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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Factorial Analysis of Tensile Properties of Areca Leaf Sheath (ALS) Subjected to Flattening

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DOI: https://doi.org/10.30880/ijie.2021.13.02.010
Received 9 June 2020; Accepted 1 December 2020; Available online 28 February 2021

Abstract: Areca leaf sheath (ALS) is a common agricultural waste produced in Southeast Asia countries, which is widely utilized over the decades to make biodegradable disposable dining wares. The workable surface of ALS for heat pressing is limited due to the concavity in the middle and folding at the edges of ALS. This study proposes that the ALS is flattened using a padding mangle prior to the forming process. The aim is to investigate the effect of ALS thickness and flattening pressure on the ultimate tensile strength and strain at break of ALS. A range of factors influencing the flattening process were investigated using design of experiment (DOE) approach based on analysis of variance (ANOVA). As the applied pressure increases, the thickness reduction of the ALS also increases. The tensile test was carried out in accordance to ASTM D3039 standard. It is found that ALS thickness and flattening pressure affect the results differently. The highest ultimate tensile strength (23.25 MPa) is obtained from 3-4 mm thick grain direction samples flattened at 5 bar; whereas the highest strain is 58.28% from perpendicular grain direction samples flattened at 1 bar, with thickness range of 3-4 mm. The results suggest that flattening process does not influence the tensile strength of ALS significantly when it is fed in parallel direction; but decreases the strain slightly.

Keywords: ANOVA, Areca leaf sheath, disposable dining ware, flattening, tensile properties

1. Introduction

There is an urgency to emphasize on environmentally friendly and sustainable products in recent years to preserve our Mother Earth [1]. Malaysia is in the eighth position among the countries that have created the worst plastic wastes among 192 countries [2]. This issue urges effective alternatives to replace plastics as the raw material to produce disposable dining wares as the usage of disposable products are understandably unavoidable in the daily lives of urban citizens. There are countless attempts done by researchers and companies to produce paper and bio-based polymers products [3]. A simple yet sustainable raw material has been used traditionally for decades in India to make disposable dining wares such as plates, cups and bowls, which is the Areca leaf sheath (ALS).

The Areca palm tree is usually referring to the most cultivated species Areca Catechu Linn. ALS is the extension of the rachis of the Areca leaf, which completely encircles the tree stem of Areca palm. The ALS sheds 5-6 times a year per tree [4][5]. An adult ALS is concaved in the center, it also has a greenish or brown, waxy and tough outer surface, with a glossy creamy-colored inner surface [4]. ALS is an agricultural waste at the Areca palm plantation fields. Usually, the fallen ALS are collected and then burnt off due to its slow decomposition rate. Open burning contributes to global warming and carbon deposit. Thus, the locals impart commercial values to this biodegradable resource by utilizing it to be the raw material for producing disposable plates and containers [6][7].

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The ALS disposable plates have a simple and energy efficient manufacturing process. The raw ALS are collected from the Areca palm plantation once the sheaths fall from the trees. After that, the sheaths need to be sun dried and stored. Normally, the drying and storage time is around six months. To shorten the time of drying ALS, there was an attempt to develop a cost-effective solar dryer [6]. Then, the sheaths are being washed manually in water by using a brush. ALS absorbed water during this process, thus gaining some moisture, making it more flexible for pressing afterward. Then, the dried sheaths were placed into the pressing machine, with the pressing dies heated up to certain temperatures by external energy source. The ALS were pressed for a while to conform its structure to the shape of the mold. It should be noted that the moisture content of the sheaths should be maintained at above 5% to prevent cracks on the material. If the moisture content of the pressed plates is too high, then the plates need to be used immediately to prevent fungi from growing; or else it needs to be dried. The dried ALS product can be stored for up to 12 months. Finally, the manufactured products are packaged in bundles in plastic bags to keep them dry and hygienic before used [6][8].

The manufacturing process of ALS disposable dining wares is similar to that of metal sheet deep drawing process, but the height of the container might not be greater than its diameter. The deep drawing process usually starts with stretch forming followed by deep drawing. Firstly, the punch moves downwards and form out the bottom during the forming process. When the bottom is formed, deep drawing process follows and form the complete shape of the punch on the material. The material experiences different stress conditions during deep drawing process on the flange area, cup wall area, and the bottom area. These stress conditions lead to strain forming where the material deforms and conform into the shape of the die and punch [9].

