



## Effect of loading parameters on mechanical properties of PA-HIPS-Kenaf composite via Full Factorial

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### KEYWORDS

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### ABSTRACT

Natural fiber-reinforced polymer composites (NFRPCs) are emerging as a sustainable alternative to conventional synthetic composites, offering advantages in environmental sustainability and biocompatibility. This study investigates the mechanical properties of NFRPCs utilizing kenaf fibers within polyamide 6,6 (PA) and hybrid matrices of polyamide and high-impact polystyrene (HIPS). A full factorial experimental design was employed to analyze the impacts of fiber content, polymer matrix, and compatibilizer (MAPP) on the elastic modulus and elongation at break. Mechanical testing was conducted in accordance with ASTM D638 standards using a universal testing machine (UTM). The results reveal that the interaction between kenaf fiber content and MAPP loading, as well as the relationship between MAPP loading and the matrix type, significantly affects the elastic modulus of the composites. Specifically, a lower MAPP content in the PA matrix, when combined with reduced kenaf fiber loading, leads to enhanced stiffness and elevated elastic modulus values. Among the tested variables, kenaf fiber loading is the only factor that positively correlates with the elastic modulus, indicating that increased kenaf content directly enhances material stiffness. The optimal conditions for maximizing elongation at break were found at the lowest kenaf fiber loading with the PA matrix. This outcome is attributed to the inherent chemical compatibility between PA and kenaf fibers, which facilitates superior bonding and flexibility. It also found that all interaction factors contribute significantly to the enhancement of elongation at break, thus improving the ductility of the composites.

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## 1.0 INTRODUCTION

Natural fiber-reinforced polymer composites (NFRPCs) have garnered significant attention due to their enhanced biocompatibility and sustainability compared to traditional synthetic fiber-reinforced composites [1-4]. Numerous studies have highlighted the potential of natural fibers in polymer composites to improve environmental and biological compatibility. For instance, Ramamoorthy et al. demonstrated that polypropylene composites reinforced with banana fibers

exhibited superior tensile and flexural properties compared to the neat polymer [5]. Similarly, Ismail et al. reported enhanced thermal stability and biodegradability in kenaf fiber-reinforced polylactic acid composites [6]. These studies underscore the growing interest in utilizing natural fibers to develop eco-friendly and sustainable composite materials.

One such natural fiber is kenaf, a cellulosic fiber derived from the kenaf plant, known for its high specific strength, low density, and renewable nature [9-10]. Kenaf fibers are already being employed in various commercial products such as high-quality paper, biocomposites for automotive interior components, bioplastics, medium-density fiberboard (MDF), textiles, and furniture [11]. Outstanding applications of kenaf fibre are in aerospace, ballistic armor, ceiling and recurve bow [12].

Matrix polymer polyamide (PA), commonly known as nylon, is a versatile synthetic polymer characterized by its high tensile strength, elasticity, and durability [13]. These properties make it widely used in textiles, automotive parts, and engineering plastics. In terms of mechanical properties, polyamide displays a tensile strength typically ranging from 70 to 100 MPa, which can be increased with fiber reinforcement [14,15]. The elastic modulus of nylon varies between 2.5 and 4 GPa, depending on its formulation and processing, indicating moderate stiffness [16,17]. Nylon also demonstrates notable ductility, with elongation at break between 10% to 80%, depending on the grade and moisture absorption, which impacts flexibility and toughness.

Another matrix polymer, high-impact polystyrene (HIPS), is produced by the radical polymerization of styrene monomer with polybutadiene rubber. HIPS is commonly used in the manufacture of toys, packaging, bottles, light-duty industrial components, and electronics [18]. Its advantages include good impact resistance, low cost, and ease of processing [19].

The mechanical properties of kenaf-reinforced PA or HIPS are vigorously study for it thermal properties as PA is highly flame-retardant [20-22]. The interactions between polymer matrices of PA and HIPS are found better with addition of binder maleic anhydride that significantly affect the mechanical performance of the resulting composites [23]. The specific effects of fiber loading, matrix composition, and processing conditions on mechanical performance are of considerable interest in NFRPC research. This study aims to investigate the influence of these parameters on the mechanical properties of PA-HIPS-Kenaf composites using a full factorial experimental design.

## 2.0 METHODOLOGY

### 2.1 Materials and equipment

The kenaf fibers underwent alkaline treatment by immersion in a 6 wt% NaOH solution (50 g) with distilled water for 24 hours. Afterward, the fibers were rinsed thoroughly until a neutral pH (pH 7) was achieved and then oven-dried at 40°C for an additional 24 hours. Following the treatment, the fibers were mechanically reduced to an average diameter of 150 µm for further processing.

The polymer matrices used were PA Novamid and HIPS Idemitsu PS HT50 Grade, with maleic anhydride grafted polypropylene (MAPP) from Sigma-Aldrich serving as the compatibilizer. The polymer matrix, kenaf fibers, and compatibilizer were blended using a Collin twin-screw extruder (Teach-Line ZK 25T). A total of 18 different mixture ratios of matrix, fiber, and compatibilizer were prepared to form the composite compound. The extruder applied heat and mechanical shear to ensure uniform dispersion of fibers within the molten polymer. After the removal of moisture and volatiles, the composite was shaped, cooled, and cut into the required lengths.

These blended compounds are then undergoing injection moulding process to produce ASTM D638 Type I tensile specimen. TOYO Ti-50GX injection moulding setting for specimen production is given in Table 1. INSTRON 3382 tensile test machine is used for mechanical tensile testing.

