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Elastic-Characteristics of Recycled Low-Density-Polyethylene-Date Palm Wood Composite by Response Surface Methodology Optimization Process for Structural Application

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Abstract

The request for utilization inexpensive plant from non-digestible agro-fiber and non-biodegradable waste from plastics in polymer composite are rudiment of zero deposition of refuse, wealth generation and eco-friendly environment. This work is aimed to optimize the mechanical properties of recycled low-density-polyethylene-date palm wood (r-LDPE-DPW) composite by considering two main process variables; particle size (PS) and fiber content (FC) for automobile parts production. The date palm wood (DPW) was introduced into the powdered recycled-low-density-polyethylene (r-LDPE) at fiber content (10-30 wt%) and particle size of (50-70 mesh no (300-212 µm)) for optimization of the produced composite properties for its eligibility to produce low cost car parts from dispose waste of r-LDPE and ready available DPW. The r-LDPE-DPW composite compounded at this condition was subjected to tensile test to determine the elastic properties using response methodology (RSM). The compounding of DPW and r-LDPE applied through injection moulding machine. The involvement of RSM was employed for its prediction and optimum condition of elastic characteristics of r-LDPE-DPW composite. The properties of r-LDPE-DPW composite studied were tensile strength (TSN), elongation (EGT) and tensile modulus (TSM). The result shows that at optimal state, the PS, FC, TSN and EGT were 60.034 mesh (250 µm), 19.16%, 9.7302 MPa, 9.2545 % and 1.1689 GPa, respectively. The coefficients of determination (R^2) and the error for the predicted results by RSM compared to real values obtained experimentally were close to 1 and less than 0.112%, respectively. From the values forecast by RSM, the r-LDPE-DPW composite would be a possible material for production of engineering components for car parts.
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Keywords: Response Surface Methodology, mechanical properties, recycle plastics, Date palm wood, r-LDPE-DPW composite

1. Introduction

The application of agricultural products from plants in polymer composite is in an amplify state (Dungani et al., 2016; Obasi, 2015; Government et al., 2019(a); Government et al., 2018: Government et al, 2021(a-b)). Globally, it has been used as perfect substitute to mineral fiber for production of structural components such as buildings, automobile, etc (Government et al., 2019 (a-d); Obasi, 2015). Plants fiber waste has a tremendous respect over other inorganic substances(André et al., 2018; Fortunati et al., 2019; Obasi & Onuegbu, 2013; Reddy et al., 2013). This includes light weight, renewable, always available, and most importantly low cost. It has the potential of improving the characteristic of composite as part of the feed in the polymeric material which is a major component of the composite (Harun & Geok, 2016 Tisserat et al., 2014). This may be the dimensional structure and electro-mechanical features of the final products (Bawon et al., 2019; Yakubu et al., 2013). When acts as filler in the polymer-matrix, it results to total enhancement of specific strength and stiffness of the composite (Atuanya et al., 2014; Obasi, 2015; Rabboni et al., 2019; Yakubu et al., 2013).

Also, another component of a composite is the matrix. This term is main component of polymeric-fiber composite(Orji & McDonald, 2020; Rajak, Pagar et al., 2019; Sood & Dwivedi, 2018). It generates the bonding of other constituent of the natural fiber polymer composite. It strengthened the reinforcement of the entire composite material (Aimi et al, 2014; Rashid et al., 2016). It is mainly sourced from petrochemicals from polymeric substances such as low density polyethylene, linear low-density-polyethylene, high-density-polyethylene, polypropylene, polyester, etc(Azeez et al, 2021; Government et al 2021(a-c); Government et al, 2022).

Composite in other words is the substance formed by the combination of different constituents which generates superlative qualities other than the singular components (Atuanya et al., 2014; Rabboni et al., 2019). It is essential to notify that the properties of a natural-fiber polymeric composite are multiples of these constraints (Government., 2019(a-c); Homkhiew et al., 2014). These are stated as follows: chemical modifying processes, the size distribution of fiber, intrinsic characterization of the fiber (Feldmann et al.., 2016; Government et al., 2022; Hakeem et al., 2015; Zhang et al., 2020), cellulosic constituents of the plant, type of the polymeric material, etc (Bhandari et al., 2013; Laadila et al., 2017; Obasi, 2015; Onuegbu et al., 2013; Onuegbu et al., 2014). The selections of suitable constraints for the manufacturing routs are paramount to ensure end-products of superior properties (Azeez et al., 2019; Azeez et al., 2013; Azeez et al.,, 2018; Government et al., 2019(a-c)).