Nomenclature	
ALS	: Areca Leaf Sheath
ANOVA	: Analysis of Variance

2. Methodology

2.1 Material

In this study, samples of ALS originated from Indonesia were used. The samples were stored in an air-conditioned laboratory (65% RH, 23˚C) after collected. Prior to the experiments, the surface of the samples was cleaned thoroughly with a wet cloth to remove the particles accumulated. The ALS has non-uniform thicknesses over the surface. The maximum and minimum thicknesses measured from the ALS using a Vernier calliper (0.05 mm accuracy) are 8.2 mm and 0.9 mm respectively. Since the thickness range of ALS is huge, this study categorised only two thickness ranges to be studied specifically, which are 2 to 3 mm and 3 to 4 mm.

2.2 Flattening Process

Due to the concavity of ALS in the centre, this study proposes that the sheaths be flattened using a vertical laboratory padding mangle (Model P-AO, China) to increase the workable surface of ALS. The padding machine has a range of flattening pressure options from 1 bar to 5 bar. ALS were fed into the padding mangle in the directions that are both parallel and perpendicular to the grain direction. Fig 1 illustrates the parallel and perpendicular to grain direction of ALS.

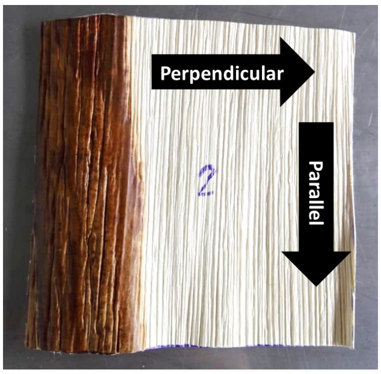

Fig. 1 - Parallel and perpendicular to grain direction of ALS

2.3 Thickness Analysis

The effect of flattening pressure on the percentage of ALS thickness reduction was investigated. Three levels of pressure were selected, which are 1 bar, 3 bar, and 5 bar. The ALS were cut into the size of 10 cm × 10 cm, then the thickness at 8 points of the samples were measured using a Vernier calliper (0.05 mm precision). Fig 2 indicated the location of the 8 measurement points by numbers. Three replicates were tested for each flattening pressure. The flattening process for each sample was repeated for five times to ensure that a flat structure is obtained. The thickness of ALS samples was measured after every repetition of flattening. The significance difference of the pressure parameters was analysed using one-way ANOVA and Tukey Pairwise Comparison Test in Minitab 18 software.

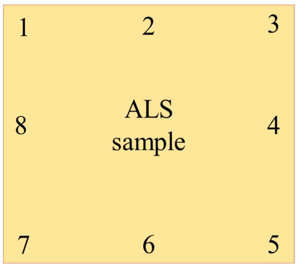

Fig. 2 - Measurement points of ALS thickness

2.4 Tensile Test

The tensile test was subjected to multilevel full factorial experimental design. The independent variables are the thicknesses of ALS (2-3 mm and 3-4 mm) and the flattening pressure (0 bar as control, 1 bar, and 5 bar). Whereas the responses are the ultimate tensile strength and strain of the ALS. Five replications were needed for each level, one experiment set requires a total of thirty experimental runs. Since ALS is an anisotropic material, two sets of experiments were carried out for both parallel and perpendicular directions to the grain of ALS. A randomized run order for one experiment set was generated using Minitab 18.1 software to minimize the biasness in the experiments as shown in Table 1.

The tensile test was conducted in accordance to ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, based on the study of Banagar et al. [11]. The testing was done on a Universal Testing Machine (Shimadzu AGS-J STD. W/O CELL, Japan). The samples were manually cut to obtain length and width of 250 mm and 25 mm respectively. The average thickness of the ALS samples was calculated after obtaining three measurement readings along the samples. Testing speeds for the parallel and perpendicular oriented samples were 2 mm/min and 5 mm/min correspondingly. The samples were expected to break within 10 mins during the test. After the thickness reduction study was done, it is decided that the ALS samples for tensile test are to be flattened three times instead of five times for time and energy efficiency.