Table 1: Injection moulding setting

Injection Mould Parameter	Range
Melting Temperature (°C)	189-206
Mould Temperature (°C)	35-40
Injection Pressure (Bar)	118

## 2.2 Design of Experiment

A design of experiment by full factorial  $3^2$  with 3 replications is applied to investigate the effects of three factors, namely kenaf fiber, compatibilizer and polymer matrix loading as shown in Table 2. Kenaf fiber loading is vary between 10% and 20% by weight, MAPP compatibilizer is vary between 2.5% and 5% by weight and finally the polymer matrix is varied between PA and PA-HIPS make up to 100% by weight.

Table 2: Design of experiment by full factorial  $3^2$ 

Parameters	Level 1	Level 2
Kenaf Fiber	10	20
MAPP Compatibiliser	2.5	5
Polymer Matrix	PA	PA-HIPS

In the Design Expert software, a full factorial  $3^2$  design with 3 replications is used to assess the effects of three factors, each at two levels, on a response variable. This setup results in 24 experimental runs (8 combinations  $\times$  3 replications) to ensure reliable results. After the experiments, ANOVA (Analysis of Variance) is applied to determine the significance of the factors and their interactions. Table 3 presents all the experimental runs with their combination of factor levels.

A p-value threshold of 0.05 was used to assess statistical significance, with factors or interactions having p-values below 0.05 deemed significant. To stabilize variance and satisfy the assumptions of ANOVA, a log base 10 transformation was applied to the response data. This transformed data was then analyzed to identify the key factors and interactions influencing the response, providing a foundation for optimization efforts.

Table 3: Factorial 3<sup>2</sup> run PA-HIPS

Experiment Run	Factor A	Factor B	Factor C
1	20	5	PA-HIPS
2	20	5	PA
3	20	5	PA-HIPS
4	10	2.5	PA-HIPS
5	10	5	PA-HIPS
6	20	2.5	PA
7	20	2.5	PA-HIPS
8	10	5	PA
9	10	2.5	PA
10	10	5	PA
11	10	5	PA-HIPS
12	10	2.5	PA-HIPS
13	10	5	PA
14	10	5	PA-HIPS
15	20	2.5	PA
16	20	2.5	PA
17	20	2.5	PA-HIPS
18	20	2.5	PA-HIPS
19	10	2.5	PA
20	10	2.5	PA
21	20	5	PA
22	20	5	PA-HIPS
23	10	2.5	PA-HIPS
24	20	5	PA

### 3.0 RESULTS AND DISCUSSION

The experimental design (DOE) was systematically structured to examine the effects of loading parameters on the mechanical properties of natural fiber-reinforced polymer composites (NFRPCs), with particular attention to elastic modulus and elongation at break. A full factorial design was utilized to explore the impact of critical factors, including fiber content, matrix composition, and processing conditions, each at multiple levels. The selection of these variables was based on their potential to influence the stiffness (elastic modulus) and ductility (elongation at break) of the composites.

By adjusting the loading parameters across all possible combinations, the full factorial approach facilitated the assessment of both the main effects and interactions among factors. Standardized mechanical testing procedures were employed to measure the properties, and ANOVA was applied to the response data, with a p-value threshold of 0.05 used to identify statistically significant effects. This methodology enabled the determination of optimal loading conditions that enhance both stiffness and ductility, contributing to the development of NFRPCs with tailored mechanical performance for specific applications.

### 3.1 Elastic modulus

The elastic modulus is a fundamental measure of a material's stiffness, indicating its resistance to deformation under applied stress. A higher elastic modulus denotes a stiffer material that deforms less under load, while a lower modulus suggests a more flexible material that deforms more easily. This study explores how the variations in fiber, matrix, and compatibilizer loadings influence the elastic modulus of natural fiber-reinforced polymer composites (NFRPCs). By adjusting the content of these components, the research aims to determine how changes in the composite's formulation affect its stiffness, providing insights into optimizing material performance for different applications.

Full factorial designs offer a robust approach for analyzing the impact of multiple factors on a response variable, providing a comprehensive understanding of both main effects and interactions. In this study, the effects of various factors on the elastic modulus were evaluated using a half-normal plot, as shown in Figure 1. The plot reveals that interaction factor BC exhibits the highest half-normal probability value, indicating it has the most significant influence on the composite's elastic modulus. Interaction factor AB follows, suggesting it also plays a substantial role. Among the main factors, A, C, and B are ranked according to their decreasing influence, while interaction factor AC shows the lowest half-normal value, signifying it has the least effect on the elastic modulus response. This ranking helps prioritize factors for optimizing composite stiffness.

