

Optimisation of Process Parameters in Kenaf/Polypropylene Composites in Connection Moulding

R.Varadaraju, J.Srinivasan

Abstract— Renewable natural fibres like kenaf can be used to produce composites as replacement to plastic boards in household and industrial applications. The objective of this study is to optimise the process parameters for compression moulding of kenaf polypropylene composite to get maximum tensile, flexural and impact strength values for three different blend ratios. Three levels of temperature (160°C, 180°C and 200 °C), compression pressure (7, 9 and 11 Mpa) and time of application (10, 20 and 30 min) for producing kenaf/ polypropylene blend ratios of 50:50, 65:35 and 80:20 have been used. The samples were produced through carding for web formation, needle punching for non woven making and finally in compression moulding machine for boards making. All the composite boards were analysed for tensile, flexural and impact strength. The tensile and flexural strengths have positive correlations with time and temperature and contact pressure in all the blend ratios kenaf / polypropylene. The impact strength has positive correlation with time, temperature whereas it has negative correlation with contact pressure in all the blend ratios. The highest tensile strength and flexural strength is achieved with 65:35 kenaf / polypropylene blend at 200 °C temperature, 11Mpa pressure and 10 minutes duration in compression moulding machine. The highest Impact strength is achieved with 80:20 blends at 180 °C, 7 Mpa pressure and 30 minutes duration. The tensile and flexural strength is the highest at the blend ratio of 65:35 whereas the Impact strength increases with the increase kenaf content up to 80%..

Keywords—tensile strength, flexural strength, impact strength, temperature, pressure, time, natural fibre

I. INTRODUCTION

The main merits and demerits of natural fibre composites [1-5] are given below: The main merits are lower density and higher specific strength, stiffness, obtained from renewable resource, consuming little energy, carbon dioxide absorption, emission of oxygen to the atmosphere lower hazard in the production processes, lesser manufacturing cost. The main demerits are lower service life, higher water absorption causing swelling, lower impact strength, higher variability in composite properties

II. LITERATURE SURVEY

The mechanical performance of NFCs are affected by the fibre properties, matrix properties, strength of fibre matrix interface, extent of dispersion of fibre, the orientation of fibre, production process and porosity. The choice of natural fibres for making composites are based on its availability in the particular country [7]. In Asian countries hemp, kenaf,

jute and sisal are available in plenty whereas flax is available in Europe and Harakeke fibre is available in New Zealand [7]. It was reported that jute and hollow conjugated polyester reinforced non woven composite of 50:50 ratio is suitable for structural materials of building [6] furniture making [8] outdoor & indoor insulation applications [9]. Longer fibres can take up higher loads but too longer fibres may entangle during mixing and result in lower reinforcement [14-16]. The length to diameter ratio of the fibre affects the mechanical properties. The fibre length must be higher than the critical length for the fibre to be broken during tensile load application in a composite [12]. For efficient reinforcement fibre length must be much higher. Even though thermoplastic and thermo set plastics can be used as matrix for making natural fibre composites [17] mostly polypropylene, polyvinyl chloride and polyethylene are used because of their lower softening temperature below 200° C whereas natural fibres degrade above 200°C [18], thermoplastics can be repeatedly softened and can also be recycled. PLA gives higher strength and stiffness among the bio derived matrix materials.

Good interfacial binding is required to achieve good reinforcement, fibre wetting is the pre requisite for good bonding [19, 20] toughness, tensile and flexural strength. Mechanical interlock, chemical bonding, electrostatic bonding and inter diffusion bonding are the mechanisms of interfacial bonding [13]. Good dispersion reduces voids for ensuring that fibres are fully surrounded by the matrix [22] and gives good interfacial strength. Time, temperature, pressure, additives and fibre surface modifications are the factors that affect dispersion [21]. Parallel alignment of fibres to the direction of load application improves the mechanical properties of the composites [11, 23-26]. Compression moulding is used for thermoplastic matrix. Time, temperature, pressure, and matrix viscosity [27] are the factors that affect the properties of composites in compression moulding. Film stacking is also done to reduce fibre degradation [28]. The optimum temperature for good mechanical properties is 150°C for flax/polyester amide composites [29], 180°C for jute [1] and 200°C for non-woven mat reinforced with polypropylene [30]. Porosity increases more rapidly with the increase in the proportion of fibres in composites after the limit to compact. In Flax/ polypropylene composites the porosity increases from 4 to 8 volume% as the fibre proportion increases from 56% to 72%

