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CHARACTERIZATION OF MECHANICAL PROPERTIES OF DATE PALM FRONDS REINFORCED COMPOSITES: A COMPARATIVE EVALUATION

K. Alzebdeh, M. Nassar,
H. Al Rawahi and N. Al–Hinai
Department of Mechanical
and Industrial Engineering,
College of Engineering,
Sultan Qaboos University,
P.O. Box 33, Al Khod, PC 123,
Sultanate of Oman.

ABSTRACT

Due to many advantages of using natural resources, natural fibers have been used recently as a method of providing added strength and ductility to reinforced polymer composites. This is mainly due to their availability, renewability, low density, cost effectiveness as well as satisfactory mechanical properties. This paper presents fabrication and experimental characterization analysis of mechanical properties of a class of bio–composite in which polypropylene (PP) and low density polyethylene (LDPE) are reinforced with date palm frond fibers. Bio–composite sheets were fabricated with controlled processing parameters based on small factorial design in order to develop a statistical model for response using fractional design of experiment. In a Design of Experiment (DoE) procedure, we identify three different factors along with three different levels; fiber volume fraction (20, 40, and 60 vt. %), alkali treatment (10, 15, and 20 Wt. %), and treatment time (2, 4, and 6 h). In this study, NaOH alkali solution is used to modify the fiber properties and improve surface characteristics. The tensile and flexural strengths of specimens prepared according to ASTM standards were measured by direct physical testing. Also, the Response Surface Methodology (RSM) is adopted to analyze interactions among the input factors and their effect on overall mechanical properties of the fabricated composite. Results revealed that fiber length and percentage of NaOH treatment have a significant impact on the composite properties. The date palm frond reinforced polypropylene composites could serve as a potential material in broad range of industrial applications in which high strength is not a main design requirement.

KEYWORDS: Date palm fronds (DPF), Low Density Polyethylene (LDPE), Mechanical Properties, Optimization, Polypropylene (PP), Response Surface Methodology (RSM)

INTRODUCTION

Recently, a stream of research works focused on developing a new class of composite materials from natural resources or degradable waste. Different forms of fibers such as cellulose, pectin, lignin, affect greatly the overall properties of natural fiber composite according to their weight content. This notion has been studied by Digabel and Avérous [1], who reported that mechanical properties of bio–composites depend on percentage of lignin in the plant fiber. More specifically, Rashid et al. [2] studied the mechanical properties of Iraqi Palm Fiber–Polyvinyl alcohol composites by ultrasonic measurements. Results indicated that mechanical properties degrade with increased concentration of palm fiber in a composite. This can be attributed to the poor adhesion between fiber and surrounding matrix. On the other hand, Al–kaabi et al. [3] characterized date palm fibers reinforced composites through the evaluation of their chemical, physical and mechanical properties. Results showed that these fibers yield to reasonable properties and could be used for low–cost applications which require low to medium strength. In a novel research by Dinesh et al. [4], sisal fiber reinforcement epoxy composite was developed in order to be used as orthopedic implant. Both tensile and compressive strengths were improved by approximately 30%. Several theoretical and empirical models have been proposed to study behavior of sisal fiber reinforced polymer composites. It was observed that fracture toughness increases with an increase of fiber content due to a strong fiber and matrix adhesion and low percentage of voids. Seedahmed [5] conducted a comparative study between theoretical and experimental results for cotton silk fiber–reinforced polypropylene composites. It was observed that cotton stalks fibers improve strength and other mechanical properties of produced composite.

One drawback of adopting natural fibers as reinforcement in plastics is the poor adhesion between fiber and resin matrix, which adversely influence the overall tensile and flexural strengths. In order to overcome such problem and enhance fiber–matrix interfacial bonding, novel processing techniques including chemical and physical treatment methods were developed. The alkali treatment of cellulose fibers yields a high degree of crystallinity and removes the hemicelluloses and lignin content. Crystallinity plays a significant role to reaching a higher tensile strength of fiber and thus improves mechanical properties of the overall composite. Similarly, surface morphology contributes effectively to a better performance of the corresponding composite [6]. Rokbi et al. [7] studied the effect of alkali treatment on the flexural properties of Stippa fiber reinforced epoxy composites and found that alkali treatment of fibers improves the quality of the fiber/matrix interface. This indicates that treating fibers with alkali enhances the interfacial bonding between fiber and matrix. Alawar et al. [8] showed different properties of date palm fibers compared to different types of treatments methods used. Soda treated fibers showed significant increase in tensile strength and considerable improvement in surface morphology. Hydrochloric acid treatment is rejected as fiber treatment due to its negative impact on the tensile strength and surface morphology of DPF. Wazzan [9] concluded that interfacial shear strength increases for all treated fibers as compared to non–treated fibers. Particularly, combination of alkaline and silane coupling agents resulted in substantial adhesion improvement to the polyester matrix in comparison to the untreated date palm fibers and fibers treated by alkaline and silane methods only. Moreover, using Agave Americana natural fiber, Thamae and Baillie [10] studied the influence of fiber extractions method, surface treatment and fiber treatment on interfacial shear strength (ISS) of reinforced waste HDPE. It was concluded that alkali treatment of Agave Americana fibers can improve the fiber properties and its interfacial strength when mixed with waste HDPE.

