

Impact of Alkali Treatment on the Mechanical Properties of Recycled Polypropylene/Biduri Fiber Composites

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Article Information	ABSTRACT
Article History Received : February 18, 2025 Revised : March 08, 2025 Published : April 10, 2025	The expansion of the automotive sector has heightened the demand for polypropylene (PP), resulting in an increase in PP waste. Nonetheless, recycling frequently undermines the mechanical and physical qualities of polypropylene (PP). This problem can be resolved by augmenting recycled polypropylene (rPP) with natural fibers, such as biduri fiber (<i>Calotropis gigantea</i>), recognized for its low density, high tensile strength, and hydrophobic-oleophilic characteristics. A potassium hydroxide (KOH) alkali treatment enhances fiber wettability and polymer adhesion by eliminating non-cellulosic constituents, hence strengthening the link between biduri fiber and the rPP matrix. This study examines the mechanical properties of rPP composites reinforced with 2% w/w biduri fiber and different KOH concentrations (0%, 2.5%, and 5% w/w). The composites were constructed into a three-layer configuration with thicknesses of 1 mm and 2 mm. Recycled polypropylene sheets were fabricated by heating rPP granules to 190°C for five minutes, subsequently compressing at 300 kg/cm², and cooling to 100°C. The composite was created by interposing nonwoven biduri fiber sheets between two rPP sheets and subjecting the assembly to heating at 210°C under a pressure of 300 kg/cm² for 10 minutes. The mechanical properties were evaluated using dog-bone-shaped specimens for tensile and impact testing. The findings indicated substantial enhancements in impact strength (up to 54,95%) and tensile strength (up to 3,6%) with elevated KOH content; however, the melt flow rate diminished, signifying a compromise between enhanced strength and processability. These results endorse the utilization of rPP-biduri fiber composites as sustainable, mechanically superior materials.
Keywords: <i>Recycled Polypropylene (rPP); Alkali Treatment; Mechanical Properties.</i>	

INTRODUCTION

Automotive components made of polypropylene (PP) have proven to be a successful way to reduce vehicle weight, which improves fuel economy and contributes to a reduction in air pollution (Aryanti, 2021). Lightweight materials like polypropylene (PP) are essential in the global effort to combat climate change and cut greenhouse gas emissions in the automobile industry. PP reduces carbon dioxide emissions and improves fuel economy by reducing vehicle weight. However, companies are now optimizing the use of raw materials because to the growing customer demand for PP-based products. This push is driven by both economic considerations and the need to address environmental sustainability issues related to waste management and plastic production (Mannheim & Simenfalvi, 2020).

Utilizing recycled polypropylene (rPP) is a good way to maximize resource use. By reducing production costs by roughly 20–50%, rPP offers economic benefits in addition to helping to reduce plastic waste, which presents serious environmental concerns (Yudha et al., 2023), (Achukwu et al., 2023). Recycling polypropylene (PP) encourages material reuse and waste reduction, which is consistent with the concepts of the circular economy (Saikrishnan et al., 2020). However, polymer chain breakdown brought on by the recycling process may result in the final product's reduced mechanical qualities and inconsistent output (Jansson et al., 2003). The main causes of this degradation include oxidative and thermal stress during reprocessing, which lowers molecular weight and induces chain scission. Because of this, the recycled material can be brittle and have less tensile strength, which would make it difficult to use in high-performance goods. Multiple recycling cycles have been shown to worsen these problems and cause additional mechanical, thermal, and chemical deterioration of the polymer (Yudha et al., 2023).

