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OPTIMISATION OF WATER ABSORPTION PARAMETERS OF DUAL-FILLER FILLED COMPOSITES USING TAGUCHI AND MODERATED TAGUCHI TECHNIQUES

Oluwaseyi A. Ajibade[1], Johnson O. Agunsoye[2] and Sunday A. Oke[3]

[1] Department of Metallurgical and Materials Engineering, University of Lagos, Lagos, Nigeria. Email: ayosheyi@yahoo.com

[2] Department of Metallurgical and Materials Engineering, University of Lagos, Lagos, Nigeria. Email: jagunsoye@unilag.edu.ng

[3] Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria. Email: sa_oke@yahoo.com

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ABSTRACT

This work contributes two novel modified Taguchi techniques to the optimal parametric setting for minimum water absorption in epoxy composites. Taguchi method, using ASTM standards was applied with factors (initial weight, final weight, length, sample thickness and time of immersion) and four levels in the experimental design. The analysis of variance (ANOVA) evaluates the significance and individual contributions of the parameters. The optimal parametric setting was A1B4C3D4E1 (initial weight, 2.61 g; final weight, 2.69 g; length, 62.73 mm; thickness, 3.88 mm; time, 15.65 hrs). The ANOVA identifies time and length as dominant parameters (98.98 and 1.02 % contributions, respectively). Taguchi-Pareto analysis found only factor-level from the time and length parameters economical to optimality. The Taguchi-ABC analysis revealed the individual weights and contributions of the factor-level irrespective of its initial groupings. The new Taguchi techniques highlighted the importance of time and length of sample in obtaining minimum water absorption of composites.

KEYWORDS: Epoxy composites, wear, Taguchi, ANOVA, regression.

1. INTRODUCTION

Undoubtedly, the idea relating to composite development, usage and maintenance is ancient in nature and traceable to the early humans (Upadhyaya, 2013). At this time, the main materials available to humans were clay, stone, skins and wood, which are called monolithic materials. (Buchmeiser, 2007; Alsuhaimi et al., 2018). As time progressed in the modern age, humans were not satisfied with the available materials as some desirable characteristics of products cannot be satisfied by monolithic materials. Beside the product characteristics, economic requirements and the drive for miniaturization are compelling factors that promoted the gradual transition from monolithic to composites (Tasdemir and Kiziltas, 2009; Sharma et al., 2018; Zhao et al., 2019; Panaitescu et al., 2019; Henning et al., 2019; Echeverria et al., 2019). The miniaturization movement objectively drove progress in composite development from macro-composite fabrication to micro-composite development. Nonetheless, progress in material development through their joining to evolve novel materials with attractive strength, corrosion resistance, impact resistance is still on.

In the past few decades when modern composite development evolved, rigorous theoretical development was experienced with full focus on metallic based composites. Soon after, development of theories shifted to resin-based composites. In recent years, composite materials have gained tremendous popularity by reason of their enormous utilization in diverse applications (for instance medical, automotive, building materials, construction materials). In the vibrant research arena of composite development, intensive scholarship has led to the development of several representations for the prediction of important parameters of tensile strength (Prakash et al, 2015), impact, etc. The literature has recently contributed significantly to an increasingly extension of the frontier of knowledge on bio-degradable polymeric composites, such as polymeric composites fortified through plant-rooted cellulose based particulates. The inclusion of these fortifiers could lessen the harmful impacts of currently employed synthetic particulate fortifiers on the environment as well as bring low, the cost of manufacturing fabricated outputs. From the list of diverse nature-rooted cellulose-based particulates, particulates that are nowadays given attention as fortifiers for polymeric composites include the palm-kernel shell, periwinkle shell, coconut shell, orange peel and the egg shell. There are also other cellulose-based particulates, for instance, groundnut shell, banana shell, rice husk as well as wood dust that are as well employed as fortifying media for the polymeric matrix resin.