In this study, chopped date palm fronds reinforced polymer composites have been fabricated using hand lay–up method to investigate the mechanical properties of filled polymers based on small factorial design developed by design expert software. The tensile, flexural strengths of fabricated composites were evaluated as per ASTM standards. Nonlinear regression models were developed for the prediction of mechanical behaviors over the specified range of fabrication parameters. Finally, coupled response surface methodology (RSM) was used to model and optimize the resultant average tensile and flexural strength.

METHODOLOGY

Fabrication

Date palm fronds have been obtained from local date palm trees and dried under the sun light for one month and cleaned to remove the contaminants and adhering dirt and dust using tap water. The dried date palm fronds were chopped into length ranging from 3 to 5 cm and width from 0.5 – 1.5 cm using convention sieving machine. Moreover, the chopped date palm fronds were sorted out according to volume percentage to be used per the design. For Chemical treatment, Sodium Hydroxide (NaOH) solution has been prepared in distilled water as well according to the design parameters as shown in Table 1. The first chopped fiber treatment is called surface hand cleaning which can be carried out by cleaning the chopped fronds by tap water; the second by chemical treatment with NaOH at room temperature using magnetic stirrer. Then, the treated chopped date palm fronds were kept in plastic bags for further work. Hand lay-up method was used to fabricate the reinforced composite sheets using molding box of required size 200mm× 200mm × 5mm which is made of mild steel as shown in Fig.1. Virgin LDPE and PP resin are considered as matrices and were supplied by Gulf Plastic Industries Co. SAOG, and Oman Polypropylene LLC (OPP) Petrochemicals, Sultanate of Oman in the form of pellets, respectively. The mechanical properties of composite matrices are listed in Table 2.

Mixing the chopped fronds with thermoplastic resins was conducted using hand lay-up method [11-12]. First, thermoplastics were melted in an electric oven at 300˚C to allow mixing the chopped date palm fronds randomly within the resins. At this temperature, although thermoplastics were melted, however, chopped fibers were not thermally degraded as found by Almaadeed et al. [13]. Next, pressure was applied manually using 25 kg load for 15 minutes from top of the mold to maintain a uniform thickness of specimen sheets as specified. Sheets were solidified using tap water. During this process, care was taken to avoid formation of air bubbles. Lastly, the composite sheet was pressed manually for 24 hours before testing.

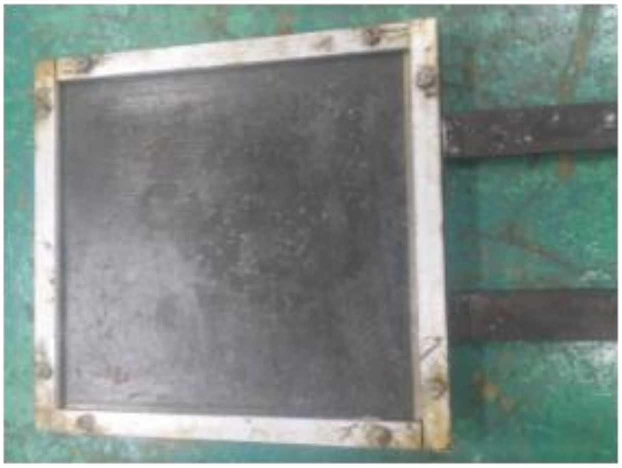


Fig. 1. Photographic View of Mild Steel Mold

Fig. 2. Fabricated Bio-composite sheet (DPF/PP)

Table 1. Fabrication and Design Parameters

Parameter	Level		
	Low	Medium	High
v_f : Chopped Fiber Content (vt.%)	20	40	60
c_p: NaOH Concentration (Wt.%)	5	10	15
T:Treatment Time (h)	2	4	6

Table 2. Mechanical Properties of Matrix

Properties	LDPE	PP
Tensile Strength (MPa)	9.65	33.1
Tensile Modulus (MPa)	393	1344.5
Elongation (%)	100	12
Flexural strength (MPa)	10.34	48.2

Mechanical Testing

Specimens were cut from the prepared composite sheets and adjusted to meet the target size using emery paper. Tensile and flexural tests of date palm chopped fronds composites were carried out using a computer controlled UTM machine with standard specimens, ASTM-D638 and ASTM-D790, respectively as shown in Fig. 3 and 4. For the tensile test, uniaxial load was applied and gage length was fixed at 57 mm. For the flexural test, span length was fixed at 80 mm and the test was conducted till failure. Cross head speed of UTM machine was fixed to 5 mm/min, at a temperature 23 ˚C and humidity 50%. In each case three samples were tested and average value is reported.