Adding reinforcing fibers to recycled polypropylene (rPP) is a promising way to lessen its drawbacks. Fibers improve rPP composites' mechanical strength, stiffness, and durability, making them more appropriate for a variety of uses (Das et al., 2022) (Ramesh et al., 2022). Issues with polymer chain breakdown and decreased structural integrity can be resolved by reinforcing rPP with natural or synthetic fibers, increasing the material's use in a variety of sectors, such as construction and automotive. Research has shown that fiber-reinforced rPP composites are a good substitute for virgin polymer-based materials due to their enhanced tensile strength, impact resistance, and general performance (Zaman & Khan, 2022). Because of their biodegradability, affordability, and renewable nature, natural fibers in particular have drawn interest as sustainable reinforcement materials. Biduri fiber (*Calotropis gigantea*) is one of these natural fibers that has a lot of potential for composite applications, but its use is still somewhat restricted. Due to its extensive biduri fiber resources, Indonesia in particular is a viable option for regional industrial uses. Every month, each biduri tree may yield about 122,553 grams of fiber. The theoretical fiber yield is 306,382 kg per month per hectare, or 3,676 tons per hectare annually, assuming a density of 2,500 trees per hectare (Sukardan dkk, 2017). The economic and environmental potential of biduri fiber as a raw material for composite manufacture is highlighted by this high yield.

Biduri fiber (*Calotropis gigantea*) is a viable reinforcement material for polymer composites due to its many beneficial qualities, which include low density, high tensile strength, and hydrophobic-oleophilic qualities (Thalib & Kuala, 2024). These characteristics aid in the creation of lightweight composites with improved mechanical capabilities. Biduri fiber's potential in composite applications has been highlighted by research showing that adding it to polyester matrix enhances tensile characteristics and machinability (Narayanasamy et al., 2020). These qualities are especially advantageous for uses like packaging and automobile parts that call for strong, lightweight materials. The potential of biduri fiber as a reinforcing material was highlighted by earlier research by (Babu et al., 2014) which showed that adding 0.35% volume of biduri fruit fiber to unsaturated polyester composites boosted their tensile strength to 52.26 MPa.

Weak interfacial adhesion between the fibers and the polymer matrix is a common problem for natural fiber-reinforced composites. This problem occurs because the fibers contain non-cellulosic materials including lignin and hemicellulose (Seisa et al., 2022). According to (Ye et al., 2018) these elements help make natural fibers hydrophilic, which results in poor adherence with matrices of polymers that are normally hydrophobic. This has a negative impact on the final composites' mechanical qualities. Several surface modification approaches have been studied to improve the compatibility and adhesion between the fibers and the polymer matrix in order to solve the issues related to weak interfacial bonding in natural fiber-reinforced composites. By improving the interfacial characteristics, these techniques hope to raise the composites' overall performance.

The physical structure of the fiber surface is changed by physical treatments like corona discharge, plasma treatment, and thermal techniques. This increases surface roughness and energy, which facilitates improved mechanical interaction with the matrix. For example, plasma treatment improves the wettability and adhesive capabilities of fibers by increasing their surface energy (Mohammadi et al., 2024a). To alter the chemical makeup of the fiber, chemical treatments include the use of materials such as graft copolymerization, silane coupling agents, and alkali solutions. Fiber components can be made less hydrophilic and impurity-free by alkalization, also known as mercerization. The fiber and polymer matrix's interfacial bonding is strengthened by this treatment.

It has been demonstrated that these surface modification techniques greatly enhance the mechanical characteristics of natural fiber composites, increasing their suitability for a variety of applications (Ngo, 2020). The resultant composites overcome the drawbacks of untreated natural fiber reinforcements by improving fiber-matrix adhesion and exhibiting enhanced strength, stiffness, and durability (Mohammadi et al., 2024b).

The composite's mechanical performance may be jeopardized by this poor bonding. Delignification, which lowers the non-cellulosic content and increases the adherence between the fiber and matrix, can be used to improve the quality of natural fibers. It has been demonstrated that alkali treatment with potassium hydroxide (KOH) efficiently eliminates non-cellulosic components, increasing the fibers' wettability and compatibility with polymer matrices (Yudhakk., 2023). Although sodium hydroxide (NaOH) solutions have been used in earlier research to characterize biduri fiber, nothing is known about how KOH treatment affects biduri fiber. The effects of KOH concentrations, such as 2.5% and 5% w/w, on the mechanical characteristics of rPP composites reinforced with biduri fiber require more research. The goal of this research is to close this gap and aid in the creation of superior, sustainable composites that can satisfy the expanding need for environmentally friendly materials across a range of industries.