The chief objective of this investigation is to propose and test two novel modified Taguchi techniques (Taguchi-Pareto and Taguchi-ABC) that establish the optimal parametric setting which produce minimum water absorption in dual-filler epoxy composites. Taguchi method was used for the design of experiments using an L_{16} orthogonal array and according to ASTM standards for water experiments. The dual blends of the following were used in the water experiment: particulate orange peels, periwinkle shells, coconut shells, palm-kernel shells and egg shells as fortifying media for the epoxy matrix resin. In the following paragraphs, the literature relating to the incentive for this study as well as the key contribution of this research is cautiously reflected on. Zhao et al. (2015) observe that the hydrophilic aspect of water enlargeable rubber could tear off without difficulty from the rubber network because the water absorption resin is not evenly distributed in the hydrophobic rubber with few boundaries between them. Dan-Asabe et al. (2017) study the water absorption of polyrinry chloride composites by reinforcing with a hybrid of doum palm leaves and kankara clay particles using design of experiments Results show that the water absorption suited the cubic model.

Nayak et al. (2016) include nano TiO_2 filler on water sorption of glass fiber fortified polymer composites. It was inferred that the presence of 0.1wt% TiO_2 minimised the water diffusion quotient by 9% in all the nano TiO_2 modified composites. Mrad et al. (2018) estimate the water absorption properties of wood-plastic composites prepared by means of industrial wood waste. It was asserted that the water absorption and swelling changed by fiber type and improved proportionally with fiber size. Chen et al. (2017) use freezing-thawing, PEG dehydration and annealing methods to fabricate PVC-HA/PAA composites. It was discovered that HA and PVA have the highest influence on water content. PVA of 16%, HA of 2%, PAA of 4% was found to possess the best set of properties. Rocha et al. (2017) use a glass/epoxy system to study the degradation process caused by water intake in wind turbine blades. The work posits that matrix degradation is followed by high differential swelling stress and rupturing of the fiber/ matrix interface in composites. Md lalose et al. (2017) present the synthesis, characterization, and application of a poly (para-phenylenediamine) (poly-PPD) organoclay-based composite for removal of cr (VI) complexes from waste water. The composite demonstrated high capacity for batch application to real industrial waste water containing high amount of cr (VI) ions and competing anions and sulfates. Martins et al. (2017) present the optimisation of wood plastic composites typified using measurements of water content angle and water absorption capacity. They conclude that the wettability and swelling ability could be determined.

Surface changes with chemical were performed on woven bamboo mate by means of benzoyl chloride, pre-impregnation, benzyl chloride and maleic anhydride (Kushwaha and Kumar, 2011). The water absorption of 16% was observed following the benzylation process of bamboo to yield bamboo epoxy fortified composite while the alternative that was not treated responded to water absorption by 41%. Velusamy et al. (2019) study the water absorption characteristics of Calotropis Gigantea fiber fortified epoxy composite and declare an elevated rate of water absorption for composites fortified by means of 0.3 volumetric measure of 3 cm Calotropis Gigantea fibers. Bian et al. (2012) examine the water absorption characteristics regarding the casting of epoxy resin as well as glass fiber. Results revealed minimum water absorption for the composite samples weighed against casting of resin. Karaduman and Onal (2010) study depleted-cost polymer composite comprising of waste from carpet of jute yarns using both epoxy and polyester matrices for their water absorption features. Composites obeyed the Fickian diffusion characteristics with diffusion parameters grew growth in fiber composition. Abd–El–Baky and Attia (2018) examine the water absorption properties of jute combined with glass and carbon as reinforcements in epoxy based composite. It was declared that the uptake of water for the jute–fortified composite together with its hybrids by means of glass with or without carbon obeys Fickian–similar characteristics. Grogan et al. (2018) study the impact of microstructure as well as hydrostatic pressure on the absorption of polymer composites by water since they are to be used as structures in devices for tidal energy development. It was disclosed that defects developed changed the complete uptake of water during the saturation state.

