Engineering and Applied Science Research April – June 2019;46(2):130-141 Research Article

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, KhonKaen University, Thailand

Poisson distribution: How tensile properties of particulate polymer composites are enhanced in a Poisson-motivated Taguchi method

Oluwaseyi Ayodele Ajibade[1)], Johnson Olumuyiwa Agunsoye[1)] and Sunday Ayoola Oke*[2)]

[1)]Department of Metallurgical and Materials Engineering, Faculty of Engineering, University of Lagos, Lagos, Nigeria
[2)]Department of Mechanical Engineering, Faculty of Engineering, University of Lagos, Lagos, Nigeria

Received 13 January 2019
Revised 21 March 2019
Accepted 3 April 2019

Abstract

This paper examines how the Poisson distribution is being used to model the tensile properties of selected particulate reinforced polymer composites. While past studies have shown that the Taguchi method provides robust optimized composites for cost and maximum wastes reinforcement utilization, the link between optimisation and particulates with an indefinitely large number of trials to optimize has not been overtly revealed. This paper proposes a Poisson distribution to obtain the probability of each tensile property occurring independently at a fixed rate within the Taguchi scheme to address this issue. These were used as factor-levels in a Poisson-motivated Taguchi optimisation process and tested on five different composite blends of a dual reinforcement and epoxy resin matrix. The composites were treated under various curing regimes (80, 100, 120 °C). Based on the tensile properties of extension, load, strain and stress, the Taguchi method yielded an optimal parametric setting of $A_4B_1C_4D_4$ for the orange peel/coconut, palm kernel/coconut and periwinkle egg shell composites, while optimal parametric settings of $A_4B_1C_4D_1$ and $A_4B_1C_4D_2$ were obtained for the orange peel/periwinkle and palm kernel/egg shell composites, respectively. The Poisson motivated-Taguchi optimisation yielded optimal parametric settings of $A_{1\text{-}2},B_{1\text{-}2},C_1D_4$, $A_{1\text{-}2},B_{1\text{-}2},C_1,D_{1,4}$, $A_{1\text{-}2},B_{1\text{-}2},C_1,D_{1,4}$, $A_{1\text{-}2},B_{1\text{-}2},C_1,D_{1,4}$ and $A_{1\text{-}2},B_{1\text{-}2},C_1,D_{1,4}$, respectively, for orange peel/coconut, palm kernel/coconut, periwinkle/egg, orange peel/periwinkle and palm kernel/egg shell blends. Hence, there is a possibility of obtaining more than one factor level as an optimum condition. Overall, by analyzing the role of the Poisson distribution to enhance the tensile properties of selected polymer composites, our model departs from existing views of Taguchi optimisation methods and sheds novel light on optimisation enhancement.

Keywords: Composite blends, Tensile properties, Curing regimes, Taguchi optimization process, Poisson distribution

1. Introduction

Scholars have long examined the tensile properties of composites as one of the fundamental mechanical tests used to select materials for practical use [1-8]. To enhance tensile strength [9], researchers [5] used Taguchi method in various disciplines (concrete [10-14], tissue engineering [15], biomaterials [16], machining [17-18], hydrothermal processing [19-20], dysprosium sorption [21], nanoparticle synthesis [22], super absorbent polymers [23], composite films [24], nanoparticles [25], adsorption [26], and sonoelectrochemical synthesis [27], among others. While the principles of tensile strength are comparatively well understood [28-30], researchers have given comparatively very little attention to the optimisation aspect of this mechanical property. The tensile approach offers much insight concerning the characteristics of many important engineering structures such as composite polymers under tensile forces. The point at which a crane's composite polymer rope (for lifting loads) may fail, for example, is of significant engineering importance. Thus, tensile property research is of theoretical and practical utility in numerous mechanical engineering applications where composite polymers are used. The report of Prakash et al. [5] is one of the very few instances of optimization attempts for composites. More recently, scholars have begun to rigorously expand Taguchi's methodical framework and examine methodology beyond the traditional factor-level considerations, development of orthogonal arrays and finally the evolution of optimal settings for the process parameters [31-33]. However, the use of Taguchi methods involving particulate reinforcements requires an indefinitely large number of trials and optimisation is sought. This is both in terms of cost and the maximum quantities of materials used for reinforcement, but this has not received attention in the literature. The particular mechanism to be optimised remains unidentified and an insight of how it impacts the tensile properties of particulate polymer composites is still unknown.

*Corresponding author.
Email address: sa_oke@yahoo.com
doi: 10.14456/easr.2019.16

Table 1 Formulations of matrix and reinforcements for composites

S/No	Formulation	Reinforcement particles (wt)%							Matrix (wt)%
1	Orange peel/coconut shell blend	OPp	25	20	15	10	5	0	Epoxy resin matrix
		CSp	0	5	10	15	20	25	
2	Palm kernel/coconut shell blend	PKSp	25	20	15	10	5	0	
		CSp	0	5	10	15	20	25	
3	Periwinkle/ egg shell blend	PSp	25	20	15	10	5	0	
		ESp	0	5	10	15	20	25	
4	Orange peel/ periwinkleshell blend	OPp	20	15	10	5	-	-	
		PSp	5	10	15	20	-	-	
5	Palm kernel/egg shell blend	PKSp	20	15	10	5	-	-	
		ESp	5	10	15	20	-	-	

In tackling this problem, the current work examines the manner in which the Poisson distribution explains the tensile properties of selected particulate reinforced polymer composites. Our theory is developed based on previous research [5] using the Taguchi method as a promising approach to optimizing composite properties. Pourjavadi et al. [23] suggested the use of a Taguchi schemeto obtain the best values for the variables influencing a system. Other authors [24-27] readily acknowledge that the Taguchi scheme is a strong tool for design of experiments. Furthermore, some evidence [21-22] indicates that the technique offers a straightforward, efficient and systematic method to obtain the best design for optimal cost as well as quality. Pourjavadi et al. [23] further notes that parametric configuration is a principal step in the Taguchi method, aimed to attain superior quality at minimal cost. The Taguchi scheme has been used in a straightforward manner by a large number of scholars [23]. Optimisation experiments can be done concurrently, which is an added benefit of the Taguchi scheme [23].

The focus of this investigation is on the optimization of the tensile strengths of five different polymer composite blends prepared from combinations of an epoxy matrix reinforced with pairs of particulate agro-waste reinforcements. Post-curing of composites at elevated temperatures to increase the cross-linking of polymer chains has been reported. This improves the mechanical and thermal properties of composites [18, 34]. Various tensile strengths were obtained for the developed composite samples treated under separate curing regimes. This gives a wide range of results for each composite blend. The development and use of a Poisson-motivated Taguchi optimization method is done to determine the optimal parametric settings of processes involving composites. These include strength [5], forming [35], wear [36], and tribological behavior [37]. The strength of the Taguchi method lies in its ability to find an exact combination of parametric values that will give a desired target quality [35, 38-41]. This is done by considering all the factors involved in the process and their descriptions simultaneously in a single experiment.

2. Methodology

2.1 Composite fabrication

Epoxy resin (*Diglycidyl ether Bisphenol A)* of an LY 556 grade was combined with an amine hardener in a ratio 10:4 until homogeneity was achieved. The epoxy matrix was combined with various weight fractions of selected agro-waste reinforcement particles as described in Table 1.

The resulting mixture was poured into a prepared mould (Figure 1) with six dog-bone cavities lubricated with engine oil for ease of removal. Four sets of composites were fabricated using this procedure. They were all allowed to cure at room temperature (RT) for 24 hours, before removal from their moulds. The remaining three sets of prepared composites were post-cured at 80, 100 and 120 ^{o}C for 6, 4 and 2 hours, respectively.

