STM JOURNALS

Journal of
Polymer & Composites

https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Issue 2, 2026
DOI (Journal): 10.37591/JoPC

Research JoPC

Kenaf Reinforced Polyamide Composite Materials: A Systematic Review

Eraaja Rajeshwari Murthy[1], Mohd Firdaus Yhaya[2], Johari Yap Abdullah[3], Nurulezah Hasbullah[4,]*

Abstract

Sustainable development has become the global target to prevent exploitation and degradation of our environment in the pursuit for industrial growth. Almost all sectors including engineering, dental, medical, aerospace, etc use synthetic polymers in daily basis. The growing need for sustainable natural alternatives has encouraged research on natural fibres reinforced polymers like kenaf reinforced polyamide composites. Comprehensive evaluation of existing studies is crucial to understand the scope in this field and to advance future research. This systematic review aims to evaluate kenaf reinforced polyamide composites based on mechanical and thermal properties. The review was performed using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). WoS (Web of Science), Scopus, PubMed and ScienceDirect databases were used yielding 1,667 records. Based on the inclusion and exclusion criteria, 3 studies were found fit and included in this review. This paper discusses the mechanical properties of kenaf reinforced polyamide composites (Tensile, Flexural and Impact strength), characterisation of composites (Scanning Electron Microscopy and Fourier Transform Infrared Spectroscopy) and also covers the thermal stability of these composites (Thermogravimetric analysis, Differential Scanning Calorimetry and Dynamic Mechanical Analysis). It was noticed that the data available on kenaf reinforced polyamide composites were limited as only three studies met the inclusion criteria despite a pool of 1,667 records. The existing studies in this field lack comparative analysis and established standards making cross comparison difficult. It was also observed that there are only limited studies available on the optimisation procedures of the fabricated composites underscoring a significant research gap. This implies the need for systematic evaluation of these studies to encourage more future exploration in this field considering the sustainability of natural resources like kenaf and the growing demand for sustainable alternatives to synthetic polymers in engineering and biomedical sectors.

***Author for Correspondence**
Nurulezah Hasbullah
E-mail: drezah@usm.my

[1]Master student, Biomaterials Synthesis Laboratory, School of Dental Sciences, Universiti Sains Malaysia, Health Campus, Kubang Kerian, 16150 Kota Bharu, Kelantan, Malaysia.
[2]Senior Lecturer, Biomaterials Synthesis Laboratory, School of Dental Sciences, Universiti Sains Malaysia, Health Campus, Kubang Kerian, 16150 Kota Bharu, Kelantan, Malaysia.
[3]Senior Lecturer, Craniofacial Imaging Laboratory, School of Dental Sciences, Universiti Sains Malaysia, Health Campus, Kubang Kerian, 16150 Kota Bharu, Kelantan, Malaysia.
[4]Senior Lecturer, Medical and Basic Dental Sciences Unit, School of Dental Sciences, Universiti Sains, Malaysia Health Campus, 16150 Kubang Kerian, Kelantan, Malaysia

Received Date: March 09, 2026
Accepted Date: March 14, 2026
Published Date: March 24, 2026

Citation: Eraaja Rajeshwari Murthy, Mohd Firdaus Yhaya, Johari Yap Abdullah, Nurulezah Hasbullah. Kenaf Reinforced Polyamide Composite Materials: A Systematic Review. Journal of Polymer & Composites. 2026; 14(2): 158–169p.

Keywords: Kenaf, polyamide, natural fibre, mechanical properties, thermal stability, reinforced composites

INTRODUCTION

Over the past few decades, research has been a major focus and integral part of human development. While research in earlier days was based on innovation and development, the global target has gradually shifted focus on sustainable means to achieve scientific development. The Sustainable Development Goals (SDGs) were outlined in the United Nation's 2030 Agenda in 2015, emphasizing environment friendly growth. 17 objectives were formulated to combat global concerns including SDG 9 (Industry, Innovation and Infrastructure) and SDG 13 (Climate action) that emphasizes the need to use eco-friendly sustainable materials like green composites in place of synthetic polymers. Along with growing ecological consciousness on diminishing fossil-fuel resources, pollution, etc, the cost effectiveness of natural resources has also strengthened the quest for sustainable alternatives in industrial applications [1–3]. This has increased the use of natural fibre reinforced polymer composites (NFRPC) in place of conventional glass reinforced and carbon reinforced polymer composites [2, 4]. Kenaf, hemp, sisal, jute and flax are some of the commonly used natural fibre reinforcements. Natural fibres have many other advantages besides renewability, that includes non-toxic nature, biodegradability, high strength, high toughness, ease of processing, low-density, low-cost, low energy needs and non-corrosive nature [4–7]. In recent years, these lignocellulosic fibres have been widely used for diverse applications in various sectors including construction, aerospace, automotive, marine, medical and dental [7].

Kenaf (*Hibiscus cannabinus L*) is a tropical plant belonging to the Malvaceae family. It is emerging as an industrial crop around the world particularly in developing nations like Malaysia. Kenaf fibres exhibit incredible sustainable qualities coupled with high mechanical strength and fast growth cycle. These plants contribute significantly to the environment with its high CO2 absorption rates. It’s versatile nature and ability to withstand a wide range of weather conditions and soil quality eases harvesting and largescale production [8, 9]. The high cellulosic content, better thermal and chemical stability along with reportedly higher tensile strength (930 MPa) compared to other natural fibres are the main factors contributing to kenaf’s popularity [9–11].

