STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 4, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Influence of Alkali Treatment on the Tensile Properties of The Hybrid Fiber Reinforced Polymer Matrix Composite

M Chrispin Das[1], S Prathap Singh[2,*], R Malkiya Rasalin Prince[3], K. Gnanasekaran[4], S Manikandan[5], A Dhanush[6], D S Sujith Kumar[7], S Yuva Praveen[8]

Abstract

In this study, the effect of alkali treatment on the tensile strength of the hibiscus fiber, gongura fiber, and treated madar fiber-reinforced Polymer Matrix Composite (PMC) is studied. The Sodium Hydroxide (NaOH) solution is utilized for madar fiber treatment. The traditional hand layup methodology was used for fabrication. The influence of tensile property control variables such as duration of fiber treatment, concentration of NaOH for treatment, and proportion of fiber hybridization on the tensile strength is examined. Taguchi's Signal to Noise Ratio (SNR) and Analysis of Variance (ANOVA) are used to find the optimum control variables and percentage contribution of control variables on the tensile strength, respectively. The 24 hours of fiber treatment, 15% concentration of NaOH, and 70% fiber hybridization were found to be the optimum control variables. Moreover, the duration of fiber treatment contributed more to the tensile behaviour of the PMC. The prolonged treatment durations can enhance the removal of contaminants, waxes, and non-cellulosic compounds. This process strengthens the matrix-fiber interaction, thereby raising the tensile strength. Finally, the Scanning Electron Microscope (SEM) is used to examine the surface of the best tensile sample, and it showed signs of fiber pullout, fiber splitting, debonding, matrix cracking, and fiber-matrix interaction.

Keywords: Natural fiber, polymer matrix composite, alkali treatment, tensile strength, matrix-fiber interaction

***Author for Correspondence**
S Prathap Singh

[1]Associate Professor, Department of Mechanical Engineering, St. Joseph's Institute of Technology, Chennai, Tamil Nadu, India
[2,4]Assistant Professor, Department of Mechanical Engineering, St. Joseph's Institute of Technology, Chennai, Tamil Nadu, India
[3]Associate Professor, Department of Mechanical Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India
[5-8]UG Student, Department of Mechanical Engineering, St. Joseph's Institute of Technology, Chennai, Tamil Nadu, India

Received Date: January 23, 2025
Accepted Date: May 05, 2025
Published Date: May 12, 2025

Citation: M Chrispin Das, S Prathap Singh, R Malkiya Rasalin Prince, K. Gnanasekaran, S Manikandan, A Dhanush, D S Sujith Kumar, S Yuva Praveen. Influence Of Alkali Treatment on The Tensile Properties of the Hybrid Fiber Reinforced Polymer Matrix Composite. Journal of Polymer & Composites. 2025; 13(Special Issue 4): S28–S34p.

INTRODUCTION

In recent decades, the utilization of natural cellulose fiber-PMCs in engineering and academic domains has rapidly expanded. Numerous studies on natural fiber PMCs have demonstrated their favorable specific belongings, such as a great strength-to-weight ratio, small cost and density, abundant availability, reduced production pollution, minimal health risks, and an eco-friendly profile. Nonetheless, the integrity of synthetic fiber-strengthened PMCs remains uncompromised [1,2,3].

Natural fibers offer numerous benefits, including lower weight, cost-effectiveness, biodegradability, and suitable specific properties compared to synthetic fibers like glass, carbon, and aramid. In addition to the benefits, there are notable disadvantages, including little impression capacity, dimensional unsteadiness, lower thermal

steadiness, and an extraordinary tendency for moisture absorption [4,5]. The incorporation of an additional element improved the properties of natural fiber PMCs. It could potentially be an alternative fiber or filler [6]. Numerous authors have conducted studies on the impact of hybridization on the performance of natural fiber PMCs. Some researchers have shown that lignin, pectin, and other impurities in fiber reduce composite adhesion. Consequently, treating coir fiber with an alkali increases its ability to stick to the polyester matrix, which makes the composite stronger [7,8].