The main effects and interaction of ALS thickness and flattening pressure on ALS tensile properties were analysed by two-way ANOVA and Tukey Pairwise Comparison Test using Minitab 18.1 software. The factors with low probability value (P≤0.05) were identified to have significant effect on the responses of tensile test in this study.

Table 1 - Randomized run order generated by Minitab 18

Standard Order	Run Order	Thickness, mm	Pressure, bar
23	1	3-4	1
9	2	2-3	5
4	3	3-4	0
21	4	2-3	5
28	5	3-4	0
16	6	3-4	0
15	7	2-3	5
5	8	3- 4	1
25	9	2-3	0
14	10	2-3	1
13	11	2-3	0
17	12	3-4	1
30	13	3-4	5
24	14	3-4	5

Table 1 (cont.) - Randomized run order generated by Minitab 18

10	15	3-4	0
12	16	3-4	5
20	17	2-3	1
11	18	3-4	1
29	19	3-4	1
1	20	2-3	0
27	21	2-3	5
8	22	2-3	1
22	23	3-4	0
6	24	3-4	5
19	25	2-3	0
26	26	2-3	1
7	27	2-3	0
18	28	3-4	5
3	29	2-3	5
2	30	2-3	1

3. Results and Discussion

3.1 Thickness Reduction

Table 2 presents the percentage of ALS thickness reduction after 5 repetitions of flattening process. The ALS thicknesses were reduced 25.08%, 21.60%, and 13.06% under 5 bar, 3 bar, and 1 bar of pressures respectively. It seems that as the pressure increases, the thickness reduction also increases.

Table 2 - Reduction of ALS thickness after 5 presses

Pressure, bar	Sample no.	Thickness reduction, %	Average, %
5	5-A	26.10	25.08
	5-B	23.34	
	5-C	25.79	
3	3-A	19.70	21.60
	3-B	19.88	
	3-C	25.22	
1	1-A	18.25	13.66
	1-B	7.41	
	1-C	15.33	

From Table 3, the one-way ANOVA result confirmed that the pressure has significant effect on the thickness reduction of ALS. The P-Value obtained is 0.026 which is lower than 0.05. The Tukey method was conducted to probe further as for which pressure has significance difference from one another. It is shown in Table 4 that the effect of 1 bar is significantly different than 5 bar, while 3 bar has no significance difference from the other two.

Table 3 - One-way ANOVA result for effect of flattening pressure on ALS thickness reduction

Source	Adj SS	Adj MS	F-Value	P-Value
Pressure, bar	205.34	102.67	7.07	0.026
Error	87.16	14.53		
Total	292.51			

Table 4 - Tukey method grouping information for the effect of pressure on thickness reduction

Pressure, bar	Mean	Grouping	
5	25.077	A	
3	21.60	A	B
1	13.66		B

3.2 Ultimate Tensile Strength

ALS is an organic anisotropic material, which the tensile properties of different directions to the grains are different. From Table 5, it is observed that the ultimate tensile strengths for parallel oriented samples are higher than perpendicular samples. The tensile strengths for parallel samples are in agreement with the tensile strength value from the study of Banagar et al. which is 16.45 MPa [11]. The highest tensile strength obtained in this study is 23.25 MPa, from the parallel oriented ALS that were between 3-4 mm thickness ranges and have undergone 5 bar of flattening pressure. This result seems to suggest that as the flattening pressure and thickness of ALS increase, the ultimate tensile strength also increases for parallel direction ALS. However, the two-way ANOVA result as shown in Table 6 denies that either pressure or ALS thickness has significant effect on ultimate tensile strength at 95% confidence level. All the P-Values for main effects and interaction of pressure and thickness are higher than 0.05. The claim in ANOVA result is supported by the result that non-flattened ALS with 2-3 mm thicknesses acquired 20.04 MPa tensile strength which is the highest reading after 23.25 MPa. The higher pressure reduces the cross-sectional area of ALS more. But theoretically, the cross-sectional area or thickness of the ALS would not influence the tensile strength much, as the tensile load force was distributed over the area according to the definition of stress.