Polyamides, also called as nylons are engineering thermoplastics with outstanding mechanical properties and comparatively lower water-sorption, lower melting temperature and better dimensional stability [12]. They have a sequence of amide linkage with polymer chains linked by hydrogen bonds, forming an amorphous structure that makes nylon rigid and gives it better strength, good elastic properties and chemical resistance [13, 14]. These thermoplastic resins are being used in various industries. Nylon is available as Polyamide-6 (PA6), Polyamide-6,6 (PA-6,6), Polyamide-11 (PA11), Polyamide-12 (PA12). Polyamides are hydrophilic in nature, therefore can bond with natural fibres without the use of coupling agents [15, 16].

Kenaf reinforced polyamide composites can serve as sustainable alternatives to conventional polymers and help tackle environmental degradation. Despite the growing interests in sustainable polymers, Kenaf reinforced polyamide composites continue to be underexplored. The major problems faced with natural fibre reinforced polyamides are: thermal degradation of fibres and PA’s affinity to atmospheric humidity [16]. Natural fibres tend to degrade at higher temperatures decreasing the thermal stability and mechanical strength of the composites formed when these fibres are incorporated in matrices with higher melting point [17].

Optimisation of the processes involved in fabricating composites with polyamide as matrix for kenaf reinforcements will help fabricate potentially better composites by reducing the risk of degradation as it would prevent burning of natural kenaf fibres that are used as fillers, making these composites better suited for biomedical and dental applications [10]. Studies focusing on optimisation techniques that involves determining the optimal fibre loading and surface treatments are sparse and there is no evident systematic evaluation of the existing studies for cross-comparison. This lack of comparative data and standardised evaluation hinders the understanding on these kenaf-polyamide composites as well as undermines the potential scope in this field for future researchers.

Therefore, this review aims to systematically compare existing studies to clearly lay-down the scope and research gap to pave way for future research to unlock the full potential of kenaf reinforced polyamide composites. This review aims to answer the following PECO question: In polyamide-based composites, does kenaf fibre reinforcement improve mechanical and thermal properties compared to neat polyamide?

METHODOLOGY

This systematic review was conducted following the principles of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines.

Table 1. Search Strategy

Database	Search strategy
WoS, Scopus, PubMed, ScienceDirect	((“Kenaf fibre” OR “Kenaf fiber” OR “Kenaf” OR “Kenaf CNC” OR “Kenaf nanocellulose” OR “Kenaf cellulose”) AND (“Polyamide” OR “Nylon” OR “PA6” OR “PA 6,6” OR “PA 12”))

Search Strategy

An extensive search was carried out in WoS (Web of Science), Scopus, PubMed and ScienceDirect databases. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines were followed. The search included studies published between January 2010 and September 2025. The search terms were used in combination with Boolean operators (“AND”, “OR”). To ensure comprehensive coverage, core keywords (“Kenaf” and “Polyamide”) were broadened using synonyms, spelling variations, abbreviations and specific polymer types. Example: “Kenaf fibre”, “Kenaf fiber”, “Kenaf CNC”, “Kenaf nanocellulose”, “Kenaf cellulose”, “Polyamide”, “Nylon”, “PA6”, “PA 6,6” and “PA 12”. Truncations were used to capture variations. The same search term was used in the mentioned databases to maintain uniformity of search. Table 1 shows the search strategy. Additional filters like year range, language, article type, etc were applied based on the decided inclusion and exclusion criteria. Manual screening of the reference list of eligible articles was also conducted to identify additional studies that met the inclusion criteria.

Inclusion Criteria

- Studies evaluating polyamide matrices reinforced with kenaf fibres.
- Experimental studies analysing the effect of kenaf fibres on mechanical and thermal properties of polyamide composites.
- Studies providing quantitative testing results relevant to the defined outcomes.

Only full-length, open access, peer-reviewed original articles published in English between January 2010 and September 2025 were considered to ensure the use of current updated data and evidence

Exclusion Criteria

- Studies focusing on non-polyamide matrices. Studies reinforcing polyamide with other natural or synthetic fibres, hybrid composites without isolated kenaf effect.
- Studies reinforcing polyamide with other natural or synthetic fibres, hybrid composites without isolated kenaf effect.
- Studies without experimental data.

Studies were excluded if they were review articles, short communications, conference proceedings, abstract, books, unpublished works or contained incomplete information. Studies published in language other than English, not reviewed by peers and studies that had restricted access were also excluded.

Study Selection and Data Extraction

All qualifying studies were organized and managed using Mendeley. Screening was carried out in two stages: an initial review of titles and abstracts, followed by a full-text assessment. Duplicate entries were removed and the remaining studies were evaluated systematically. Initially, the abstracts and titles of the studies identified using the search strategy were screened by two independent investigators and then the selected papers were independently analysed by the same two investigators to check their eligibility according to the inclusion and exclusion criteria. In case of disagreement between the investigators, a consensus was reached through discussion with third investigator. In total, three articles met the criteria.

Database search was done between September 20–30, 2025. Duplicate records were removed immediately after export. Title and abstract screening were carried out from October 1–7, 2025, followed by full-text screening between October 8–15, 2025. Manual reference list screening was done simultaneously with full-text review. Data extraction from the final set of eligible studies was completed between October 16–20, 2025.

Quality Assessment

The Joanna Briggs Institute (JBI) Critical Appraisal Checklist was used to evaluate the quality of the included research. Each study was rated as low, moderate or high quality and only those with moderate or high scores were incorporated in this review.

RESULTS AND DISCUSSION

A PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram summarising the study selection process is presented in Figure 1. A comprehensive database search was conducted across PubMed (n=0), WoS (n=14), Scopus (n=38) and ScienceDirect (n=1,615) yielding a total of 1,667 records. Initial screening was done to exclude ineligible items such as publications before 2010, reviews, book-chapters, preprints, conference proceedings and other non-original research leading to exclusion of 1,185 records. 484 articles were retained for eligibility screening based on predefined inclusion and exclusion criteria. A total of 428 articles were excluded due to abstract-only availability, duplicate records, not in English language and area of focus being irrelevant to the review objective. Titles and abstracts of 56 remaining articles were screened for eligibility and finally 4 articles were chosen for full text assessment. Out of this, 1 article was excluded due to irrelevance in focus area. In total, 3 studies fulfilled the inclusion criteria and were incorporated into this systematic review as shown in Table 2.