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[12].With non-woven fabric containing polypropylene and kenaf, we can achieve higher proportion of fibre than stacked composites and also to give higher impact strength [10, 11] higher biodegradability. In a study with 6mm layer composite with kenaf/ polypropylene blend ratio of 50:50 it was reported that temperature and time in compression moulding are main factors influencing the properties of composite [31]. 230 ° C temperature and 120 second duration was found to give higher tensile and flexural modulus whereas 200 ° C and 60 seconds was found to give higher Impact strength in layered composite with kenaf/ polypropylene [31]

The literature review revealed that not much detailed studies were available on the effect of processing parameters in compression moulding machine to produce kenaf polypropylene fibre non woven composite on tensile, flexural and impact strength values for different blend ratios.

A Objectives

The objective of this study is (1)To investigate the influence of temperature, time of application and compression pressure of applied in compression moulding machine to produce kenaf polypropylene composite on tensile, flexural and impact strength values for different blend ratios. (2) To decide the most suitable kenaf/ polypropylene blend ratio to achieve the highest tensile, flexural and impact strength values.

III. EXPERIMENTAL

A Method

Twenty seven kenaf/ polypropylene composite boards in each of three blend ratios were produced with variations in its processing parameters. (temperature, time and compression pressure); They were tested for their tensile, flexural and impact strength;The influence of processing parameters on its properties were analysed and also developed the regression equations for each of the tensile, flexural and impact strength from its processing parameters for the three blend ratios. Kenaf/ polypropylene blends in the ratios of 50: 50, 65:35 and 80:20 were selected for the study.

B Materials

The kenaf fibre of 30 mm length and polypropylene fibre of 32mm*1.5 denier were selected for the study. The above fibres were blended in the weight ratios of 50: 50, 65:35 and 80:20 and made into web for random dispersion of fibres. The web formed in the carding machine was needle punched

to make it compact non woven material of 6.5mm thickness to ensure that a controlled composite boards of 3mm thickness can be produced. The non woven material of 30cm*30 cm was processed in a compression moulding machine (Velan Engineering, India) to produce boards of 3mm thickness. The composite boards were cut into required size depending upon the type of test. Three levels of Temperature (160 ° C, 180 ° C and 200 ° C), compression pressure (7, 9 and 11 Mpa) and time of application (10,20 and 30 min) for producing kenaf/ polypropylene blend ratios of 50:50, 65:35 and 80:20 have been used.

The non woven materials are chosen for making the composite because of the following reasons: There are more overlapping area between the fibre and polymer matrix; higher fraction up to 80% of kenaf can be used which improves the biodegradability of the composite; the structure will be more porous with higher kenaf fraction which absorbs impact loads and sound; random distribution of kenaf/ polypropylene fibres which makes the fibres bind together with the help of polypropylene melt as glue.

C Testing of fabric properties

All the samples under study were tested All the composite boards were tested for tensile strength (ASTM 638-90); flexural strength (ASTM D 790-90) in universal strength testing machine and impact strength (ASTM D4812) were tested in charpy impact pendulum strength tester under standard atmospheric conditions of 65±0.5% relative humidity and 27± 0.2 °C Ten readings were taken in each type of test and blend ratio for calculating the average of the properties

D Statistical Analysis

The analysis of data was done using MINI TAB 14 (Minitab Inc., State College, Pennsylvania) statistic software for analysis for variance and regression.

IV. RESULTS

The tensile strength, flexural strength and impact strength of kenaf/ polypropylene composites in the blend ratios of 50: 50, 65:35 and 80:20 for three levels of Temperature (160 ° C, 180 ° C and 200 ° C), compression pressure (7, 9 and 11 Mpa) and time of application (10, 20 and 30 min) for producing in compression moulding are given in Table I. The analysis of variance (ANOVA) of the results and the response regression coefficients of temperature, time and pressure for tensile strength, flexural strength and impact strength are given in Tables II and III.

