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PRODUCTION OF COMPOSITE MATERIALS FROM FIBER OBTAINED FROM THE KENAF PLANT

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Abstract. This article analyzes the fabrication technologies, physical–mechanical properties, and industrial application prospects of polymer composite materials reinforced with kenaf fiber (*Hibiscus cannabinus* L.). The study provides a technological overview of key composite manufacturing methods, including extrusion, injection molding, hot pressing, and the hand lay-up technique, highlighting their practical relevance and processing characteristics. Kenaf-based composites are approximately 20–30% lighter than conventional glass fiber–reinforced materials. When applied in automotive components, this reduced weight contributes to improved fuel efficiency, enhanced noise insulation, and better overall safety performance. In addition to their mechanical advantages, kenaf composites offer environmental benefits due to their renewable origin and lower ecological footprint. Overall, kenaf-reinforced polymer composites demonstrate strong potential as sustainable and high-performance engineering materials, particularly in the automotive industry.

Keywords: Kenaf fiber; Hibiscus cannabinus L.; natural fiber–reinforced composites; polymer matrix; epoxy resin; extrusion; injection molding; hot pressing; hand lay-up; automotive industry; sustainable materials; biodegradable composites.

Annotatsiya. Mazkur maqolada kenaf (Hibiscus cannabinus L.) tolasi bilan mustahkamlangan polimer kompozit materiallarning tayyorlash texnologiyasi, ularning fizik-mexanik xususiyatlari hamda sanoatda, xususan

avtomobilsozlikda qo‘llanilish istiqbollari tahlil qilingan. Kompozit tayyorlashning ekstruziya, inyeksion qoliplash, issiq presslash va qo‘lda yotqizish (Hand Lay-up) usullari texnologik jihatdan izohlangan. Kenaf asosidagi kompozitlar shisha tolali materiallarga nisbatan 20–30% yengilroq bo‘lib, avtomobil detallarida qo‘llanganda yoqilg‘i tejamkorligini oshiradi, shovqinni kamaytiradi va xavfsizlik ko‘rsatkichlarini yaxshilaydi. Kenaf kompozitlari barqaror va ekologik toza muhandislik materiallari sifatida yuqori istiqbolga ega.

Kalit so‘zlar: Kenaf tolasi, Hibiscus cannabinus L., tabiiy tolali kompozit, polimer matritsa, epoksid smola, ekstruziya, inyeksion qoliplash, issiq presslash, Hand Lay-up, avtomobilsozlik, barqaror materiallar, bioparchalanuvchan kompozit.

Аннотация. В данной статье проанализированы технология изготовления полимерных композиционных материалов, армированных волокном кенафа (Hibiscus cannabinus L.), их физико-механические свойства, а также перспективы применения в промышленности, в частности в автомобилестроении. Технологически рассмотрены методы получения композитов: экструзия, инжекционное формование, горячее прессование и ручная укладка (Hand Lay-up). Композиты на основе кенафа по сравнению со стекловолоконными материалами на 20–30% легче, а их применение в автомобильных деталях способствует повышению топливной экономичности, снижению уровня шума и улучшению показателей безопасности. Композиты на основе кенафа обладают высоким потенциалом как устойчивые и экологически чистые инженерные материалы.

Ключевые слова: волокно кенафа, Hibiscus cannabinus L., натуральноволокнистый композит, полимерная матрица, эпоксидная смола, экструзия, инжекционное формование, горячее прессование, Hand Lay-up, автомобилестроение, устойчивые материалы, биоразлагаемые композиты.

INTRODUCTION.

Sustainable composites reinforced with natural fibers are gaining increasing attention in both scientific research and industrial applications [1]. This growing interest is primarily driven by the economic efficiency, biodegradability, recyclability, and renewability of natural fibers. Kenaf (*Hibiscus cannabinus* L.) has emerged as one of the most promising raw materials for the production of advanced composite materials due to its favorable mechanical strength, low

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density, and environmentally friendly characteristics. These properties make kenaf particularly attractive for the development of lightweight and sustainable engineering materials.

The production of kenaf fiber–reinforced composite materials generally involves the following key stages:

RESEARCH METHODS. Fiber Preparation and Treatment: Natural fibers contain components such as lignin, pectin, and waxes, which may hinder effective interfacial bonding with the polymer matrix. Therefore, appropriate pretreatment is required to enhance fiber–matrix compatibility. Initially, mechanical processing is applied to separate the fibrous portion from the kenaf stem.

Subsequently, the fibers undergo alkali treatment, typically using a sodium hydroxide (NaOH) solution. This chemical modification removes surface impurities and partially eliminates non-cellulosic constituents, resulting in a rougher fiber surface. The increased surface roughness improves interfacial adhesion between the fiber and the polymer matrix.

Since moisture can negatively affect the quality and mechanical performance of composite materials, the treated fibers are thoroughly dried at a temperature of 60–80°C to ensure complete moisture removal prior to composite fabrication [2].