In a study by Low and Abu–bakar (2014), hollow epoxy particulates were created for water absorption experiments. It was declared that the coefficient of diffusion for the polyester composite grew by means of growth of the loading on the hollow epoxy composite. Rajeshkumar et al. (2017) examine the characteristics of composites when immersed in water subjected to various environmental situations. Composites having 300 mm particulate were reported to exhibit the least water absorption behaviour irrespective of the environmental situation. Swain and Biswas (2017) examine the influence of including ceramic filler on the water absorption characteristics of jute fortified epoxy composites when treated and not treated with alkali as well as benzoyle chloride. The utmost resistance of the composite to water was noted to be associated with benzoyl chloride treatment. Gupta and Deep (2018) analyse the influence of water absorption considering the mechanical characteristics of a polymer composite with the reinforcement recognized as the combination of sisal and glass. It was concluded that the water antagonistic features of sisal composite improved as the glass fibre

was added. Alvarez and Vazquez (2007) examine the water absorption of vinylester as well as epoxy matrices with their composites by means of mat glass fiber. It was noticed that a growth in water absorption accompanied by the cycle was experienced. As two instances of composites were formulated, the results for the epoxy composites revealed higher water absorption than the vinylester. Zhou and Lucas (1996) provide research information on the influence of water–propelled physical as well as chemical characteristic adjustment of laminate made of graphite and epoxy. It was noted that the retention of water within the composite follows the following descriptions: (i) water was trapped within defects; (ii) the interface of water was related to the weak hydrogen interface inside the resin; and (iii) water had links with the hydrophilic polymer chains.

From the extensive literature review, it was noted that investigations concerning the novel ways to establish the optimal parametric setting which produce minimum water absorption in dual-filler epoxy composites are missing (Ajibade et al., 2017a,b,c; Grogan et al., 2018). Consequently, an effort is invested in the current investigation to bridge this gap. In this paper, the Taguchi scheme and Pareto analysis were amalgamated on one side, while Taguchi scheme and ABC analysis were joined on the other side. These analytical tools are discussed and applied in the current research work. This paper adds to knowledge on polymeric composite by establishing the idea of novel optimisation methods for prioritization of water absorption process factors (Yuan et al., 2017; Mahmoudet al., 2017; Liu et al., 2017). This paper makes a contribution by creating a rich understanding of the manner in which Taguchi scheme could be applied to track prioritization bearing in mind the complex decisions involved in picking the most advantageous set of parameters in a polymeric composite development endeavour.

This paper is organised along the following paths. The first part motivates the need for the research and specifies the research objectives. It also discusses the literature, revealing the important gaps, and clearly demonstrating how the current contribution has bridged the gaps. The second segment of the paper is the methodological aspect that reveals the groundwork of the representation by stating the core fundamentals of the Taguchi-Pareto and Taguchi ABC schemes. The third section deals with the data collection analysis, and discussion of results. Finally, the conclusion is given.

2. METHODOLOGY

2.1. Experimental

Epoxy resin was combined with amine hardener in the ratio 10:4 until a homogenous whole is formed. The epoxy matrix was combined with dual mixtures of reinforcement particles using a

fabricated electric powered mixer (Fig. 1). The new material was poured into a prepared impact sample mould. The composites were allowed to cure at room temperature (RT) for a period of 24 hours. After removal, the physical dimensions of the composites were measured in terms of weight, length and thickness before the commencement of the water absorption experiment. Each composite was carefully labelled and immersed with a string for ease of removal in a graduated measuring cylinder (Fig. 3). The water absorption experiment was set up in accordance with ASTM D5229 for moisture absorption of polymer composite materials. Measurements of weight, length and thickness were carried out at regular periodic intervals to evaluate the effect of water uptake at these intervals on the physical dimensions of the composites.



Fig. 1. Electric powered mechanical mixer.



Fig. 2. Fabricated impact samples.