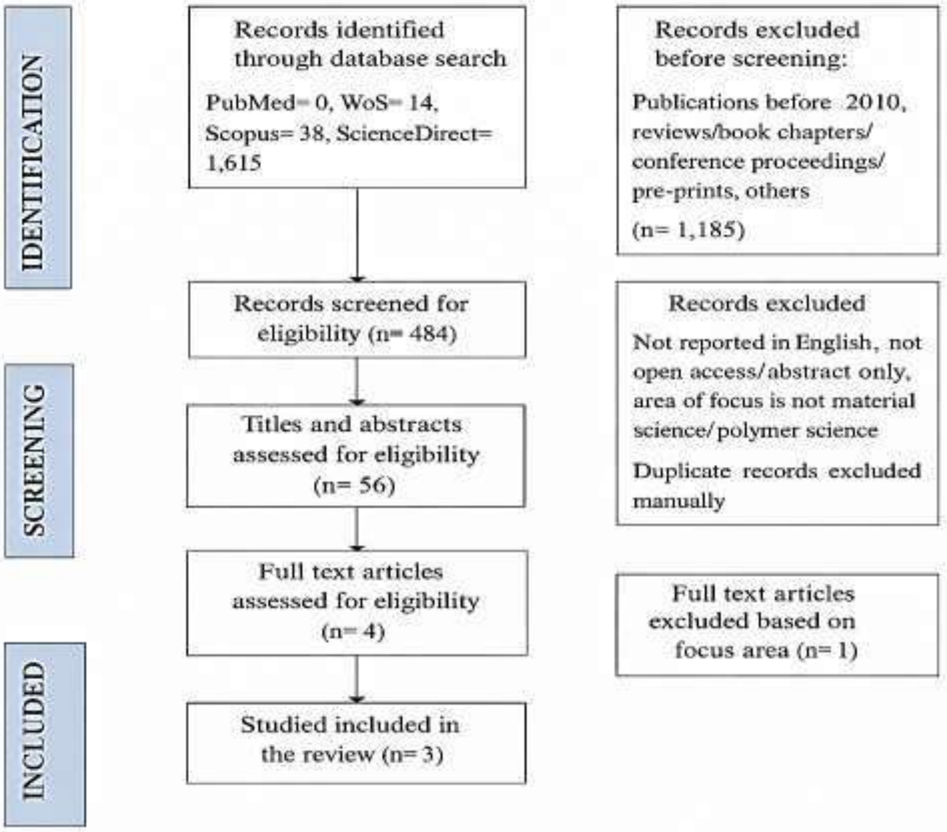

Figure 1. PRISMA flow diagram of the study selection process.

Table 2. Characteristics of included studies

Study title	**Study ID**	**PA* type**	**Fibre treatment**	**Kenaf loading (wt%)**	**Thermal stability**	**Tensile strength (MPa)**	**Flexural strength (MPa)**
Properties of Kenaf fiber reinforced Polyamide 6	Abdullah et al (2024) [10]	PA6	Untreated	10, 20, 30	Tdecomposed Neat PA6: 426℃ 10 wt%: 407℃	Neat PA6: 48 10wt%: 24	Neat PA6: 91
Thermal properties of Kenaf fiber reinforced Polyamide 6 composites by melt processing	Abdullah et al (2023) [18]	PA6	Untreated	5, 10, 15	T_{max} : Neat PA6-425℃ 10 wt%: 395℃	-	-
Influence of alkali treatment on mechanical, physical thermal and morphological properties of Kenaf fibre/ Polyamide 6 composites	Rafiqah et al (2025) [19]	PA6	Alkali Treated (3%, 6%, 9% NaOH)	10, 20, 30	Tdecomposed 10 wt% 6% NaOH treated: 408℃	10 wt% 6% NaOH treated: 47	10 wt% 6% NaOH treated: 88

**(PA 6 = Polyamide 6)*

Titles and abstracts of 56 remaining articles were screened for eligibility and finally 4 articles were chosen for full text assessment. Out of this, 1 article was excluded due to irrelevance in focus area. In total, 3 studies fulfilled the inclusion criteria and were incorporated into this systematic review as shown in Table 2.

Literature Trends and Gaps

The systematic search yielded only three eligible studies on kenaf fibre reinforced polyamide composites, underscoring research gap in this narrow domain. Current literature is dominated by Polyamide 6 (PA6) and it was noted that there are only few studies on other polyamide variants such as PA66, PA12 and complete absence of studies related to kenaf reinforcements in these variants. Furthermore, the eligible studies that were chosen also focus on untreated or alkali treated kenaf fibres, depicting lack of exploration of other fibre treatment techniques. This lack of comparative studies across PA grades and fibre treatments restricts broader generalisation and optimisation of composite performance [10, 18, 29].

Mechanical Properties and Chemical Composition

Tensile Strength and Tensile Modulus

A significant difference is observed in tensile strength between the neat PA6 and its kenaf reinforced composites [10]. This can be attributed to the ineffective interactions between the kenaf fibre and matrix that affects the load transfer and thereby the mechanical strength of the composites [20]. When untreated fibres are used, the lignin content in them affects the interfacial bonding with the PA matrix [21]. Study by Abdullah et al (2024) compared neat PA6 with 10wt%, 20wt% and 30wt% kenaf/PA6 composites. It reported that the tensile strength of composite decreased with increase in fibre loading. Maximum tensile strength of 48 MPa obtained from neat PA6. 10wt% kenaf/PA6 composite exhibited strength of 24 MPa whereas 20wt% and 30wt% exhibited 21 and 20 MPa respectively. On the other hand, 10wt% kenaf/PA6 demonstrated maximum tensile modulus of 2,100 MPa compared to neat PA6, 20 and 30wt% with 1,247, 2,046 and 1,918 MPa respectively [10].