Selection of the Matrix (Binder Material): The integration of kenaf fiber with a polymer matrix represents more than the production of “green plastic”; it constitutes an advanced engineering solution aligned with the future of sustainable materials. Proper matrix selection enables the effective combination of the inherent strength and low density of kenaf with modern polymer technologies, thereby enhancing material performance while contributing to the reduction of plastic pollution [3].

Kenaf fibers can be combined with several categories of polymers, depending on the intended application and processing method:

✓ **Thermoplastics:** polypropylene (PP), polyethylene (PE);
✓ **Thermosetting polymers:** epoxy resins, polyester resins;
✓ **Biopolymers:** polylactic acid (PLA), which enables the development of fully biodegradable composite materials.

The choice of matrix significantly influences the mechanical properties, environmental performance, and industrial applicability of the resulting composite.

RESULTS AND DISCUSSION. Composite Forming Methods: Extrusion is a processing technique aimed at achieving a homogeneous dispersion of fibers within the polymer matrix at the molecular and microstructural levels. In this method, kenaf fibers and polymer granules are fed into the hopper of an extruder. Inside the barrel, rotating screws convey the material forward while simultaneously applying heat and shear forces.

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The processing temperature is typically maintained between 180–220 °C, at which point the polymer melts and uniformly encapsulates the kenaf fibers [4]. The resulting molten composite mixture exits the extruder as a continuous strand, which is subsequently cooled and pelletized into small granules. These granules serve as a ready-to-use composite feedstock containing uniformly distributed kenaf reinforcement.

For the production of final components, the prepared pellets are further processed using injection molding or hot pressing techniques, depending on the desired geometry and application requirements [5].



Figure 1. Appearance of kenaf fiber composite materials

1) Injection Molding - Injection molding is primarily used for manufacturing components with complex geometries, such as automotive panels and structural housings. In this process, the composite pellets are remelted and injected under high pressure into a cooled metal mold using a piston-driven system. The material solidifies within seconds inside the mold cavity, forming the final component with precise geometry and surface quality [6].

2) Hot Pressing - Hot pressing is widely applied in the production of flat panels and sheet structures. In this method, the fiber–polymer mixture is arranged in layers within a mold and subjected to simultaneous heating and compression using a hydraulic press. This technique ensures effective consolidation of the composite structure and is particularly suitable for achieving high mechanical strength [7].

The efficiency of these processes depends on three critical factors.

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First, viscosity control is essential. When the processing temperature is optimal, the molten polymer fully encapsulates the kenaf fibers, ensuring strong interfacial adhesion.

Second, elimination of air voids is crucial. High pressure removes trapped air from the material. The presence of voids can increase brittleness and reduce mechanical performance.

Third, the thermal stability of the fiber structure must be maintained. If the temperature exceeds approximately 230 °C, thermal degradation of kenaf fibers begins, resulting in a loss of mechanical strength. Therefore, maintaining an optimal balance between temperature and pressure is essential for producing high-quality composites.

Second Method – Hand Lay-Up Technique - The hand lay-up method is one of the oldest, simplest, and most versatile technologies used in composite manufacturing. When working with kenaf fibers, this technique is primarily applied to produce large-scale and geometrically uncomplicated structures, such as boat hulls, roofing panels, and certain automotive body components.

The process generally consists of five main stages. It begins with the preparation of a clean and smooth mold surface. To prevent adhesion between the composite and the mold, a release agent—typically wax—is applied to the mold surface.

The first reinforcement layer is then carefully placed into the mold. Due to its natural porous structure, kenaf fiber readily absorbs epoxy resin. The epoxy resin is mixed with a hardener in a specified ratio and uniformly applied over the fiber layer.

Two primary tools are used during resin application:

✓ **Brush:** Ensures that the resin adequately penetrates all areas of the fiber layer.

✓ **Roller:** A critical tool that facilitates deeper resin impregnation into the fiber structure and, importantly, helps remove trapped air bubbles.

Depending on the required mechanical strength and thickness, this layering process is repeated multiple times. Each additional layer increases the composite's thickness and enhances its load-bearing capacity [8].

The overall thickness of the composite can be estimated as:

$$\textit{Total thickness} \approx n \times (\textit{fiber layer thickness} + \textit{resin layer thickness})$$

where n represents the number of layers applied.

After all layers have been placed, the product is left to cure either at room temperature or in a controlled oven environment to accelerate the process. During curing, the epoxy resin undergoes a chemical cross-linking reaction, transforming from a liquid into a rigid solid state. As a result, the kenaf fibers become integrated into a unified monolithic structure with enhanced mechanical integrity.

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The main advantages and limitations of this method are summarized as follows:

Table 1

№	Advantages	Limitations
1	Does not require expensive equipment (such as extruders or presses).	Time-consuming process due to its non-automated nature.
2	Suitable for manufacturing large-scale components	Product quality largely depends on the operator's skill and attention.
3	Allows easy modification of mold shape and design	Protective equipment is required when handling epoxy resins due to vapor exposure..

