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APPENDICES

Appendix A Calculations

A1 Percent weight loss of sisal fibers after NaOH treatment

About 1 g of sisal fibers were dried at 110 °C for 2 h and weight immediately. Fibers were immersed in the NaOH solutions, concentration of 2, 4, and 6 percent by weight (wt%), at room temperature for 1, 5, and 24 h. Amount of fibers in each condition is about 1 g. The treated fibers were rinsed several times by distilled water until neutral. Then fibers were dried in an oven for 2 h at 110°C and then weight immediately.

$$\%\text{weight loss} = \frac{(\text{weight of untreated fibers} - \text{weight of treated fibers}) \times 100}{\text{weight of untreated fibers}}$$

A2 Tensile strength of fibers

Tensile tests of single sisal fibers were carried out using Lloyd universal testing machine, LRX. A gage length of 50 mm was employed with a crosshead speed of 10 mm/min in accordance with ASTM C1557-03. Twenty single fibers of 15 cm were tested. The cross-sectional area of fibers was determined by SEM.

$$T = F/A$$

where:

T = tensile strength, Pa

F = force to failure, N, and

A = fiber cross-sectional area at fracture plane, m^2

Appendix B Experimental Data

Table B1 Percent weight loss of sisal fibers after 2% NaOH treatment

Sample	Weight of fiber (g)	Treatment Time (hours)		
		1	5	24
I	weight of untreated fibers	1.8326	1.8574	1.8549
	weight of treated fibers	1.7100	1.7248	1.7196
	%weight loss	6.69	7.14	7.29
II	weight of untreated fibers	1.8512	1.8786	1.8631
	weight of treated fibers	1.7224	1.7392	1.7028
	%weight loss	6.96	7.42	8.60
Average	%weight loss average	6.82	7.28	7.95

Table B2 Percent weight loss of sisal fibers after 4% NaOH treatment

Sample	Weight of fiber (g)	Treatment Time (hours)		
		1	5	24
I	weight of untreated fibers	1.8692	1.8685	1.9462
	weight of treated fibers	1.7112	1.7035	1.7529
	%weight loss	8.45	8.83	9.93
II	weight of untreated fibers	1.8608	1.8911	1.9556
	weight of treated fibers	1.7054	1.6989	1.7391
	%weight loss	8.35	10.16	11.07
Average	%weight loss average	8.40	9.50	10.50

Table B3 Percent weight loss of sisal fibers after 6% NaOH treatment

Sample	Weight of fiber (g)	Treatment Time (hours)		
		1	5	24
I	weight of untreated fibers	1.8397	1.9191	1.8713
	weight of treated fibers	1.6545	1.7089	1.6171
	%weight loss	10.07	10.95	13.58
II	weight of untreated fibers	1.8443	1.9297	1.8609
	weight of treated fibers	1.6493	1.6959	1.6039
	%weight loss	10.57	12.12	13.81
Average	%weight loss average	10.32	11.54	13.70

Table B4 Water contact angle of untreated and γ-APS treated sisal fibers

Time (s)	Untreated	0.1%γ-APS	0.5%γ-APS	NaOH/ 0.1% γ-APS	NaOH/ 0.5%γ-APS
0.0	61.7	72.3	82.8	69.0	89.4
0.1	59.5	70.6	81.2	68.0	87.2
0.2	59.1	69.1	79.6	67.6	86.5
0.3	55.8	67.4	78.6	66.0	85.3
0.4	53.6	66.2	76.8	65.4	85.3
0.5	48.3	64.8	75.0	64.6	85.0
0.6	-	64.2	73.7	64.0	85.0
0.7	-	63.6	73.1	63.0	84.7
0.8	11.6	62.1	72.4	62.2	84.5
0.9	-	60.8	71.6	61.1	84.5
1.0	-	58.6	70.8	60.5	84.2
1.1	-	58.3	69.5	59.8	84.2
1.2	8.1	56.6	67.8	58.8	84.0
1.3	-	52.6	66.7	57.6	83.8
1.4	-	-	65.5	57.2	83.5
1.5	5.1	-	64.5	56.8	83.3
1.6	-	-	63.6	55.5	83.2
1.7	-	-	63.9	-	83.0
1.8	-	-	58.5	-	82.8
1.9	-	-	-	-	82.3
2.0	-	-	-	-	82.2