Figure 1 Wooden tensile mould

The tensile samples were tested using an Instron universal tester at the Engineering Materials Development Institute (EMDI), Akure, Ondo State, Nigeria, in accordance to ASTM D3039 standards for polymer matrix composite samples. The pre-test and post-test samples are shown in Figure 2.

2.2 Taguchi optimisation

Under the various curing regimes, dissimilar ranges of values were obtained in extension, load, strain and stress of the materials for each composite under the various curing regimes. The average values of extension, load, stress and strain of the composite blends were determined and used as the factor levels for Taguchi optimisation according to Table 2.

(a) (b)

Figure 2 (a) Tensile samples before test, and (b) after fracture

Table 2 Factors and levels for Taguchi optimization of tensile strength of polymer composites

S/No	Factors			
	A: Extension (mm)	B: Load (N)	C: Strain	D: Stress (MPa)
	Orange peel/coconut shell composite blend			
1	6.5	506.13	0.08	16.05
2	6.7	562.13	0.1	17.65
3	7.01	598.28	0.11	19.07
4	7.97	686.18	0.12	22.13
	Palm kernel/coconut shell composite blend			
1	6.36	1009.76	0.09	29.47
2	6.56	1134.83	0.095	32.88
3	6.73	1150.84	0.1	34.24
4	6.93	1196.17	0.105	36.63
	Periwinkle/egg shell composite blend			
1	5.14	1165.79	0.0775	35.27
2	5.63	1201.77	0.0825	37.54
3	5.88	1240.87	0.0875	38.72
4	5.89	1391.67	0.095	44.56
	Orange peel/periwinkle shell composite blend			
1	5.63	881.83	0.0925	24.13
2	6.02	892.45	0.095	28.11
3	6.65	949.54	0.1	28.23
4	7.1	1066.55	0.1025	33.44
	Palm kernel/egg shell composite blend			
1	5.525	903.05	0.0675	29.47
2	5.81	1009.76	0.0775	30.4
3	6.19	1181.72	0.083	37.9
4	7.06	1391.67	0.0875	44.56

Table 3 $L_{16}4^4$ Orthogonal array

S/No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

In the composites, “higher-the-better” quality characteristicsto obtain the maximum tensile conditionswere determined as follows:

$$S/N = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right] \quad (1)$$

where S/N is the signal-to-noise ratio, n is the number of variables and y is the value of each variable.

Table 2 describes formulation of 4-factor and 4-level optimisation problems that are solved using an orthogonal array. The choice of an appropriate orthogonal array was not done arbitrarily, but with the aid of the *Minitab* 16 statistical software package. As a result, an $L_{16}4^4$ orthogonal array was used as described in Table 3.

2.3 Poisson motivated-Taguchi optimisation

The Poisson distribution describes the possibility of a given number of events taking place within a specific time or place, if the observations take place at a regular rate and

Table 4 Factors and levels for Poisson motivated-Taguchi optimisation of tensile strength of polymer composites

S/No	Factors			
	Extension (mm)	**Load (N)**	**Strain**	**Stress (MPa)**
	Orange peel/coconut shell composite blend			
1	0.2911	0.0004	1.1105E-9	0.001
2	0.1432	1.48E-7	7.985E-18	1.5501
3	6.60E-03	3.00E-17	9.7865E-30	0.0928
4	3.56E-06	4.2612E-28	1.2065E-43	0.213
	Palm kernel/coconut shell composite blend			
1	0.0981	0.1747	9.8464E-12	3.7139E-9
2	0.407	4.124E-7	5.4063E-26	0.4423
3	5.3194E-5	3.9612E-14	2.3523E-37	0.04
4	6.2012E-8	2.3209E-22	2.2643E-51	0.1631
	Periwinkle/egg shell composite blend			
1	0.109	1.8076E-5	9.4747E-12	6.685E-10
2	0.092	4.009E-11	2.4375E-26	0.001
3	4.838E-6	3.643E-18	7.5448E-38	7.7559E-5
4	1.6057E-9	5.0328E-26	2.0717E-52	0.0008
	Orange peel/periwinkle shell composite blend			
1	0.0544	0.0126	4.795E-12	4.794E-5
2	0.3109	3.3937E-9	5.0843E-26	13.7889
3	4.9494	7.3624E-17	3.478E-37	0.3099
4	1.0305E-7	4.1057E-24	5.6439E-49	0.4713
	Palm kernel/egg shell composite blend			
1	0.1186	0.0579	6.7889E-12	1.8843E-9
2	0.4993	1.7815E-9	1.1133E-26	0.0021
3	1.4316E-5	3.4075E-15	2.7511E-38	0.0001
4	1.6663E-8	1.8664E-21	9.8268E-51	0.3695

areindependent of previous occurrences. The extension, load, stress and strain of each composite blend were recorded as observations. The average of all the observations for each composite blend is taken as the average number of observations of the total possible outcomes. Adapting the Poisson distribution to the tensile property optimisation problem in Equation (2), yields:

$$P(k \text{ observations}) = \frac{e^{-\lambda}.\lambda^k}{k!} \qquad (2)$$

where λ = average number of observations per interval
e = Euler's number, taken as 2.718
k = observation number, 0,1,2,3 etc.
$k!$ = factorial of k

Equation (2) was used to generate a new set of values from the observations (i.e., events). The new events were multiplied by the corresponding value of observations to produce the Poisson motivated observations. The observations were bifurcated at regular intervals to generate new factor levels for the Taguchi optimization, as described in Table 4. The Poisson motivated-Taguchi optimal parametric settings are used to derive new optimal values from the table of factors and levels for the Taguchi optimization, as shown in Table 2.

3. Results and discussion

3.1 Taguchi optimal parametric settings

Various optimal parameter settings were obtained that can be interpreted specifically for groups of composite blends. The main effect plots show the influence of the S/N response as it reacts to changes in the factor levels of a parameter, while the interaction plots are used to understand the relationship between two physical parameters as it is influenced by the S/N response.

3.1.1. Orange peel/coconut shell composite blend

The orange peel/coconut shell composite blend obtained an optimal parameter setting of $A_4B_1C_4D_4$, which corresponds to an extension of 7.97 mm, load of 506.13 N, strain of 0.12 and a stress of 22.13 MPa.

Main effect plots

The optimal setting for the orange peel/coconut shell composite blend is read graphically as shown in Figure 3. The influence of each parameter level on the S/N ratios is shown.

Interaction plots

The interaction plots for the orange peel/coconut shell composite are described in Figure 4. The points on the graph show the relationship between the parameters on the S/N ratio response.