Study by Rafiqah et al (2025) used treated kenaf fibres attempting to treat them with three different concentrations of NaOH i.e. 3%, 6% and 9% [19]. The cellulose content of fibres used affects the chemical composition of the resultant composites impacting its mechanical strength as well. Cellulose has higher crystallinity and lesser hydrophilicity compared to hemicellulose and lignin making it more difficult to break down [22, 23]. Study by Abbas et al (2023) and Brahma et al (2020) also demonstrates better mechanical properties after treatment using alkali [17, 24]. Rafiqah et al (2025) concluded that 10wt% treated Kenaf/PA6 composite and 6% NaOH treatment used demonstrated maximum tensile strength of 47 MPa compared to 20 and 30wt% as well as treatment with 3% and 9% NaOH. Similar trend was observed in tensile modulus too with 6% NaOH treated 10wt% Kenaf/PA6 exhibiting young's modulus of 2,884 MPa [19]. This trend of decrease in tensile strength with increase in fibre content may be because of the poor penetration of polymer matrix between the fillers and agglomeration of fibres. This leads to poor wettability of fibres and fibre pull-out, affecting the transfer of stress through the composite [10, 25, 26]. Similarly, the increase in tensile modulus with higher overall fibre loading is due to the increase in overall stiffness of the composite that prevents elastic deformation of the PA matrix [27–29].

Researchers have discovered that alkali treatment of kenaf fibres increases the matrix interpretation at fibre surface by removing impurities like lignin, hemicellulose, wax and exposes cellulose resulting in increased number of reaction sites [30, 31]. 6% NaOH was concluded as the desirable concentration to obtain superior mechanical properties. Increase in NaOH concentration above 6% (ex: 9% NaOH) reduced the stiffness of Kenaf/PA6 composite and triggered lignocellulosic degradation leading to poor mechanical strength and fibre-matrix interaction [19, 32, 33]. NaOH concentration lower than 6% (ex: 3% NaOH) was insufficient to remove impurities from the fibre surface and affected the adhesion of fibres to the matrix.

Flexural Strength and Modulus

Study by Abdullah et al (2024) obtained a flexural strength of 91 MPa for neat PA6 that of Kenaf/PA6 composites decreased by 47%, 48% and 60% with fibre loading of 10, 20 and 30wt% respectively. Same trend was observed in flexural modulus with neat PA6 yielding 2,506 MPa. Flexural modulus decreased by 39%, 46% and 52% with increase in fibre content [10]. Study by Rafiqah et al (2025) concluded that better interfacial adhesion between the polyamide matrix and kenaf fibres as a result of 6% NaOH treatment enhanced the flexural properties compared to 3% and 9% NaOH treatments. Similar to the results obtained from tensile test, 10wt% 6% NaOH treated Kenaf/PA6 composite outshined composites treated with other NaOH concentrations by exhibiting a flexural strength of 88 MPa [19]. The decrease in flexural properties is due to the poor dispersion of fibres in the matrix and agglomeration that leads to the formation of uneven stress concentration and weaker points affecting the uniformity of the composite [29].

Impact Strength

The downward trend observed in tensile and flexural strength was observed in impact strength too. The notched impact strength observed by Abdullah et al (2024) was 2.37, 2.23 and 1.71 $KJ.m^{-2}$ for 10, 20 and 30wt% kenaf loading respectively whereas neat PA6 demonstrated significantly higher impact strength of 3.72 $KJ.m^{-2}$ [10]. The reduction in interface compatibility made the Kenaf/PA6 composites more fragile and affected the flexural modulus too leading to reduced toughness. Ultimately, the capacity of Kenaf/PA6 composites to withstand higher impact loads declined [34]. The mechanical properties of Kenaf/Polyamide composites are shown in Table 3. Comparison of tensile and flexural strength of neat polyamide, untreated 10wt% kenaf CNC reinforced polyamide and 6% NaOH treated 10wt% kenaf CNC reinforced polyamide composites are given in Figure 2.

Table 3. Mechanical properties of Kenaf/Polyamide composites.

Study ID	PA type	Fibre treatment	Kenaf loading (wt%)	Tensile strength (MPa)	Flexural strength (MPa)	Impact Strength (kJ/m^2)
Abdullah et al (2024) [10]	PA6	Untreated	10, 20, 30	Neat PA6: 48 10wt%: 24	Neat PA6: 91 10wt%: 48	Neat PA6: 3.72 10wt%: 2.37
Abdullah et al (2023) [18]	PA6	Untreated	5, 10, 15	–	–	–
Rafiqah et al (2025) [19]	PA6	Alkali Treated (3%, 6%, 9% NaOH)	10, 20, 30	10 wt% 6% NaOH treated: 47	10 wt% 6% NaOH treated: 88	10 wt% 6% NaOH treated: 3.4