When kenaf fibers are combined with epoxy resin, a strong interfacial adhesion is achieved, resulting in enhanced mechanical integrity of the composite material. Compared with other polymer matrices, such as polyester resins, epoxy exhibits superior mechanical strength and greater resistance to moisture. This combination enables the development of durable and environmentally responsible structural components with extended service life [9].

Kenaf-reinforced composites offer several notable advantages. In comparison with conventional glass fiber (fiberglass) materials, they are significantly lighter and easier to process and recycle. Despite their reduced weight, they maintain favorable strength-to-weight ratios. Moreover, the cultivation of kenaf contributes to reduced atmospheric CO_2 levels, as it is a fast-growing and relatively low-cost renewable resource.

Currently, kenaf-based composites are widely applied in the automotive industry, particularly in door panels and dashboard components, as well as in construction (e.g., insulation materials) and consumer goods such as furniture and protective casings. Major automotive manufacturers, including Toyota and BMW, incorporate kenaf fiber into interior vehicle components. The adoption of kenaf composites in automotive engineering is not merely an environmental trend; it represents a technically sound solution that enhances material efficiency, reduces vehicle weight, and improves overall sustainability. Leading global automotive companies such as Toyota, BMW, Mercedes-Benz, and Ford have already integrated these materials into their production systems.

Why Kenaf?

There are three primary reasons why automotive manufacturers increasingly prefer kenaf-reinforced composites over conventional plastics such as acrylonitrile butadiene styrene (ABS) or polypropylene (PP):

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1. **Weight Reduction and Fuel Efficiency.** Kenaf fiber–reinforced composites are approximately 20–30% lighter than traditional glass fiber (fiberglass) materials. This reduction in component weight contributes to a lower overall vehicle mass, thereby improving fuel efficiency and reducing energy consumption.

2. **Enhanced Impact Performance and Safety.** Unlike brittle plastic materials that may fracture into sharp fragments under impact, kenaf fibers tend to absorb and dissipate energy. This energy-absorbing behavior enhances crash performance and helps create a safer environment for passengers.

3. **Improved Acoustic Insulation.** Natural fibers exhibit superior sound absorption properties compared with many synthetic plastics. As a result, the use of kenaf composites contributes to reduced interior cabin noise, improving overall passenger comfort.

These combined mechanical, safety, and acoustic advantages make kenaf-based composites a technically and environmentally attractive alternative in modern automotive engineering.

Table 2

Application of Kenaf–Polymer Composites in the Automotive Industry

№	Component	Function and Characteristics	Engineering Advantages
1	Door Panels	Interior covering and structural reinforcement	20–25% lighter than glass fiber panels; contributes to improved fuel efficiency
2	Dashboard Panels	Thermal stability and safety performance	Low thermal conductivity; surface temperature remains 5–8°C lower under direct sunlight
3	Rear Parcel Shelves	Vibration damping and acoustic performance	Higher sound absorption coefficient (3–5 dB improvement in acoustic insulation)
4	Seat Back Panels	Structural rigidity (stiffness)	Does not shatter into sharp fragments upon impact; enhances passenger safety and reduces injury risk
5	Headliners (Roof Liners)	Noise insulation and lightweight structure	Reduces weight at the highest point of the vehicle, improving stability and lowering the center of gravity

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6	Trunk Linings	Impact and abrasion resistance	Natural fiber structure provides durability under high loads; service life up to approximately 10 years

Kenaf–polymer composites represent one of the most effective alternatives to conventional plastics and glass fiber–reinforced materials in the automotive industry. By reducing the weight of vehicle components by approximately 20–25%, these materials contribute directly to improved fuel efficiency and overall energy performance. In addition, their superior sound absorption capacity—typically reducing interior noise levels by 3–5 dB—enhances acoustic comfort within the passenger cabin.

These composites also exhibit high thermal stability. When exposed to elevated temperatures, such as under direct sunlight, they do not release harmful gases and maintain structural integrity. Furthermore, unlike brittle synthetic materials, kenaf-reinforced composites do not fragment into sharp pieces upon impact, thereby contributing to improved passenger safety.

Overall, the integration of kenaf-based composites enables the production of durable vehicles—with service lives exceeding 10 years—while simultaneously advancing environmental sustainability and economic efficiency in modern transportation systems.

CONCLUSION. In conclusion, kenaf fiber–reinforced polymer composites represent a sustainable material solution that meets the demands of modern engineering and industrial applications. Alkali treatment of the fiber surface significantly enhances interfacial adhesion with the polymer matrix, thereby improving the mechanical strength and overall performance of the composite. Careful control of processing parameters, particularly temperature and pressure, remains a critical factor in determining material quality during composite fabrication. Compared with conventional glass fiber–reinforced materials, kenaf–polymer composites offer a lighter, environmentally safer, and economically efficient alternative, with especially strong potential in the automotive sector. The integration of kenaf-based composites enables vehicle weight reduction, improved fuel efficiency, and a decreased environmental footprint.

Accordingly, the development and implementation of kenaf-reinforced composites constitute an important direction in the advancement of innovative materials aligned with the principles of sustainable development.

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