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Optimization of Hot Pressing Process for Unidirectional Kenaf Polypropylene Composites by Full Factorial Design

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ABSTRACT

In recent years, the use of kenaf fibers as a reinforcement agent in the composite preparation has grown rapidly due to increasing requirement for developing sustainable materials. In this research, unidirectional kenaf polypropylene (PP) composites were prepared using the hot pressing method. However, there has been insufficient research in fabricating the unidirectional kenaf/PP composites that focus on optimum parameter's settings for hot pressing process. Therefore, a study of the optimization process emphasizing on temperature, pressure, time and percentage of kenaf fibers on the tensile properties was conducted with a two-level full factorial design. In addition, the effects of the individual factors and their interaction were also observed. The result showed that the main factor that affects the high-performance of tensile strength, and modulus were due to the kenaf percentage with 21.67% contribution. While, the interaction of kenaf percentage and pressing time influenced 13.26% contribution on the composite properties. Concluding that at temperature 190°C, pressure 5MPa, with 5 minutes pressing time and 50% fiber content will enable optimum tensile strength and young modulus which is 163.12 MPa and 11.17 GPa respectively. Therefore, this also ensures an improvement of 486% tensile strength compared to pure PP.

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Introduction

The great interest in natural fiber polymer composites is growing rapidly due to environment and sustainability issues. Compared to synthetic fibers such as glass, carbon and aramid, natural fibers offer less expensive, renewable, low cost, light weight, high strength and stiffness makes it widely used in production of lightweight composites [1]. This is supported by Mohanty et al. [2], stated that natural fiber composite deliver the same performance for lower weight and 25-30% stronger for the same weight of glass composite. The potential of natural fibers such as kenaf as a reinforcement agent in the polymer composites has proven when the automobile industry, Toyota RAUM equipped with a spare tire cover made of kenaf fiber composites [3]. Kenaf fibers are used in different forms in fiber reinforced polymer composite, such as continuous or non-continuous long fiber, randomly oriented and as woven mat. Woven form are found to be more attractive reinforcements as they provide excellent integrity and conformability for advanced structural applications [4]. Ismail and Hassan [5] prepared the woven kenaf from the kenaf yarn using in-house developed machine while Kobayashi et al. [6] use the woven fabric from micro-braiding technique that weaved on a loom. Non-woven form are produced a lot by needle punching process. The form of non-woven mat will ensures that the fiber are arranged homogenously and exhibit better mechanical properties compared to composites produced using randomly oriented [7]. The core fibers of kenaf is weaker and has excellent absorbing properties and it suitable for binder less pressed panels for thermal and sound insulation [8].

However, there are challenges in handling natural fibers to be used in producing composite which is large variation in fiber properties due to various types of plant fiber, plant maturity, plant originality, location in plant and retting process. This challenges indirectly will affect the properties of the composites [9]. While Hashim et al. [10], in their study suggest that a few factors should be considered and improved to get the superior mechanical properties such as fiber orientation, fiber length, fiber content and processing parameter. For this purpose the optimization process using design of experiment is suggested.

Full factorial design is the important engineering tool for improving a process where it was used to optimize the effect of variable factors, minimize time with reduce the total number of experiment in order to achieve the best of operating conditions and reduced overall costs of the manufacturing [11]. It also has an extensive application in the development of new processes.

According to Sharifi et al. [12], stated that factorial design give the main effect of each parameter on the change in the level of other parameters and the effects of the interactions for different factors. This research is focused on four factor two level full factorial design and analysed using Design Expert version 7.0.0 software. The aim of this study is to investigate the optimum parameters for the hot pressing process on tensile properties by using full factorial design.

Material and Method

The materials used in this study comprise of kenaf bast fibers and polypropylene in the form of pallet and powder. Kenaf bast fibers which has undergone water retting process in order to produce continuous long kenaf fibers. This is locally purchased from Lembaga Kenaf dan Tembakau Negara (LKTN), Kelantan. Kenaf fibers are combed in order to untangle the strong bonding between the fibers and also to eliminate the impurities or contaminant that come from the soil, wax, lignin, pectin and others. Besides, the combed fibers will ease to control the process of fiber alignment or orient especially in the direction that have been decide in the composite fabrication. Figure 1 shows the different between the combed and uncombed continuous long kenaf fibers. While, Polypropylene (TITANPRO PX 617) in the form of pallet and powder (HM20/70P) were supplied by Lotte Chemical Titan (M) Sdn. Bhd., Malaysia and Goonvean Fibres Ltd., United Kingdom respectively.