Fig. 3. Water absorption experimental set up

2.2. Taguchi method

The emergence of the Taguchi method as a choice tool for carrying out process and system optimisation stems from the limitation of other optimisation methods which use one factor at a time. This drawback was overcome with the optimisation of two or more factors at a time in a single experiment by the Taguchi method. The objective function of the Taguchi method uses the signal-to-noise quotient (S/N) method, which is statistical measure of the logarithmic expression of the expected target of the experiment. In the Taguchi method (TM), the signal factors shows the average performance of the process, while factors that are cumbersome and

difficult to control are termed as noise. Three designs have been identified in the Taguchi methodology. They are the system design which makes it possible to select the appropriate working levels that describes the conditions of the parameters in the experiment. Next, is the parametric design which helps to establish the parametric ranks, which lead to the most advantageous accomplishment of the system/process while the tolerance design is used to reduce the tolerance of factors that make important contributions to the system (Zareh et al., 2013). The parametric design is used in the current work to obtain the most advantageous factors, which gives the minimum water absorption in the dual-filler composites. Taguchi method makes use of three quality characteristics, namely, the "lesser-the-superior", "bigger-the-superior" and the "nominal-the-most excellent" quality characteristics. For minimum water absorption in the composites, the SB is chosen as the preferred quality characteristic in this investigation. The objective function is defined according to the SB quality characteristic in Equation (1).

$$S/N = -10 * \log 10\left(1/n * \sum y_i^{\,2}\right) \quad (1)$$

Where: y_i is the measured value of the smaller-the-better quality characteristic, n is the number of tests in every trial condition and S/N is the signal-to-noise ratio of the system. Five parameters and their descriptions in the experiment designated as factors and levels, namely, initial weight, final weight, length, thickness and time have been considered in this investigation as described in Table 1. The experimental design is carried out using an L16 orthogonal array selected with the use of Minitab 16 statistical software package.

Table 1. Parameters and their levels.

S/No	Parameters	Levels			
		1	2	3	4
1	A: Initial weight (g)	2.61	2.74	2.95	3.15
2	B: Final weight (g)	2.61	2.74	3.17	3.19
3	C: Length (mm)	62.73	62.75	63.28	63.4
4	D: Thickness (mm)	3.88	4	4.4	4.51
5	E: Time (s)	15.65	24.19	30.36	35.48

2.3. Taguchi-Pareto Analysis

The Pareto 80-20 rule states that80 % of end results are obtained from 20 % reasons or causes. It has been applied in various endeavours of life such as law, economics, statistics, medical practice, but its application in solving engineering problems is scarce in the literature. Adapting this rule to the Taguchi method, 20 % of the factor levels were found to represent 80 % of the

total cumulative percent which indicates that they are economical to optimality over other factor levels. In other words, the other factor levels are not economical to optimality and are not considered for further investigation. Equation (2) describes the modified objective function of the optimisation as follows:

$$S/N = -10*\log10\left(1/n * \sum P_{80/20} y_i^{\,2}\right) \quad 2$$

where y_i is the measured value of the lower-the-better quality characteristic, n is the number of tests in every trial condition and S/N is the signal-to-noise ratio of the system

2.4. Taguchi-ABC Analysis

The ABC classification has been used to rank data or observations based on their cumulative percentage of the sum total. Thus, the observations which have a cumulative percentage of 66.6 % to the total sum are designated as A. The observations which makes up the next 23.3 % are termed B, while the last set of observations which adds up 10.1 % are regarded as C. Applying this rule to the Taguchi method, the factor levels are ranked A,B and C. These new factor levels classified as A, B and C are grouped as factors for Taguchi optimisation irrespective initial factor groupings. Thus, the optimal results are not in terms of units but in terms of individual contributions to the quality characteristic. The objective function is modified as follows in Equation (3)

$$S/N = -10*\log10\left(1/n * ABC \sum y_i^{\,2}\right) \quad 3$$

where y_i is the measured value of the lower-the-better quality characteristic, ABC is the application of the ABC classification to the factor levels, n is the number of tests in every trial condition and S/N is the signal-to-noise ratio of the system.