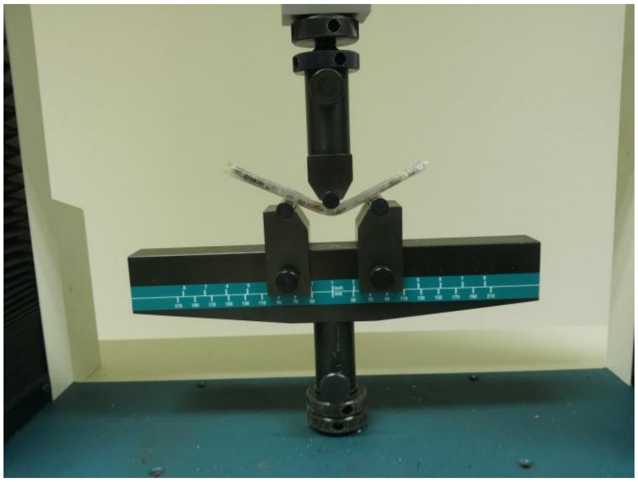


Fig. 3. Photographic View of Tensile Testing

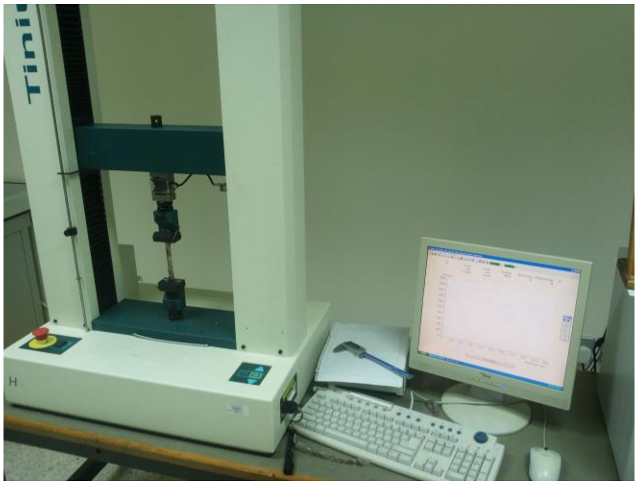


Fig. 4. Photographic View of Flexural Testing

Response Surface Methodology (RSM)

RSM is one of the techniques used to analyze relationships between independent variables and dependent variables and obtain optimal solutions. RSM is also able to illustrate the effect of interaction among the input parameters on a certain output of the experiment using combination of statistical techniques and mathematical models. RSM is applied within the Design Expert 9.0.6 software in this research.

RESULTS AND DISCUSSION

Experimental Results

A small factorial design with a total of 15 experimental runs was carried out on the flaked date palm fronds reinforced composites. The average values of both tensile and flexural strength are reported in Table 3. Also, Fig. 5 shows a comparison between tensile strengths of LDPE and PP composites. A significant drop in tensile strength for both composites has occurred especially at high fiber volume content. A similar trend of drop for such composites has been reported in the literature [14–16]. While, Fig. 6 shows a comparison between flexural strengths of LDPE and PP composites. An improvement in flexural strength for both composites has occurred at low fiber volume content. A gain, a similar observation was reported in the literature [17].

According to Figs. 5 and 6, the maximum flexural strength is obtained for sample number 4 (20 vt. % chopped fronds content, 15 w. % NaOH concentration and 2 h treatment time) for both LDPE and PP based composites. However, the maximum tensile strength is obtained for sample number 3 (20 vt. % chopped fronds content, 5 w. % NaOH concentration and 6 h treatment time) for LDPE and sample 2 (20 vt. % chopped fronds content, 5 w. % NaOH concentration and 4 h treatment time) for PP composite.