Samples were prepared by hot pressing method where the fibers will align unidirectional and sandwiching between the two sheet of PP film that produce from the PP pallet as shown in Figure 2. Prior to that, the fibers will shake together manually in container with PP powder to make sure that the good adhesion between the fibers and powder can occurred.

(a) (b)

Figure 1 : (a) Uncombed Kenaf Fiber (b) Combed Kenaf Fiber

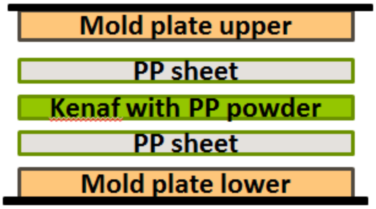


Figure 2: Schematic diagram of sandwiching

Modeling of Full Factorial Design

The properties of unidirectional Kenaf/PP composites may affected by material preparation or processing parameters. In order to determine the optimum processing parameters four factors (percentage of kenaf fibers, processing temperature, time and pressure) were identified as likely to impact the mechanical properties of the composites. In the present study, two level factorial design was applied to explore the effect of each factors on the response which is tensile properties. In order to measure the effect of all the factors combinations which influence the tensile properties, 17 factorial experiments were carried out at two levels including one other at the center point. The factors and level for full factorial design are listed in Table 1. The low and high levels for the factors were assigned according to some preliminary experiments.

Table 1: Experimental ranges and levels of factors in full factorial design

Factors	Level		
	Low	**Center**	**High**
A : Temperature (^{0}C)	190	200	210
B : Pressure (MPa)	5	7.5	10
C : Time (minutes)	5	10	15
D : Fiber Content (%)	30	40	50

At each combination of these factors the hot pressing is conducted to produce samples for the testing. Table 2 shows the experimental design matrix with the result of 2 level full factorial design. Tensile test were performed according to standard ASTM 638. Five samples were prepared for each processing parameter. All the test specimens were tested at room temperature with a cross head speed 5mm/min.

Table 2: Experimental design matrix with the results of 24 full factorial design

Run no.	Factors			
	A: Temperature	**B: Pressure**	**C: Time**	**D: % Kenaf**
1	190	10	15	50
2	190	5	5	50
3	210	5	5	30
4	210	10	15	30
5	210	10	5	50
6	200	7.5	10	40
7	190	5	15	50
8	210	5	5	50
9	210	10	5	30
10	190	10	15	30
11	190	5	15	30
12	190	5	5	30
13	210	5	15	30
14	190	10	5	30
15	210	5	15	50
16	210	10	15	50
17	190	10	5	50

Result and Discussion

Mechanical properties which is tensile strength and modulus of unidirectional kenaf/PP composites with the experimental and predicted results are presented in Table 3. The effect of the factors that been studied is determine by a change in the range of low to the high level. The factors is frequently called a main effect that refers to main factors in the experiment. From the analysis the main effect and the interaction of the different factors were determined. The mathematical model for two level full factorial design can be given as below:

$$\text{Tensile} = 108.51 - 3.08A - 5.07B - 9.65C + 13.06D - 5.86BC + 7.25BD - 10.23CD + 10.5ACD + 9.86BCD - 7.15ABCD$$

$$\text{Modulus} = 9088.4 - 9.81A - 589.65B - 116.08C + 1354.27D + 67.64AC - 175.71CD + 665.87ACD$$

where *A*, *B*, *C* and *D* stands for temperature, pressure, time and % kenaf.

Analysis of Variance

After estimating the main effect, the interacting factors were determined by performing the analysis of variance (ANOVA). Sum of squares (SS) of each factor quantifies its important in the process and the increase of SS value will increase the significant of the corresponding factor in the undergoing process. The main and interaction effects of each factor have P value <0.05 and will considered as potentially significant as shown in Table 4.