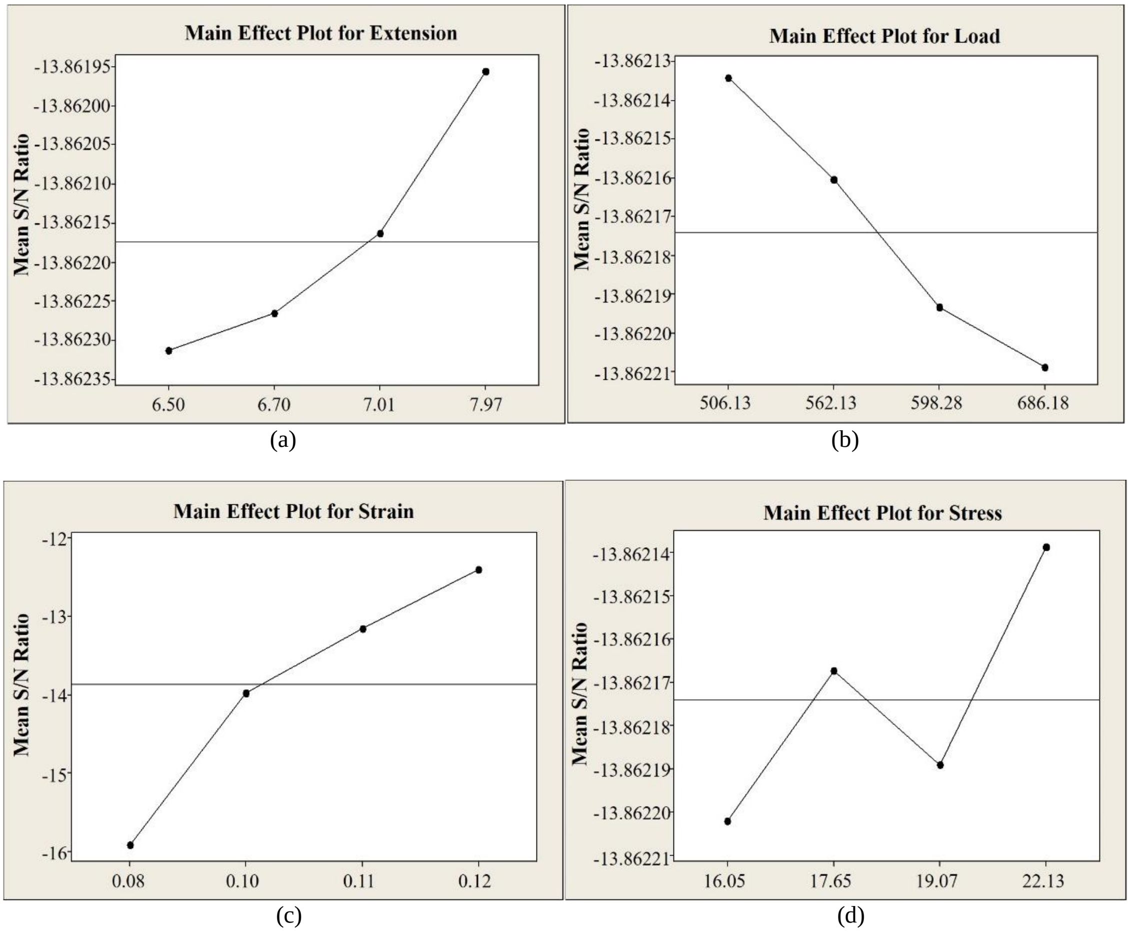

Figure 3 Main effect plots for (a) extension, (b) load, (c) strain, and (d) stress for orange peel/coconut shell blend tensile properties at optimal parameter settings

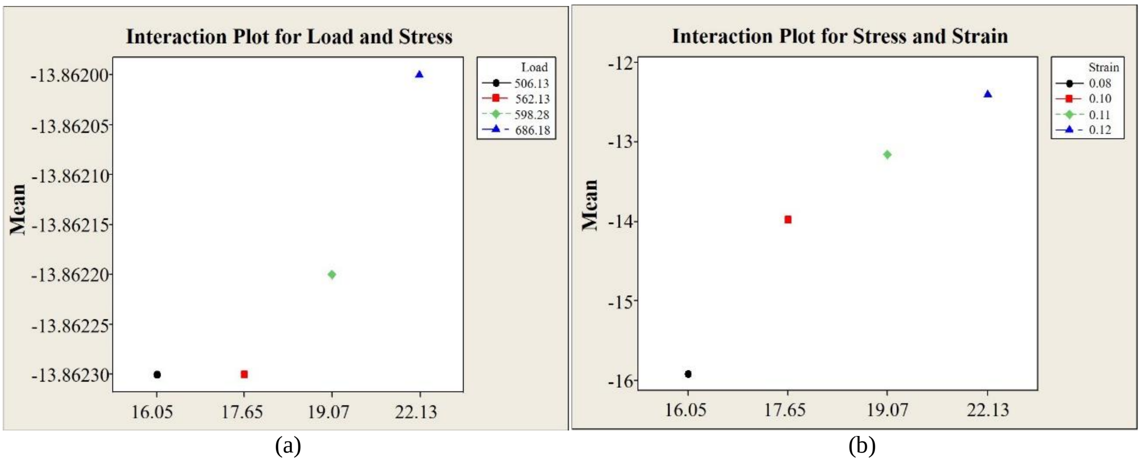

Figure 4 Interaction plots for orange peel/coconut shell composites (a) load and stress (b) stress and strain

3.1.2. Palm kernel/coconut shell composite blend

The palm kernel/coconut composite shell blend has an optimal parametric setting of A_4,B_1,C_4,D_4, which corresponds to an extension of 6.93 mm, load of 1009.76 N, strain of 0.105 and stress of 29.47 MPa. Figure 5 depicts the main effect plots describing the optimal parameter settings for the palm kernel/coconut shell composite blend.

Main effect plots

The optimal settings for the palm kernel/coconut shell composite blend are shown in Figure 5. The effect of each parameter level on the S/N ratios is depicted.

Interaction plots

The interaction plots for the palm kernel/coconut shell composite are shown in Figure 6. The points on the graph represent the relationship between the parameters on the S/N ratio response.