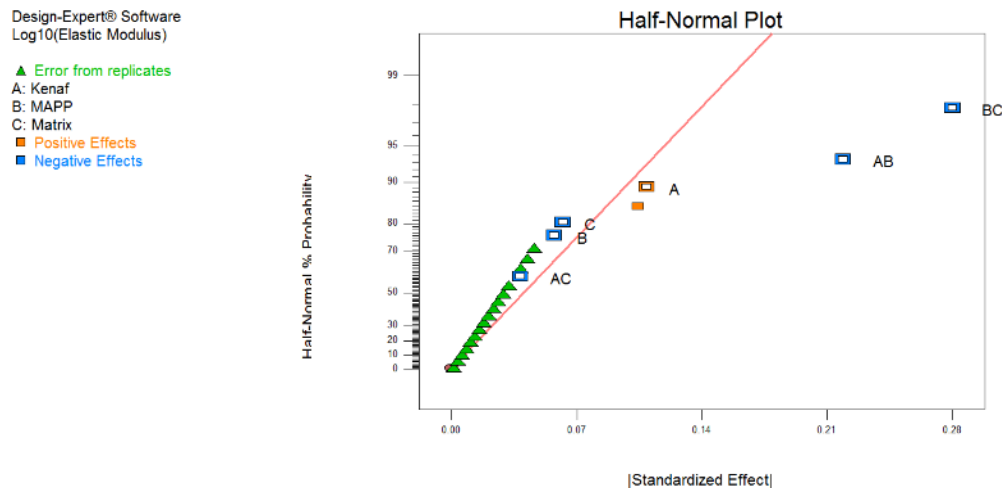


Figure 1: Half-normal plot against standardized effect

Pareto chart in Figure 2 was analyzed to determine the factors with the most significant influence on the composite's elastic modulus. The largest effect on the elastic modulus is attributed to the interaction between factors B and C, followed by the interaction between factors A and B. Among the main factors, A (kenaf fiber loading) has the most pronounced impact, followed by factors C and B. The least effect on elastic modulus of composite is interaction factor AC. Notably, only main factor A exhibits a positive effect on elastic modulus, indicating that increasing the kenaf fiber content

enhances the stiffness of the composite. The interaction factor ABC, represented by the solid orange bar, is excluded from the ANOVA analysis as it did not significantly contribute to the elastic modulus.

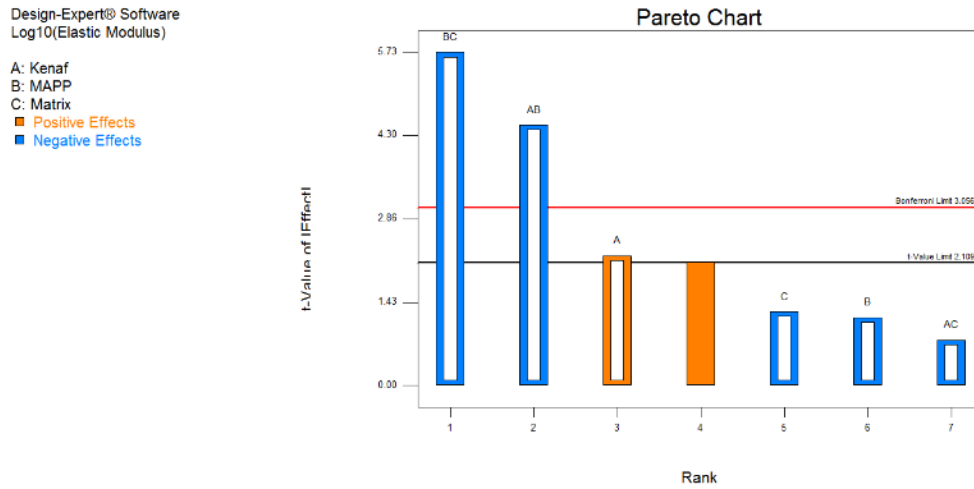


Figure 2: Pareto chart for elastic modulus response

Interactions BC and AB exhibit greater effects than the individual factor A, but both BC and AB have negative effect on composite’s stiffness. This suggest that reducing the interaction between MAPP and polymer matrix and interaction between kenaf and MAPP would result in an increase in the elastic modulus. Factors B, C and AC are fall below the t-value therefore they are not very influential to the elastic modulus.

The analysis of variance (ANOVA) for the elastic modulus of the PA-HIPS-kenaf composite is presented in Table 4. Statistically, the quadratic model shows an F-value of 10.24 and a p-value of less than 0.0001, indicating that the model is significant. The main factors A is the only main factor that is significant with p-value 0.0394 and it has positive effect on stiffness as shown in Figure 2. This means increasing the kenaf loading will increase the elastic modulus of the composites. The other main factors, B and C are not significant, confirming the findings from the half-normal plot and Pareto chart. Interaction factor AB and BC are significant as they have the p-value less than 0.05, and interaction factor AC is not significant.

Table 4: ANOVA analysis of elastic modulus for PA-HIPS

Source	Sum of Squares	df	Mean Square	F Value	p-Value Prob>F	
Model	0.85	6	0.14	10.24	<0.0001	significant
A-Kenaf	0.069	1	0.069	4.98	0.0394	
B-MAPP	0.019	1	0.019	1.38	0.2564	
C-Matrix	0.022	1	0.022	1.62	0.2200	
AB	0.28	1	0.28	20.03	0.0003	
AC	8.580E-003	1	8.580E-003	0.62	0.4421	
BC	0.45	1	0.45	32.80	<0.0001	
Residual	0.24	17	0.014			
Lack of fit	0.063	1	0.063	5.84	0.0280	significant
Pure Error	0.17	16	0.011			
Cor Total	1.09	23				

The interaction between factor A (kenaf loading) and factor B (MAPP loading) shown in the interaction plot of AB in Figure 3. AB is significant and has the largest negative effect on the elastic

modulus. At lower kenaf loading, higher content of MAPP results in a higher elastic modulus. However, at higher kenaf loading, the elastic modulus is not affected by MAPP content. This is because AB interaction has a negative effect to the elastic modulus of composite.