Main and Interaction Effect

The main and interaction effects of the processing parameters are determined using analysis of variance (ANOVA). Based on the findings, Figure 3(a) which graphical represents the effects of tensile strength showed that by increasing the kenaf content (D) from 30% up to 50% will significantly effect higher tensile strength. This finding is supported by Mahjoub et al. [13] where by increasing the fiber loading by 40% of kenaf and jute fiber reinforced PP composites, will increase the tensile strength and modulus up to 180%. Meanwhile, by extending the pressing time (C), the composite properties will be reduced. In addition, 5 minute pressing time will obtain the highest tensile modulus compared to 10 minutes.

It was also found that by increasing processing temperature (A) and pressure (B) it also lowered the tensile strength. Kobayashi et al. [6] also found that the decrease in strength with temperature is due to fiber degradation. Where higher pressure attributed to pour out of PP polymer during pressing process contributed to lower impregnation to kenaf fiber. Results from the main effect leads to the interaction effect as shown in Figure 3(b). From the graph an interaction between pressing time and percentage of kenaf gives a positive effect which is an increase in tensile strength. The optimum properties obtained with 50% of kenaf content and 5 minute pressing time.

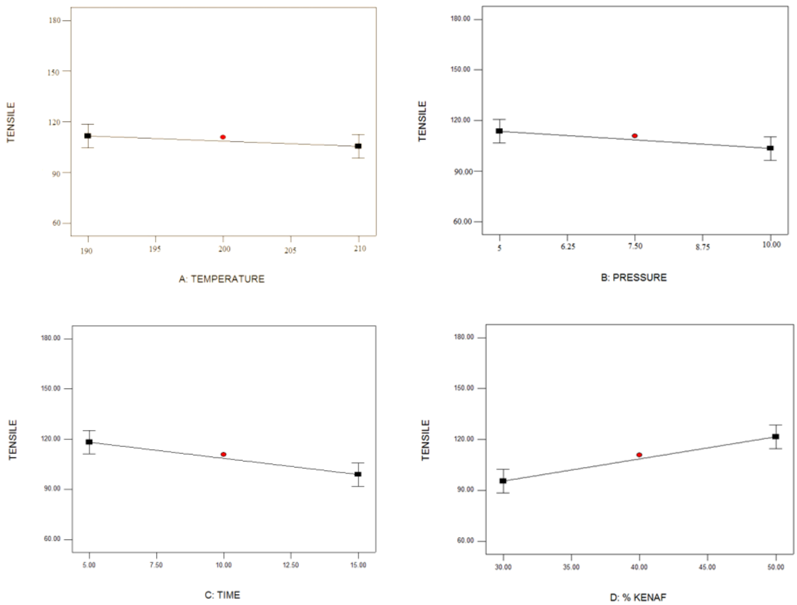
Meanwhile, the tensile modulus also shows the same attribute as tensile strength as in Figure 3(a). The interaction between pressing time and fiber content give the maximum tensile modulus. From ANOVA, it also shows that an interaction of ACD give a significant effect to the tensile modulus. Lastly it can be concluded that from the ANOVA there have a processing factor that need to be control in order to fabricate the optimum composite properties. Previous research done by S. Lee [14] shows that by using the same methode and fix the processing parameter contribute to 120 MPa of tensile strength. This shows that, the need of optimization process due to get the optimum processing parameters.

Table 3: Factorial design matrix of four factors with experimental and predicted responses