2.5. Analysis of variance (ANOVA)

The analysis of variance (ANOVA) is a statistical technique that is used to measure the individual contributions of the controllable factors on the quality characteristic. The Taguchi method provides the details for selecting the optimal setting of parameters for the system and important information useful for further evaluation. With the use of the ANOVA, the overall variation from the mean S/N ratio is separated into individual parameters with corresponding errors. This is made possible as a result of the statistical independence of the Taguchi method. The total sum of squares (TSS) is first determined as follows (Zareh et al., 2013):

$$TSS = \sum_{k=1}^{n} (S/N)_i^2 - \frac{1}{n}\left[\sum_{k=1}^{n} (S/N)_k\right]^2 \quad 4$$

n is defined as the number of experimental trials in the orthogonal array and (S/N)k is the S/N ratio of the kth experiment. The sum of squares due to the deviation from the total mean S/N ratio for each of the parameter is defined mathematically as follows (Zareh et al., 2013):

$$SSA = \sum_{s=1}^{m} \frac{[(S/N)_s]^2}{p} - \frac{1}{n}\left[\sum_{j=1}^{n}(S/N)_j\right]^2 \quad 5$$

where m is the number of parametric levels, s is defined as the level number of the parameter A, (S/N)i is the sum of the S/N ratios involving this parameter A and level s, and p is the repetition of each level of parameter A. The contribution of the Ath parameter can be obtained in terms of percentage as follows (Table 2) (Zareh et al., 2013):

$$PCA\ (\%) = \frac{SSA}{TSS} \times 100 \quad 6$$

Table 2. ANOVA table for minimum water absorption of dual-filler epoxy composite.

Dual-filler epoxy composite				
Factor	**Degree of freedom**	**Sum of square**	**Mean square**	**Percentage contribution (%)**
*A	3	3.6×10^{-6}	1.18×10^{-6}	0.00018
*B	3	1.09×10^{-4}	3.6×10^{-5}	0.0057
C	3	0.0196	0.0065	1.0145
*D	3	6.47×10^{-5}	2.2×10^{-6}	0.0033
E	3	1.9149	0.6383	98.98
Error	0			
Total	15	1.9152	0.6384	100
(Error)	6	0.01963	0.0065	0

*Factors used for pooling

The ANOVA results for the minimum water absorption of dual filler epoxy composites have been presented in Table 2. The time parameter was found to have the highest and most dominant contribution to the water absorption of the epoxy composites with a percentage contribution of 98.98 %, followed distantly by the length parameter with a percentage contribution of 1.0145 %. The percentage contributions of the initial and final weights as well as the thickness parameters were to be 0.00018, 0.0057 and 0.0033 %, respectively, which are negligible to the water absorption of the composites. These were pooled together to form the error estimate. The high percentage contribution of time as indicated from the ANOVA results shows that the amount of time a sample spends immersed in water has the highest significance on its moisture absorption.

3. RESULTS AND DISCUSSION

3.1. Taguchi method (TM)

The S/N ratio (signal-to-noise) analysis is a distinct feature of the Taguchi optimisation method that affords a statistical measure of the ratio between the factors which control the average performance of the system and the factors which are cumbersome or complicated to control. The contribution of the control factors on the S/N ratio can be broken down as a result of the statistical independence of the Taguchi experimental design. Thus, the S/N ratio response table of each factor is described by Tables 3 and 4. Regardless of the quality characteristic used in the optimisation process, the level with a larger S/N ratio indicates a lower variation between the signal and noise factors and is picked as the optimal level of the parameter. The main effect plots showing the variability of the S/N ratios as they affect each parameter as shown in Fig. 4.

Table 3. Taguchi L_{16} Experimental design for water absorption of dual-filler epoxy composites.