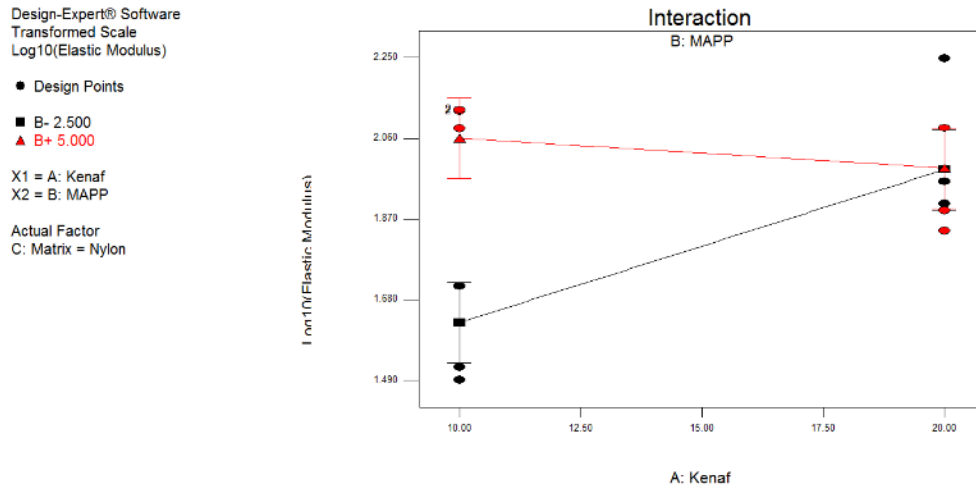


Figure 3: Interaction plot of AB

Second ranked significant interaction factor is between factor B (MAPP loading) and C (matrix). It is shown in Figure 4, at lower kenaf loading, PA-HIPS gives higher elastic modulus than PA. On higher kenaf loading, the opposite effect is observed. Elastic modulus obtained at higher kenaf loading is slightly higher than that at lower kenaf loading. The BC interaction has negative effect on elastic modulus. This observation is due to the different of hydrophobicity levels exhibit by Polyamide (PA) and high-impact polystyrene (HIPS), which creates challenges when blending them with hydrophilic natural fibers like kenaf. PA is inherently hydrophilic due to its amide groups, which readily form hydrogen bonds with water, leading to significant moisture absorption. This property can affect its mechanical performance, particularly reducing stiffness and increasing toughness in moist environments (24). In contrast, HIPS is more hydrophobic, with its polystyrene backbone making it resistant to water absorption. This disparity complicates the compatibility of PA and HIPS when combined with kenaf, which is also hydrophilic (25).

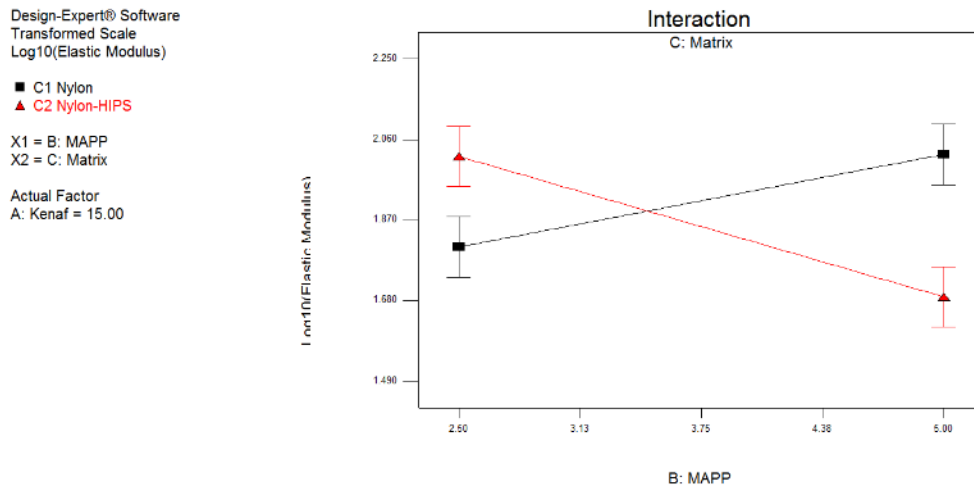


Figure 4: Interaction plot of BC

Those not significant factors, such as B, C, and AC are eliminated from the model. Thus, for maximum composite's elastic modulus, the optimum parameters are A+ and interaction factor AB- and BC-.

### 3.2 Elongation at break

Elongation at break is a main mechanical property representing a material's ability to undergo plastic deformation under tensile stress before fracture. It serves as a measure of ductility and toughness, reflecting how much the material can stretch without breaking. This property is crucial for applications that require flexibility and impact resistance, where materials need to absorb energy without failure. A higher elongation at break signifies greater deformation capability, which is particularly beneficial in materials designed for impact-resistant or flexible applications.

In the context of this study, a full factorial experimental design was used to systematically assess the influence of various parameters on elongation at break. The analysis involved a half-normal plot (Figure 5), where factors with the highest probability values were identified as having the greatest influence on this property. According to the analysis, factor A demonstrated the most significant impact on elongation at break, followed by interaction factors AC and BC. Other influential elements included main factor C, the interaction of AB, and main factor B. The green points on the plot represent errors derived from replicate measurements, helping to ensure the reliability of the experimental results.