Furthermore, plenty of plastic wastes supersaturates the global society in this present time (André et al, 2018). These wastes litter in the environment across the metropolis of each state in the world at large(Government et al., 2022; Homkhiew, Ratanawilai et al., 2014; Laadila et al., 2017). Nevertheless, they are non-biodegradable and contribute to negative influence on human existence(Verma et al., 2019; Zakaria et al., 2018). Therefore, the ideal thinking is to recycle the wastes and incorporate a cheap renewable material from biomass as fiber in the polymer-fiber-application for innovation of engineering components in industrial and domestics uses (Laadila et al., 2017;Turku et al., 2018). Also, the outcome of combined-recycle polymeric wastes and the agro-fiber leads to wealth generation and self-reliance toward ensuring zero wastes in the environment (Harun & Geok, 2016; Laadila et al., 2017; Najafi et al., 2013; Turku et al., 2018; Government et al., 2021(a); Government et al., 2022).

Most previous researchers as introduced many recycled plastic reinforced with various natural fibers in industrial and domestics applications for societal problem. These include ladadila et al., (2017), Turku et al,, (2018), Homkhiew et al., (2014), and Government et al., (2022).

In this context, this work is aimed to optimize the elastic-properties of date-palm fiber-r-LDPE composite by considering these constraints (particle size and fiber content of date-palm fiber) for low cost composite production at optimum condition for its suitability in car parts production.

2.0 Material and methods

2.1 Experimental

2.1.1 DPW processing

The DPW was extracted in Unizik, Department of Fisheries and Aquaculture Fish Pond Farm, permanent site, Awka, Anambra State of Nigeria. The DPW was dried for 14 days on the sun at 8 h, followed by crushing, grinding and sieving. The sieve sizes employed were 50 mesh (300 µm), 60 mesh (250 µm) and 70 mesh (212 µm) and then stored in a water proof container. These unit operations of DPW were done at Scientific Equipment Development Institute, (SEDI), Akwuke, Enugu

2.1.2 Recycled LDPE preparation

The recycled LDPE was sourced from Enugu Metropolis and washed with cleaned water and detergent to eliminate dirt, sun dried for 4 h, crushed and pulverized and stored in a polythene bag. The crushed and pulverization r-LDPE were carried out by applying grinder at old Kenyetta market Enugu.

2.1.3 r-LDPE-date-palm fiber production

The DPW was compounded at fiber content of 10-30 wt% in the r-LDPE at 90-70 wt%, respectively using injection molding machine MODEL HUICHON/5SON10/500.1000. No. 6241 1990-6. The compounding of r-LDPE and DPW at varies compositions was done by Olikaeze Factory in Ekenedirichukwu Workshop Awada, Onitsha, Anambra State. The DPW-r-LDPE composite formed was passed through tensile testing for obtaining tensile properties.

2.1.4 Analysis of tensile properties

The tensile properties were determined using universal testing machine MODEL TUC-100. The analysis of tensile testing took place at Standard Organization of Nigeria, Enugu district. The sample was fixed into the machine using ASTM specification. The tensile strength (TSN), elongation (EGT) and elastic modulus (TSM) was recorded. The elastic characteristics of the sample was digitally recorded after 5 seconds. The dimension of the sample for this test was 3 mm by 12.5 mm by 60 mm.

2.1.5 Formulation of the experimental design

The design-Expert version7.0.0 was used the modeling and optimization. A faced centre composite design of response surface methodology was chosen for the design of experiment. It is compose of 13 runs of experiment. The design was made up of five levels in coded form: -α, -1, 0, 1, +α which is proportional to lowest, lower, middle, higher, highest of the process parameters considered. But, for this design, -α=-1 and 1=+α. Table 1 presents arrangement of the factors based on the levels of design.

Table 1: arrangement factors on the level of design in coded fom

Factors	Unit	Level in coded form				
		-α,	-1,	0,	1,	+α
Particle size	mesh	50	50	60	70	70
Fiber content	%	10	10	20	30	30

3.0 Results and Discussions

The DPW content of 10, 20 and 30 wt% and particle size of 50, 60, 70 mesh was injected in the r-LDPE matrix for the prediction of responses (TSN, EGT and TSM) of the composite after substituting the experimental values of the properties of the composites with their factors combination. The factors for the actual and coded equivalent were expressed to show how the factors combined to obtain the corresponding TSN, EGT and TSM for the formation of design matrix of the r-LDPE-DPW composite. Table 2 displayed the design matrix of r-LDPE-DPW composite.