Table 3. Experimental Results of Tensile and Flexural Strengths

No.	v_f	c_p	T	t_s (MPa)		f_s (MPa)	
				DPF/ LDPE	DPF/ PP	DPF/ LDPE	DPF/ PP
1	20	5	2	5.81	18.29	15.71	44.6
2	20	5	4	5.62	19.34	15.47	49.29
3	20	5	6	6.56	13.57	13.63	41.15
4	20	15	2	7.2	15.95	16.06	51.19
5	20	15	6	6.78	16.48	15.77	32.35
6	40	5	4	4.51	13.27	12.34	36.91
7	40	10	2	4.13	13.1	13.45	48.44
8	40	10	4	3.62	17.05	13.85	46.91
9	40	10	6	5.86	12.86	12.08	43.69
10	40	15	4	5.86	12.55	14.71	42.21
11	60	5	2	3.67	12.37	8.57	15.98
12	60	5	6	4.13	6.61	10.31	13.32
13	60	10	4	3.67	9.41	9.25	22.91
14	60	15	2	5.45	8.17	10.81	14.14
15	60	15	6	4.75	11.27	10.95	9.67

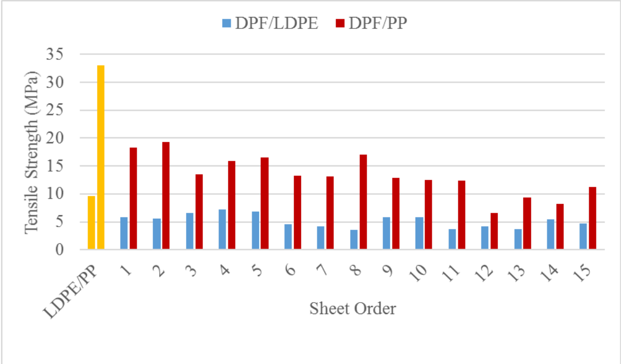


Fig. 5. Tensile Strength of Tested Specimens of DPF/LDPE and DPF/PP

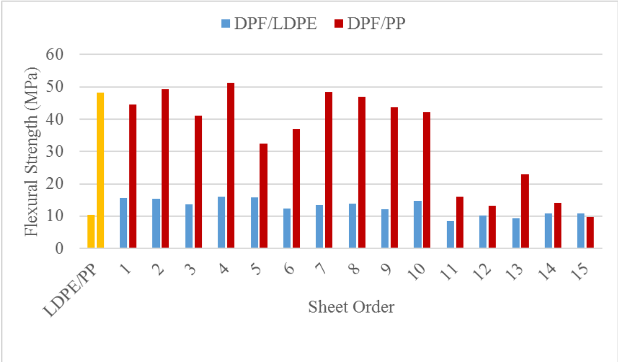
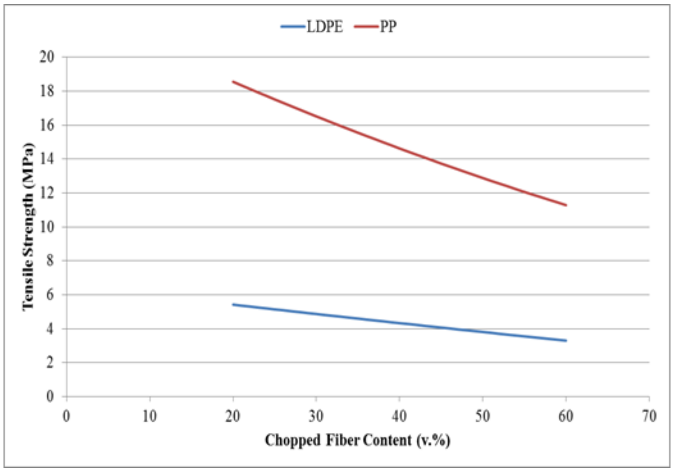
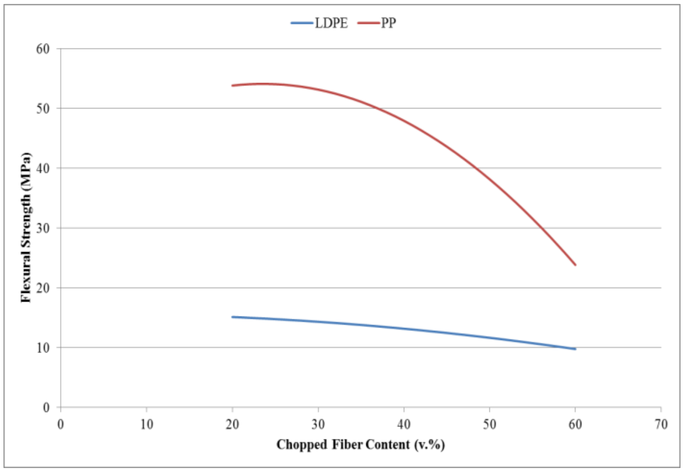


Fig. 6. Flexural Strength of Tested Specimens of DPF/PP and DPF/LDPE

The effect of fiber volume content on output strengths are shown in Fig. 7. Clearly, increasing fiber content yields a reduction in both strengths for both composites (LDPE, PP). This can be attributed to the fabrication method and poor adhesion between fiber and sounding matrix.