RESEARCH METHODS

Equipment and Materials

Recycled polypropylene (rPP), fibers from *Calotropis gigantea* fruits, potassium hydroxide (KOH), acetic acid, and distilled water were used in the creation of composite materials. The apparatus used included a digital analytical balance for accurate mass measurements, volumetric flasks and beaker glasses for preparing solutions, an oven for drying procedures, Teflon sheets, scrapers, a hot press machine for composite molding, and instruments like a specimen ejector and a pneumatic specimen punch for sample preparation. Tensile and compressive strengths were measured using a Universal Testing Machine (UTM), impact resistance was evaluated using an Impact Tester, and the flow characteristics of the polymer melt were measured using a Melt Flow Index (MFI) Tester. These tools are crucial for describing the rheological and mechanical characteristics of polymer composites

Alkali Treatment of *Calotropis* Fruit Fibers

Potassium hydroxide (KOH) solutions were used to alkali treat *Calotropis gigantea* fruit fibers at weight concentrations of 2.5% and 5%. At room temperature, the fibers were submerged in these solutions for five minutes. To get rid of any remaining alkali, the fibers were thoroughly rinsed with distilled water after submersion. The fibers were immersed in a 1% acetic acid solution until they reached a neutral pH of 7 in order to remove any residual alkalinity. Following eight hours of air drying in the sun, the fibers were oven-dried for two and a half hours at 50°C. To maintain a consistent weight, mass readings

were obtained every 30 minutes. Drying at 50°C ensures that the fibers retain their structural integrity and mechanical properties. Higher temperatures could lead to thermal degradation or loss of moisture essential for maintaining fiber flexibility. After drying completely, the fibers were arranged at random and heated to create sheets of nonwoven fiber. By eliminating surface contaminants and altering the fiber structure, alkali treatment is a popular technique to improve the interfacial interaction between natural fibers and polymer matrices. Acetic acid neutralization guarantees the elimination of surplus alkali, averting the deterioration of fiber characteristics. The goal of this treatment combination is to enhance the final composite materials' mechanical performance

Preparation of Recycled PP Sheets

Granules of recycled polypropylene (rPP) were hot-pressed into sheets before the composite was constructed. The granules, which had thicknesses of either 0.1 or 0.2 cm, were put into molds that were 20 cm by 20 cm. The granules were heated to 190°C for five minutes while being compressed at 300 kg/cm² as part of the molding process. Temperatures above 190°C may lead to thermal degradation, causing discoloration, loss of mechanical properties, or chemical changes in PP. The chosen temperature minimizes these risks while ensuring proper melting. High pressure helps eliminate air pockets trapped between granules during melting, which could otherwise weaken the mechanical properties of the final sheet. The substance was then left to cool until it reached 100°C. After that, the granules are melted for five minutes at 190 degrees Celsius while being compressed by 300 kg/sq cm. Until the temperature reaches 100 degrees Celsius, the cooling process keeps going. Cooling to 100°C allows the molten polypropylene to solidify gradually, reducing internal stresses that may develop due to rapid cooling.

Composite Fabrication

A composite structure is created by sandwiching the nonwoven Calotropis fiber sheets between two rPP sheets in the following order: rPP sheet, fiber sheet, and rPP sheet. Teflon sheets are positioned on the top and bottom plates to stop the molten composite from adhering. A manual forming press is then used to melt the composite for 10 minutes at 210 degrees Celsius and 300 kilograms of pressure per square centimeter. Calotropis fibers have good thermal stability up to approximately 220°C. By setting the temperature at 210°C, the process avoids thermal degradation of the fibers while ensuring proper bonding between the rPP matrix and fiber sheet. Allowing 10 minutes at 210°C ensures that the rPP sheets are fully melted and can flow uniformly over the fiber sheet, creating a strong composite structure. High pressure ensures that the molten rPP spreads evenly across the fiber sheet, eliminating air pockets and voids that could weaken the composite structure.