Table 2. Design matrix of r-LDPE-DPW composite

	Factors		Responses		
Run	A:Particle size	B:Fiber content	TSN	EGT	TSM
	Actual and Coded		Properties		
	Mesh	%	MPa	%	GPa
1	60(0)	20(0)	9.72	9.15	1.18
2	70(1)	30(1)	9.51	7.35	1.3
3	70(1)	20(0)	9.7	8.66	1.13
4	70(1)	10(-1)	9.8	9.75	0.94
5	60(0)	20(0)	9.72	9.15	1.18
6	60(0)	30(1)	9.56	7.76	1.34
7	60(0)	20(0)	9.72	9.15	1.18
8	50(-1)	20(0)	9.64	8.8	1.13
9	60(0)	20(0)	9.72	9.15	1.18
10	60(0)	20(0)	9.72	9.15	1.18
11	50(-1)	10(-1)	9.79	10.04	0.94
12	50(-1)	30(1)	9.5	7.2	1.22
13	60(0)	10(-1)	9.82	10.22	1

Table 3: ANOVA for r-LDPE-DPW composite

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
TSN						
Model	0.130105	5	0.026021	151.4994	< 0.0001	Significant
PS	0.001067	1	0.001067	6.210325	0.0415	
FC	0.1176	1	0.1176	684.6883	< 0.0001	
PSFC	0	1	0	0	1.0000	
PS^2	0.005636	1	0.005636	32.81262	0.0007	
FC^2	0.00175	1	0.00175	10.18929	0.0152	
Residual	0.001202	7	0.000172			
Lack of Fit	0.001202	3	0.000401			
Pure Error	0	4	0			
Cor Total	0.131308	12				
			R-Squared	0.990844		
			Adj R-Squared	0.984303		
			Pred R-Squared	0.908542		
			Adeq Precision	38.01937		
EGN						
Model	10.72416	5	2.144831	1454.568	< 0.0001	Significant
PS	0.013067	1	0.013067	8.86147	0.0206	
FC	9.881667	1	9.881667	6701.487	< 0.0001	
PSFC	0.0484	1	0.0484	32.82361	0.0007	
PS^2	0.470545	1	0.470545	319.1111	< 0.0001	
FC^2	0.06445	1	0.06445	43.70802	0.0003	
Residual	0.010322	7	0.001475			
Lack of Fit	0.010322	3	0.003441			
Pure Error	0	4	0			
Cor Total	10.73448	12				
			R-Squared	0.999038		
			Adj R-Squared	0.998352		
			Pred R-Squared	0.990258		
			Adeq Precision	116.6364		
TSM						
Model	0.178365	5	0.035673	264.9375	< 0.0001	Significant
PS	0.001067	1	0.001067	7.921951	0.0260	
FC	0.160067	1	0.160067	1188.788	< 0.0001	
PSFC	0.0016	1	0.0016	11.88293	0.0107	
PS^2	0.009829	1	0.009829	72.99756	< 0.0001	
FC^2	0.001067	1	0.001067	7.92439	0.0260	
Residual	0.000943	7	0.000135			
Lack of Fit	0.000943	3	0.000314			
Pure Error	0	4	0			
Cor Total	0.179308	12				
			R-Squared	0.994744		
			Adj R-Squared	0.990989		
			Pred R-Squared	0.951659		
			Adeq Precision	49.85143		

Table 3 presents ANOVA (analysis of variance) of r-LDPE-DPW composite. From Table 3, the models for the elastic properties of r-LDPE-DPW composite were completely significant. For TSN, EGT and TSM, all attributed a great significance in terms of individual single factors, PS and FC, respectively.