Table B5 Water contact angle of untreated and γ-GPS treated sisal fibers

Time (s)	Untreated	0.1%γ-GPS	0.5%γ-GPS	NaOH/ 0.1% γ-GPS	NaOH/ 0.5%γ-GPS
0.0	61.7	72.0	77.1	78.3	78.58
0.1	59.5	69.7	75.6	77.8	77.3
0.2	59.1	67.9	74.5	77.4	76.9
0.3	55.8	66.1	71.8	77.0	76.7
0.4	53.6	65.3	68.8	76.3	76.1
0.5	48.3	63.1	67.1	76.2	75.5
0.6	-	61.2	64.5	75.0	75.3
0.7	-	59.4	65.5	74.1	74.3
0.8	11.6	59.0	63.7	74.0	74.0
0.9	-	58.5	63.4	73.8	73.2
1.0	-	57.7	62.7	73.6	72.7
1.1	-	57.4	62.1	72.7	72.2
1.2	8.1	56.7	61.0	72.5	71.8
1.3	-	-	57.1	71.6	71.3
1.4	-	-	-	70.8	70.1
1.5	5.1	-	-	69.0	69.3
1.6	-	-	-	68.3	67.9
1.7	-	-	-	66.7	66.8
1.8	-	-	-	64.2	65.9
1.9	-	-	-	-	64.4
2.0	-	-	-	-	62.5

Table B6 Tensile strength of sisal-benzoxazine/epoxy composites at different fiber volume fraction

Sample	Tensile strength of sisal-benzoxazine/epoxy composites (MPa)			
	0% vol. fiber	5% vol. fiber	10% vol. fiber	15% vol. fiber
I	26.1	23.6	34.7	65.3
II	18.7	23.9	55.2	57.5
III	30.1	24.0	53.3	48.6
IV	17.1	24.1	39.0	75.5
V	26.9	30.9	40.8	69.5
Average	23.7	25.3	44.6	63.3
S.D.	5.6	3.1	9.1	10.5

Table B7 Young's modulus of sisal-benzoxazine/epoxy composites at different fiber volume fraction

Sample	Young's modulus of sisal-benzoxazine/epoxy composites (MPa)			
	0% vol. fiber	5% vol. fiber	10% vol. fiber	15% vol. fiber
I	4324.0	9439.1	8789.4	14259.7
II	3280.3	8389.9	9759.3	14277.5
III	6087.1	7564.2	6694.7	12327.1
IV	6209.8	7449.7	9876.2	12116.6
V	5268.5	5438.1	10783.2	11029.0
Average	5033.9	7656.2	9180.5	12802.0
S.D.	1237.6	1473.8	1558.8	1426.6

Table B8 Flexural strength of sisal-benzoxazine/epoxy composites at different fiber volume fraction

Sample	Flexural strength of sisal-benzoxazine/epoxy composites (MPa)			
	0% vol. fiber	5% vol. fiber	10% vol. fiber	15% vol. fiber
I	58.7	57.2	65.0	82.3
II	70.5	74.7	64.3	76.3
III	73.1	67.2	70.7	66.3
IV	74.8	64.5	71.7	72.9
V	76.6	87.9	91.0	85.4
Average	70.8	70.3	72.6	76.6
S.D.	7.1	11.7	10.8	7.6

Table B9 Flexural modulus of sisal-benzoxazine/epoxy composites at different fiber volume fraction

Sample	Flexural modulus of sisal-benzoxazine/epoxy composites (MPa)			
	0% vol. fiber	5% vol. fiber	10% vol. fiber	15% vol. fiber
I	1714.9	1765.2	2827.3	2881.7
II	1877.2	1838.4	2548.4	2893.7
III	1858.9	1835.8	2340.9	2685.0
IV	1182.9	1804.0	2478.9	3441.1
V	1824.5	1879.5	2431.4	3348.2
Average	1691.7	1824.6	2525.4	3049.9
S.D.	291.3	42.7	184.9	327.1

Table B10 Impact strength of sisal-benzoxazine/epoxy composites at different fiber volume fraction

Sample	Impact strength of sisal-benzoxazine/epoxy composites (MPa)			
	0% vol. fiber	5% vol. fiber	10% vol. fiber	15% vol. fiber
I	36.8	69.1	157.3	215.3
II	28.5	56.4	171.3	242.8
III	22.4	65.2	155.3	196.1
IV	28.1	65.4	145.4	248.5
V	16.4	72.9	163.2	254.8
Average	26.4	65.8	158.5	231.5
S.D.	7.6	6.1	9.6	24.9

Table B11 Tensile strength of sisal-benzoxazine/epoxy composites at different matrix composition

Sample	Tensile strength of sisal-benzoxazine/epoxy composites (MPa)			
	25%w epoxy	50%w epoxy	75%w epoxy	100%w epoxy
I	44.7	34.7	65.4	51.3
II	35.2	55.2	59.9	46.0
III	34.1	53.3	54.1	54.1
IV	49.3	39.0	52.3	53.6
V	51.6	40.8	53.8	41.9
Average	43.0	44.6	57.1	49.4
S.D.	8.0	9.1	5.4	5.3

Table B12 Young's modulus of sisal-benzoxazine/epoxy composites at different matrix composition