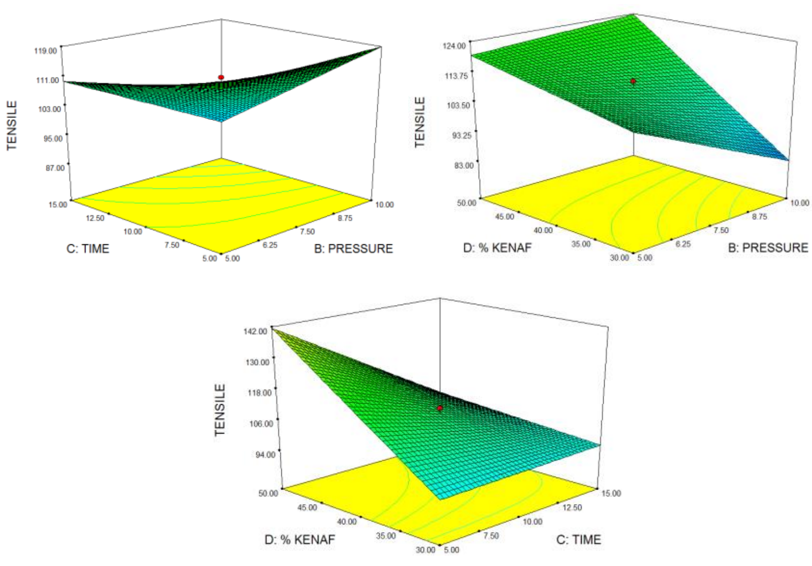
Run No.	Factors				Tensile Strength (MPa)			Tensile Modulus (MPa)		
	A: Temperature	B: Pressure	C: Time	D: % Kenaf	Experimental	Predicted	Residual	Experimental	Predicted	Residual
1	190	10	15	50	85.42	76.9	8.52	7333.97	7675.72	-341.75
2	190	5	5	50	97.51	106.03	-8.52	8311.65	8852.57	-540.92
3	210	5	5	30	89.28	98.01	-8.73	7129.23	6496.42	632.81
4	210	10	15	30	107.29	98.56	8.73	7923.14	7673.28	249.86
5	210	10	5	50	141.57	144.8	-3.23	10126.33	8991.45	1134.88
6	200	7.5	10	40	106.57	103.34	3.23	8660.92	7775.37	885.55
7	190	5	15	50	68.42	74.44	-6.02	6968.34	7812.16	-843.82
8	210	5	5	50	67.59	61.57	6.02	5419.46	6596.07	1176.61
9	210	10	5	30	170.46	164	6.46	11234.41	12067.42	-833.01
10	190	10	15	30	116.08	122.54	-6.46	10655.95	10580.78	75.17
11	190	5	15	30	148.83	146.05	2.78	11430.07	10888.12	541.95
12	190	5	5	30	130.41	133.19	-2.78	9617.37	9401.48	215.89
13	210	5	15	30	75.66	80.95	-5.29	10686.83	10016.82	670.01
14	190	10	5	30	115.37	110.08	5.29	10414.29	11464.23	1049.94
15	210	5	15	50	113.12	107.62	5.5	7876.45	8837.52	-961.07
16	210	10	15	50	102.66	108.16	-5.5	11625.93	10284.93	1341
17	190	10	5	50	110.79	110.79	0	9518.26	9518.26	0

Table 4 : Analysis of Variance

Response	Factor	% Contribution	Coefficient	Sum of squares	Standard error	F- value	P-value
Tensile strength	A	1.21	-3.08	151.76	2.75	1.25	0.3141
	B	3.26	-5.07	410.5	2.75	3.38	0.1252
	C	11.82	-9.65	1488.48	2.75	12.27	0.0172
	D	21.67	13.06	2728.41	2.75	22.5	0.0051
	BC	4.36	-5.86	549	2.75	4.53	0.0867
	BD	6.67	7.25	840.08	2.75	6.93	0.0464
	CD	13.26	-10.23	1673.29	2.75	13.8	0.0138
	ACD	14.01	10.5	1763.65	2.75	14.54	0.0125
	BCD	12.36	9.86	1556.63	2.75	12.83	0.0158
	ABCD	6.49	-7.15	817.63	2.75	6.74	0.0485
Tensile Modulus	A	0.003	-9.81	1539	239.82	0.002	0.9685
	B	10.43	-589.65	5563000	239.82	6.05	0.0435
	C	0.4	-116.08	215600	239.82	0.23	0.6431
	D	55.04	1354.27	29340000	239.82	31.89	0.0008
	BC	5.05	-410.13	2691000	239.82	2.92	0.131
	BD	2.43	284.44	1294000	239.82	1.41	0.2743
	CD	0.93	-175.71	494000	239.82	0.54	0.4876
	ACD	13.31	665.87	7094000	239.82	7.71	0.0274