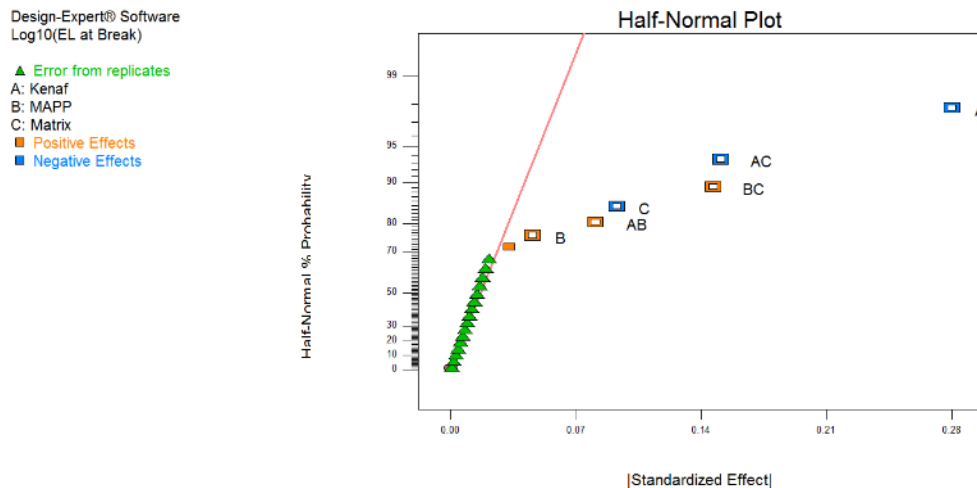


Figure 5: Half-normal plot against standardized effect

In addition to the residual analysis, the Pareto chart is used to visualize the effects of different parameters on the composite's elongation at break, as shown in Figure 6. The Pareto chart ranks the factors by their influence, with the main factor A (kenaf fiber loading) having the most significant effect, followed by the interaction of AC (kenaf and matrix), and then BC (matrix and MAPP). Other contributing factors include main factor C (matrix) and the interaction of AB (kenaf and MAPP), with main factor B (MAPP) ranking last.

Notably, factors A, C, and BC negatively impact elongation at break, meaning that increasing the levels of kenaf fiber, matrix, or their interaction will reduce the material's flexibility. Although these factors exhibit a strong effect on elongation, their negative contribution highlights the trade-off between stiffness and ductility in composite materials.

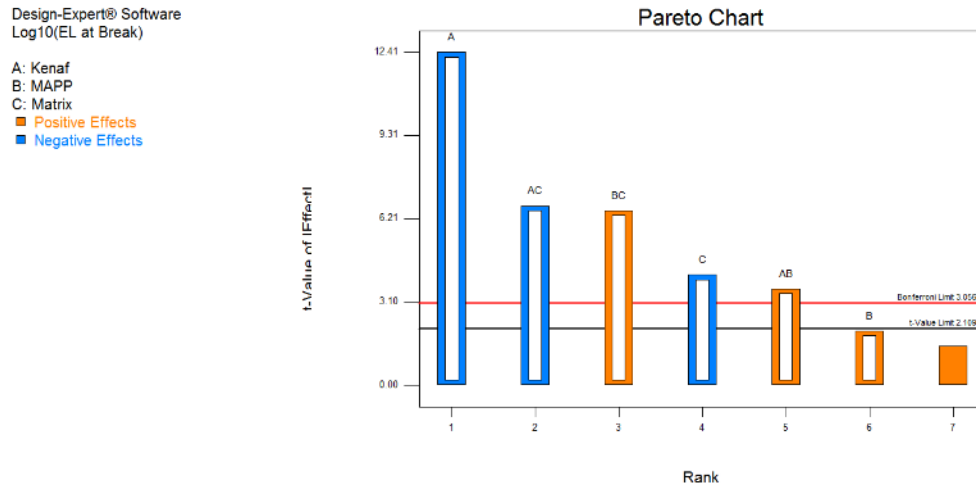


Figure 6: Pareto chart for elongation at break response

ANOVA statistical analysis for identifying which factors and interactions significantly influence the response variable and for optimizing experimental conditions. Table 5 is the ANOVA analysis for elongation at break of the composite. It shows that the model is significant with p-value <0.0001. The main factors A (Kenaf), and C (Matrix) are significant where these parameters give significant influence on the composite’s ductility. As for the interaction factors, all interaction factor AB, AC and BC are significant as the p-values of these interaction factors are less than 0.05. The lack of fit is not significant relative to the pure error.

Table 5: ANOVA analysis of elongation at break response

Source	Sum of Squares	df	Mean Square	F Value	p-Value Prob>F	
Model	0.83	6	0.14	45.84	<0.0001	significant
A-Kenaf	0.46	1	0.46	154.01	<0.0001	
B-MAPP	0.012	1	0.012	4.12	0.0583	
C-Matrix	0.051	1	0.051	16.98	0.0007	
AB	0.039	1	0.039	12.88	0.0023	
AC	0.13	1	0.13	44.78	<0.0001	
BC	0.13	1	0.13	42.28	<0.0001	
Residual	0.051	17	3.000E-003			
Lack of fit	6.381E-003	1	6.381E-003	2.29	0.1498	not significant
Pure Error	0.045	16	2.788E-003			
Cor Total	0.88	23				

The interaction factor AC shows the most significant negative interaction effect on elongation at break. Figure 7 illustrates the interaction between factor A (kenaf fiber loading) and factor C (matrix type). The plot reveals that at lower fiber loading, both polyamide (PA) and the PA-HIPS blend exhibit higher ductility. However, at increased fiber content, the PA matrix maintains better ductility than PA-HIPS. Notably, PA-HIPS demonstrates superior ductility at lower fiber loadings, while PA outperforms at higher fiber loadings. This variation can be attributed to the hydrophilic nature of both PA and kenaf, enhancing their compatibility and overall ductility at higher loadings, compared to the more hydrophobic HIPS matrix [24].