S/N	Initial weight (g)	Final weight (g)	Length (m)	Thickness (mm)	Time (s)	Water absorption (%)	S/N Ratio
1	2.95	3.17	62.75	4.51	15.65	9.19	-30.2341
2	2.95	3.19	62.75	4.4	24.19	9.89	-30.6331
3	2.95	2.69	63.28	4	30.36	8.55	-30.8714
4	2.95	2.81	63.4	3.88	35.48	2.17	-31.2304
5	3.15	3.17	62.75	4	35.48	1.5	-31.2215
6	3.15	3.19	62.75	3.88	30.36	2.2	-30.8764
7	3.15	2.69	63.4	4.51	24.19	0.66	-30.6467
8	3.15	2.81	63.28	4.4	15.65	0.77	-30.2296
9	2.61	3.17	63.28	3.88	24.19	1.44	-30.5615
10	2.61	3.19	63.4	4	15.65	3.35	-30.3115
11	2.61	2.69	62.75	4.4	35.48	4.55	-31.1643
12	2.61	2.81	62.75	4.51	30.36	3.43	-30.9352
13	2.74	3.17	63.4	4.4	30.36	2.82	-30.9501
14	2.74	3.19	63.28	4.51	35.48	1.98	-31.1660
15	2.74	2.69	62.75	3.88	15.65	2.46	-30.2929
16	2.74	2.81	62.75	4	24.19	2.11	-30.5634

Table 4. Taguchi S/N ratios response table ratios for water absorption of dual-filler composite

Level	A	B	C	D	E
1	*-30.7422	-30.7418	-30.7096	-30.7455	*-30.2670
2	-30.7435	-30.7468	-30.7707	-30.7443	-30.6012
3	-30.7431	-30.7438	*-30.7071	-30.7419	-30.9083
4	-30.7431	*-30.7397	-30.7847	*-30.7403	-31.1955

*optimal level

Zareh *et al*. (2013) noted that irrespective of the quality characteristic used, a higher S/N ratio indicates the desired quality characteristic is being met. From the Taguchi S/N response table in Table 3, the optimal setting of parameters for the minimal water absorption in the dual filler composites is $A_1B_4C_3D_4E_1$, which can be read as an initial weight of 2.95 g, final weight of 3.17 g, length of 63.4 mm, thickness of 3.88 mm and a time of 15.65 hours.

3.2. Main effect plots

The main effect plot shows the displays the contributive effect of each parameter to the water absorption quality characteristic represented vertically as the mean S/N ratios. For each of the parameters, the level which gives the highest S/N ratio is the optimum condition.