Specimen Preparation for Mechanical Testing

The composite samples are shaped into precise standard dimensions in order to prepare them for mechanical testing. Using a pneumatic specimen punch set to five bars of pressure, the tensile test specimens are formed into dog bone specimens in accordance with ASTM D638 Type IV. An Ibertest TESTCOM-5 Universal Testing Machine is used to perform the tensile test at a speed of five millimeters per minute and a grip-to-grip distance of sixty-five millimeters. The ISO 179 standard dimensions are followed in the preparation of the composite samples for impact testing.

Composite Characterization

To assess their qualities, the manufactured composite specimens go through a number of mechanical tests. The impact test adheres to ISO 179, the tensile test is carried out in compliance with ASTM D638, and the melt flow rate test is carried out in compliance with ASTM D1238. Every test is conducted at Politeknik STMI Jakarta's Polymer Laboratory.

RESULTS AND DISCUSSION

The Impact of KOH Concentration on Composites' Impact Strength Following Alkali Treatment of Biduri Fiber

During the alkali treatment of the fibers, different concentrations of potassium hydroxide (KOH) were used to maximize the impact strength of recycled polypropylene (rPP) composites reinforced with biduri (*Calotropis gigantea*) fibers. The impact strengths of rPP composites with biduri fibers treated with varying KOH concentrations were compared to two control groups in the study: rPP with untreated biduri fibers and rPP without any fiber reinforcement. The impact strength of the unreinforced rPP sample was 24.66 kJ/m², as shown in Figure 1. By eliminating surface contaminants and altering the fiber structure, alkali treatment is known to increase the interfacial bonding between natural fibers and polymer matrices, improving the composites' mechanical qualities. Alkali treatment, for example, increased the tensile strength and Young's modulus of Alfa fiber-reinforced polypropylene composites by 16% and 23%, respectively, according to a study on the subject (El Abbassi et al., 2015).

By encouraging improved adhesion between the fiber and matrix, the application of KOH treatment is expected to enhance impact strength in the context of biduri fiber-reinforced rPP composites. A baseline for evaluating the efficacy of fiber reinforcing and the effects of alkali treatment on composite performance is provided by the observed impact strength of 24.66 kJ/m² in unreinforced rPP. The impact strength of RPP/biduri fiber composites tends to decrease when biduri fiber is added to the RPP matrix, per study by Viani and Prayudie (2024) Alkali treatment was used to increase the impact strength because it strengthens the interfacial bond between the rPP and the fiber. Impact strength values of 25.67 kJ/m² and 33.19 kJ/m² were obtained by adding 2% by weight of biduri fiber treated with 2.5% and 5% KOH to the rPP matrix, respectively. When compared to RPP reinforced with untreated biduri fiber, which had an impact strength of 21.42 kJ/m², these findings indicate increases of 19.8% and 54.95%, respectively.