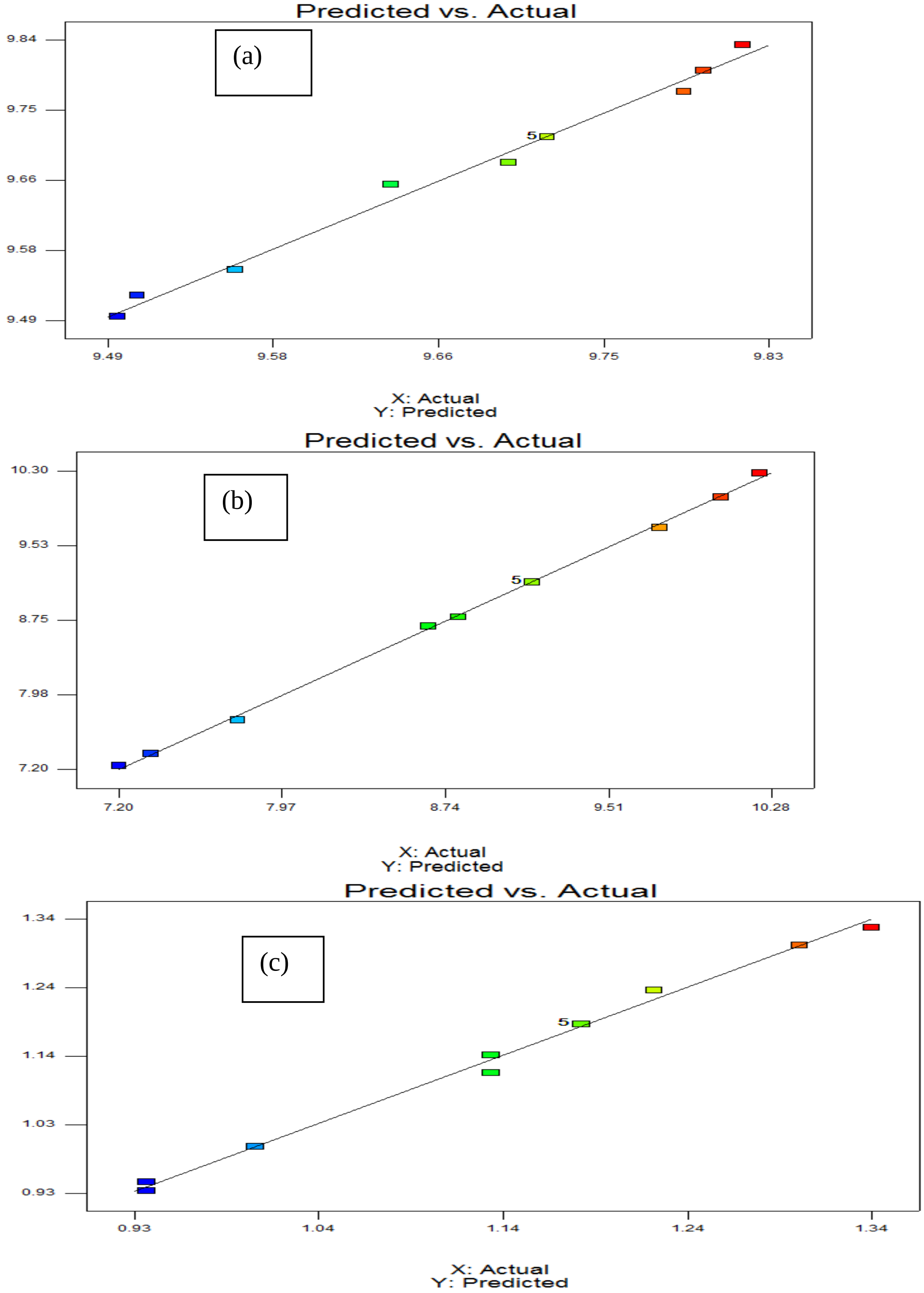

Figure 1: Predicted versus actual plots for (a) TSN (b) EGT (c) TSM of r-LDPE-DPW composite

Moreover, coefficient of interaction factors (PS FC) for the EGT and TSM were < 0.05, while that of TSN observed a value >0.05. Also, coefficients for the squared process variables (PS^2 and FC^2) were highly significant for TSN, EGT and TSM of r-LDPE-DPW composite. Furthermore, the R^2 indicated that it is approximately close to unity for both adjusted and predicted values in accordance to each other. At this point, based on ANOVA results of the significance of the process parameters for all the three tensile properties; it can be concluded that all the variables meet the conditions for good precision and reliance in conducting the experiment (Government et al., 2019(c-d); Kandar & Akil, 2016; Peng et al., 2015; Rostamiyan et al., 2014; Rostamiyan et al., 2014; Rostamiyan et al., 2015; Government et al., 2018). The results obtained were related past scholarly works(Government, 2021(a); Government et al., 2022; Homkhiew et al., 2014; Government et al,, 2019; Peng et al., 2015; Rostamiyan et al., 2015).