TABLE I. MECHANICAL PROPERTIES OF KENAF: POLYPROPLENE COMPOSITE OF DIFFERENT BLEND RATIOS

Temperature(° C)/ Time(min)/ Pressure(Mpa)	Tensile Strength (Mpa)	Flexura l Strengt h (Mpa)	Impact Strengt h (KJ/m ²)	Tensile Strengt h (Mpa)	Flexura l Strengt h (Mpa)	Impact Strengt h (KJ/m ²)	Tensile Strengt h (Mpa)	Flexural Strength (Mpa)	Impact Strengt h (KJ/m ²)
	Kenaf/PP 50: 50 blend			Kenaf/PP 65:35 blend			Kenaf/PP 80:20 blend		
180/10/7	110	78	3.9	136.5	98.7	6.3	115.93	86.59	11.03

180/20/7	122	85	4.49	156.98	113.51	7.25	133.32	99.58	15.44
180/30/7	125	88	4.29	150.15	108.57	6.93	127.53	95.25	16.54
160/10/7	90	63	2.6	110.11	78.96	4.2	91.09	68.92	5.51
160/20/7	100	70	2.99	126.63	90.8	4.83	104.75	79.26	8.82
160/30/7	103	72	2.99	126.63	90.8	4.83	104.75	79.26	9.92
200/10/7	135	91	3.9	174.72	126.9	6.3	132.5	97.2	6.62
200/20/7	150	105	3.71	165.98	120.56	5.99	125.87	92.34	12.13
200/30/7	155	108	3.51	157.25	114.21	5.67	119.25	87.48	12.13
180/10/9	112.2	79.56	4.1	150	105	6	127.4	92.12	10.5
180/20/9	124.44	86.7	4.71	172.5	120.75	6.9	146.51	105.94	14.7
180/30/9	127.5	89.76	4.5	165	115.5	6.6	140.14	101.33	15.75
160/10/9	91.8	64.26	2.73	121	84	4	100.1	73.32	5.25
160/20/9	102	71.4	3.14	139.15	96.6	4.6	115.12	84.32	8.4
160/30/9	105.06	73.44	3.14	139.15	96.6	4.6	115.12	84.32	9.45
200/10/9	137.7	92.82	4.1	192	135	6	145.6	103.4	6.3
200/20/9	153	107.1	3.89	182.4	128.25	5.7	138.32	98.23	11.55
200/30/9	158.1	110.16	3.69	172.8	121.5	5.4	131.04	93.06	11.55
180/10/11	113.32	80.36	3.85	154.5	108.15	5.92	140	98	10
180/20/11	125.68	87.57	4.43	177.68	124.37	6.81	161	112.7	14
180/30/11	128.78	90.66	4.23	169.95	118.97	6.51	154	107.8	15
160/10/11	92.72	64.9	2.57	124.63	86.52	3.95	110	78	5
160/20/11	103.02	72.11	2.95	143.32	99.5	4.54	126.5	89.7	8
160/30/11	106.11	74.17	2.95	143.32	99.5	4.54	126.5	89.7	9
200/10/11	139.08	93.75	3.85	197.76	139.05	5.92	160	110	6
200/20/11	154.53	108.17	3.66	187.87	132.1	5.63	152	104.5	11
200/30/11	159.68	111.26	3.46	177.98	125.15	5.33	144	99	11