Sample	Young's modulus of sisal-benzoxazine/epoxy composites (MPa)			
	25%w epoxy	50%w epoxy	75%w epoxy	100%w epoxy
I	11217.6	8789.4	5998.7	5185.9
II	8200.5	9759.3	5911.3	6705.9
III	8082.8	6694.7	9469.9	5770.4
IV	11513.4	9876.2	5083.0	5562.9
V	12146.4	10783.2	6485.5	5329.4
Average	10232.1	9180.5	6589.7	5710.9
S.D.	1938.0	1558.8	1687.1	599.3

Table B13 Flexural strength of sisal- benzoxazine/epoxy composites at different matrix composition

Sample	Flexural strength of sisal-benzoxazine/epoxy composites (MPa)			
	25%w epoxy	50%w epoxy	75%w epoxy	100%w epoxy
I	60.4	65.0	93.6	102.3
II	93.9	64.3	112.5	99.8
III	51.4	70.7	96.6	104.3
IV	59.9	71.7	90.7	109.6
V	59.6	91.0	85.2	105.9
Average	65.0	72.6	95.7	104.4
S.D.	16.6	10.8	10.3	3.7

Table B14 Flexural modulus of sisal- benzoxazine/epoxy composites at different matrix composition

Sample	Flexural modulus of sisal-benzoxazine/epoxy composites (MPa)			
	25%w epoxy	50%w epoxy	75%w epoxy	100%w epoxy
I	2876.9	2827.3	2318.1	2503.1
II	2953.2	2548.4	2504.9	1696.1
III	2715.0	2340.9	2564.4	1796.2
IV	3607.7	2478.9	2521.2	2610.9
V	2862.5	2431.4	2524.6	2602.4
Average	3003.1	2525.4	2486.6	2241.7
S.D.	348.8	184.9	96.7	455.8

Table B15 %Tensile strain at break of sisal- benzoxazine/epoxy composites at different matrix composition

Sample	%Tensile strain at break of sisal-benzoxazine/epoxy composites			
	25%w epoxy	50%w epoxy	75%w epoxy	100%w epoxy
I	0.711	0.725	1.436	1.302
II	0.859	1.087	0.846	1.195
III	0.765	1.114	0.819	1.195
IV	0.752	0.765	1.235	1.007
V	0.805	0.832	1.007	0.859
Average	0.778	0.905	1.069	1.112
S.D.	0.056	0.183	0.264	0.177

Table B16 Toughness of sisal- benzoxazine/epoxy composites at different matrix composition

Sample	Toughness of sisal-benzoxazine/epoxy composites (MPa)			
	25%w epoxy	50%w epoxy	75%w epoxy	100%w epoxy
I	0.094	0.131	0.246	0.287
II	0.193	0.117	0.336	0.352
III	0.085	0.193	0.227	0.298
IV	0.094	0.14	0.206	0.281
V	0.134	0.221	0.182	0.365
Average	0.120	0.160	0.239	0.317
S.D.	0.045	0.044	0.059	0.039

Table B17 Tensile strength of sisal- benzoxazine/epoxy composites with different fiber surface modifications

Fiber treatment	Tensile strength of sisal- benzoxazine/epoxy composites (MPa)						
	I	II	III	IV	V	Average	S.D.
Untreated	34.7	55.2	53.3	39.0	40.8	44.6	9.1
NaOH	44.2	48.7	42.4	29.4	36.4	40.2	7.5
γ-APS	33.6	45.0	33.9	49.6	38.4	40.1	7.0
NaOH/γ-APS	47.5	21.2	46.1	29.3	47.9	38.4	12.3
γ-GPS	37.3	49.8	51.0	43.7	43.6	45.1	5.5
NaOH/γ-GPS	56.2	47.7	39.0	41.2	55.4	47.9	7.9

Table B18 Young's modulus of sisal- benzoxazine/epoxy composites with different fiber surface modifications

Fiber treatment	Young's modulus of sisal- benzoxazine/epoxy composites (MPa)						
	I	II	III	IV	V	Average	S.D.
Untreated	8789.4	9759.3	6694.7	9876.2	10783.2	9180.5	1558.8
NaOH	12878.2	8704.1	11977.1	21071.9	14254.0	13777.0	4561.4
γ-APS	7212.0	23222.2	7107.0	8784.5	10422.7	11349.7	6773.4
NaOH/γ-APS	12071.5	13902.4	10193.6	10989.8	9326.2	11296.7	1773.7
γ-GPS	10316.9	8738.1	10725.1	8316.0	8495.6	9318.3	1117.4
NaOH/γ-GPS	8047.8	7168.0	8029.7	6595.8	7531.6	7474.6	613.7

Table B19 Flexural strength of sisal- benzoxazine/epoxy composites with different fiber surface modifications