Finally, after extracting the insignificant terms from ANOVA of TSN, EGT and TSM of r-LDPE-DPW composite, the following equations were generated. These equations were employed to forecast the elasticity of the composite for TSN, EGT and TSM using Eq (1), Eq (2) and Eq (3), respectively.

$$TSN = 8.19172 + 0.05554PS - 3.93103 \times 10^{-3}FC - 4.51724 \times 10^{-4}PS^2 - 2.51724 \times 10^{-4}FC^2 \quad (1)$$

$$EGT = 2.15575 + 0.46864\mathrm{PS} - 0.13323\mathrm{FC} + 1.1 \times 10^{-3}\mathrm{PSFC} - 4.12759 \times 10^{-3}\mathrm{PS}^2 - 1.52759 \times 10^{-3}\mathrm{FC}^2 \quad (2)$$

$$TSM = -1.21011 + 0.068920\mathrm{PS} + 0.012195\mathrm{FC} + 2 \times 10^{-4}\mathrm{PSFC} - 5.96552 \times 10^{-4}\mathrm{PS}^2 - 1.196552 \times 10^{-4}\mathrm{FC}^2 \quad (3)$$

Figure 2 (a-c) captures the predicted versus actual plots for TSN, EGT and TSM of the r-LDPE-DPW composite, respectively. The plotted points of predicted and actual values of TSM, EGT and TSM of the composite were in harmony with diagonal line. These confirmed that the prediction of elastic characteristic of the composite as indicated for Figure 1(a), 1(b) and 1(c) using RSM were perfectly executed for TSN, EGT and TSM, respectively. Similar outcome was also discuss previously (Government et al., 2019b; Kandar & Akil, 2016; Rostamiyan et al., 2014).

Figure 2 (a-c) indicates the contour plots for TSN, EGT and TSM of r-LDPE-DPW composite. It can be noticed that at constant PS for 50 mesh in Figure 2(a), the addition of FC in the r-LDPE showed a deceased in TSN prediction of r-LDPE-DPW composite. In another word, at constant FC (10%); the TSN steadily improved as PS increases at optimum value of 60 mesh, then a reduction was experienced in the TSN of r-LDPE-DPW composite. However, due to the interaction of the two factors; various prediction of TSN of the composite was depicted. This continues until the optimum condition of the r-LDPE-DPW composite was obtained. This was indicated in the region at flag in the contour graph. The same behavior was experienced by later scholars (Government et al., 2022; Homkhiew et al., 2014; Government et al., 2019(d): Government et al.,2018)

Figure 2(b) exhibits the contour plot for EGT of r-LDPE-DPW composite. The same sequence was displayed in Figure 2(a). As the PS remain constant, during the addition of FC, the prediction of TSN of the r-LDPE-DPW composite advances. But, at a fixed FC, the EGT was enhanced to a particular PS which later retarded at further increased in PS. At that point, this is the optimum point of PS, FS and EGT as displayed in the flag axis in Figure 2(b). Later works present similar pattern of results (Government et al., 2022: Homkhiew et al., 2014: Government et al., 2019(b-d)).

Lastly, Figure 2(c) portrays the contour plot for the interaction of PS and FC on the TSM of r-LDPE-DPW composite. When PS is fixed at 70 mesh, the prediction of TSM experiences a rise during the injection of more FC in the r-LDPE matrix.