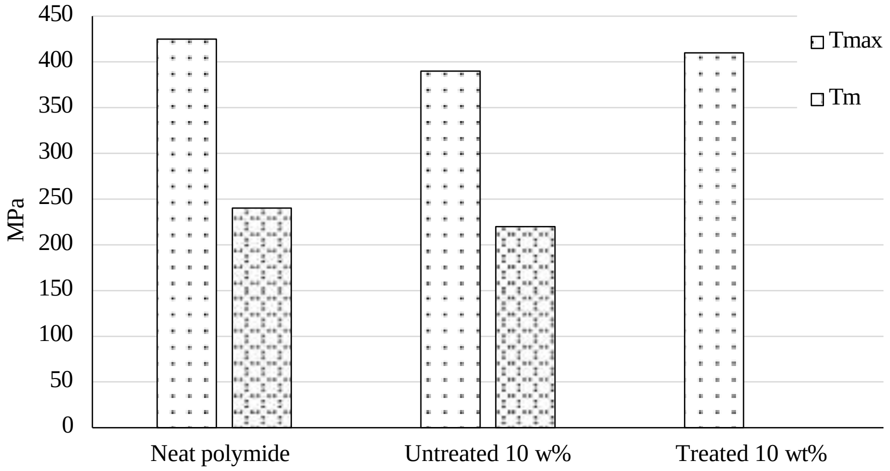

Figure 2. Comparison of tensile and flexural strength of Neat polyamide, Untreated 10wt% Kenaf-polyamide and 6%NaOH treated 10wt% Kenaf-polyamide composites

Characterisation of Kenaf-Polyamide Composites

Scanning Electron Microscopy (SEM)

Surface roughness of the reinforced fibres can effectively enhance interfacial bonding with the matrix. The incorporation of kenaf fibres increases the surface roughness [10, 35]. SEM micrograph shows voids, regions of fibre pull-out and agglomeration of fibres depicting the debonding regions and weak fibre-matrix interaction in Kenaf/PA composites. These voids in the composites also denote its thermal degradation and slipping-out of fibre from the matrix. SEM also reveals regions where the kenaf fibres are covered in matrix demonstrating regions of good adhesion. It is also observed that Kenaf/PA6 composite's structure is more like an interconnecting network compared to neat PA6 which may be the contributing factor for higher tensile modulus of the composites [10, 19, 36, 37].

Most importantly, the SEM micrographs in Abdullah et al (2024) and Rafiqah et al (2025) reveals breakage of fibres and fibre pull-out at the fracture surface of Kenaf/PA6 composites that indicates load transfer from PA matrix to the kenaf fibres symbolising strong interfacial bonding between fibre and matrix [10, 19]. According to study by Rafiqah et al (2025) 10wt% Kenaf/PA6 composite that was treated with 6% NaOH demonstrated lesser voids and fibre pull-outs [19]. Studies reveal weakening of fibre-matrix adhesion with increase in fibre loading depicted by presence of larger voids, discontinuous interfaces and increased pull-out [10, 21].

Fourier Transform Infrared Spectroscopy (FTIR)

Study by Abdullah et al (2024) investigated the FTIR spectra of neat PA6 and kenaf reinforced PA6. Authors have reported the presence of characteristic peaks corresponding to the functional groups of both PA6 and kenaf fibres. Increase in fibre content leads to downward shift in wave numbers revealing the weaker hydrogen bonds involving C-H, N-H and O-H groups [10]. Difference in absorption intensity is also noted between kenaf fibre and PA6. These findings confirm the network structure formed and chemical bonding [37, 38].

Thermal Stability of Kenaf-Polyamide Composites

Thermogravimetric analysis (TGA)

Neat PA and Kenaf/PA composites can be compared based on their thermal stability by comparing three values, i.e. $T_{initial}$ (Initial decomposition temperature), T_{final} (Final decomposition temperature) and T_{max} (Maximum decomposition temperature) [18, 39]. Study by Abdullah et al (2023) shows that neat PA6 recorded a $T_{initial}$ of 249℃ and T_{final} of 457℃ whereas Kenaf/PA6 composites decompose at temperatures lower than this. On comparing three fibre loadings namely 5,10 and 15wt%, lowest decomposition temperature was 361℃ recorded at 15wt% kenaf loading indicating its low thermal stability. TGA curves of Kenaf/PA6 composites usually have three stages of loss in mass. There is a minimal initial loss of around 3% of weight in the first stage at temperatures up to 200℃ due to loss of moisture and other volatiles [18]. Over 90% of total weight is lost at temperatures between 200℃ and 500℃ and the final zone of mass loss occurs up to temperature of 600℃ [10, 37, 40].

Study by Abdullah et al (2024) recorded T_{max} of neat PA6 as 426℃ whereas T_{max} of 10, 20 and 30wt% fibre loadings were lower around 407℃, 401℃ and 404℃ respectively. Kenaf fibre being a natural resource tends to decompose at lower temperatures, making it less thermally stable compared to PA matrix [10]. In Kenaf/PA composites, thermally stable polyamide is replaced by less stable fibres and eventually leads to rapid disintegration of the crystalline structure of PA. Fibre loading is directly proportional to the residue formation due to the presence of higher concentration of lignin [18, 29, 39, 41].

Researchers have observed that treated fibres increase the thermal stability of composites. Alkali treatment has proven to reduce thermal degradation, with 10wt% Kenaf/PA6 composites treated with 6% NaOH demonstrating highest decomposition temperature of 410℃. Effective removal of lignin and hemicellulose reduces thermal degradation which is not achieved using 3% NaOH treatment. On the other hand, use of higher concentrations of NaOH like 9% NaOH leads to excess delignification and weakening of the fibres [19, 36, 42].

Differential Scanning Calorimeter (DSC)

Kenaf fibre incorporation in PA matrix negatively impacts the melting temperature (T_m) and crystallisation temperature (T_c). Though kenaf fibres acts as a nucleating agent to aid in crystallisation, they also hinder the same [18, 39] Study by Abdullah et al (2024) observed that 20wt% Kenaf/PA6 composite had higher crystallisation temperature than neat PA6 signifying the positive nucleating effect of the fibres [10]. At the same time, 30wt% kenaf loading hindered matrix flow and reduced T_c [43, 44]. The glass transition temperature increases in Kenaf/PA6 composites as more energy is required to achieve this transition when compared to neat PA due to reduced mobility of the matrix in the presence of fibres [16, 18, 45].