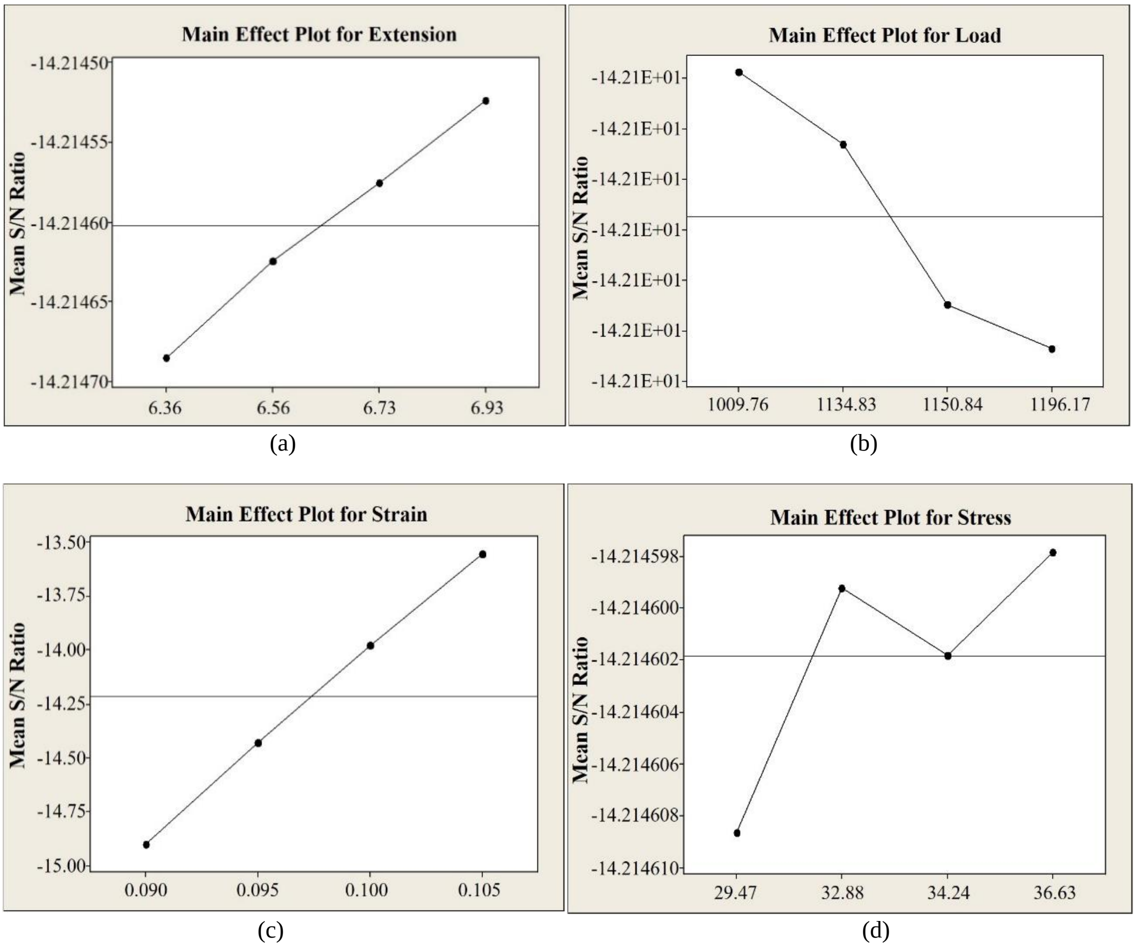

Figure 5 Main effect plots for (a) extension, (b) load, (c) strain, and (d) stress for palm kernel/coconut shell blend tensile properties at optimal parameter settings

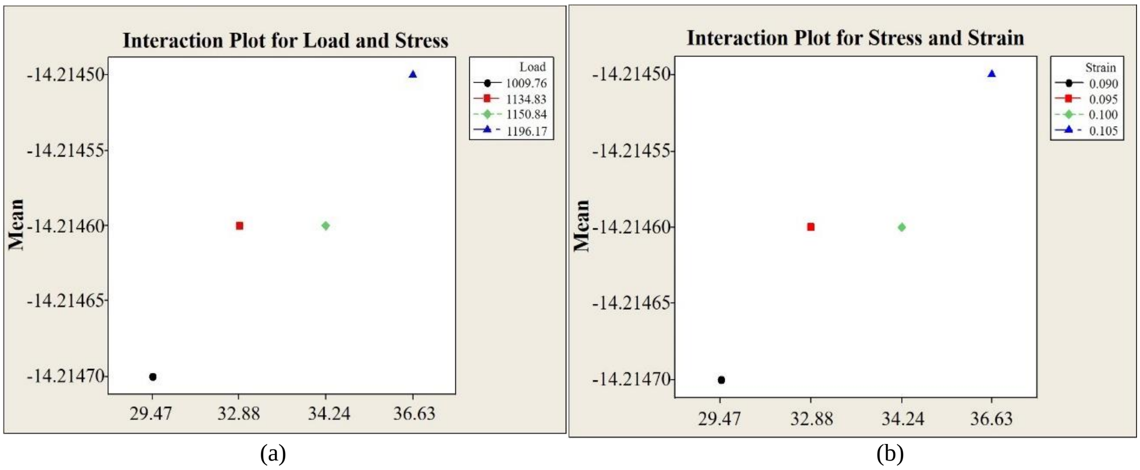

Figure 6 Interaction plots for palm kernel/coconut shell composite (a) load and stress (b) stress and strain

3.1.3. Periwinkle/egg shell composite blend

The periwinkle/egg shell blend has an optimal parametric setting of A_4,B_1,C_4,D_4 which corresponds to an extension of 5.89 mm, load of 1165.79 N, strain of 0.095 and stress of 35.27, MPa.

Main effect plots

The optimal settings for the periwinkle/egg shell composite blend are shown graphically in Figure 7. The influence of each parameter level on the S/N ratios is shown.

Interaction plots

The interaction plots for the periwinkle/egg shell composite are shown in Figure 8. The relationship between the parameters on the S/N ratio response is described by the graph.

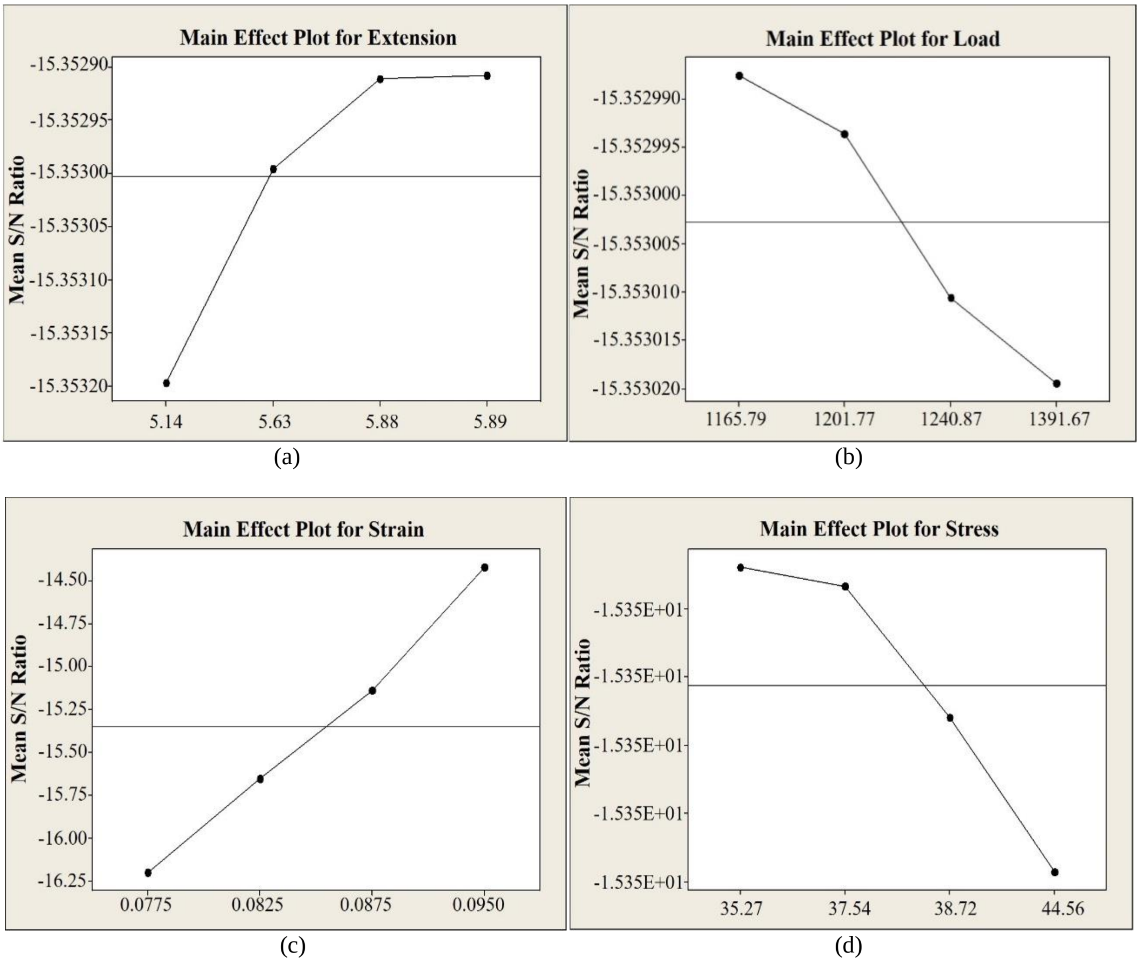

Figure 7 Main effect plots for (a) extension, (b) load, (c) strain, and (d) stress for periwinkle/egg shell blend tensile properties at optimal parameter settings