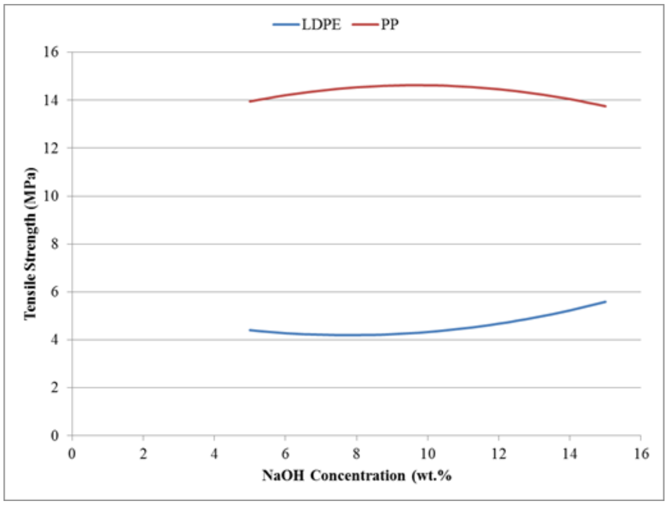
(a)



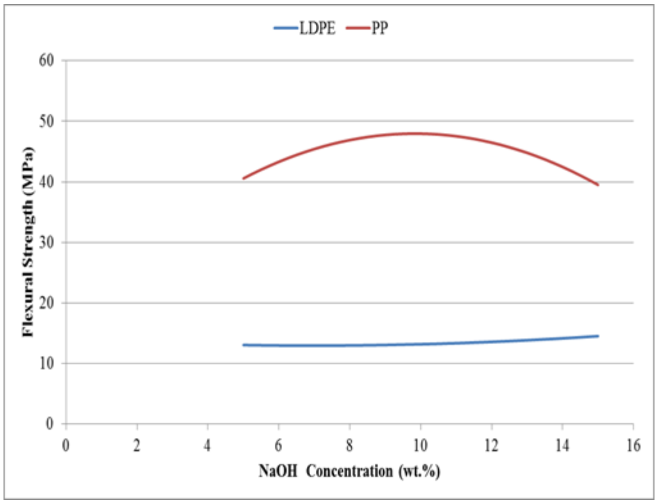
(b)

Fig. 7. The Effect of Chopped Fiber Content on; (a) Tensile Strength, and (b) Flexural Strength Properties

Also, the impact of amount of chemical agent on output strength is shown in Fig. 8. A distinct effect of NaOH concertation on both strengths is obtained for the two types of matrices. In case of PP composite, a moderate amount of NaOH is recommended to use.



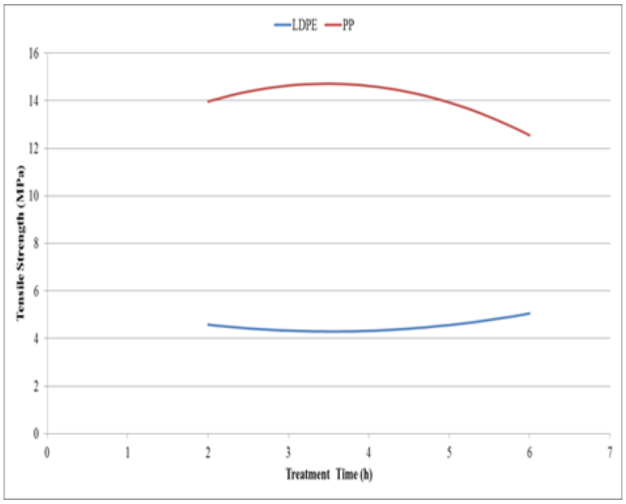
(a)



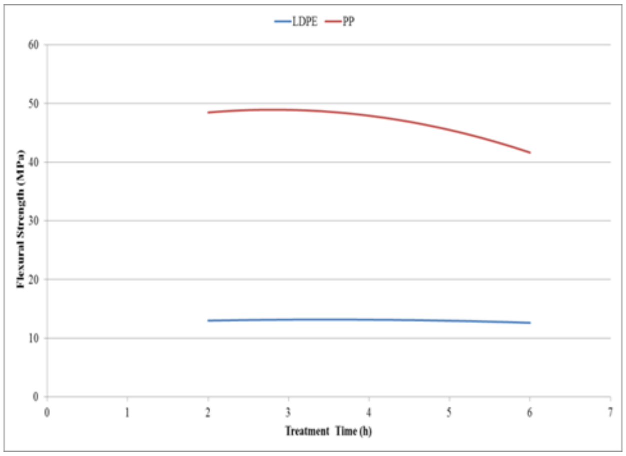
(b)

Fig. 8. The Effect of NaOH Concentration on; (a) Tensile Strength, and (b) Flexural Strength Properties

The effect of treatment time is depicted in Fig. 9 which is minimal in the case of LDPE composite and more pronounced in the case of PP composite. A treatment time of 4 hours seems reasonable to produce optimal results.