Dynamic Mechanical Analysis (DMA)

DMA is used to investigate thermos-mechanical properties. Kenaf reinforced PA6 composites have lower storage modulus than pure PA6 due to poor interfacial adhesion [46]. Study by Abdullah et al (2023) recorded storage modulus of 1,177 MPa for neat PA6 and 1,076 MPa for 5wt% composite. Loss modulus was 111 MPa for neat PA6 and 89 MPa for 15wt% composite [18]. Storage modulus and loss modulus increases with higher loadings indicating better stress transfer and increased energy consumption [29]. Thermal properties of Kenaf-Polyamide composites are shown in Table 4. Comparison of maximum temperature and melting temperature of neat polyamide, untreated 10wt% kenaf CNC reinforced polyamide and 6% NaOH treated 10wt% kenaf CNC reinforced polyamide composites are given in Figure 3.

Table 4. Thermal properties of Kenaf/Polyamide composites.

Study ID	**Tmax (℃)**	**Melting temperature, T_m (℃)**	**Crystallization temperature, T_c (℃)**	**Glass transition, T_g (℃)**	**Crystallinity index, X_c (%)**
Abdullah et al (2024) [10]	PA6: 426 10wt%:407	PA6: 217 10wt%: 212	PA6: 205 10wt%: 206	PA6: 45 10wt%: 46	PA6: 33 10wt%: 25
Abdullah et al (2023) [18]	PA6: 425 10wt%: 395	PA6: 220 10wt%: 218	PA6: 208 10wt%: 205	PA6: 52 10wt%: 151	PA6: 26 10wt%: 23
Rafiqah et al (2025) [19]	10wt% 6% NaOH treated: 408	–	–	–	–

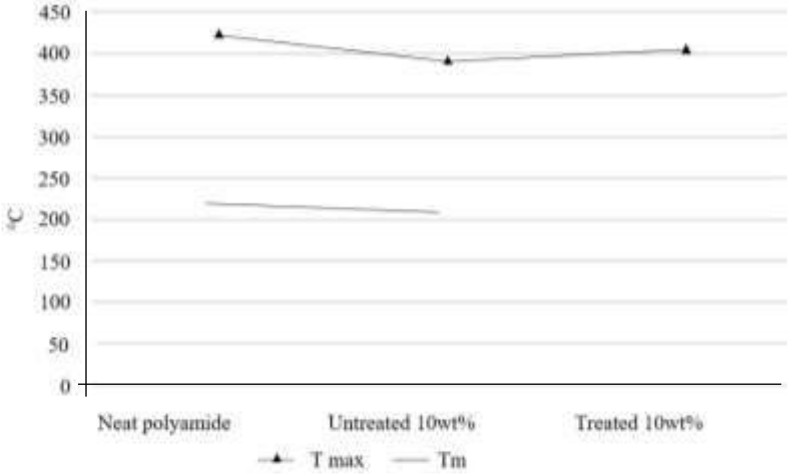

Figure 3. Comparison of maximum temperature and melting temperature of neat polyamide, untreated 10wt% and 6% NaOH treated 10wt% kenaf-polyamide composite.

CONCLUSION

This systematic review examined the current literature on kenaf fibre-reinforced polyamide composites, revealing a promising domain. Despite an initial pool of 1,667 records, only three studies met the inclusion criteria, highlighting a significant research gap particularly on polyamide variants beyond PA6. Kenaf fibres offer advantages including biodegradability, high tensile modulus, and environmental benefits. However, their integration into polyamide matrices presents challenges in interfacial bonding, thermal stability, and mechanical performance. Studies reviewed used kenaf fibre loadings of 5, 10, 15, 20 and 30% signifying the range, out of which 10% CNC loading produced maximum tensile strength of 24MPa. Neat polyamide proves to exhibit better mechanical strength of 48 MPa than fibre incorporated composites. Previous studies show that morphological analyses using SEM revealed voids, fibre pull-out, and agglomeration at higher fibre loadings indicating compromised matrix adhesion.

Alkali treatment, particularly with 6% NaOH, emerged as the most effective method for enhancing fibre-matrix interaction and improving mechanical properties with 10% CNC loading of fibres treated with 6% NaOH demonstrating a tensile strength of 47 MPa. Chemical characterization through FTIR confirmed the formation of hydrogen bonds and network structures, while thermal analyses (TGA, DSC, DMA) demonstrated reduced decomposition temperatures and crystallinity with increased fibre content. Neat Polyamide exhibited maximum degradation temperature around 425℃ while that of 10% CNC incorporated composite was around 395℃ to 405℃.

Studies reveal that though treated fibres showed improved thermal stability, neat PA emerged with better mechanical properties and thermal stability. To advance this field, future research should conduct comparative analyses across polyamide grades, explore alternative fibre surface treatments and optimisations to improve thermal stability and mechanical strength and investigate long term durability and biocompatibility of kenaf-Polyamide 12 composites. By addressing these gaps, researchers can unlock the full potential of kenaf-polyamide composites in building a sustainable world.

Data Availability

The data used in this systematic review will be made available at reasonable request.

Ethical Statement

Not applicable

Author Contributions

E.R.M: Conceptualization, writing, review, and editing. M.F.Y: Supervision and review. J.Y.A: Supervision and review. N.H: Conceptualizing, supervising, writing, review, and editing.

Conflict Of Interests

The authors declare no conflict of interest with respect to research, authorship and/or publication of this article.

Funding

Grant from government agency, Lembaga Kenaf dan Tembakau Negara, Kota Bharu, Kelantan, Malaysia (Grant number: R504 – KR - GAL006– 0000000437 – L120) obtained by Dr Nurulezah Hasbullah.