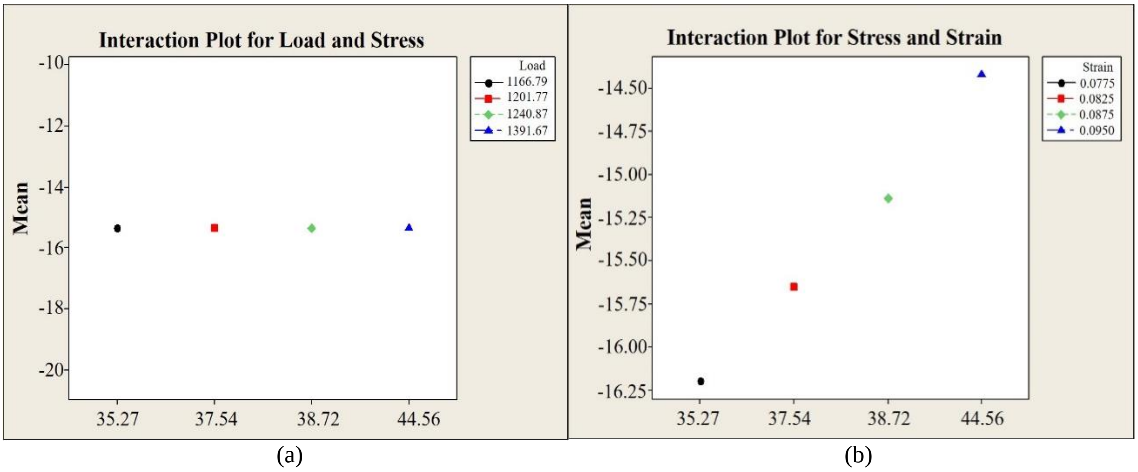

Figure 8 Interaction plots for periwinkle/egg shell composite (a) load and stress (b) stress and strain

3.1.4. Orange peel/periwinkle shell composite blend

The orange peel/periwinkle shell blend has an optimal parameter setting of A_4,B_1,C_4,D_1 which corresponds to an extension of 7.1 mm, load of 881.83 N, strain of 0.1055 and stress of 33.44 MPa.

Main effect plots

The optimal settings of the periwinkle/egg shell composite blend are graphically shown in Figure 9. The effect of each parameter level on the S/N ratios is depicted.

Interaction plots

The interaction plots for the orange peel/periwinkle shell composite are shown in Figure 10. The figure depicts the interaction between the parameters on the S/N ratio response.

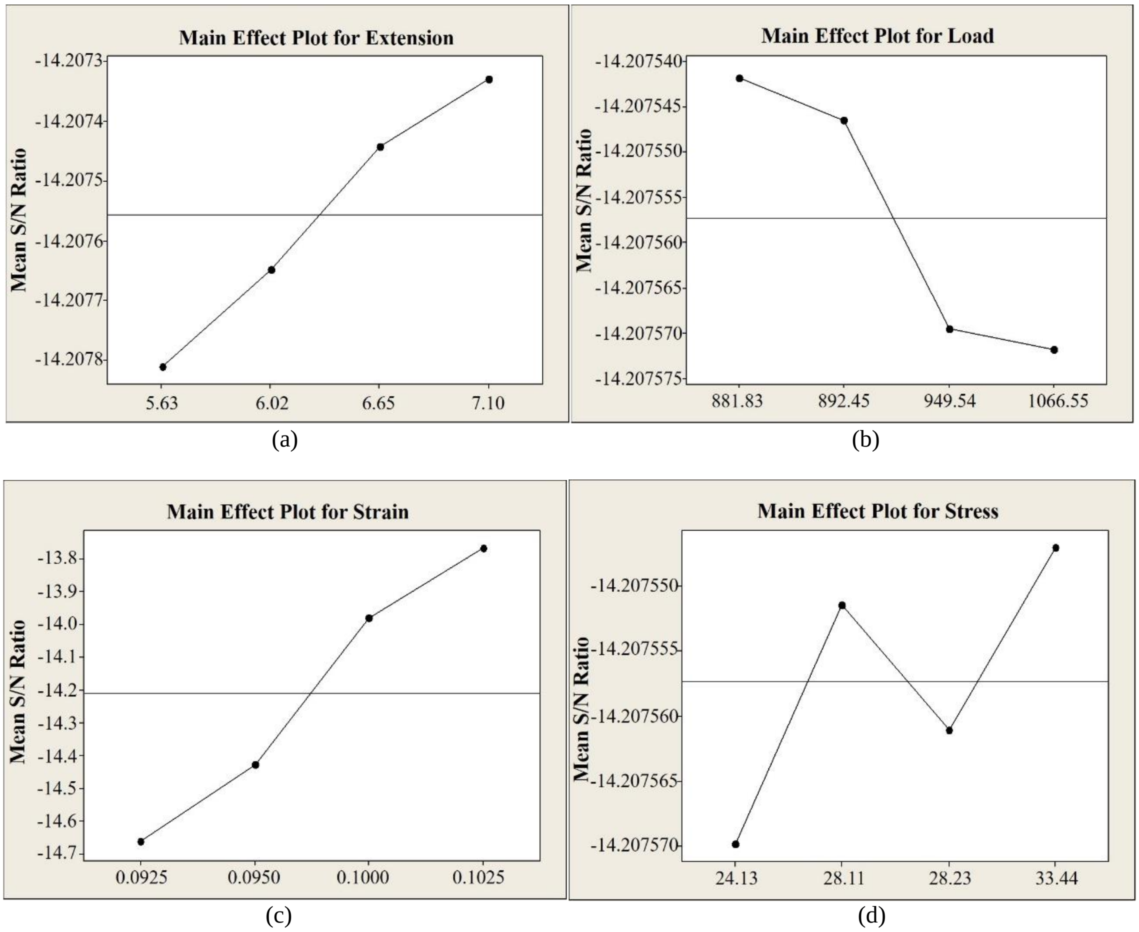

Figure 9 Main effect plots for (a) extension, (b) load, (c) strain, and (d) stress for orange peel/periwinkle shell blend tensile properties at optimal parameter settings

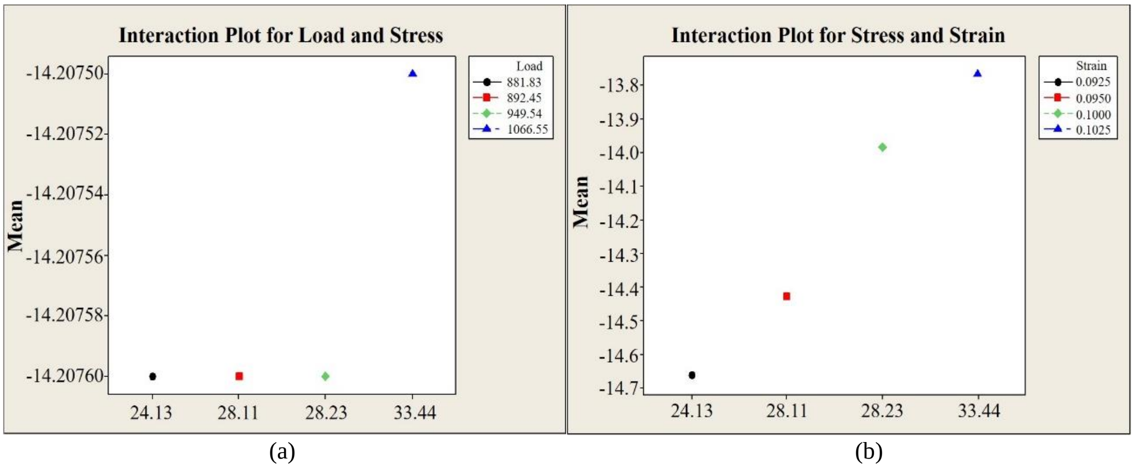

Figure 10 Interaction plots for orange peel/periwinkle shell composite (a) load and stress and (b) stress and strain

3.1.5. Palm kernel/egg shell composite blend

The palm kernel/egg shell blend has an optimal parametric setting of A_4,B_1,C_4,D_2 corresponding to an extension of 7.06 mm, load of 903.05 N, strain of 0.0875 and stress of 28.11 MPa.