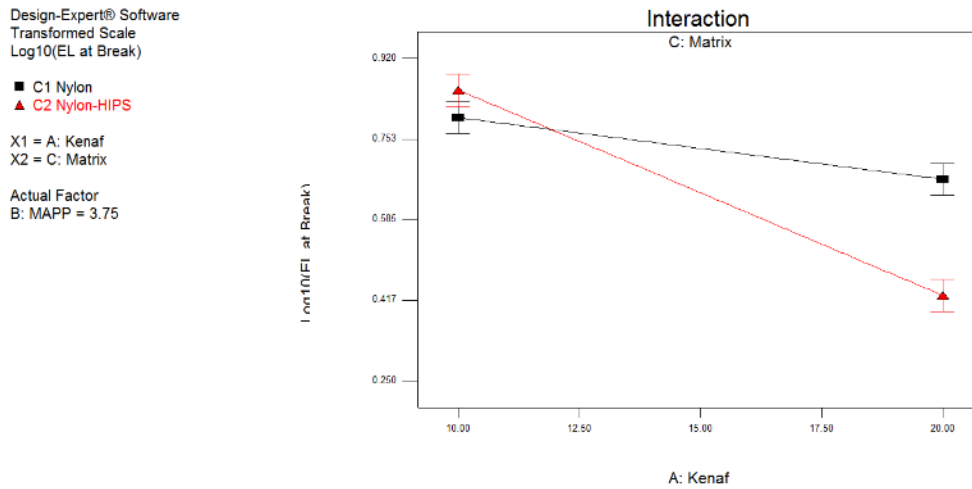


Figure 7: Interaction plot of AC

The second most influential interaction factor impacting the ductility of the composite is BC, which exhibits a significant negative effect. As shown in Figure 8, the interaction plot between factor B (MAPP compatibilizer loading) and factor C (matrix type) illustrates the influence of these factors on ductility. At lower MAPP loadings, the PA matrix contributes more to the composite's overall ductility. Conversely, at higher MAPP loadings, the PA-HIPS matrix takes precedence in affecting ductility. Given that BC is a significant negative effect, the optimal condition for maximizing the composite's ductility is achieved with low MAPP and a lower matrix content. This combination results in improved flexibility and elongation at break due to better interaction between the fiber and matrix under reduced compatibilizer levels.

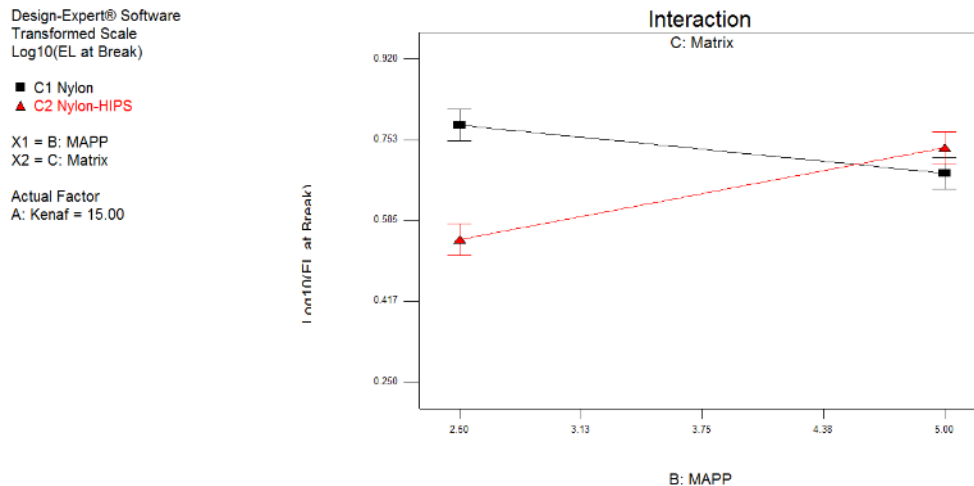


Figure 8: Interaction plot of BC

The last significant factor is the interaction factor between A (Kenaf) and B (MAPP). This interaction factor is a positive significant factor for higher composite's ductility. The interaction plot for interaction between factor A and B is given in Figure 9. It shows that MAPP loading at lower or higher kenaf loading is dominated by the lower level that give higher ductility. It can be concluded that less MAPP in kenaf composite will give better ductility.

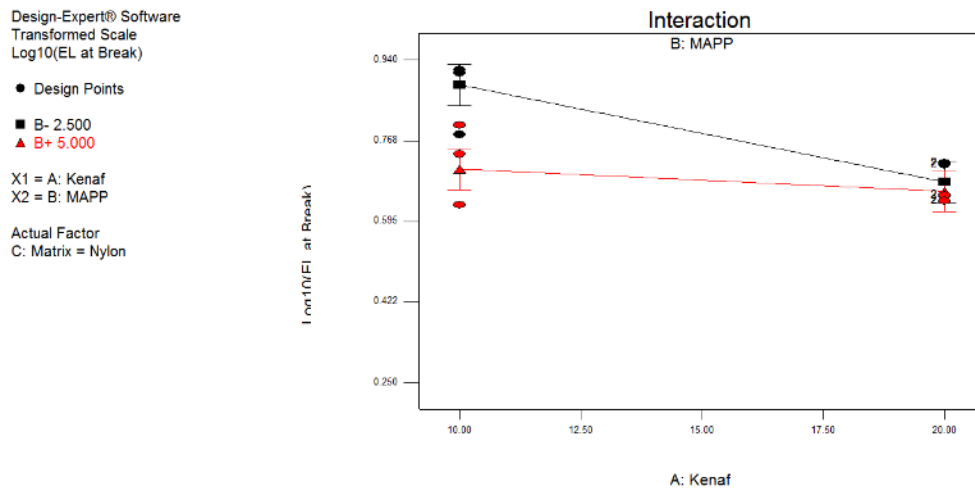


Figure 9: Interaction plot of AB

Factor B is eliminated from the model since it is the only factor that is not significant. Thus, for maximum composite's ductility, the optimum parameters are A- (Kenaf at lower loading), C- (PA matrix is the best), then followed by AB+, AC- and BC+.

#### 4.0 CONCLUSIONS

The study compares the mechanical properties of NFRPCs, particularly those reinforced with kenaf fibers in polyamide 6,6 (PA), and hybrid polyamide 6,6 (PA) and high-impact polystyrene (HIPS) matrices.