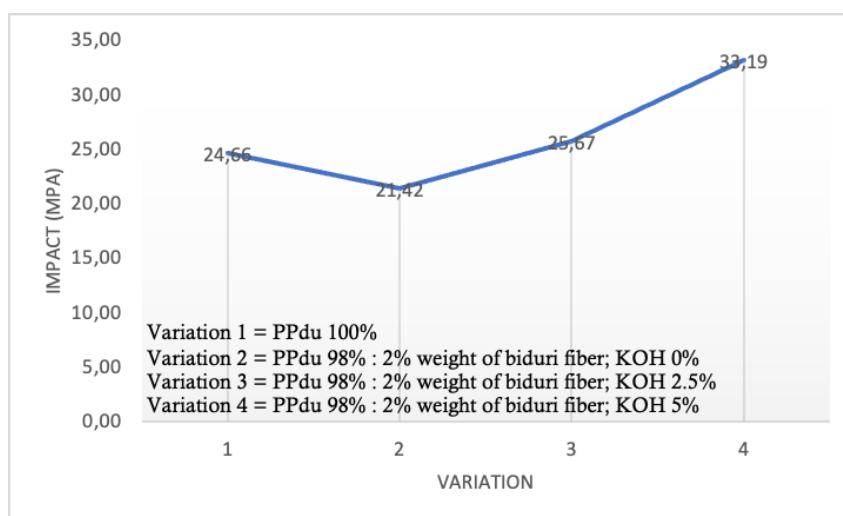


Figure 1. Graph of the effect of alkali treatment on biduri fiber on the impact strength values of RPP composites reinforced with biduri fiber.

One popular technique for improving the interfacial adhesion between natural fibers and polymer matrices in composite materials is alkali treatment, often known as mercerization. This method efficiently eliminates surface contaminants such as lignin, hemicellulose, waxes, and oils by submerging fibers in an alkaline solution, usually sodium hydroxide (NaOH). The fiber's surface becomes rougher and more cellulose hydroxyl groups are exposed when these non-cellulosic components are removed, which improves wettability and chemical interaction with the polymer matrix. Stronger interfacial adhesion between the treated fibers and the composite allows for improved mechanical characteristics and more effective stress transfer. According to studies, composites reinforced with alkali-treated fibers exhibit better tensile strength, modulus, and overall durability than those reinforced with untreated fibers (Verma & Goh, 2021). Additionally, hemp fiber was submerged in KOH solutions at concentrations of 0%, 2%, 5%, and 8% as part of a study carried out by (Pramitasari et al., 2021). A 5% KOH immersion produced the maximum impact strength value, measuring 0.711 J/mm^2 , while a 0% immersion produced 0.244 J/mm^2 . The strong alkali treatment, which removes waxy layers from the fiber surface and perfects the bond between the fiber and resin, is responsible for this improvement. Consequently, the treated composites are more mechanically strong than the untreated ones.

Figure 2 illustrates that specimens with a thickness variation of 2 did not shatter during impact testing utilizing the Charpy unnotched method. This is probably because the composite was not completely homogenous, which could have had an impact on how stress was distributed during the test. The absence of fracture in these samples indicates that.



Figure 2. Fracture of impact test specimens for variation 1 (rPP 100%) (left) and variation 2 (rPP 98%:2% by weight biduri fiber; KOH 0%) (right).

The lack of KOH alkali treatment is the cause of the uneven distribution between the fiber and matrix. In the absence of this treatment, the fiber retains a layer of contaminants, lignin, pectin, and hemicellulose that hinders the fiber's ability to properly adhere to the matrix. Consequently, untreated fibers have a weaker bond than natural fibers that have been treated with alkali (Lastri, 2023)

The fiber and matrix have weak interfacial bonding in composites that have not been alkali-treated. This is mostly because the fiber surface has a waxy coating that prevents adherence and serves as a barrier. As a result, the total strength of the composite is decreased since the fiber-matrix interface is still weak and does not create an ideal mechanical interlocking (Nurdin et al., 2019).

Additionally, voids and microcracks might result from the untreated fibers' poor interaction with the polymer matrix, which impairs the composite's mechanical qualities. Alkali treatment improves the mechanical interlocking and stress transfer between the fiber and the matrix by roughening the fiber surface in addition to eliminating non-cellulosic components. Alkali treatment is therefore necessary to maximize fiber-matrix adhesion and improve the composite material's overall performance.

The Impact of KOH Concentration on the Composite's Tensile Strength during Biduri Fiber Alkalization

Tensile strength data for recycled polypropylene (rPP) composites reinforced with Biduri fibers and rPP without fiber reinforcement are shown in Figure 3. Without fiber reinforcing, rPP has an average tensile strength of 14.517 MPa. RPP composites reinforced with untreated Biduri fibers have an average tensile strength of 16.672 MPa, while those treated with 2.5% and 5% KOH solutions have an average tensile strength of 17.108 MPa and 17.275 MPa, respectively.