Main effect plots

The optimal settings of the palm kernel/egg shell composite blend are graphically shown in Figure 11. These plots show the influence of each parameter level on the S/N ratios.

Interaction plots

The interaction plots for the palm kernel/egg shell composite are shown in Figure 12. The relationship between the parameters on the S/N ratio response is revealed.

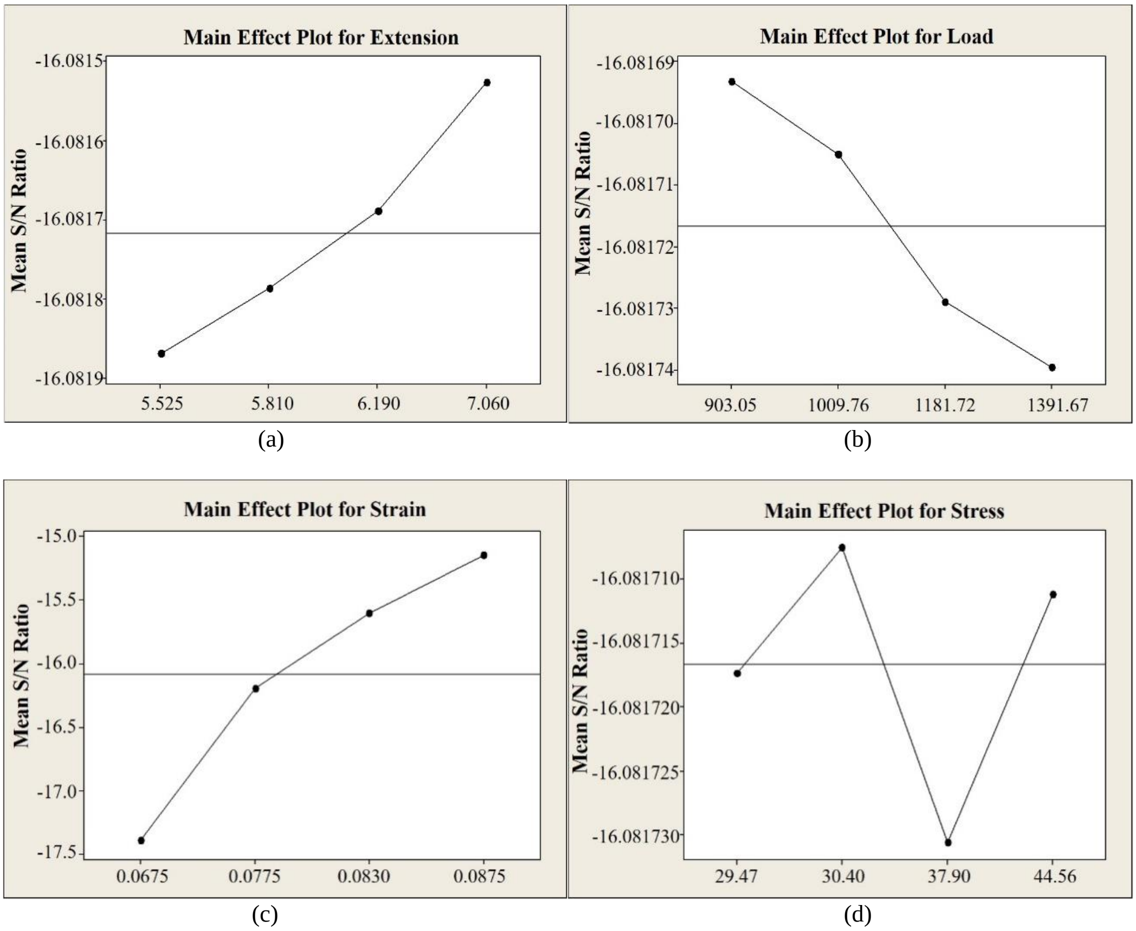

Figure 11 Main effect plots for (a) extension, (b) load, (c) strain, and (d) stress for palm kernel/egg shell blends on tensile properties at optimal parametric settings

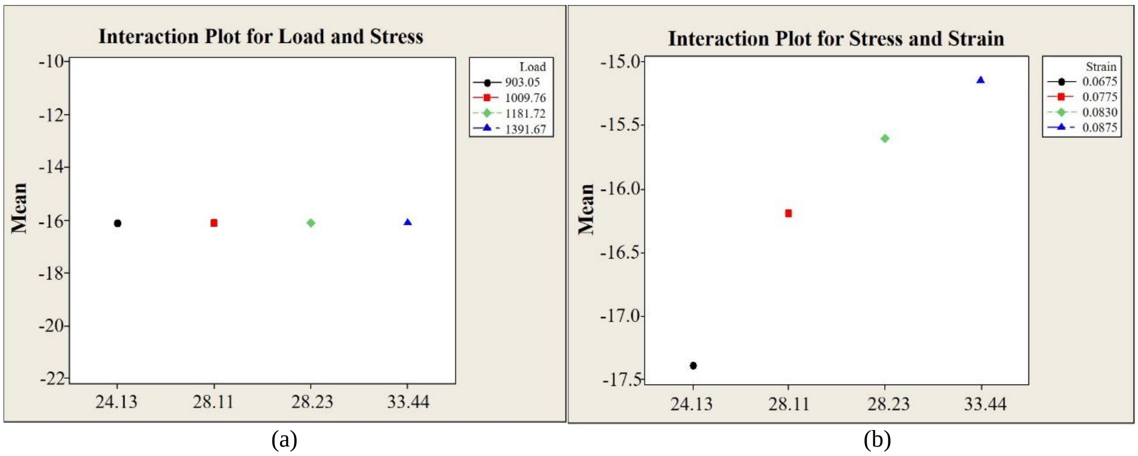

Figure 12 Interaction plots for palm kernel/egg shell composite (a) load and stress, and (b) stress and strain

3.2 Poisson motivated-Taguchi optimal parametric settings

Using the Poisson motivated-Taguchi optimisation, the optimal parametric setting can be read for all the composite groups.

3.2.1. Orange peel/coconut shell composite blend

The orange peel/coconut shell composite blend shows an optimal parametric setting of A_{1-2},B_{1-2},C_1D_4 that can be interpreted as any extension in the range of [6.5, 6.7]mm, any load in the range[506.13, 562.13]N, a strain of 0.08 and a stress of 22.13 MPa.

3.2.2. Palm kernel/coconut shell composite blend

The optimal parametric setting for the palm kernel/coconut shell blend was obtained as A_{1-2},B_{1-2},C_1,$D_{1,4}$.This can be interpreted as any extension in the range[6.36, 6.56] mm, any load in the range[1009.76, 1134.83]N, a strain of 0.09 and any stress in the range[29.47, 36.63] MPa.

