity. Then add the hardener at a standard mixing ratio at 2 g to 100 g to be within the weight of the polyester. The polyester is mixed with a hardener continuously and slowly using a glass rod to avoid bubbles. Using a glass mold with dimensions of (250×250×5) mm see figure 1. The mold is fixed by silicone fingers. The inner face of the mold is covered with a layer of nylon thermal paper made of nylon PVA is polyvinyl, then pour the mixture into the mold. The fibers are placed according to the orientation required for each sample. The cast is left for 24 hours at room temperature. Then the sample was extracted from the cast and the product is plate. Using CNC machined to cut the plate according to international standards and dimensions for each experiment specimen’s test.

| Parameters          | Symbol | Levels of Parameter |     |     |
|---------------------|--------|---------------------|-----|-----|
|                     |        | 1                   | 2   | 3   |
| Fiber arrangement   | A      | 0/0                 | 0/90| 45/45|
| Carbon filler (wt%) | B      | 2.5%                | 5%  | 7.5%|
| Nano Aluminum (wt%) | C      | 0%                  | 1%  | 3%  |

| Table 2. Parameters and their levels using Taguchi orthogonal array |
|----------------------------------|---------------|-------------|
| Exp. No. | Parameters and level | Unsaturated Polyester Wt.% |
|          | A | Level | Angles | B | Wt.% | Level | C | Wt.% |     |
| 1        | 1 | 0/0   | 1      | 2.5| 1    | 0     | 67.5|
| 2        | 1 | 0/0   | 2      | 5 | 2    | 1     | 64  |
2.2 Experimental tests

The test was performed on the specimens at room temperature in the laboratories of university of Technology- Iraq/ Material engineering department. Three test samples be done for each test and the average result listed. To achieve the goal of the research, the following tests were conducted:

1. The tensile test done using the tensile test device in which manufactured by (The Laryea Company/ China). The tensile test specimen shown in figure 2 were prepared according to ASTM D 638-3 [12,13]. The sample was placed in the device and linked by one jaw from the top and the second from the bottom. Then a tensile force is applied to the sample.

2. The impact test was done at room temperature using Charpy impact test device in which used to measure the impact strength of the prepared specimen. Specimens have been cut into the dimensions (80*10*5) mm according to ISO 179 [14] as shown in figure 2. Where the specimen is fixed in the device and subjected to force by a hammer in the form of a pendulum.

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Figure 1: The shape of the prepared mold.

Figure 2: Standard test specimens.
3. Results and discussion
After performing the tensile test and impact test on the prepared specimens, the tensile strength, modulus of elasticity, and impact strength were found, as shown in Table 3. The pure unsaturated polyester has (0.4 Gpa modulus of elasticity, 8 Mpa tensile strength and 0.2 J/mm² impact strength).

| Exp. No. | Modulus of Elasticity | Tensile strength | Impact strength |
|----------|-----------------------|------------------|-----------------|
|          | Gpa                   | S/N              | Mpa             | S/N             | J/mm² | S/N  |
| 1        | 0.67                  | -3.478           | 31              | 29.827          | 1.725 | 4.735|
| 2        | 0.8                   | -1.9382          | 62              | 35.847          | 2.325 | 7.3285|
| 3        | 0.7                   | -3.098           | 55              | 34.807          | 1.775 | 4.984|
| 4        | 1.013                 | 0.1121           | 24              | 27.604          | 1.35  | 2.606|
| 5        | 1                     | 0.00000          | 26              | 28.299          | 1.45  | 3.227|
| 6        | 0.88                  | -1.1103          | 22              | 26.848          | 1.225 | 1.762|
| 7        | 0.55                  | -5.1927          | 17              | 24.609          | 0.45  | -6.935|
| 8        | 0.68                  | -3.349           | 18              | 25.105          | 0.325 | -9.762|
| 9        | 0.47                  | -6.558           | 19              | 25.575          | 0.3   | -10.457|

3.1 Signal to Noise Ratio (S/N)
Since the goal is to achieve the higher strength to weight ratio, so the “bigger is better” be used to check the mechanical properties (tensile strength, modulus of elasticity, and impact strength) [15].

\[
S/N = -10 \log_{10} \left[ \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right]
\]

(1)

Where: n is the observations number.
yi is the data observed.