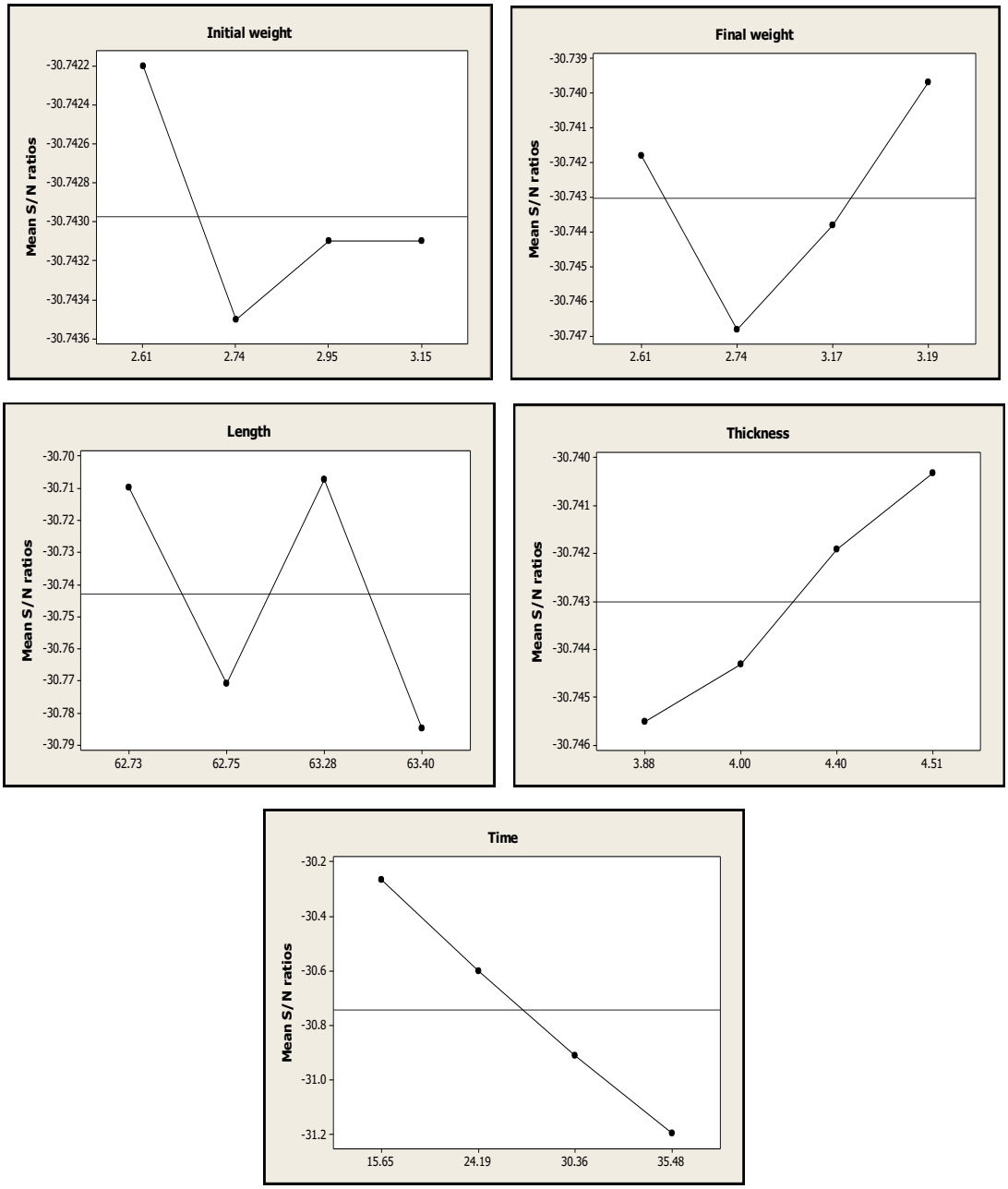


Fig. 4. Main effect plots for Taguchi optimization.

3.3. Taguchi-Pareto Analysis (TPA)

The combination of the Taguchi method and 80-20 Pareto rule reduces the number of the controllable factor levels used in the TM from 20 to 7 (Table 5). The remaining factor levels indicate the factor levels that are economical to optimality while the others are considered not economical to optimality. The seven factor levels are grouped into an $L_{16}2^2$ orthogonal array (Table 6). A revised S/N ratios response table was obtained for the TPA.

Table 5. Taguchi-Pareto $L_{16}2^2$ Experimental design for water absorption of dual-filler composites

S/No	Parameters	Levels			
		1	2	3	4
1	Length (m)	62.75	63.28	62.73	63.4
2	Time (s)		24.19	30.36	35.48

Table 6. Taguchi-Pareto $L_{16}2^2$ Experimental design for water absorption of dual-filler composites

S/N	Length, (mm)	Time, (hrs)	S/N Ratio
1	62.73		-32.9392
2	62.73	24.19	-33.5413
3	62.73	30.36	-33.8532
4	62.73	35.78	-34.1625
5	63.28		-33.0150
6	63.28	24.19	-33.6074
7	63.28	30.36	-33.9147
8	63.28	35.78	-34.2198
9	62.73	-	-32.9392
10	62.73	24.19	-33.5413
11	62.73	30.36	-33.8532
12	62.73	35.78	-34.1625
13	63.4	-	-33.0315
14	63.4	24.19	-33.6217
15	63.4	30.36	-33.9281
16	63.4	35.78	-34.2323

A revised S/N ratios response table was obtained for the TPA as described in Table 7 which produces an optimal parametric setting of A_3B_1, which could be interpreted as a length of 62.33 mm and a time of 24.19 hours.