TABLE II ANALYSIS OF VARIANCE OF KENAF/POLYPROPYLENE COMPOSITE PROPERTIES

Responses	Temperature- ⁰ C (x ₁)			Time-min (x ₂)			Pressure (Mpa) (x ₃)			Error
	<i>F</i>	<i>p</i>	% contri- -bution	<i>F</i>	<i>p</i>	% contri- -bution	<i>F</i>	<i>p</i>	% contri- -bution	% contri- -bution
Kenaf/PP 50: 50 blend										
Tensile Strength (Mpa)	24.96	0.001	87.11	63.0 6	0.000	10.74	2.853	0.000	0.34	1.82
Flexural Strength(Mpa)	18.74	0.003	83.75	78.1 5	0.000	13.99	2.853	0.000	0.35	1.91
Impact Strength (KJ/m ²)	24.09	0.001	84.93	12.2 7	0.000	10.13	10.86	0.000	2.45	2.48
Kenaf/PP 65:35 blend										
Tensile Strength (Mpa)	16.62	0.004	74.32	3.17 2	0.027	9.78	50.62	0.000	13.24	2.67
Flexural Strength(Mpa)	17.98	0.003	79.03	5.99 3	0.001	11.63	26.75	0.000	6.73	2.61
Impact Strength (KJ/m ²)	24.07	0.001	85.32	12.3 7	0.000	10.2	13.49	0.000	2.49	2
Kenaf/PP 80:20 blend										
Tensile Stength (Mpa)	10.6	0.011	56.81	1.49 3	0.236	5.86	193.36	0.000	35.49	1.84
Flexural Strength(Mpa)	8.725	0.027	60.72	3.49	0.018	16.83	83.62	0.000	20.03	2.42
Impact Strength (KJ/m ²)	3.78	0.087	47.29	76.7 8	0	50.37	52.06	0.000	1.96	0.38

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TABLE III RESPONSE REGRESSION COEFFICIENTS KENAF/POLYPROPYLENE COMPOSITE PROPERTIES

Responses	R ² %	Regression coefficients			
		Constant(k)	Temperature- ⁰ C (x ₁)	Time-min	Pressure (Mpa)
				(x ₂)	(x ₃)
Kenaf/PP 50: 50 blend					
Tensile Strength (Mpa)	97.6	-127.23	1.256	0.8	0.937
Flexural Strength(Mpa)	97.4	-85.3	0.856	0.588	0.625
Impact Strength (KJ/m ²)	32.4	-0.234	0.0214	0.0064	-0.119
Kenaf/PP 65:35 blend					
Tensile Strength (Mpa)	82.4	-108.84	1.2079	0.2279	4.78
Flexural Strength(Mpa)	83.2	-75.1	0.8873	0.1584	2.508
Impact Strength (KJ/m ²)	34.7	0.2613	0.0329	0.0101	-0.0872
Kenaf/PP 80:20 blend					
Tensile Strength (Mpa)	65.4	-51.058	0.675	0.325	6.125
Flexural Strength(Mpa)	53.6	-12.125	0.419	0.238	3
Impact Strength (KJ/m ²)	40.4	-2.044	0.0606	0.261	-0.3

A Regression Equations

Equations of the form $y = k + ax_1 + bx_2 + cx_3$ were formed to predict the mechanical properties from the composite processing parameters for each of the 50:50, 65:35, 80:20 blend ratios and the regression coefficients of equations are given in Table III.

Where x_1 is temperature; x_2 is time and x_3 is compression pressure which are independent variables. The regression coefficients for tensile strength ($R^2 = 97.6$; $p < .001$), flexural strength ($R^2 = 97.4$; $p < .001$), and impact strength ($R^2 = 41.7$; $p < .001$) in 50:50 blend are significant; tensile strength ($R^2 = 82.4$; $p < .001$), flexural strength, ($R^2 = 83.2$; $p < .001$) and impact strength ($R^2 = 34.7$; $p < .001$) in 65:35 blend are also significant; tensile strength ($R^2 = 65.4$; $p < .001$), flexural strength ($R^2 = 53.6$; $p < .001$) and Impact strength ($R^2 = 40.4$; $p < .001$) in 80:20 blend are also significant.