Huang demonstrated that the application of alkali usage on coir fiber effectively eliminated contaminations such as pectin, fats, and lignin, leading to a roughened fiber surface. The enhancements augment the bonding agent capacity of the coir fiber in conjunction with the base polymer matrix within the constructed component, leading to an increased tensile power of the component [9]. Saravanakumaar *et al.* conducted a study on the use of alkali-treated kenaf fiber for strengthening a polypropylene matrix. They examined the mechanical properties of the developed composites both with and without the alkali-treated fiber. They reported a notable enhancement in mechanical properties when utilizing treated fiber [7]. According to Asumani *et al.,* they studied papaya fibers by putting them in an aqueous NaOH solution at room temperature and changing the treatment time in a planned way. Their study concluded that the duration of treatment also influences the mechanical properties of the material developed [10].

Despite extensive research on fiber-reinforced polymer composites, there is a notable lack of studies investigating the impression of NaOH surface processing on the tensile belongings of hibiscus fiber, gongura fiber, and treated madar fiber-strengthened polymer-based composites [11]. In light of this context, the current research endeavor has been initiated with the aim of examining the potential application of hibiscus fiber, gongura fiber, and treated madar fibers as reinforcing agents in polymer composites, as well as assessing their impact on the tensile power of the resultant polymer-based composites [12]. This study involved the treatment of madar fibers with NaOH at different concentrations. The tensile power of the fabricated varieties was assessed, and an investigation utilizing SEM was conducted.

MATERIALS AND METHODS

Materials For the Polymer Composite

The raw ingredients designated for the recent exploration are hibiscus fiber, gongura fiber, and madar fiber. The madar fiber was treated in the NaOH solution for different periods of time with different compositions of NaOH, and these fabrication variables were optimized. Figures 1(a), 1(b), and 1(c) show the hibiscus fiber, gongura fiber, and treated madar fiber, respectively. Polyester resin was chosen for PMCs. Polyester resin came from POOJA Chemicals in Madurai, Tamil Nadu.

Figure 1. (a) hibiscus fiber, (b) gongura fiber, (c) treated madar fiber.

Table 1. Tensile property control variables and their stages.

S no	Tensile property control variables	Low	Medium	High
1	Duration of fiber treatment (Hours)	6	12	24
2	Concentration of NaOH for treatment (%)	5	10	15
3	Proportion of fiber hybridization (%)	65	70	75

Fabrication

The polymer composite sheets were fabricated using the hand layup technique. A mold constructed from mild steel, measuring 150 x 150 x 10 mm, was utilized for tensile testing properties. A freeing manager was initially applied to facilitate the calm elimination of PMC plates. The fibers were arranged in the mold layer by layer, with resin applied according to the specified proportions. It is essential to prevent the appearance of cavities. The roller is employed to eliminate surplus matrix resin from the mold. Compression is applied above the upper part of the mold, and it is allowed to cool at ambient conditions for 72 hours.

Tensile Property Evaluation

After fabrication, the assessment specimens were exposed to mechanical tests at room temperature as per ASTM standards using a universal testing machine, the INSTRAN 5500 R-60211 Machine. The standards followed are ASTM-D638 for the tensile experiment with the crosshead speed of 5 mm/min. The design of experiments was used to perform the tensile test experiment via L27 orthogonal array tables, and Taguchi's methodology was utilized to optimize the tensile property control factors. Table 1 indicates the tensile property control variables and their three stages.

The significant tensile property control variables with levels were observed through the Signal-to-Noise Ratio (SNR) for producing a maximum tensile strength. The statistical software MINITAB 21 was used to randomly generate the order of the experiment. Taguchi's 'Smaller is better'' feature was utilized to inspect the determined tensile strength, whose equation is given by

$$SNR = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} Z_i^2\right)$$

Where Z denotes the calculated tensile strength, and n denotes the volume of repetitive investigations. On the basis of the SNR data, the delta value of the tensile property control variables was deduced. An Analysis of Variance (ANOVA) helps researchers identify factors that significantly affect response variables.

RESULT AND DISCUSSION

Statistical Exploration of Tensile Strength

Table 2 shows the outcome of the tensile experiment performed via L27 orthogonal array tables and their respective tensile strength values.

Table 3 shows the mean SNR measurements of the calculated tensile strength, and it is explored that the fiber treatment duration is the tensile property control variable having the highest impact on the tensile strength, followed by the fiber hybridization proportion and the concentration of NaOH for fiber treatment. Furthermore, the mean SNR plot (Figure 2) reveals the optimal tensile strength based on the tensile property control variables. There is a 24- hour fiber treatment, 15% concentration of NaOH, and 70% fiber hybridization were found to be the optimum control variables.