Fiber treatment	Flexural strength of sisal- benzoxazine/epoxy composites (MPa)						
	I	II	III	IV	V	Average	S.D.
Untreated	65.0	64.3	70.7	71.7	91.0	72.6	10.8
NaOH	68.1	76.0	90.7	88.0	84.1	81.4	9.3
γ-APS	63.1	88.2	68.5	80.3	81.8	76.4	10.2
NaOH/γ-APS	72.5	94.6	76.5	64.4	72.1	76.0	11.3
γ-GPS	72.0	75.0	64.9	76.3	73.8	72.4	4.4
NaOH/γ-GPS	80.7	111.8	81.8	74.6	84.3	86.6	14.5

Table B20 Flexural modulus of sisal- benzoxazine/epoxy composites with different fiber surface modifications

Fiber treatment	Flexural modulus of sisal- benzoxazine/epoxy composites (MPa)						
	I	II	III	IV	V	Average	S.D.
Untreated	2827.3	2548.4	2340.9	2478.9	2431.4	2525.4	184.9
NaOH	2933.4	2626.0	3091.6	2530.6	2345.2	2705.4	303.2
γ-APS	2545.9	2643.7	3134.1	2466.1	2390.1	2636.0	293.9
NaOH/γ-APS	2498.9	2696.1	2494.7	2638.3	2315.9	2528.8	147.8
γ-GPS	2938.2	2934.8	2579.0	2537.0	2738.8	2745.5	189.9
NaOH/γ-GPS	2434.3	2893.9	2655.9	2869.7	2958.4	2762.4	215.7

Table B21 Impact strength of sisal- benzoxazine/epoxy composites with different fiber surface modifications

Fiber treatment	Impact strength of sisal- benzoxazine/epoxy composites (MPa)						
	I	II	III	IV	V	Average	S.D.
Untreated	157.3	171.3	155.3	145.4	163.2	158.5	9.6
NaOH	67.8	70.1	67.3	71.8	73.5	70.1	2.6
γ-APS	109.3	135.1	113.6	109.6	116.7	116.9	10.6
NaOH/γ-APS	95.9	56	47	61.3	50.7	62.2	19.6
γ-GPS	94.7	66.8	105.2	70.1	129.7	93.3	26.0
NaOH/γ-GPS	36.5	66.1	46.8	55.6	67.9	54.6	13.2

Table B22 Tensile strength of sisal fibers after NaOH treatment for 1 h

Sample	Tensile strength of sisal fibers (MPa)			
	Untreated	2 % NaOH	4 % NaOH	6 % NaOH
1	464.0	347.2	229.6	191.3
2	514.8	443.8	343.9	196.7
3	520.3	341.6	290.0	289.0
4	505.1	345.8	249.0	331.3
5	482.9	334.2	274.7	268.1
6	555.4	239.2	375.6	347.1
7	512.0	262.2	338.8	215.9
8	472.1	371.8	333.6	323.8
9	425.2	279.8	312.3	286.7
10	446.0	233.5	241.4	331.2
Average	446.2	319.9	298.9	278.1
S.D.	39.0	65.8	49.6	58.5

Table B23 Tensile strength of sisal fibers after 6% NaOH treatment

Sample	Tensile strength of sisal fibers (MPa)			
	Untreated	1 h treatment	5 h treatment	24 h treatment
1	464.0	191.3	338.9	238.9
2	514.8	196.7	225.4	190.8
3	520.3	289.0	162.2	248.4
4	505.1	331.3	187.0	248.4
5	482.9	268.1	173.5	264.3
6	555.4	347.1	193.6	271.0
7	512.0	215.9	241.5	210.8
8	472.1	323.8	292.0	241.6
9	425.2	286.7	354.5	207.8
10	446.0	331.2	267.0	278.4
Average	446.2	278.1	243.6	240.0
S.D.	39.0	58.5	68.2	28.8

Table B24 Tensile strength of untreated and modified sisal fibers

Sample	Tensile strength of sisal fibers (MPa)					
	Untreated	NaOH	γ-APS	NaOH/ γ-GPS	γ-GPS	NaOH/ γ-GPS
1	464.0	338.9	258.4	173.1	503.1	378.6
2	514.8	225.4	202.8	277.9	329.0	314.9
3	520.3	162.2	224.5	160.7	494.8	340.2
4	505.1	187.0	335.5	197.0	503.8	325.2
5	482.9	173.5	218.1	157.8	487.2	298.6
6	555.4	193.6	212.5	193.0	566.4	351.3
7	512.0	241.5	297.3	212.3	452.7	266.8
8	472.1	292.0	225.2	171.0	477.0	330.1
9	425.2	354.5	249.2	184.6	401.7	275.2
10	446.0	267.0	225.6	160.9	623.4	346.1
Average	446.2	243.6	223.5	172.6	440.8	294.3
S.D.	39.0	68.2	42.0	36.0	80.9	34.8

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