REFERENCES

1. Sorooshian S. The sustainable development goals of the United Nations: A comparative midterm research review. J Clean Prod. 2024; 453: 142272. https://doi.org/10.1016/j.jclepro.2024.142272
2. Kamarudin SH, Mohd Basri MS, Rayung M, et al. A review on natural fiber reinforced polymer composites (NFRPC) for sustainable industrial applications. Polymers. 2022; 14(17): 3698. https://doi.org/10.3390/polym14173698
3. Vishnu P, Amal Alliyankal V, Jose T. A comprehensive review of sustainability in natural-fiber-reinforced polymers. Sustainability. 2024; 16(3): 1223. https://doi.org/10.3390/su16031223
4. Mohammed K, Zulkifli R, Tahir MFM. A study of mechanical properties and performance of bamboo fiber/polymer composites. Results Eng. 2024; 16: 100113. https://doi.org/10.1016/j.rineng.2024.100113
5. Mokhothu TH, John MJ. Review on hygroscopic aging of cellulose fibres and their biocomposites. Carbohydr Polym. 2015; 131:337-354. https://doi.org/10.1016/j.carbpol.2015.06.027
6. Espinach FX. Advances in natural fibers and polymers. Materials. 2021; 14(10): 2607. https://doi.org/10.3390/ma14102607
7. Puttegowda M. Eco-friendly composites: Exploring the potential of natural fiber reinforcement. Discov Appl Sci. 2025; 7:469. https://doi.org/10.1007/s42452-025-069818
8. Selvaraj VK, Subramanian J, Suyambulingam I, et al. Influence of bio-based kenaf polymer composites on mechanical and acoustic properties for futuristic applications: An initiative towards net-zero carbon emissions. Polym Test. 2024; 134: 108409. https://doi.org/10.1016/j.polymertesting.2024.108409
9. Huang Y, Sultan MTH, Shahar FS, et al. Kenaf fiber-reinforced biocomposites for marine applications: A review. Materials. 2025; 18(5): 999. https://doi.org/10.3390/ma18050999
10. Abdullah N, Abdan K, Roslim, et al. Properties of kenaf fiber-reinforced polyamide 6 composites. e-Polym. 2024; 24(1): 20228112.https://doi.org/10.1515/epoly-2022-8112
11. Keya KN, Kona NA, Koly FA, et al. Natural fiber reinforced polymer composites: History, types, advantages and applications. Mater Eng Res. 2019; 1(2): 006. https://doi.org/10.25082/MER.2019.02.006
12. Kohli S, Bhatia S. Polyamides in dentistry: A review. Int J Sci Study. 2013; 1: 20–25.
13. Thanabalan L, Al-Rawas M, Ghazalli NF, et al. Revolutionizing healthcare: Recent advances of polyamide 12 in medical applications. Glob J Med Pharm Biomed Update. 2025; 20(10). https://doi.org/10.25259/GJMPBU_19_2025
14. Vidakis N, Petousis M, Tzounis L, et al. Sustainable additive manufacturing: Mechanical response of polyamide 12 over multiple recycling processes. Materials. 2021; 14(2): 466. https://doi.org/10.3390/ma14020466
15. Nguyen LG, Kopperud HM and Øilo M. Water sorption and solubility of polyamide denture base materials. Acta Biomater Odontol Scand. 2017; 3(1): 47–52. https://doi.org/10.1080/23337931.2017.1326009

16. Erbas Kiziltas E, Yang HS, Kiziltas A, et al. Thermal analysis of polyamide 6 composites filled by natural fiber blend. BioResources. 2016; 11(2):4758–4769. https://doi.org/10.15376/biores.11.2.4758-4769
17. Brahma S, Tritrian G, Pillay S, et al. Development and testing of high performance nylon12 (PA12) based natural fiber composites. Univ J Mater Sci. 2020; 8(3): 45–55. https://doi.org/10.13189/ujms.2020.080301
18. Abdullah N, Abdan K, Roslim, et al. Thermal properties of kenaf fiber reinforced polyamide 6 composites by melt processing. Pertanika J Sci Technol. 2023; 31(5):2361–2374. https://doi.org/10.47836/pjst.31.5.16
19. Rafiqah SA, Abdullah N, Abdan K, et al. Influence of alkali treatment on mechanical, physical, thermal and morphological properties of kenaf fiber/polyamide 6 composites. J Nat Fibers. 2025; 22(1):2515468. https://doi.org/10.1080/15440478.2025.2515468
20. Nematollahi M, Karevan M, Fallah M, et al. Experimental and numerical study of the critical length of short kenaf fiber reinforced polypropylene composites. Fibers Polym. 2020; 21(4): 821–828. https://doi.org/10.1007/s12221-020-9600-x
21. Alonso-Montemayor FJ, Tarrés Q, Oliver-Ortega, et al. Enhancing the mechanical performance of bleached hemp fibers reinforced polyamide 6 composites: A competitive alternative to commodity composites. Polymers. 2020; 12(5):1041. https://doi.org/10.3390/polym12051041
22. Yusuff I, Sarifuddin N and Ali AM. A review on kenaf fiber hybrid composites: Mechanical properties, potentials, and challenges in engineering applications. Prog Rubber Plast Recycl Technol. 2012; 37(1): 66–83. https://doi.org/10.1177/1477760620953438
23. Sepe R, Bollino F, Boccarusso L, et al. Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites. Compos Part B Eng. 2018; 133: 210–217. https://doi.org/10.1016/j.compositesb.2017.09.030
24. Abbas H, Alawi R, Hussin MH, et al. Characterization of reinforced nanohybrid dental composite resin made of nano silica rice husk with the reinforcement utilizing kenaf fiber. Cellulose. 2023; 30: 9693-9708. https://doi.org/10.1007/s10570-023-05486-0
25. Lee K, Chung J, Kwak SY, et al. Highly branched polycaprolactone/glycidol copolymeric green plasticizer by one-pot solvent-free polymerization. ACS Sustain Chem Eng. 2018; 6(12):16319–16327. https://doi.org/10.1021/acssuschemeng.8b01356
26. Mohd Roslim MH, Sapuan SM, Leman Z, et al. Effect of fibre loading on the physical, mechanical and thermal properties of sugar palm fibre reinforced vinyl ester composites. Fibers Polym. 2019; 20(5): 1077–1084. https://doi.org/10.1007/s12221-019-10400
27. Arjmandi R, Yıldırım I, Hatton F, et al. Kenaf fibers reinforced unsaturated polyester composites: A review. J Eng Fibers Fabr. 2021;16:15589250211040184. https://doi.org/10.1177/15589250211040184
28. Ozen E, Kiziltas A, Kiziltas EE, et al. Natural fiber blend-nylon 6 composites. Polym Compos. 2013; 34(4): 544–553. https://doi.org/10.1002/pc.22463
29. Zhu S, Guo Y, Chen Y, et al. Low water absorption, high-strength polyamide 6 composites blended with sustainable bamboo-based biochar. Nanomaterials. 2020; 10(7): 1367. https://doi.org/10.3390/nano10071367
30. Hashim MY, Mohd Amin A, Marwah OMF, et al. The effect of alkali treatment under various conditions on physical properties of kenaf fiber. J Phys Conf Ser. 2017; 914: 012030. https://doi.org/10.1088/17426596/914/1/012030
31. Karthi N, Kumaresan K, Sathish S, et al. An overview: Natural fiber reinforced hybrid composites, chemical treatments and application areas. Mater Today Proc. 2020; 27, 2828–2834. https://doi.org/10.1016/j.matpr.2020.01.011
32. Asim M, Paridah MT, Saba N, et al. Thermal, physical properties and flammability of silane treated kenaf/pineapple leaf fibres phenolic hybrid composites. Compos Struct. 2018; 202:1330–1338. https://doi.org/10.1016/j.compstruct.2018.06.068