(a)



(b)

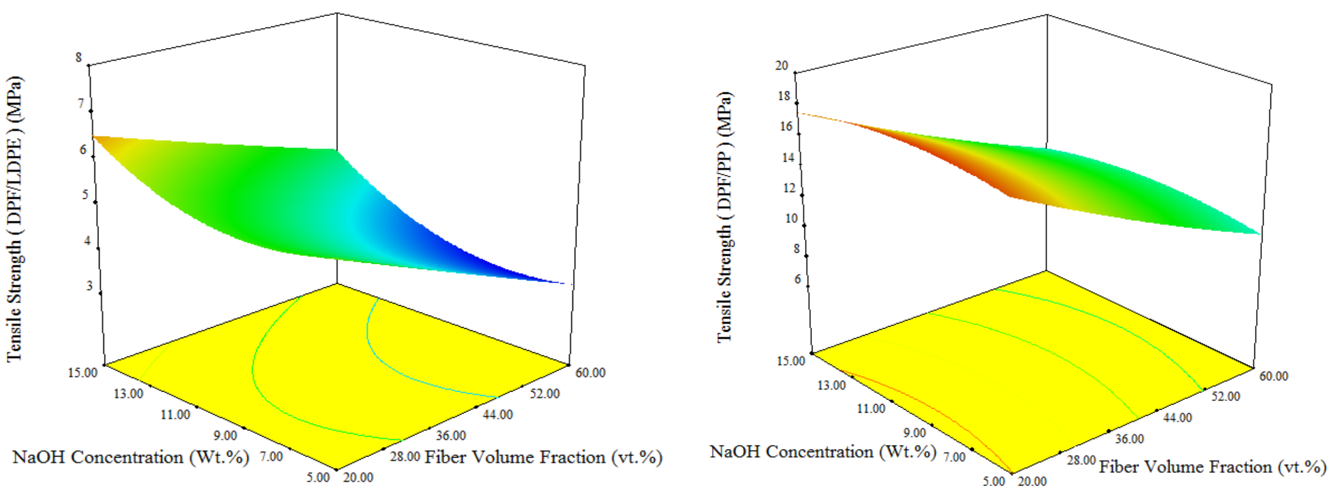
Fig. 9. The Effect of Treatment Time on; (a) Tensile Strength, and (b) Flexural Strength Properties

3D Response Surface Plots

Quadratic models have been selected based on the best fit of experimental data. Using regression equations, the quadratic models are tested and analyzed for significance. Also, the lack of fit and coefficients are developed via Analysis of Variance (ANOVA). The distribution of response surfaces with respect to two different parameters were illustrated using 3D surface plot. Contour lines display the connections of all points that have the same response to produce constant lines. The 3D Response surface and contour plots for tensile, flexural models of DPF/LDPE and DPF/PP are shown in Figs. 10 and 11.

Response Surface Plots of Tensile Strength

Referring to surface plots in Fig. 10, it can be observed that the dominant factor is volume fraction of filler material. At low volume fraction with high chemical treatment percentage and time, improved tensile strength in case of LDPE matrix is obtained. In contrary, this interaction is not highly affecting the DPF/PP tensile strength as shown in Fig. 11(a–d). The interaction of NaOH concentration and treatment time yields a notable effect on the tensile strength. It is recommended to use high chemical percentage and treatment time to achieve higher values of tensile strength in case of DPF/LDPE. Whereas, medium chemical percentage and treatment is suggested for DPF/PP.