Table 5 - Ultimate tensile strength of ALS

Pressure, bar	Thickness, mm	Ultimate tensile strength, MPa	
		Parallel	Perpendicular
5	2-3	19.15	0.78
5	3-4	23.25	0.85
1	2-3	16.72	0.52
1	3-4	15.64	1.53
0	2-3	20.04	1.67
0	3-4	16.83	1.59

Table 6 - Two-way ANOVA result for ultimate tensile strength of parallel oriented ALS

Source	Adj SS	Adj MS	F-Value	P-Value
Pressure	126.226	63.1130	2.45	0.108
Thickness	0.030	0.02970	0.00	0.973
Pressure*Thickness	70.727	35.3635	1.37	0.273
Error	618.496	25.7707		
Total	815.479			

From the results obtained for perpendicular oriented ALS (Table 5), the maximum ultimate tensile strength reading is observed from the non-flattened 2-3 mm thick ALS. It is interesting to note that the samples that went through 5 bar pressure of flattening generally have lower tensile strength than non-flattened and 1 bar pressed samples. This could be caused by cracking of ALS due to brittleness in perpendicular grain direction. Another problem encountered was that, the centre part thickness was always higher than the edges for perpendicular oriented ALS samples. The thicker part at the centre may be caused by more intense lignification, giving it more rigid structure and stronger strength [12]. This shape caused the tendency that the sample break outside of the gauge length range of the samples.

In the ANOVA result from Table 7, the ultimate tensile strength of perpendicular oriented ALS is said to be significantly affected by the main effects and interaction of flattening pressure and ALS thicknesses.

Table 7 - Two-way ANOVA result for ultimate tensile strength of perpendicular oriented ALS

Source	Adj SS	Adj MS	F-Value	P-Value
Pressure	3.5684	1.78418	22.84	0.000
Thickness	0.8404	0.84043	10.76	0.003
Pressure*Thickness	1.7268	0.86341	11.05	0.000
Error	1.8748	0.07812		
Total	8.0105			

The significance difference within the factor groups was studied further using Tukey Pairwise Comparison method and the results are as displayed in Table 8. The perpendicular oriented ALS gave higher tensile strength when it is not flattened and when it has higher thickness. The ALS samples that had been flattened at 1 bar pressure show higher tensile strength for 3-4 mm thickness but lower tensile strength for 2-3 mm thickness. Meanwhile, all the non-flattened ALS show higher tensile strength than the pressed ones.

Table 8 - Tukey method grouping information for effects of pressure and thickness on ultimate tensile strength of perpendicular oriented ALS

Source	Level	Mean	Grouping	
Pressure	0	1.62968	A	
	1	1.02354		B
	5	0.81700		B
Thickness	3-4	1.32412	A	
	2-3	0.98937		B
Pressure*Thickness	0*2-3	1.66515	A	
	0*3-4	1.59421	A	
	1*3-4	1.52788	A	
	5*3-4	0.85026		B
	5*2-3	0.78375		B
	1*2-3	0.51919		B

Thus, it can be summarised that the flattening process is most appropriate to be done parallel to the grain direction of ALS. This can avoid reduction of ultimate tensile strength of the material due to cracking.

3.3 Strain

Fracture strain is the elongation of a material after tensile test at breakage. This property helps to describe the ductility of ALS for forming process. From Table 9, the perpendicular samples possessed higher strain than the parallel samples. This means that ALS is stiffer at the parallel to grain direction but is more ductile at the perpendicular direction when it is subjected to uniaxial stress. ALS as an organic complex composite, the fibre-fibre adhesion through hemicellulose and lignin matrix was gradually overcame by tension force at perpendicular grain direction [13,14]. The lowest strain (3.06%) is obtained from the 3-4 mm thick parallel oriented ALS that were pressed at 5 bar, while the highest (58.28%) is from the 3-4 mm thick perpendicular oriented ALS that were pressed at 1 bar pressure. It is noticed that the strain of parallel ALS is the highest for 1 bar pressure, and lowest for 5 bar pressure. The thickness range of 2-3 mm show slightly higher strain than 3-4 mm thickness for parallel ALS. However, the strains for perpendicular oriented ALS do not show a uniform pattern. Two dramatically high strain values occurred, which are 58.28% and 52.64% for 3-4 mm thick ALS after 1 bar pressed and 3-4 mm thickness ALS without being flattened respectively.