3.2.3. Periwinkle/egg shell composite blend

The optimal parametric setting for the periwinkle/egg shell blend is obtained as A_{1-2},B_{1-2},C_1,$D_{1,4}$, which can be translated as any extension in the range[5.14, 5.63]mm, any load in the range[1165.79, 1201.77]N, a strain of 0.0775 and any stress in the range[35.27, 44.56]MPa.

3.2.4. Orange peel/periwinkle shell composite blend

The optimal parametric setting for the orange peel/periwinkle shell blend was A_{1-2},B_{1-2},C_1,$D_{1,4}$, which can be understood as any extension in the range[5.63, 6.02]mm, any load in the range[881.83, 892.45]N, a strain of 0.0925 and any stress in the range[24.13, 44.56]MPa.

3.2.5. Palm kernel/egg shell composite blend

The optimal parametric setting for the palm kernel/egg shell blend was obtained as A_{1-2},B_{1-2},C_1,$D_{1,4}$, which can be interpreted as any extension in the range[5.525, 5.81]mm, any load in the range[903.05, 1009.76] N, a strain of 0.0675 and any stress in the range [29.47, 44.56]MPa.

In practice, tensile properties are very important engineering parameters, especially in the broad areas associated with structural engineering, materials science, as well as mechanical engineering, where an overall insight into the behavior materials is compulsory to assure structural integrity of the material under the influence of tensile stress. The essential tensile properties include the breaking strength and the ultimate tensile strength. In practice, the tensile strength materials are determined so that they will not fail in use. Additionally, tensile properties of materials that bend when subjected to force must be considered in composite material development. In practice, the following unique situations exist, requiring special quantification in composite optimization, such as the use of a Poisson–motivated Taguchi method:

- When two different particle reinforcements are mixed, such as periwinkle and orange peel particles, interactions occur between these materials. Interfaces exist between these materials and the epoxy composite matrix. However, circumstances exist, such that interaction between any two periwinkle and orange peel reinforcement particles act independently of other particle-particle interfaces. These interactions may be strictly independent and strongly influence the tensile properties of the overall composite. Few studies have examined this issue.
- Interactions of two sets of periwinkle shell and orange peel particulates may occur simultaneously. In this instance the particles interact in a manner where the rate may not be higher or lower than in either group. This special instance has not been studied in the epoxy composite literature. Specifically, the particulate reinforcements relevant to periwinkle shells, orange peels, palm kernel shells, coconut shells and egg shells have not be subjected to rigorous experimental tests under this special situation of particulate interactions in attempts to enhance the tensile properties of composites.

This section reveals interesting results concerning the feasibility of applying the suggested framework in practical composite product development for tensile properly optimization. In the next subsection, the unique elements of the current study are defined.

3.3 Novelty, contributions and implications

From the authors' viewpoint, the engineering composite community currently focuses on the use of technical information for composite design parameters in the emerging field of engineering composite optimization. As such, there is an urgent need for enhanced tensile information for design of composites. This, coupled need for more rigorous treatment of composite design makes research on tensile property optimization mandatory. Thus, to fill the research gap for the expanding adaptation of Taguchi's classical method to polymer composites, the paper, for the first time, explores the tensile properties of particulate polymer composites. It shows that they can be enhanced using a Poisson–motivated Taguchi method as a new framework to optimize tensile properties of polymers. The current study validates this novel method with various unique polymer composite blends with a statistical method in the experimental design. The second novelty involves the testing of composite blends containing binary particulate mixtures of coconut shells, egg shells, periwinkle shells, orange peels and palm kernel shells. This was done for tensile property optimization for the first time on polymer composites. It demonstrates novelty by changing from the commonly used reinforced composites and uses both the new and commonly used methods to show associated advantages. Overall, the current research demonstrates tensile property optimization. This is an important mechanical property for polymer composite design and development.

From the foregoing discussion, the following contributions are attributable to this paper. Our research makes a significant contribution to the literature that expands tensile strength analysis of polymer composites. While some optimisation attempts have been made in the area of tensile strength [5], we extend this by revealing that particulate reinforced composites, by nature, can show a distributed pattern in their impacts on the tensile properties of particulate reinforced composites. Specifically, this research reveals how a Taguchi method can be used to examine materials containing particulates with an indefinitely large number of trials to optimize composite tensile strength. Composite designers and engineers can use this method to enhance tensile strength evaluation of composites.

This research supports previous literature, revealing that the Taguchi scheme for optimisation enhances understanding of the tensile properties of polymer composites. Furthermore, our findings reveal that the optimisation process may not produce acceptable results in situations where particulate polymer composites are considered. This is because the number of trials needed to optimize the particular criteria of cost and maximum material utilization of the reinforcement in the composite becomes indefinitely large. In this situation, the probability of accomplishing a specific optimisation task for every attempt tends towards zero. Poisson distribution characterization plays a mediating role, offering a binomial approximation. As there are numerous particulate reinforcements in the composite, there is a requirement to compute only the probabilities to establish the estimated distribution of events within the Taguchi optimisation scheme. Our research findings offer understanding of a two or more factor-level configuration that produces the same optimal parametric setting. This enhances optimisation outcomes.

4. Conclusions

The use of Taguchi optimisation makes it possible to determine the optimal settings for best tensile properties of the polymer composites. The introduction of Poisson motivated factor levels for the Taguchi optimisation factoring in the various probabilities considers numerous combinations of tensile properties for the composite groups under different curing regimes. The Poisson motivated factor levels shows the possibility of each of the tensile properties occurring independently and at a regular/fixed interval. This Poisson motivated Taguchi optimisation is used to identify the optimal parametric setting using these probabilities to give the best tensile behaviour in the composites. As a result, new optimal parametric settings are derived for each of the composite blends. Poisson motivated Taguchi optimisation methodology has the advantage of providing two or more levels for optimal parametric settings. This is different from the conventional optimal parametric settings obtained from Taguchi and other optimization methods in the literature. Engineers can have more than one factor level to choose from.

5. Acknowledgements

We would like to thank the Engineering Materials Development Institute (EMDI) Akure, Ondo State, Nigeria as well as the University of Johannesburg, Johannesburg, South Africa, for their technical support and enabling environment in the course of this work.

6. References

[1] Kolarik J. Three-dimensional models for predicting the modulus and yield strength of polymer blends, foams and particulate composites. Polym Composite. 1997;18(4):433-41.

[2] Liang JZ, Li RKY. Mechanical properties and morphology of glass bead ternary composites. Polym Composite. 1998;19(6):698-703.

[3] Liang JZ, Li RKY, Tjong SC. Tensile properties and morphology of PP/EPDM/glass bead ternary composites. Polym Composite. 1999;20(3):413-22.

[4] Turkman I, Gul R, Celik C. A Taguchi approach for investigation of some physical properties of concrete produced from mineral admixtures. Build Environ. 2008;43(6):1127-37.

[5] Pourjavadi A, Ayyari M, Amini-Fazl MS. Taguchi optimized synthesis of collagen-g-poly (acrylic acid)/kaolin. Euro Polym J. 2008;44(4):1209-16.

[6] Kim SM, Park KS, Kim KD, Park SD, Kim HT. Optimization of parameter for the synthesis of bimodal Ag nanoparticles by Taguchi method. J Indust Eng Chem. 2009;15(6):894-7.

[7] Krishna R, Revathi R, Srihari S, Rao R. Post-curing effects on hygrothermal behavior of RT-cured glass/epoxy composites. J Reinf Plast Compo. 2010;29(3):325-30.

[8] Karnwal A, Hasan MM, Kumar N, Siddiquee AN, Khan ZA. Multi-response optimization of diesel engine performance parameters using Thumba biodiesel-diesel blends by applying the Taguchi method and grey relational analysis. Int J Auto Tech. 2011;127(4):599-610.