With the use of ANOVA, it is possible to determine which of the three tensile property control variables - the duration of fiber treatment, the concentration of NaOH for treatment, and the fraction of fiber hybridization -have a significant impact on the tensile strength performances. This study used analysis of variance to get a confidence range for tensile strength that was 95%. A p-value that is less than 0.05 indicates that the tensile property control variable has a substantial impact on the tensile capability of the material when compared to other variables.

Table 2. Tensile strength values for the experiments.

Run no	Duration of fiber treatment (Hours)	Concentration of NaOH for treatment (%)	Proportion of fiber hybridization (%)	Tensile Strength (MPa)
1	6	5	65	31.51
2	6	5	65	33.37
3	6	5	65	32.41
4	6	10	70	34.21
5	6	10	70	35.29
6	6	10	70	37.81
7	6	15	75	41.21
8	6	15	75	39.25
9	6	15	75	38.89
10	12	5	70	51.21
11	12	5	70	53.11
12	12	5	70	52.58
13	12	10	75	43.02
14	12	10	75	44.98
15	12	10	75	46.44
16	12	15	65	39.50
17	12	15	65	34.82
18	12	15	65	46.38
19	24	5	75	42.18
20	24	5	75	43.91
21	24	5	75	46.39
22	24	10	65	40.29
23	24	10	65	41.98
24	24	10	65	43.97
25	24	15	70	55.18
26	24	15	70	58.48
27	24	15	70	57.24

Table 3. Mean SNR values for tensile strength.

Level	Duration of fiber treatment (hours)	Concentration of NaOH for treatment (%)	Proportion of fiber hybridization (%)
1	31.08	32.49	31.53
2	33.10	32.18	33.51
3	33.48	33.00	32.63
Delta	2.40	0.83	1.98
Rank	1	3	2

Table 4 tabulated the proportion of involvement of each tensile property controlling variable to the tensile strength of the hybrid PMC. The table showed that the duration of fiber treatment contributed the major percentage of 47.03%. The other tensile property control variables, such as the proportion of fiber hybridization (30.22%) and concentration of NaOH for treatment (6.8%), had a minor percentage of contribution over the tensile strength.