(a) (b)

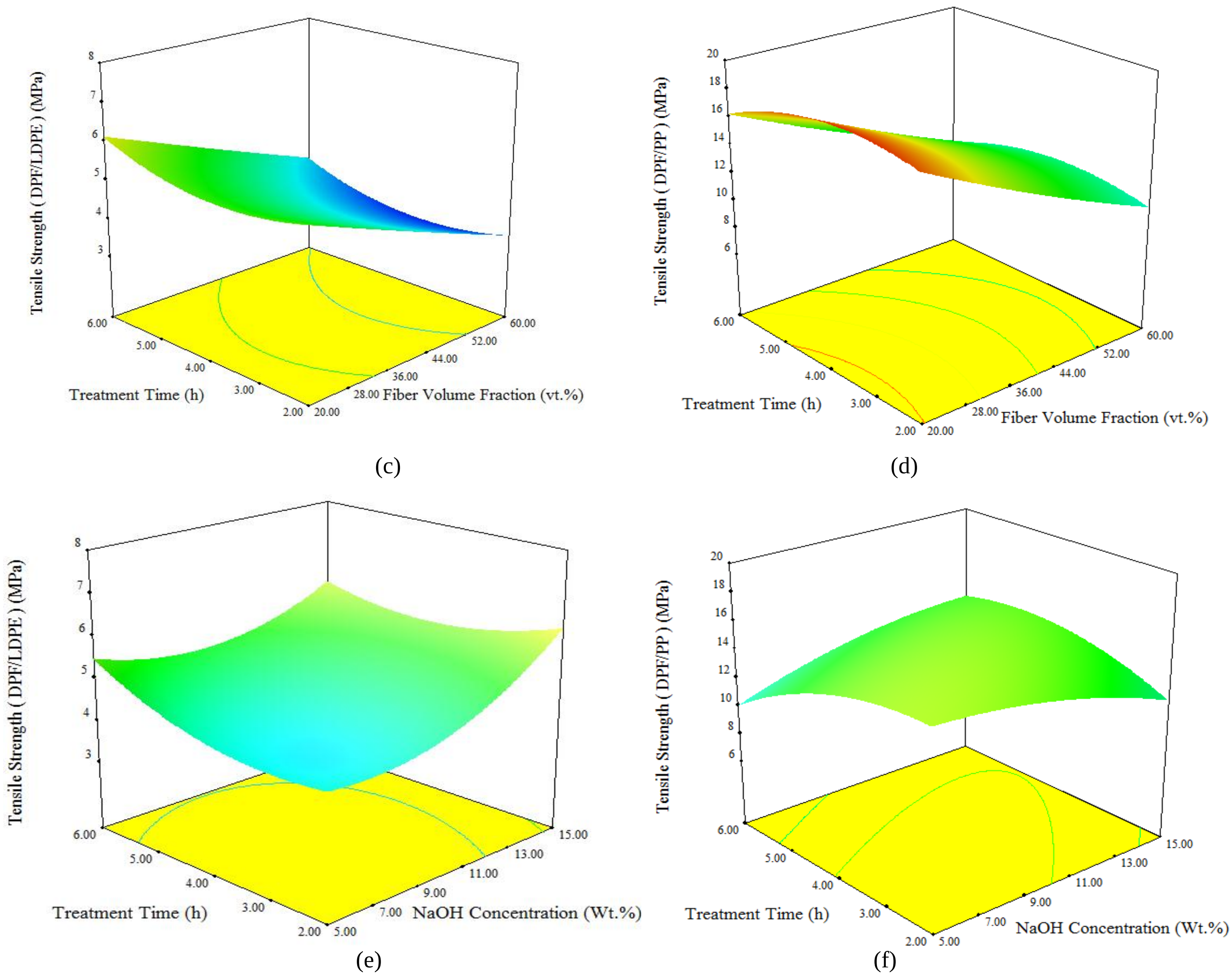


Fig. 10. 3D Surface Plots for Fabrication Parameters Interaction Effect on Tensile Strength

Response Surface Plots of Flexural Strength

Fig. 11 reveals that low fiber volume fraction and high NaOH concentration, regardless the treatment time, contribute to higher flexural strength for DPF/LDPE. However, for DPF/PP low or medium fiber volume content and moderate NaOH concentration is recommended to maximize the response. The interaction of NaOH concentration and treatment time is not significantly affecting the flexural strength of DPF/LDPE. While, in case of DPF/PP, interaction between NaOH concentration and treatment time has a small effect on the flexural strength.