The results from the full factorial experimental design show that fiber, matrix, and compatibilizer loadings have notable effects on the mechanical properties, specifically the elastic modulus and elongation at break. The key findings include:

**Elastic Modulus:** The interaction between kenaf fiber and MAPP loading, as well as MAPP loading and the matrix, has a significant influence on the elastic modulus of the composites. Low MAPP content in the PA matrix, combined with low kenaf fiber loading, results in greater stiffness and higher elastic modulus values. Among the main factors, kenaf fiber loading is the only variable that shows a significant positive effect on the elastic modulus, indicating that increasing kenaf content directly enhances the material's stiffness.

**Elongation at Break:** The optimum condition for maximizing elongation at break occurs at the lowest kenaf fiber loading, with the PA matrix. This is due to the inherent chemical compatibility between PA and kenaf fibers, which promotes better bonding and flexibility. Furthermore, all interaction factors, including those between fiber, matrix, and MAPP loading, significantly contribute to increasing the elongation at break, thereby improving the composite's ductility.

#### Author Contribution

N. Irfilzati Ruslan: Conduct experiment; N. Bahiyah Baba: Data analysis and discussion A. Mohd: Investigation and supervision, N. Azinee Said: Methodology, writing and editing; N. Ngh: Methodology, writing and editing.

## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## 5.0 REFERENCES

- [1] Siti Hasnah Kamarudin, Mohd Salahuddin Mohd Basri, Marwah Rayung, Falah Abu, So'bah Ahmad, Mohd Nurazzi Norizan, Syaiful Osman, Norshahida Sarifuddin , Mohd Shaiful Zaidi Mat Desa , Ummi Hani Abdullah, Intan Syaifinaz Mohamed Amin Tawakkal and Luqman Chuah Abdullah, A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications, September 2022, *Polymers* 14(3698):1-36, 14(3698):1-36, DOI:[10.3390/polym14173698](https://doi.org/10.3390/polym14173698)
- [2] Composites of Polymer Blends and Their Applications Using Natural Fibres: A Review, A. Mohd, N. Bahiyah Baba, M. Z. Umor and R. M. Mohamed, Published under licence by IOP Publishing Ltd [IOP Conference Series: Materials Science and Engineering, Volume 1068, International Conference on Automotive Innovation & Green Energy Vehicle \(AIGEV 2020\) 10th-11th November 2020, Pekan, Malaysia \(2021\). 1068 012006 DOI 10.1088/1757-899X/1068/1/012006](https://doi.org/10.1088/1757-899X/1068/1/012006)
- [3] Muhammad Yasir Khalid, Ans Al Rashid, Zia Ullah Arif, Waqas Ahmed, Hassan Arshad, Asad Ali Zaidi, Natural fiber reinforced composites: Sustainable materials for emerging applications, *Results in Engineering*, Volume 11, 2021,100263, ISSN 2590-1230, <https://doi.org/10.1016/j.rineng.2021.100263> .
- [4] Dejene, B. K. (2024). Advancing Natural Fiber-Reinforced Composites Through Incorporating ZnO Nanofillers in the Polymeric Matrix: A Review. *Journal of Natural Fibers*, 21(1). <https://doi.org/10.1080/15440478.2024.2356015>
- [5] Sunil Kumar Ramamoorthy, Dan Åkesson, Rathish Rajan, Aravin Prince Periyasamy, Mikael Skrifvars, Mechanical performance of biofibers and their corresponding composites, Editor(s): Mohammad Jawaid, Mohamed Thariq, Naheed Saba, In Woodhead Publishing Series in Composites Science and Engineering, Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites, Woodhead Publishing, 2019, Pages 259-292,ISBN 9780081022924, <https://doi.org/10.1016/B978-0-08-102292-4.00014-X>.
- [6] N I Ismail and Z A M Ishak IOP Conference Series: Materials Science and Engineering, Effect of fiber loading on mechanical and water absorption capacity of Polylactic acid/Polyhydroxybutyrate-cohydroxyhexanoate/ Kenaf composite 2018, IOP Conf. Ser.: Mater. Sci. Eng. 368 012014
- [7] Syaza Najwa Mohd Farhan Han, Mastura Mohammad Taha, Muhd Ridzuan Mansor and Muhamad Arfauz A. Rahman, Investigation of tensile and flexural properties of kenaf fiber-reinforced acrylonitrile butadiene styrene composites fabricated by fused deposition modelling, *Journal of Engineering and Applied Science* (2022) 69:52, <https://doi.org/10.1186/s44147-022-00109-0>
- [8] Muhammad Ikram Shaharudin, Nor Bahiyah Baba, Alias Mohd, Rabiatul Manisah Mohamed, Mashelmie Sidik, An Experimental Investigation on Melt Flow Index and Water Absorption of rHIPS/ABS/Kenaf Composite, *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 108, Issue 1 (2023) 103-113, ISSN: 2289-7879, <https://doi.org/10.37934/arfmts.108.1.103113>
- [9] Adole Michael Adole, Jamaludin Mohamad Yatim, Suhaimi Abubakar Ramli, Athirah Othman and Norazura Azmi Miza, Kenaf Fibre and Its Bio-Based Composites: A Conspectus, *Pertanika J. Sci. & Technol.* 27 (1): 297 - 329 (2019) *Pertanika J. Sci. & Technol.* 27 (1): 297 - 329 (2019), ISSN: 0128-7680, e-ISSN: 2231-8526
- [10] Mashelmie, S., Rabiatul Manisah, M., Bahiyah Baba, N., Mohd, A. (2022). The effect of kenaf loading on kenaf/ABS composites structure and thermal properties. *Journal of Achievements in Materials and Manufacturing Engineering*, 111(2), 49–56. <https://doi.org/10.5604/01.3001.0015.9994>
- [11] Silva, T. T., Silveira, P. H., Ribeiro, M. P., Lemos, M. F., da Silva, A. P., Monteiro, S. N., Nascimento, L. F. (2021). Thermal and chemical characterization of kenaf fiber (*hibiscus cannabinus*) reinforced epoxy matrix composites. *Polymers*, 13(12), 2016. <https://doi.org/10.3390/polym13122016>