B Error Analysis of Regression Equations for Validation

Regression equations were tested for their validity by calculating the % R^2 (square of correlation coefficient) values between the actual and predicted values. The root mean square deviation % (RMSD) of predicted values actual values was also calculated and given in Table IV. The % RMSD for tensile strength, flexural strength and impact Strength are 2.11, 2.22 and 22.42 respectively in 50:50 blend; The % RMSD for tensile strength, flexural strength and impact Strength are 4.79, 4.65 and 11.70 respectively in 65:35 blend; The % RMSD for tensile strength, flexural strength and impact Strength are 6.17, 6.23 and 22.72 respectively in 80:20 blend. The deviation in impact strength is higher due to lower coefficient of determination (R^2)

TABLE IV % RMSD VALUES BETWEEN PREDICTED AND ACTUAL VALUES

Properties	50:50 blend	65:35 blend	80:20 blend
Tensile Strength	2.11	2.22	22.42
Flexural Strength	4.79	4.65	11.70
Impact Strength	6.17	6.23	22.72

C Influence of composite processing Parameters on Mechanical properties

1) **Tensile Strength:** The tensile Strength has positive correlation with time and temperature and contact pressure in all the three blend ratios. This is due to good melt formation of polypropylene which spread across the entire volume of the non woven blend material. The individual fibres are well interfaced with the adjacent fibres by polypropylene melt. The compression pressure enables good contact between fibres and polymer melt. The value % R^2 % is 97.6 for 50:50 blend ratio, 82.4 for 65:35 blend ratio and 65.4 for 80:20 blend ratios. The coefficient of determination (R^2) reduces with the increase in kenaf content. This is due to reduced availability of polypropylene for melting and influencing. The tensile strength increases from with increase in kenaf content from 50% to 65% but drops with a further increase to 80% in all processing conditions.

The ANOVA results show that the variance in Tensile Strength is attributed due to temperature by 87.11% ($F=24.96$; $p=0.001$) time 10.74% ($F=63.0687$; $p=0.000$) and compression pressure by 0.34% ($F=2.853$ $p=0.000$) in 50:50 kenaf/polypropylene blend composite; due to temperature by 74.32% ($F=16.62$; $p=0.004$) time by 9.78% ($F=3.172$; $p=0.027$) and compression pressure by 13.24% ($F=50.62$; $p=0.000$) in 65:35 kenaf/polypropylene blend composite; due to temperature by 56.81% ($F=10.6$; $p=0.011$) time 5.86% ($F=1.493$; $p=0.236$) and compression pressure by 35.49% ($F=193.36$; $p=0.000$) in 80:20kenaf/polypropylene blend composite.

2) *Flexural Strength*: The Flexural Strength also has positive correlation with time, temperature and contact pressure in all the three blend ratios. This is due to good melt formation of polypropylene which spread across the entire volume of the non woven blend material. The individual fibres are well interfaced with the adjacent fibres by polypropylene melt. The compression pressure enables good contact between fibres and polymer melt. The value of % R^2 is 97.4 or 50:50 blend ratio, 83.2 for 65:35blend ratio and 53.6 for 80:20 blend ratio. The coefficient of determination (R^2) reduces with the increase in kenaf content. This is due reduce availability of polypropylene for melting and influencing. The flexural strength increases from with increase in kenaf content from 50% to 65% but drops with a further increase to 80% in all processing conditions.

The ANOVA results show that the variance in flexural strength is attributed due to temperature by 83.75% ($F=18.749$; $p=0.001$) time 13.99% ($F=78.15$; $p=0.000$) and compression pressure by 0.35% ($F=2.853$ $p=0.000$) in 50:50 kenaf/polypropylene blend composite; due to temperature by 79.03% ($F=17.98$; $p=0.003$) Time 11.63% ($F=5.993$; $p=0.001$) and compression pressure by 6.73% ($F=26.75$ $p=0.000$) in 65:35 kenaf/polypropylene blend composite; due to temperature by 60.72% ($F=8.725$; $p=0.027$) time 16.83% ($F=3.49$; $p=0.018$) and compression pressure by 20.03% ($F=83.62$; $p=0.000$) in 80:20kenaf/polypropylene blend composite.