Table 9 - Strain of ALS

Pressure, bar	Thickness, mm	Strain, %	
		Parallel	Perpendicular
5	2-3	3.42	24.55
5	3-4	3.06	19.28
1	2-3	7.77	14.57
1	3-4	6.10	58.28
0	2-3	5.06	18.17
0	3-4	4.80	52.64

Both the flattening pressure and ALS thickness significantly affect the strain of the parallel oriented ALS samples as indicated by ANOVA results in Table 10. There is no significant interaction between these two factors. From Table 11, all the groups within pressure and thickness factors are said to be significantly different from one another. The flattening pressure, thickness and their interaction influenced the strain of perpendicular oriented ALS significantly according to the ANOVA results (Table 12). Table 13 presents the Tukey comparison test for perpendicular samples on strain as the response. The pressure of 5 bar is significantly different from the 0 bar and 1 bar pressure, as it caused the strain to be low. This can be a result of the cracking of fibres by the high pressure. A higher thickness also produced higher strain for ALS in perpendicular grain direction.

Table 10 - Two-way ANOVA result for strain of parallel oriented ALS

Source	Adj SS	Adj MS	F-Value	P-Value
Pressure	68.432	34.2161	60.74	0.000
Thickness	4.327	4.3269	7.68	0.011
Pressure*Thickness	3.063	1.5314	2.72	0.086
Error	13.520	0.5633		
Total	89.342			

Table 11 - Tukey method grouping information for effects of pressure and thickness on strain of parallel oriented ALS

Source	Level	Mean	Grouping
Pressure	1	6.93418	A
	0	4.93190	B
	5	3.23898	C
Thickness	2-3	5.41480	A
	3-4	4.65524	B
Pressure*Thickness	1*2-3	7.76510	A
	1*3-4	6.10327	B
	0*2-3	5.06400	B
	0*3-4	4.79980	B C
	5*2-3	3.41529	C D
	5*3-4	3.06267	D

Table 12 - Two-way ANOVA result for strain of perpendicular oriented ALS

Source	Adj SS	Adj MS	F-Value	P-Value
Pressure	1312	656.06	6.80	0.005
Thickness	4428	4428.27	45.89	0.000
Pressure*Thickness	3386	1692.81	17.54	0.000
Error	2316	96.50		
Total	11442			

Table 13 - Tukey method grouping information for effects of pressure and thickness on strain of perpendicular oriented ALS

Source	Level	Mean	Grouping
Pressure	1	36.4246	A
	0	35.4035	A
	5	21.9127	B
Thickness	3-4	43.3964	A
	2-3	19.0975	B
Pressure*Thickness	1*3-4	58.2752	A
	0*3-4	52.6369	A
	5*2-3	24.5485	B
	5*3-4	19.2770	B
	0*2-3	18.1700	B
	1*2-3	14.5740	B

4. Conclusion

As the result of flattening the ALS at different pressures, the thickness along the ALS was reduced increasingly as the pressure increases. The results also show that the flattening pressure does not affect the ultimate tensile strength in the parallel to grain direction. It is found that after the ALS was pressed at 1 bar pressure, the strain for parallel grain direction increased slightly up to 7.77%. It is not advisable that the ALS be fed into the padding mangle in perpendicular grain direction as this will result in breakage of ALS fibres, thus reducing its tensile strength and strain. In conclusion, the effects of flattening pressure and thickness on ultimate tensile strength and strain on different grain directions of ALS have been investigated. It is proven that the flattening process is able to increase the workable surface for ALS disposable dining ware production while maintaining the tensile properties of the material.

Acknowledgement

The authors are grateful to Universiti Tun Hussein Onn Malaysia for the financial funding through Multidisciplinary Research Grant (MDR) vot H512 and Universiti Tun Hussein Onn Malaysia (UTHM) for the support through GPPS grant, under Vot no. H338.

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