After conducting the tests for the nine specimens, the S/N ratios were calculated and included in Table 3. It was found that the experiment No.2 present the greatest tensile strength and impact strength which represent the combination set of parameters with their level of A1B2C2 that equivalent to (0/90 fiber orientation, 5% carbon filler and 1% aluminum oxide nano filler) with 64% unsaturated polyester. While experiment No. 4 has the maximum modulus of elasticity that represent A2B1C2 which is equivalent to (0/90 fiber orientation, 2.5% carbon filler and 1% al uminum oxide nano filler) with 66.5% unsaturated polyester.

The optimum combination levels were predicted by estimating the three parameters with different levels and listed in table 4. Figure 3 show the distributions of the average S/ N ratio.

From table 4 and figure 3 it can be notice that the optimum parameters combinations with their levels to get the higher modulus of elasticity is A2B1C1 in which equivalent to (0/90 fiber orientation, 5% carbon filler and 0% aluminum oxide nano filler) with 65% unsaturated polyester. The optimum combination for bigger tensile strength value is A1B2C1, this combination represents experiment No. 2. While the optimum combinations for the higher impact strength with their levels is A1B2C3, that equivalent to (0/0 fiber orientation, 5% carbon filler and 3% aluminum oxide nano filler) with 62% unsaturated polyester.
3.2 Analysis of Variance (ANOVA)

ANOVA analysis is used to analyze the experimental results [16], where the effect of parameters (glass fiber orientation angle, weight fraction of carbon filler and aluminum oxide nano filler) on the mechanical properties of the prepared samples have been studied. The analysis of variance possible to determine the independent parameter that dominates than the other with its percentage contribution. Table 5 show the results of the ANOVA. The glass fibers orientations angle presents the most parameter effect than the other parameters on the modulus of elasticity, tensile strength and impact strength with a contribution of 81.8%, 83.39% and 96.75% respectively. The carbon filler presents more effect rather than the aluminum oxide nano filler on the modulus of elasticity and impact strength. While the aluminum oxide nano filler effect followed the glass fiber orientation angle effect on the tensile strength.

Table 4. Average S/N ratio for different parameter levels

| Parameter                       | Symbol | Average of S/N (dB) of different level | Max-Min | optimum level |
|---------------------------------|--------|---------------------------------------|---------|---------------|
|                                 |        | 1          | 2       | 3             |             |
| **Modulus of Elasticity**       |        |            |         |               |             |
| Fiber arrangement               | A      | -2.838     | -0.332  | -5.033        | 4.7008       |
| Carbon filler                   | B      | -2.853     | -1.762  | -3.588        | 1.8261       |
| Nano Aluminum Oxide filler      | C      | -2.646     | -2.794  | -2.763        | 0.1485       |
| **Tensile Strength**            |        |            |         |               |             |
| Fiber arrangement               | A      | 33.49      | 27.58   | 25.1          | 8.4          |
| Carbon filler                   | B      | 27.35      | 29.75   | 29.08         | 2.4          |
| Nano Aluminum Oxide filler      | C      | 27.26      | 29.68   | 29.24         | 2.42         |
| **Impact Strength**             |        |            |         |               |             |
| Fiber arrangement               | A      | 5.687      | 2.5323  | -9.051        | 14.7346      |
| Carbon filler                   | B      | 0.1356     | 0.2645  | -1.237        | 1.5015       |
| Nano Aluminum Oxide filler      | C      | -1.087     | -0.174  | 0.4252        | 1.5131       |
Figure 3. The average S/N ratio of Mechanical properties.