3) *Impact Strength*: The Impact Strength has positive correlation with time, temperature whereas it has negative correlation with contact pressure in all the three blend ratios. Binding improvement is due to good melt formation of polypropylene with the increase in temperature and time which spread across the entire volume of the non woven blend material. The increase in pressure reduces the porosity of the material and reduces the shock load absorbing capacity. The value of R^2 % is 41.7 or 50:50 blend ratio, 34.7 for 65:35 blend ratio and 40.4 for 80:20 blend ratios. This is due to lesser influence of processing parameters on impact strength.

The ANOVA results show that the variance in Impact strength is attributed due to temperature by 84.93% ($F=24.09$; $p=0.001$) time 10.86% ($F=12.27$; $p=0.000$) and compression pressure by 2.45% ($F=10.86$ $p=0.000$) in 50:50 kenaf/polypropylene blend composite; due to temperature by 85.32% ($F=24.07$; $p=0.001$) Time 10.2% ($F=13.49$; $p=0.000$) and compression pressure by 2.42% ($F=10.86$ $p=0.000$) in 65:35 kenaf/polypropylene blend

composite; attributed due to temperature by 47.29% ($F=3.78$; $p=0.087$) time 50.37% ($F=76.78$; $p=0.000$) and compression pressure by 1.96% ($F=52.06$ $p=0.000$) in 80:20 kenaf/polypropylene blend composite.

D Optimum composite processing parameters for higher mechanical properties

The highest tensile strength of 197.76 Mpa and flexural strength of 139.05 Mpa is achieved with 65:35 kenaf / polypropylene blend composite at 200 ° C temperature, 11Mpa pressure and 10 minutes duration in compression moulding machine. The maximum tensile strength of 161 Mpa and flexural strength of 112 Mpa is achieved in 80: 20 kenaf / polypropylene blend with 180 ° C temperature, 11Mpa pressure and 20 minutes duration in compression moulding machine. The maximum tensile strength of 159.7 Mpa and flexural strength of 112.26 Mpa is achieved in 50:50 kenaf / polypropylene blend with 200 ° C temperature, 11Mpa pressure and 30 minutes duration in in compression moulding machine. The density of polypropylene is about 0.95 g/cc where as the density of kenaf fibre is 1.45g/cc , Due to this density difference the volume of kenaf fibre in 65:35 blend is nearly 50 % and makes good interfacial binding with polypropylene melt resulting in the highest tensile strength and flexural strength. In 50:50 blend the volume of kenaf is 40% only resulting in lower tensile strength and flexural strength whereas in80:20 blend the volume of polypropylene is only 25% which is too low to bind the kenaf fibres which resulted in lower tensile strength and flexural strength.

The highest Impact strength of 16.54 KJ/m² is achieved with 80:20 blend composite at 180 °C, 7 Mpa pressure and 30 minutes duration processing parameters in compression moulding machine. The maximum Impact strength of 7.25 KJ/m² is achieved in 65:35 blends at 180° C, 7 Mpa pressure and 20 minutes duration the maximum impact strength of 4.49 KJ/m² is achieved in 50:50 blend at 180°C, 7 Mpa pressure and 20 minutes duration. The tensile and flexural strength are the highest at a blend ratio of 65:35 whereas the impact strength increases with the increase kenaf content up to 80:20. With the increase in kenaf fibre content from 50% to 65% and to 80% the porosity and cushioning effect of the composite increases which absorbs the impact load and improves the impact strength.

V. CONCLUSIONS

The tensile and flexural strengths have positive correlations with time and temperature and contact pressure in all the blend ratios kenaf / polypropylene. The impact strength has positive correlation with time, temperature whereas it has negative correlation with contact pressure in all the blend ratios. The highest tensile strength of 197.76 Mpa and flexural strength of 139.05 Mpa in 65:35 kenaf / polypropylene blend is achieved with 200 ° C Temperature, 11Mpa pressure and 10 minutes duration in compression moulding machine.



The highest Impact strength of 16.54 KJ/m² is achieved with 80:20 blend at 180 ° C, 7 Mpa pressure and 30 minutes duration. The tensile and flexural strength is the highest at the blend ratio of 65:35 whereas the Impact strength increases with the increase kenaf content up to 80%.

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