[9] Liang JZ. Predictions of tensile strength of short inorganic fibre reinforced polymer composites. Polym Testing. 2011;30(7):749-52.

[10] Olivia M, Nikraz H. Properties of fly ash geopolymer concrete designed by Taguchi method. Mater Des. 2012;36:191-8.

[11] Sadat-Shojai M, Khorasani MT, Jamshidi A. Hydrothermal processing of hydroxyapatite nanoparticle-a Taguchi experimental design approach. J Crys Grow. 2012;361:73-84.

[12] Zareh B, Gorji AH, Bakhshi M, Nourouzi S. Study on the effect of parameters in sheet hydrodynamic deep drawing using FEM-based Taguchi method. Int J Advanc Des Manuf Tech. 2012;6(1):87-99.

[13] Kumar DS, Shukla MJ, Mahato KK, Rathore DK, Prusty RK, Ray BC. Effect of post-curing on thermal and mechanical behavior of GFRP composites. Mater Sci Eng. 2015;75:1-6.

[14] Simsek B, Ic YT, Simsek Eh. A TOPSIS-based Taguchi optimization to determine optimal mixture proportions of the high strength self-compacting concrete. Chemom Intell Lab Syst. 2013;125:18-32.

[15] Ashengroph M, NahviI, Amini J. Application of Taguchi design and response surface methodology for improving conversion of isoeugenol into vanillin by resting cells of *psychrobacter* sp. CSW4. Iranian J Pharma Res. 2013;2(3):411-21.

[16] Tanyildizi H. Post-fire behavior of structural lightweight concrete designed by Taguchi methods. Construction Build Mater. 2014;68:565-71.

[17] Gupta V, Pandey PM, Garg MP, Khanna R, Batra WK. Minimization of kerf taper angle and kerf width using Taguchi's method in abrasive water jet machining of marble. Procedia Mater Sci. 2014;6:140-9.

[18] Santra D, Joarder R, Sarkar M. Taguchi design and equilibrium modeling for fluoride adsorption on cerium loaded cellulose nanocomposite bead. Carboh Polym. 2014;111:813-21.

[19] Sudeepan J, Kumar K, Barman TK, Sahoo P. Tribological behavior of ABS/TiO_2 polymer composite using Taguchi statistical analysis. Procedia Mater Sci. 2014;5:41-9.

[20] Asghar A, Abdul Raman AA, Wan Daud WMA. A comparison of central composite design and Taguchi method for optimizing Fenton Process. Sci World J. 2014;2014:1-14.

[21] Ashassi-Sorkhabi H, Bagheri R. Sono electrochemical synthesis, optimized by Taguchi method, and corrosion behaviour of polypynrole-silicon nitride nanaocomposite on St-12 steel. Synth Met. 2014;195: 1-8.

[22] Paul ML, Samuel J, Chandrasekaran N, Mickherjee A. Preparation and characterization of layer-by-layer coated nano metal oxides-polymer composite film using Taguchi design method for Cr(VI) removal. J Environ Chem Eng. 2014;2:1937-46.

[23] Prakash A, Sarkhel G, Kumar K. Strength optimization of kaolin reinforced epoxy composite using Taguchi method. Mater Today: Proc. 2015;2:2380-8.

[24] Yadav KK, Dasgupta K, Singh DK, Varshney Singh H. Dysprosium sorption by polymeric composite bead: robust parametric optimization using Taguchi method. J Chromat A. 2015;1384:37-43.

[25] Ajibade OA, Agunsoye JO, Oke SA. Metal removal process optimisation using Taguchi-simplex method with case study applications. Cankaya Univ J Sci Eng. 2015;12(2):33-58.

[26] Chung YT, Ba-Abbed MM, Mohammad AW, Hairom NHH, Benamor A. Synthesis of minimal-size ZnO nanoparticles through sol-gel method: Taguchi design optimization. Mater Des. 2015;87:780-7.

[27] Simsek B, Uygunoghi T. Multi-response optimization of polymer blended concrete: A TOPSIS based Taguchi application. Const Building Mater. 2016;117: 251-62.

[28] Ben-Arfa BAE, Salvado IMM, Frade JR, Pullar RC. Fast route for synthesis of stoichiometric hydroxyapatite by employing the Taguchi method. Mater Des. 2016;109:547-55.

[29] Praveen AS, Sarangan J, Suresh S, Channabasappa BH. Optimization and erosion wear response of NiCrSiB/WC-Co HVOF coating using Taguchi method. Ceramics Int. 2016;42:1094-104.

[30] Azad FN, Ghadi M, Dashtian K, Hajati S, Pezeshpour V. Ultrasonically assisted hydrothermal synthesis of activated carbon-HKUST-1 MOF hybrid for efficient simultaneous ultrasound-assisted removal of ternary organic dyes and antibacterial investigation: Taguchi optimization. Ultras Sonochem. 2016;31:383-93.

[31] Ajibade OA, Agunsoye JO, Oke SA. Tapped density optimisation for four agricultural wastes: part ii - performance analysis, main effects of process parameters and Taguchi-Pareto. Acta Period Techno. 2016;47:129-42.

[32] Ighravwe DE, Oke SA. Application of Taguchi-fuzzy model in integrated maintenance-production workforce sizing problem via optimization. KKU Eng J. 2016;43(2):69-77.

[33] Agunsoye JO, Bello SA, Adetola LO. Experimental investigation and theoretical prediction of tensile properties of *Delonix regia* seed particulate reinforced polymeric composites. J King Saud Univ - Eng Sci. 2019;31(1):70-7.

[34] Zare Y, Rhee KY. Expansion of Kolarik model for tensile strength of polymer particulate composites as a function of matrix, nanoparticles and interphase properties. J Collo Interf Sci. 2017;506:582-8.

[35] Gloria GO, Teles MCA, Lopes FPD, Vieira CMF, Monteiro SN, de Almeida Gomes M, et al. Tensile strength of polyester composites reinforced with PALF. J Mater Res Tech. 2017;6(4):401-5.

[36] Fallahiarezoudar E, Ahmadipourroudposht M, Idris A, Yusof NM. Optimisation and development of Maghemite (γ-Fe_2O_3) filled poly-lactic acid (PLLA)/thermoplastic polyurethane (TPU) electrospun nanofibers using Taguchi orthogonal array for tissue engineering heart valve. Mater Sci Eng: C. 2017;76:616-27.

[37] Kavimani V, Prakash KS. Tribological behavior predictions of r-GO reinforced Mg composite using ANN coupled Taguchi approach. J Phys Chem Solids. 2017;110:409-19.

[38] Vignesh P, Venkatachalam G, Shankar AG, Singh A, Pagaria R, Prasad A. Studies on tensile strength of sugarcane fiber reinforced hybrid polymer matrix composite. Mater Today: Proc. 2018;5:13347-57.

[39] Gazz TS, Luaibi HM, Al-Amiery Kadhum AAH. Effect of phosphoric acid on the morphology and tensile properties of halloysite-polyurethane composites. Results in Phys. 2018;9:33-8.

[40] Dai HL, Huang ZW, Mei C, Lin ZY. Prediction of the tensile strength of hybrid polymer composites filled with spherical particles and short fibers. Compo Struct. 2018;187:509-17.

[41] Reddy MI, Kumar MA, Raju CRB. Tensile and flexural properties of jute pineapple leaf and glass fiber reinforce polymer matrix hybrid composites. Mater Today: Proc. 2018;5:458-62.