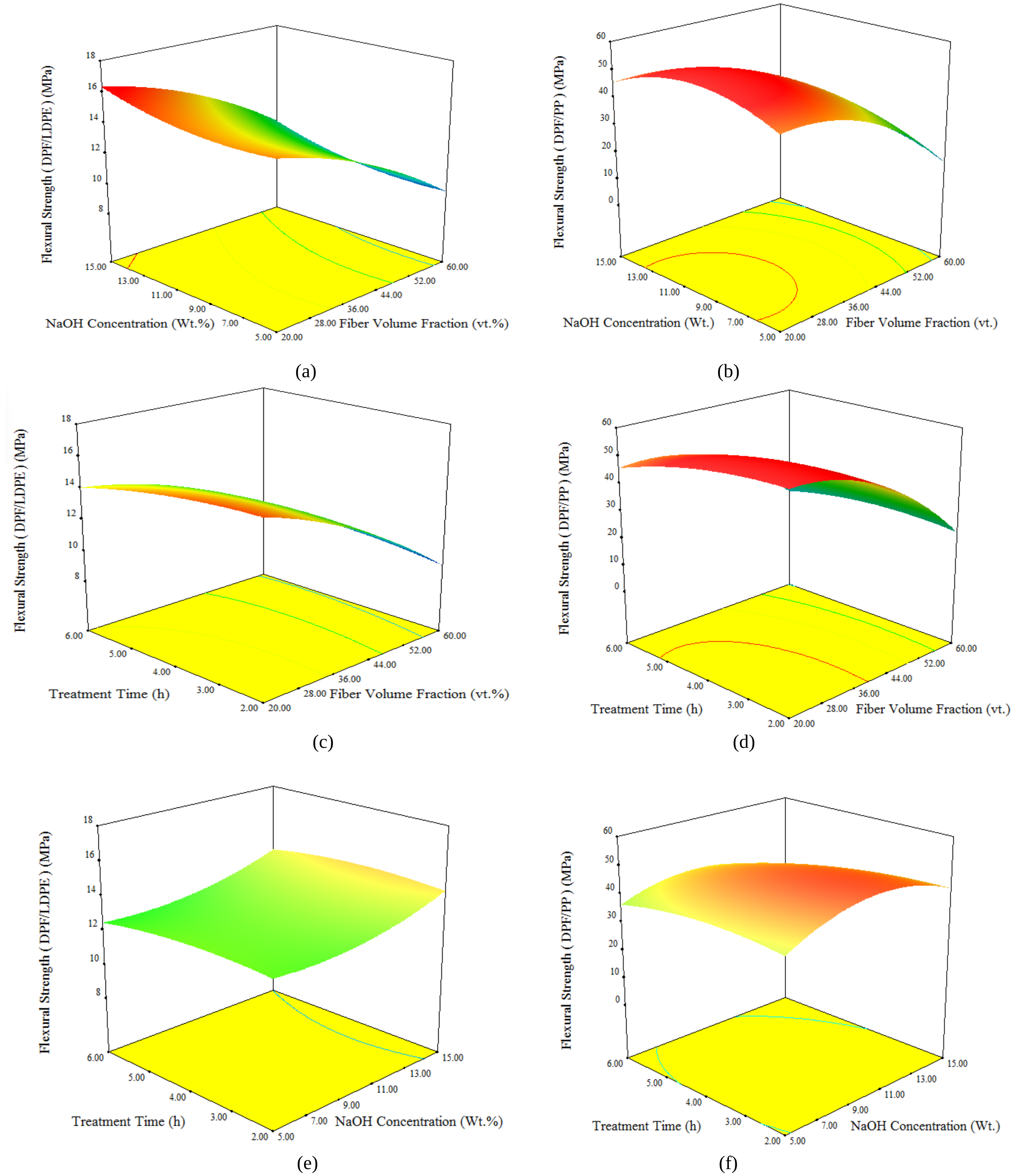


Fig. 11. 3D Surface Plots for Fabrication Parameters Interaction Effect on Flexural Strength

CONCLUSIONS

An experimental setup for evaluation of mechanical strength of chopped date palm fronds reinforced LDPE and PP was presented. Statistical modeling and analysis for both tensile strength and flexural strengths was developed. Three process parameters; chopped DPF content, NaOH concentration and treatment time were considered for statistical analysis. Results obtained in this study have indicated a reasonable enhancement in both strengths of LDPE based-composite. For PP based-composite, while a small improvement in flexural strength was achieved, a degradation in tensile strength has occurred. The RSM was effectively used to determine the impact of interacting fabrication parameters on output strength.

The developed composites can be used in a broad range of applications in which tensile strength is not a major design requirement. Further investigation on effect of fabricating parameters on other thermal and mechanical properties is planned in future.

NOMENCLATURE

ANOVA	Analysis Of Variance
c_p	Chemical Percentage (Wt.%)
DoE	Design of Experiments
LDPE	Low Density Polyethylene
DPF	Date Palm Fronds
f_s	Flexural Strength (MPa)
l	Fiber Length (mm)
NaOH	Sodium Hydroxide
NFRCs	Natural Fiber Reinforced Composites
PP	Polypropylene
RSM	Response Surface Methodology
t_s	Tensile Strength (MPa)
UTM	Universal Testing Machine
v_f	Fiber Volume Fraction (vt. %)
T	Time

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