These findings suggest that adding Biduri fibers improves the composite's tensile strength. By eliminating non-cellulosic substances like hemicellulose, pectin, and lignin, the alkali treatment with KOH also enhances fiber-matrix adhesion and increases the interfacial interaction between the fibers and the matrix. Tensile strength somewhat improves when the KOH concentration is increased from 2.5% to 5%, indicating that greater KOH concentrations aid in improved fiber surface modification. However, because too many fiber elements may be removed, an excessive alkali treatment may degrade the fiber structure. In order to achieve the best balance between fiber surface modification and composite mechanical properties, it is imperative to optimize the KOH concentration.

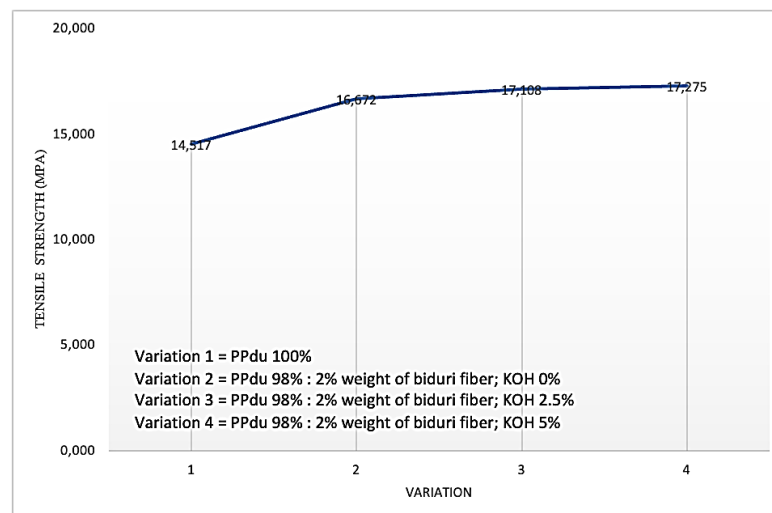


Figure 3. Graph of the effect of Biduri fiber alkali treatment on the tensile strength of rPP composite reinforced with Biduri fiber.

According to the test results, the material's tensile strength is considerably increased with the inclusion of Biduri fibers. Tensile strength can be increased by up to 14% by adding 2% untreated Biduri fibers. Additionally, alkali treatment with 2.5% and 5% KOH raises tensile strength to 17.108 MPa and 17.275 MPa, respectively, as opposed to 16.672 MPa for composites without alkali treatment. This enhancement implies that alkali treatment improves load transmission by strengthening fiber-matrix adhesion.

The maximum tensile strength achieved, 17.275 MPa, is still less than the 18.276 MPa norm for raw materials used in PP-based side mirror covers (Sriyanto, 2017) This emphasizes the necessity of additional optimization in the formulation of fiber composition as well as in chemical treatment procedures. The tensile strength of the composite has been significantly increased by alkali treatment with KOH. This process reduces the lignin and hemicellulose content in Biduri fibers, as reported by Akbar (2023). The reduction of amorphous structures in the fiber leads to increased crystallinity, which contributes to improved tensile strength. Additionally, the surface morphology of Biduri fibers becomes rougher after alkali treatment, increasing the adhesion contact area between the fibers and the rPP matrix. Figure V.2 illustrates the difference in the surface structure of Biduri fibers before and after alkali treatment.

These results are in line with a study by (Ichsanudin et al., 2024), which found that abaca fibers treated with KOH solution increased in tensile strength by up to 30.38% as a result of the

lignin and hemicellulose content being reduced. (Nisa et al., 2022) noted a similar result in coconut coir fiber biocomposites with polyester resin, where the tensile strength increased from 1.41 MPa to 6.92 MPa after alkali treatment with KOH.