33. Hamidon M, Sultan M, Ariffin A, et al. Effects of fibre treatment on mechanical properties of kenaf fibre reinforced composites: A review. J Mater Res Technol. 2019; 8(5): 4903–4914. https://doi.org/10.1016/j.jmrt.2019.04.012
34. Oliver-Ortega H, Méndez JA, Espinach FX, et al. Impact strength and water uptake behaviors of fully bio-based PA11-SGW composites. Polymers. 2018; 10(7):717. https://doi.org/10.3390/polym10070717
35. Guo A, Sun Z, Satyavolu J. Impact of chemical treatment on the physiochemical and mechanical properties of kenaf fibers. Ind Crops Prod. 2019; 141: 111726. https://doi.org/10.1016/j.indcrop.2019.111726
36. Ismail N, Radzuan NAM, Sulong A, et al. The effect of alkali treatment on physical, mechanical and thermal properties of kenaf fiber and polymer epoxy composites. Polymers. 2012; 13:2005. https://doi.org/10.3390/polym13122005
37. Xu K, Zheng Z, Du G, et al. Effects of polyamide 6 reinforcement on the compatibility of high-density polyethylene/environmental-friendly modified wood fiber composites. J Appl Polym Sci. 2019; 136(27): 47984. https://doi.org/10.1002/app.47984
38. Salem I, Rozyanty AR, Betar B, et al. Study of the effect of surface treatment of kenaf fiber on chemical structure and water absorption of kenaf filled unsaturated polyester composite. J Phys Conf Ser. 2017; 908: 012001. https://doi.org/10.1088/1742-6596/908/1/012001
39. Kamarudin SH, Abdullah LC, Aung, et al. Thermal and structural analysis of epoxidized jatropha oil and alkaline treated kenaf fiber reinforced poly (lactic acid) biocomposites. Polymers. 2020; 12(11): 2604. https://doi.org/10.3390/polym12112604
40. Seker B, Yorur H, Mengeloglu F. Effects of filler type and content on the mechanical, morphological, and thermal properties of waste casting polyamide 6 (W-PA6G)-based wood plastic composites. BioResources. 2020; 16(1): 655–668. https://doi.org/10.15376/biores.16.1.655668
41. Pereira PHF, Ornaghi HL, Arantes V, et al. Effect of chemical treatment of pineapple crown fiber in the production, chemical composition, crystalline structure, thermal stability and thermal degradation kinetic properties of cellulosic materials. Carbohydr Res. 2021; 499: 108227. https://doi.org/10.1016/j.carres.2020.108227
42. Abdullah N, Abdan K, Ching Hao L, et al. Thermal properties of wood flour reinforced polyamide 6 biocomposites by twin screw extrusion. Phys Sci Rev. 2022; 8: 20220082. https://doi.org/10.1515/psr-2022-0082
43. Nagarajan V, Mohanty AK, Misra M. Perspective on polylactic acid (PLA) based sustainable materials for durable applications: Focus on toughness and heat resistance. ACS Sustain Chem Eng. 2016; 4(6): 2899-2916. https://doi.org/10.1021/acssuschemeng.6b00321
44. Bhattacharjee S, Bajwa DS. Degradation in the mechanical and thermo-mechanical properties of natural fiber filled polymer composites due to recycling. Constr Build Mater. 2018; 172: 1–9. https://doi.org/10.1016/j.conbuildmat.2018.03.010
45. Bangalore Sridhara PK, Vilaseca F. Assessment of fiber orientation on the mechanical properties of PA6/cellulose composite. Appl Sci. 2020; 10:5565. https://doi.org/10.3390/app10165565
46. Akil HM, Omar MF, Mazuki AAM, et al. Kenaf fiber reinforced composites: A review. Mater Des. 2011; 32(8): 4107–4121. https://doi.org/10.1016/j.matdes.2011.04.008