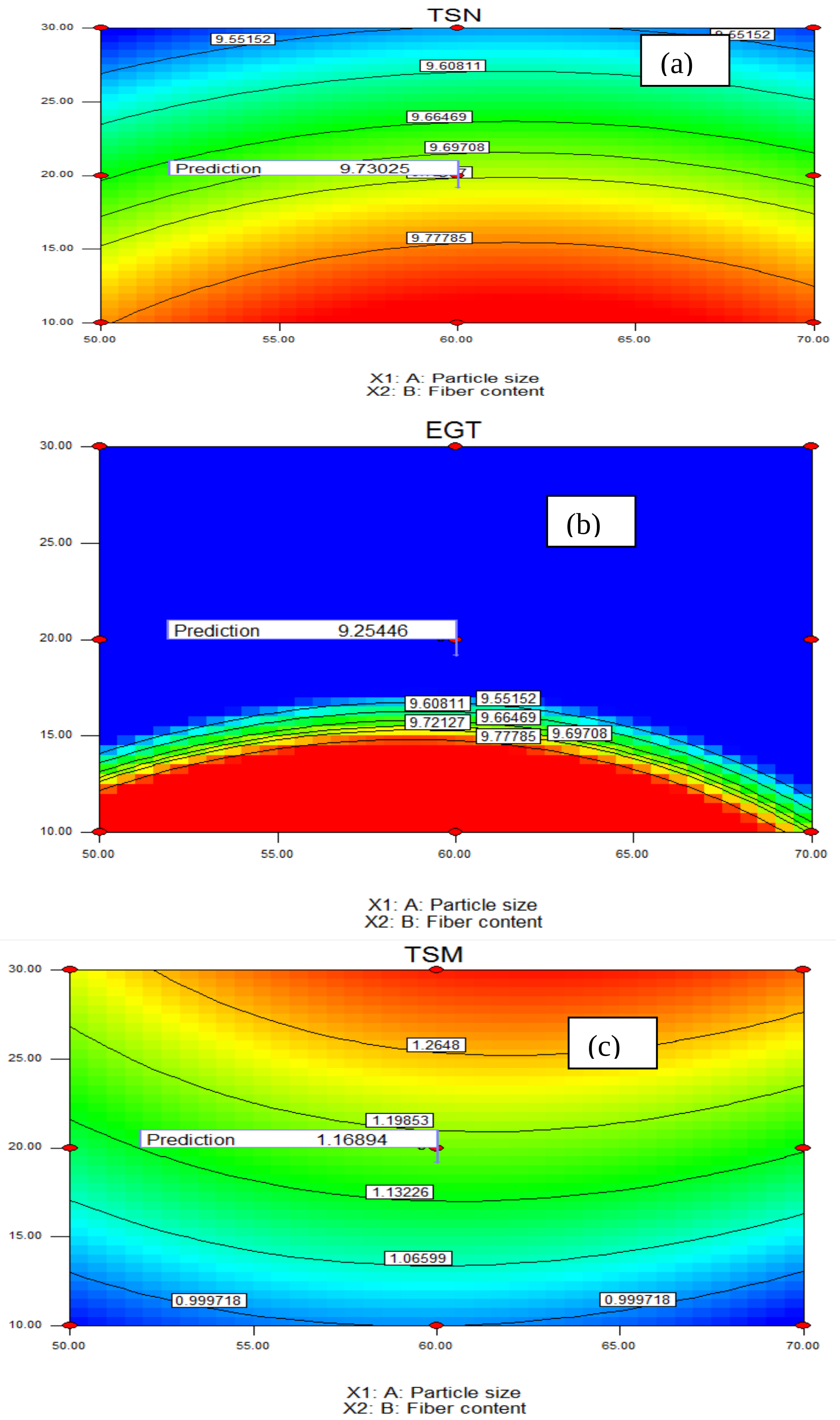

Figure 2: Contour plots for (a) TSN (b) EGT (c) TSM of r-LDPE-DPW composite

This trend occurs when more of FC is added in the r-LDPE, the provision of void is formed which reduces ductile effect of the r-LDPE, which then increases stiffness of r-LDPE-DPW composite. However, when FC is constant; the TSM prediction of r-LDPE-DPW composite showed a significant improvement with the variation of PS. This gradually development of TSM is as result of addition of PS which stiffen the composite. This continuously enhanced till the peak of PS which displayed a retardation of the predicted TSM of r-LDPE-DPW composite. This is the optimum point of the r-LDPE-DPW composite as illustrated by the flag of prediction in Figure 2(c). This result was obtained at previous works(Government et al., 2022; Homkhiew et al., 2014; Government et al, 2019 (a-d)). The outlays plot for the optimum parameters of elastic properties of r-LDPE-DPW composite is shown in Figure 3. From this plot, it can be deduced that the optimum process condition of r-LDPE-DPW composite occurred at PS, FC, TSN, EGT and TSM of 60.03 mesh, 19.16 %, 9.73022 MPa, 9.25423 % and 1.16897 GPa. This data obtained from the optimal state show that the material is important for structural component for car parts production.