Table 5. ANOVA results of mechanical properties

| Parameters             | Sum of Squares | Degree of Freedom | Mean Squares | Contribution (%) |
|------------------------|----------------|-------------------|--------------|------------------|
|                        | Modulus of elasticity |                   |              |                  |
| Fiber arrangement      | 33.1947        | 2                 | 16.5973      | 81.8             |
| Carbon filler          | 5.0650         | 2                 | 2.5325       | 12.4             |
| Nano Aluminum Oxide    | 0.0368         | 2                 | 0.0184       | 0.09             |
| Error                  | 2.2834         | 2                 | 1.1417       | 5.71             |
| Total                  | 40.5799        | 8                 |              | 100              |
|                        | Tensile strength |                   |              |                  |
| Fiber arrangement      | 111.636        | 2                 | 55.818       | 83.39            |
| Carbon filler          | 9.227          | 2                 | 4.614        | 6.89             |
| Nano Aluminum Oxide    | 9.938          | 2                 | 4.969        | 7.42             |
| Error                  | 3.065          | 2                 | 1.533        | 2.3              |
| Total                  | 133.867        | 8                 |              | 100              |
|                        | Impact strength |                   |              |                  |
| Fiber arrangement      | 361.227        | 2                 | 180.613      | 96.75            |
| Carbon filler          | 4.155          | 2                 | 2.077        | 1.11             |
| Nano Aluminum Oxide    | 3.484          | 2                 | 1.742        | 0.93             |
| Error                  | 4.494          | 2                 | 2.247        | 1.2              |
| Total                  | 373.36         | 8                 |              | 100              |

3.3. Confirmation Test
The Taguchi method confirms the results of the analysis [17]. The optimum levels of practical parameters obtained by analyzing the signal to noise ratio and laboratory results of mechanical properties were used for the purpose of developing the confirmation test. The values of the optimum levels were used together
with the mean value of each of the signal to noise ratio and the laboratory results. The confirmation test done using equation 2 [17].

$$\eta_{opt} = \eta_m + \sum_{i=1}^{k} (\eta_i - \eta_m)$$

(2)

Where:

- $\eta_{opt}$: Predicted optimum value.
- $\eta_m$: Total mean value.
- $\eta_i$: Mean value at optimum levels from table (4).
- $k$: Number of main design parameters that affect the quality characteristics.

Higher mechanical properties of modulus of elasticity, tensile strength and impact strength were obtained by combining the optimum parameters with their levels, are $A_2B_2C_1$, $A_1B_2C_2$ and $A_1B_2C_3$ respectively. Since the higher tensile strength value is introduced from the combination of $A_1B_2C_2$ which equivalent to experiment No. 2, while the other two combinations not have experiment test. So, the combinations of $A_2B_2C_1$ and $A_1B_2C_3$ specimens be prepared and the experimental test done. Table 6 show the results of the confirmation test, as it was found that the experimental and expected results are very close with an error that does not exceed 5%. This results from the fact that the result of the experiment is related with the expected result.

| characteristic          | Optimum Parameter Level | Experiment | Predication | Difference (%) |
|-------------------------|-------------------------|------------|-------------|----------------|
| Modulus of elasticity (GPa) | $A_2B_2C_1$             | 1.03       | 1.04        | 0.96           |
| Impact strength (MPa)    | $A_1B_2C_3$             | 2.225      | 2.325       | 4.3            |

4. Conclusions

The following conclusions were obtained:

1. The mechanical properties of reinforced composite material are improved as compared with pure unsaturated polyester.
2. The glass fibers orientations angle presents the most parameter effect than the other parameters on the modulus of elasticity, tensile strength and impact strength with a contribution of 81.8%, 83.39% and 96.75% respectively. Followed by carbon and aluminum oxide nano filler.
3. The optimum parameter with their levels for the highest modulus of elasticity was obtained at (0/90 fiber orientation, 5% carbon and 0% nano aluminum oxide filler). While the highest tensile strength and impact strength present with using (0/0 fiber orientation and 5% carbon filler).
4. The experimental and expected results are very close, with an error ratio not exceeding 5%.

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