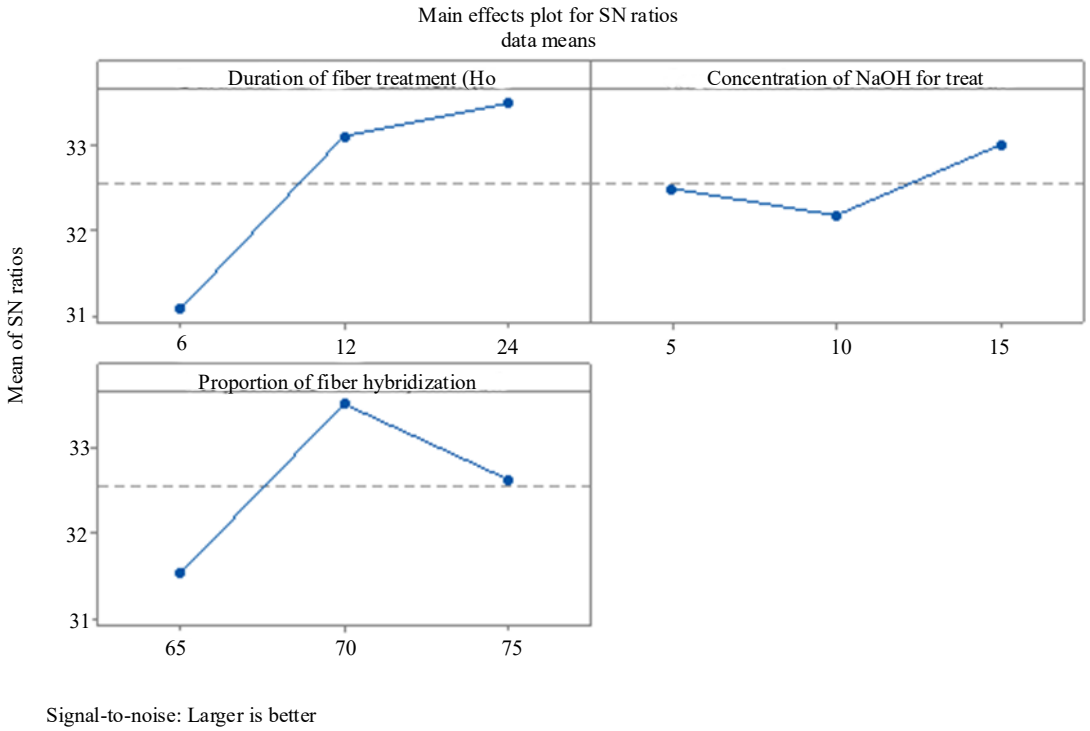

Figure 2. Mean SNR graph for tensile strength.

Table 4. Table of ANOVA consequences for the tensile capability.

Tensile property control variable	DF	Adj SS	Adj MS	F-Value	P-Value	Impact proportion (%)
Duration of fiber treatment (Ho	2	712.4	356.205	29.74	0.000	47.03
Concentration of NaOH for treat	2	103.1	51.556	4.31	0.028	6.8
Proportion of fiber hybridization	2	459.7	229.850	19.19	0.000	30.22
Error	20	239.5	11.976			17.78
Lack-of-Fit	2	131.1	65.552	10.88	0.001	8.66
Pure Error	18	108.4	6.023			7.16
Total	26	1514.7				

Effect of Tensile Property Control Variable on the Tensile Capability

Figure 3 indicates the influence of tensile property control variables on the mean tensile strength of the hybrid PMC. The tensile capability of polymer composites is enriched with the duration of fiber treatment. Longer treatment times can improve the cleaning of dirt, wax, and other non-cellulose materials like lignin and hemicellulose from the outside of the fiber. The longer treatment can also make the surface rougher and reveal reactive functional groups, like hydroxyl groups, which makes it easier for the fiber and polymer matrix to stick together. The enhanced bonding facilitates stress transmission under tensile loading, thereby augmenting strength. Prolonged treatment may result in the composite's fiber breaking or degradation, thereby reducing its mechanical properties.

As the intensity of NaOH in the fiber process solution rose, so did the composite's tensile strength. This increase could be owing to the elimination of non-cellulosic substances such as lignin and hemicellulose, along with supplementary impurities, from the fiber exterior area. This process strengthens the matrix-fiber interaction, exposes more hydroxyl groups, and roughens the surface. The improved load transmission from the treated fibers increases the composite's tensile strength. However, a high concentration of NaOH may weaken or break down fibers, changing the properties of the polymer-based fiber-strengthened composite.