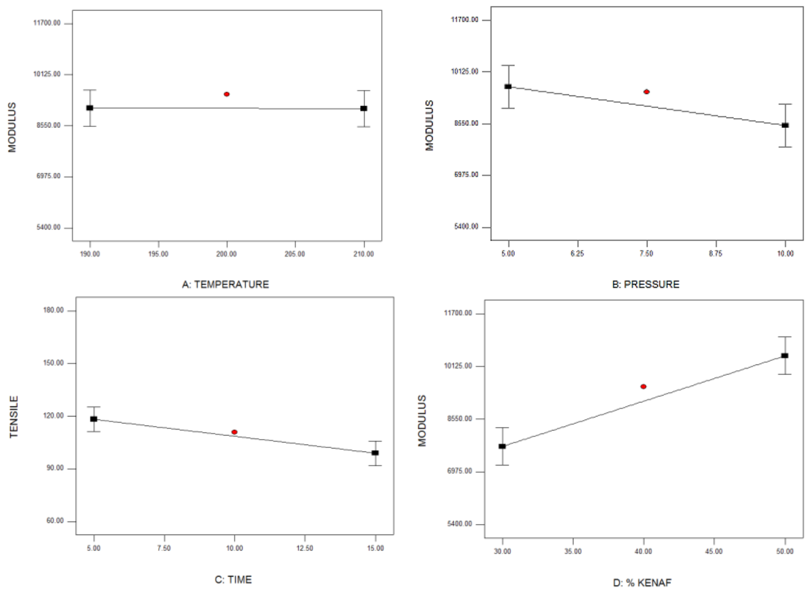


(a)

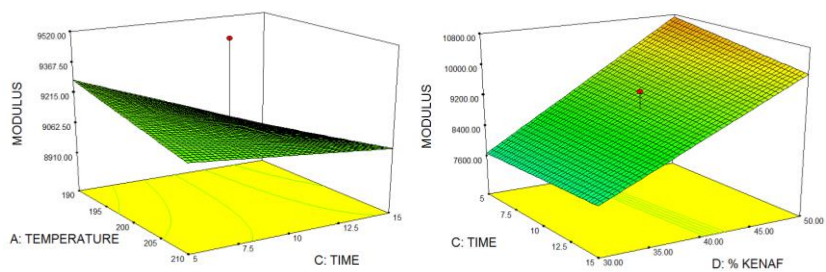


(b)

Figure 3: Tensile Strength (a) Main effect plot (b) Interaction plot



(a)



(b)

Figure 4: Tensile Modulus : (a) Main effect plot (b) Interaction plot

Optimization

The optimization of processing parameter was carried out by a multiple response method to optimize different combination of parameters to achieve maximum tensile strength and tensile modulus. Figure 5 shows the graphical desirability for tensile and modulus generated from 29 optimum solution via numerical optimization. It can be concluded that the processing parameter is optimum at temperature 190˚C, pressure 5MPa, 5 minutes pressing time and 50% of fibers contained with desirability 0.928. By apply this parameter at hot pressing process, will give the optimum tensile strength and modulus which is 163.12 MPa and 11.17 GPa respectively. The confirmation test had been done to ensure the parameter is valid and it was found that the percentage of error is different less than 10%. This indicated that, this model is suitable to be used for further experiment.

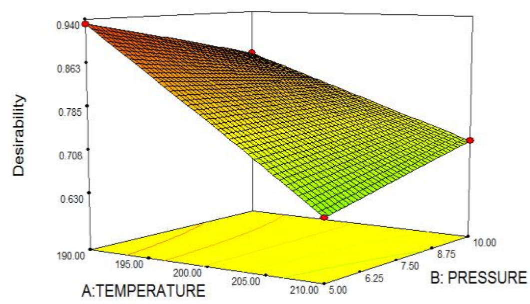


Figure 5: Contour plot of desirability

Conclusions

In this work, the optimum parameter of the hot pressing process was successfully achieved. The result obtained agreed with the previous studies which have shown that by increasing the fiber content up to 50% will give higher tensile values for all types of composite. On the other hand, for the processing temperature can be conclude that 190°C is suitable in fabrication of kenaf/PP composite. At higher temperature kenaf fiber will decompose and will cause lower impregnation that effects the mechanical properties of the composite. While the increase of molding pressure will increase the amount of resin to pour out from a mold and also will decline the bonding between the fibers and polymer. Lastly, it can be conclude that by the optimization process will produce the optimum tensile strength of unidirectional kenaf/PP composite for the appropriate application.

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