- [12] J. Jefferson Andrew, H.N. Dhakal, Sustainable biobased composites for advanced applications: recent trends and future opportunities – A critical review, *Composites Part C: Open Access*, Volume 7, 2022, 100220, ISSN 2666-6820, <https://doi.org/10.1016/j.jcomc.2021.100220>.
- [13] Safaei, B., Memarzadeh, A., Asmael, M. *et al.* Challenges and Advancements in Additive Manufacturing of Nylon and Nylon Composite Materials: A Comprehensive Analysis of Mechanical Properties, Morphology, and Recent Progress. *J. of Materi Eng and Perform* **33**, 6261–6305 (2024). <https://doi.org/10.1007/s11665-024-09368-9>
- [14] Mohammadzadeh, M.; Fidan, I. Tensile Performance of 3D-Printed Continuous Fiber-Reinforced Nylon Composites. *J. Manuf. Mater. Process.* **2021**, *5*, 68. <https://doi.org/10.3390/jmmp5030068>
- [15] Helena Oliver-Ortega, Fernando Julian, Francesc X. Espinach, Quim Tarrés, Marc Delgado-Aguilar, Pere Mutjé, 6 - Biobased polyamide reinforced with natural fiber composites, Editor(s): Kuruvilla Joseph, Kristiina Oksman, Gejo George, Runcy Wilson, Saritha Appukuttan, In *Woodhead Publishing Series in Composites Science and Engineering, Fiber Reinforced Composites*, Woodhead Publishing, 2021, Pages 141-165, ISBN 9780128210901, <https://doi.org/10.1016/B978-0-12-821090-1.00008-9>.
- [16] Zhang, B., Wu, Q., Zu, L. *et al.* Dynamic compressive behavior and constitutive model of polyamide-6 at different temperatures and strain rates. *Acta Mech* **235**, 5411–5430 (2024). <https://doi.org/10.1007/s00707-024-03997-w>
- [17] Zhao, Y.; Meng, Y.; Zhu, F.; Su, J.; Han, J. Mechanical Reinforcement in Nylon 6 Nanocomposite Fiber Incorporated with Dopamine Reduced Graphene Oxide. *Materials* **2022**, *15*, 5095. <https://doi.org/10.3390/ma15155095>
- [18] Hýlová, L., Mizera, A., Mizera, M., Grund, R., Ovsík, M. (2018). Mechanical Properties Study of High Impact Polystyrene Under Impact and Static Tests. *IOP Conference Series: Materials Science and Engineering*. <https://iopscience.iop.org/article/10.1088/1757-899X/448/1/012044>
- [19] El Houda Aouadi, N., Hellati, A., Cherupurakal, N., Guessoum, M., Mourad, A.-H. I. (2021). Investigation of mechanical properties and biodegradability of compatibilized thermoplastic starch/ high impact polystyrene blends reinforced by organophilic montmorillonite. *Polymers and Polymer Composites*, 29(9\_suppl). <https://doi.org/10.1177/096739112111046803>
- [20] Norihan Abdullah, Khalina Abdan, Muhammad Huzaifah Mohd Roslim, Mohd Nazren Radzuan, Ayu Rafiqah Shafi, and Lee Ching Hao, Properties of kenaf fiber-reinforced polyamide 6 Composites, *e-Polymers*, 24(1), 2024, DOI:[10.1515/epoly-2022-8112](https://doi.org/10.1515/epoly-2022-8112)
- [21] Norihan Abdullah, Khalina Abdan, Mohd Huzaifah Mohd Roslim, Mohd Nazren Radzuan, Lee Ching Hao and Ayu Rafiqah Shafi, Thermal Properties of Kenaf Fiber Reinforced Polyamide 6 Composites by Melt Processing, *Pertanika J. Sci. & Technol.* **31** (5): 2361 - 2374 (2023), DOI: <https://doi.org/10.47836/pjst.31.5.16>
- [22] Xia, Y., Liu, R., Lyu, X. *et al.* Study on kenaf flame retarded by halogen-free flame retardant/HIPS composites. *Fibers Polym* **15**, 2181–2185 (2014). <https://doi.org/10.1007/s12221-014-2181-9>
- [23] Chen, G. X., & Liu, J. J. (2000). Morphology, Crystallization Behaviors, And Mechanical Properties of PA1010/HIPS And Pa1010/HIPS-G-Ma Blends. *Polymer-Plastics Technology and Engineering*, 39(3), 529–542. <https://doi.org/10.1081/PPT-100100045>
- [24] Sambale, Anna Katharina, Michael Maisl, Hans-Georg Herrmann, and Markus Stommel. 2021. Characterisation and Modelling of Moisture Gradients in Polyamide 6, *Polymers* **13**, no. 18: 3141. <https://doi.org/10.3390/polym13183141>
- [25] Hosen, M.S.S., Abedin, M.J., Hoque, M.E., Rahman, M.Z. (2022). Influence of Moisture Absorption on Physico-Chemical Properties of Natural Fiber-Based Hybrid Composites. In: Muthukumar, C., Krishnasamy, S., Thiagamani, S.M.K., Siengchin, S. (eds) *Aging Effects on Natural Fiber-Reinforced Polymer Composites*. *Composites Science and Technology*. Springer, Singapore. [https://doi.org/10.1007/978-981-16-8360-2\\_16](https://doi.org/10.1007/978-981-16-8360-2_16)