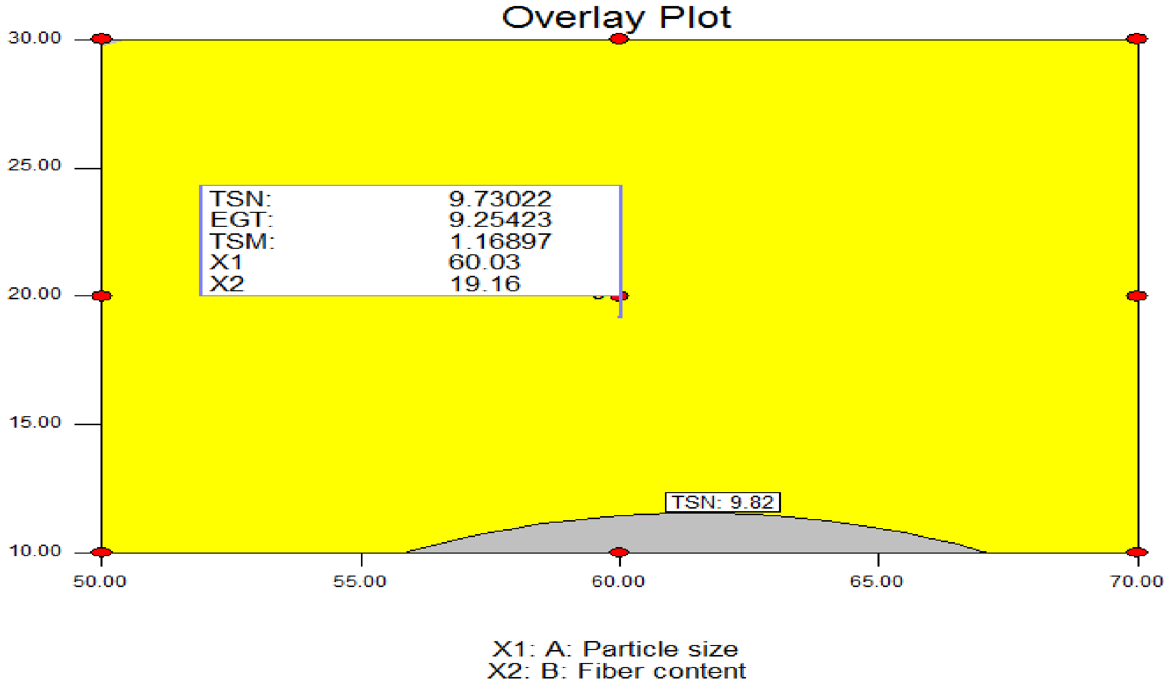

Figure 3: Overlay plot for (a) TSN(b) EGT (c) TSM of r-LDPE-DPW composite

Table 4 shows the comparison between the experimental and RSM values at optimum condition of the r-LDPE-DPW composite. It was noticed that the TSN, EGT and TSM of r-LDPE-DPW composite for the experiment and the RSM predicted values were relatively deviated by 0.052442%, 0.023778% and 0.111339%, respectively. This had shown that the error deviations were smaller than 0.12%. This is fully confirmed that the RSM software gave better prediction of tensile properties of the composite. Similar situation was predicted by later researchers (Government et al., 2022; Homkhiew et al., 2014; Government et al., 2019 (b-d)).

Table 4: Variation of experimental readings and the predicted elastic-characteristic of r-LDPE-DPW composite at optimal state.

Properties	Particle Size (mesh)	Fiber content (%)	Experimental readings	Forcasting readings	Relative error (%)
TSN (MPa)	60.034	19.16	9.7251	9.7302	0.052442
EGN (%)	60.034	19.16	9.2523	9.2545	0.023778
TSM (GPa)	60.034	19.16	1.1676	1.1689	0.111339

4.0. Conclusion

The study on the optimization of elastic properties of r-LDPE-DPW composite by applying RSM was fully examined. Also, the prudent use of recycled plastic waste from LDPE and low cost agro-fiber have fully utilized for polymer-fiber composite for generation of wealth from wastes. Thereby, this would alleviate plastics deposition in the society. The tensile properties of r-LDPE-DPW composite had shown that it has impact on the PS and FC. The difference between the RSM predicted value and the experiment showed that that the error was minimal. The results showed that the optimum condition for r-LDPE-DPW composite were 9.73 MPa, 9.25% and I.18 GPa for TSN, EGN and TSM, respectively. The PS and FC at these conditions were 60.03 mesh size and 19.16 wt%. The results obtained from this RSM can be an effective means of reducing material and cost for production of engineering components. This RSM values of this work can be recommended to be applied in car parts production.

5.0 Recommendation

These RSM values of this work can be recommended to be applied in car parts production.

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