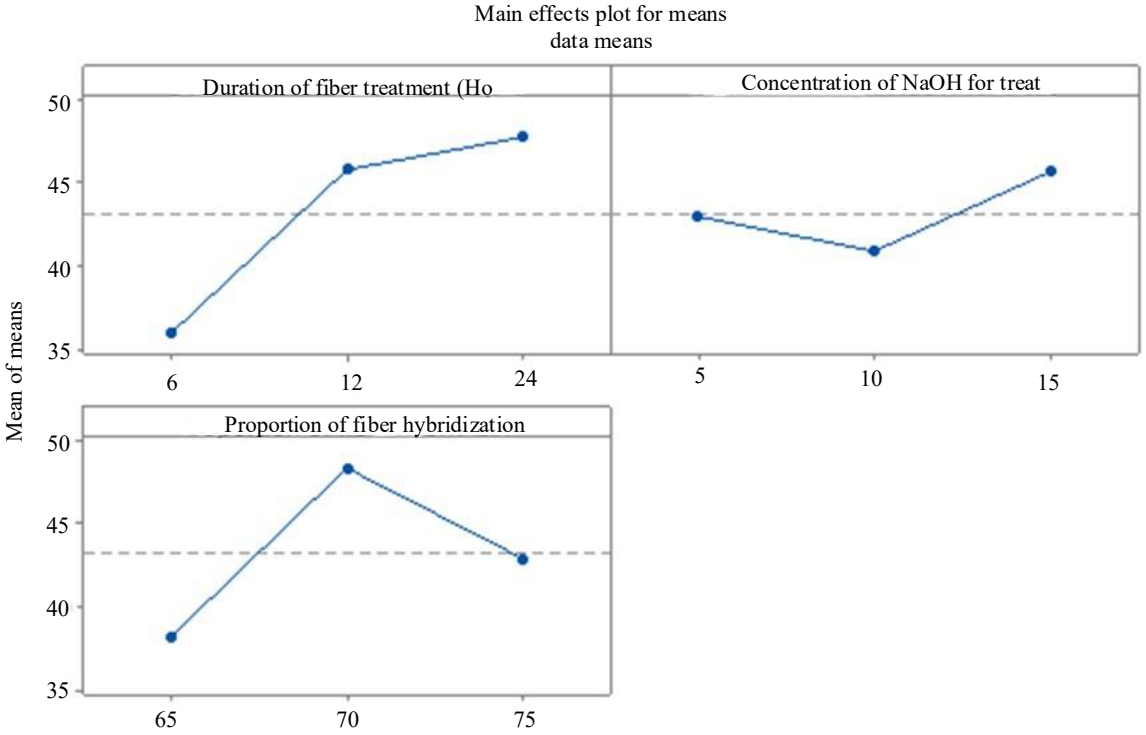

Figure 3. Impression of tensile property control variables on the tensile capability.

The maximum tensile capability was achieved with 70% fiber hybridization. The optimal balance between the characteristics of the two fibers used in hybridization may account for this. At this percentage, the properties of fiber stiffness, strength, and flexibility work together to enhance load distribution and energy absorption. The 70% hybridization might improve stress transfer at the fiber-matrix interface and lower the composite void content, which means there are fewer weak spots that could cause the material to break. The presence of a dominant fiber type can disrupt this equilibrium and diminish tensile strength beyond this threshold.

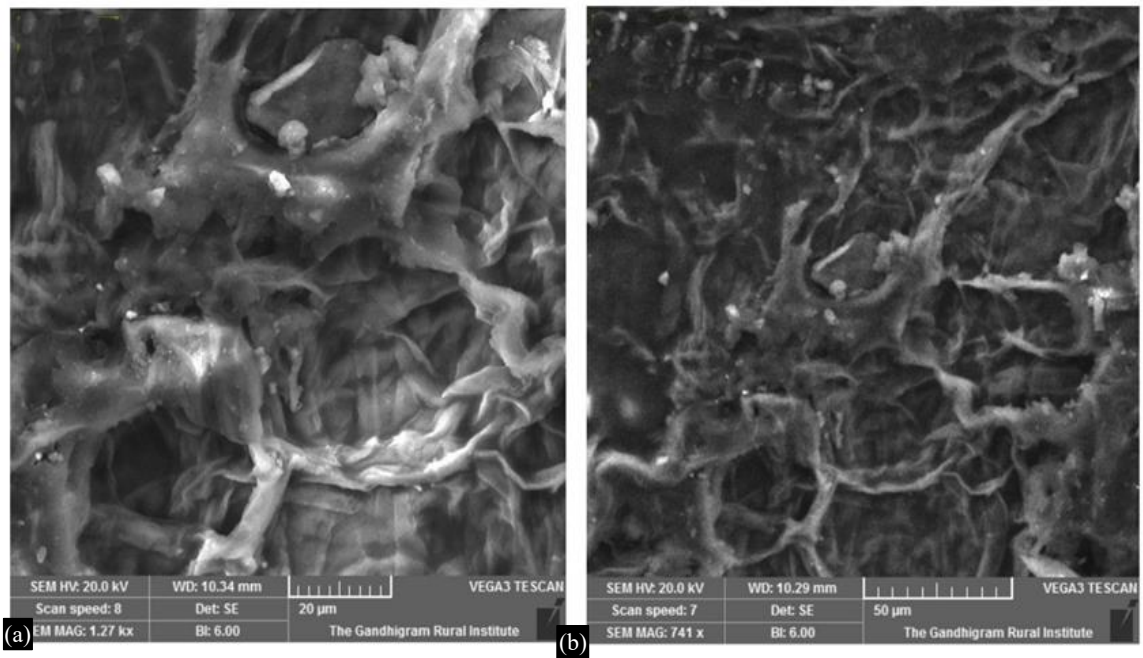

Figure 4. Fracture surface of hybrid polymer composite.