Table 7. Revised Taguchi-Pareto S/N ratios response table for water absorption of dual-filler composites

Level	A	B
1	-33.6241	-32.9812
2	-33.6892	-33.5779
3	-33.624	-33.8873
4	-33.7034	-34.1942

The results of the Taguchi-Pareto analysis strongly correlate with the findings of the ANOVA that the contributions of the time and length parameters were the most significant to the minimum water absorption of the epoxy composites.

3.4. Taguchi-ABC Analysis

The ABC classification was used to group the factor levels into factors A, B and C. The Taguchi method with the ABC classification was combined to produce new optimal results irrespective of their initial factor groupings using a special mix-design L24 orthogonal array for the design of the experiments as described by Table 8. As a result, the new optimal results are not based on their initial groupings but on the individual weights of the factor levels. This produces an optimal parameter setting based on the individual contributions of the factor levels regardless of their initial factor groupings. A revised Taguchi-ABC S/N response table is described in Table 9.

The optimal parameter setting for the minimum water absorption of the epoxy dual-filler composites using the Taguchi-*ABC* analysis is $A_1B_1C_8$. This can be interpreted as 62.73, 15.65 and 2.95. This means that the combination of these factor levels can produce minimum water absorption in the epoxy composites as a result of their individual contributions.

Table 8. Taguchi-ABC L24 Experimental design for water absorption of dual-filler composites

S/N	A	B	C	S/N Ratio
1	63.4	35.78	4.51	-32.4738
2	63.4	30.36	4.4	-32.1694
3	63.4	24.19	4	-31.8627
4	63.4	15.65	3.8	-31.5300
5	63.4	35.78	3.19	-32.4714
6	63.4	30.36	3.17	-32.1672
7	63.28	24.19	3.15	-31.8465
8	63.28	15.65	2.95	-31.5119
9	63.28	35.78	2.81	-32.4589
10	63.28	30.36	2.74	-32.1538
11	63.28	24.19	2.69	-31.8465
12	63.28	15.65	2.61	-31.5119
13	62.75	35.78	4.51	-32.4036
14	62.75	30.36	4.4	-32.0945
15	62.75	24.19	4	-31.7828
16	62.75	15.65	3.8	-31.4431
17	62.75	35.78	3.19	-32.4036
18	62.75	30.36	3.17	-32.0945
19	62.73	24.19	3.15	-31.7804
20	62.73	15.65	2.95	-31.4405
21	62.73	35.78	2.81	-32.4015
22	62.73	30.36	2.74	-32.0923
23	62.73	24.19	2.69	-31.7804
24	62.73	15.65	2.61	-31.4405

Table 9. Revised Taguchi-ABC S/N ratios response table for water absorption of dual-filler composites

S/N	A	B	C
1	-32.1124	-32.4355	-32.4387
2	-31.8882	-32.1286	-32.1319
3	-32.037	-31.8165	-31.8227
4	-31.8226	-31.4797	-31.4865
			-32.4375
			-32.1309
			-31.8134
			-31.4762
			-32.4302
			-32.123
			-31.8134
			-31.4762

4. CONCLUSION

In this work, the optimisation of water absorption of dual-filler epoxy composites was pursued using the Taguchi method, Taguchi-Pareto and Taguchi-*ABC* Analyses, while the ANOVA was used to measure the individual contributions of the parameters to the Taguchi quality characteristic. Different optimal setting of parameters was obtained using the three different optimisation approaches. This investigation showed for the first time the factor levels and optimal parametric setting of the novel Taguchi-Pareto analysis correlates strongly with findings from the ANOVA which identified the significant contributions of time and length. Minimum water absorption of the epoxy composites can be obtained using the conventional Taguchi method, while specific interpretation and understanding of the results was obtained with the ANOVA. Further, the moderated Taguchi techniques helped to achieve optimal results from the perspective of factor levels that are economical to optimality and optimal results regardless of primary groupings but individual weights of the factor levels.

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