Fractured Surface Examination

The SEM was utilized to investigate the fracture exterior of the composite specimen to assess the fiber pullout, fiber splitting, debonding, matrix cracking, and fiber-matrix interaction. Figures 4(a) and (b) show the SEM pictures of the tensile examination fracture surface of the polymer composite at optimum tensile property control variables. It revealed the proper bonding and adhesion between the polymer matrix resin and the reinforced fiber materials.

CONCLUSIONS

The hibiscus fiber, gongura fiber, and treated madar fiber-reinforced PMC were made using the traditional hand layup method. The tensile property control variables were then optimized to get the lowest tensile strength. The study has drawn major conclusions.

1. The SNR analysis revealed the major contribution of the span of fiber treatment on the tensile strength. Moreover, 24-hours of fiber treatment, 15% concentration of NaOH, and 70% fiber hybridization were found to be the optimum control variables.
2. The ANOVA confirmed that the duration of fiber treatment significantly contributes to the tensile strength, with a percentage contribution of 47.03.
3. The prolonged treatment durations can enhance the removal of contaminants, waxes, and non-cellulosic compounds, such as lignin and hemicellulose, from the fiber exterior area, thereby increasing the tensile strength.
4. The SEM evaluation revealed the proper bonding and adhesion among the matrix resin and the reinforced fiber materials.

REFERENCES

1. Prabhuram T, Prathap Singh S, Elil Raja D, Immanuel Durairaj J, Chrispin Das M, Ravichandran P. Development and mechanical characterization of jute fibre and multi-walled carbon nanotube-reinforced unsaturated polyester resin composite. Materials today proceeding 2023.
2. Chrispin Das M, Prathap Singh S, Rangarajan V, Prabhuram T. Characterization of pineapple leaf fiber, areca fiber and egg shell powder reinforced phenolic resin composites and finding optimal parameters for sustainable machining. Materials today proceeding 2023.
3. Chrispin das M, Arthur Jebastine Sunderraj D, Arun Vasantha Geethan K, Elilraja D, Prabhuram T, Prathap Singh S. Mechanical and moisture absorption behaviour of Woven pineapple leaf phenol formaldehyde composites. Materials today proceeding 2023; 62(2): 1303-1307.
4. Khan ZR, Srivastava SK, Gupta MK. Tensile and flexural properties of natural fiber reinforced polymer composites: A review. J. Reinf. Plast. Compos. 2018; 37 (24):1-21.
5. Ayushi Gupta, Narendra Kumar, Anish Sachdeva. Factors affecting the ageing of polymer composite: A state of art. Polymer Degradation and Stability. 2024; 221: 110670
6. Qingguo Chen, Kailun Yang, Yu Feng, Liang Liang, Minghe Chi, Zhonghua Zhang, Xuesong Chen. Recent advances in thermal-conductive insulating polymer composites with various fillers. Composites Part A: Applied Science and Manufacturing. (2024); 178: 107998.
7. Jun-Wei Zha, Fan Wang, Baoquan Wan. Polymer composites with high thermal conductivity: Theory, simulation, structure and interfacial regulation. Progress in Materials Science. (2024); 148: 101362.
8. Khalid Mohammed, Rozli Zulkifli, Mohd Faizal Mat Tahir, Tayser Sumer Gaaz. A study of mechanical properties and performance of bamboo fiber/polymer composites. Results in Engineering (2024); 23: 102396.
9. Monteiro SN, Santaf JR, Costa LL. In TMS Conference, San Francisco, CA, USA, 2009.
10. Huang GU. Mater. Des. 2009, 30, 3931–3934.
11. Annamalai Saravanakumaar, Arunachalam Senthilkumar, Balasundaram Muthu Chozha Rajan. Effect of Fillers on Natural Fiber–Polymer Composite: An Overview of Physical and Mechanical Properties. Int. J. Polym. Anal. Charact. 2018; 23: 529-536.
12. Asumani OML, Reid RG, Paskaramoorthy R. The effects of alkali–silane treatment on the tensile and flexural properties of short fibre non-woven kenaf reinforced polypropylene composites. Part A Appl. Sci. Manuf. 2012; 43:1431-1440.