According to a study by n and Khan (2022), adding Biduri stem fibers to pure PP increased its tensile strength from 28.2 MPa to 38.7 MPa at a fiber composition of 30%. This trend of increasing tensile strength is consistent with the addition of Biduri fibers to rPP. Even while the RPP-Biduri fiber composite's tensile strength hasn't yet met that benchmark, the notable gain shows that Biduri fibers have the potential to be used as reinforcing materials that can be further tuned for structural purposes.

Impact of KOH Concentration on Composite Flow Rate during Biduri Fiber Alkalization

The melt flow rate (MFR) of the rPP composite reinforced with Biduri fibers was calculated by varying the KOH concentration during the alkalization of Biduri fibers. RPP with untreated Biduri fibers and pure rPP without fiber addition were used to compare the effects of various KOH concentrations.

The MFR value of rPP without Biduri fiber reinforcement is 12.183 g/10 min, as seen in Figure 4. The MFR drops to 7.130 g/10 min when 2 weight percent untreated Biduri fibers are added. This drop is explained by the increased viscosity brought on by fiber deformation, which interferes with chain mobility and blocks polymer flow (Nordin, 2020).

Additionally, MFR values of 5.838 g/10 min and 5.430 g/10 min are obtained by adding 2 weight percent Biduri fibers treated with 2.5 weight percent and 5 weight percent KOH to the rPP matrix, respectively. This suggests that alkali treatment further inhibits polymer flow, most likely as a result of enhanced fiber stiffness and fiber-matrix adhesion. Fiber crystallinity is improved by alkalization, which removes amorphous materials like hemicellulose and lignin. This makes the fibers more structured and less pliable, which raises viscosity.

This pattern is consistent with results from earlier research, which showed that fibers treated with alkali had a stronger interfacial bond with polymer matrices, which decreased melt flow and increased viscosity. The reduction in MFR indicates that the alkali treatment strengthens the composite structure by enhancing the mechanical interaction between the fiber and matrix. To balance strength with manufacturability, it may be necessary to optimize the fiber composition and treatment conditions, as this could also affect the material's processability.

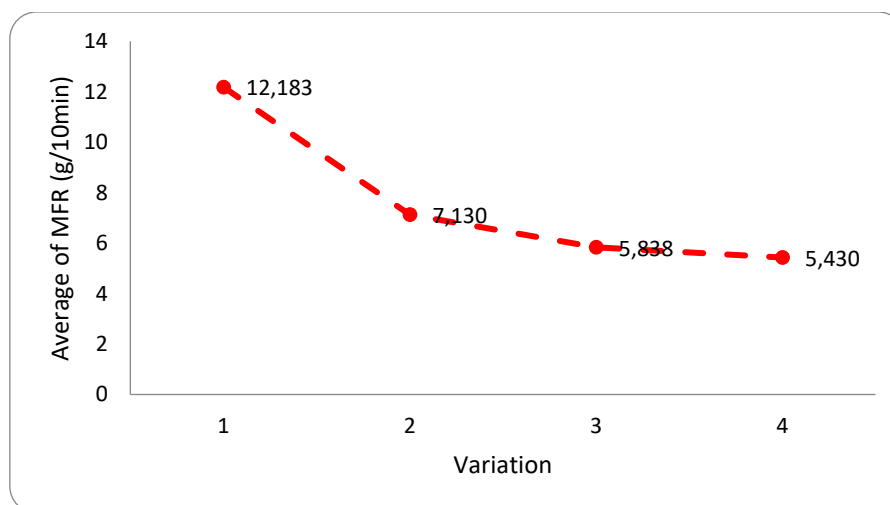


Figure 4. Graph of effect of KOH Concentration in Biduri Fiber Alkalization on the Melt Flow Rate of rPP Composite Reinforced with Biduri Fibers.

By eliminating hemicellulose and other contaminants, the alkalization process seeks to improve the compatibility between the fiber and matrix. But viscosity can be greatly increased by this procedure. This happens because alkalization improves fiber-matrix bonding by changing the fiber structure, which decreases the flowability of the polymer. More flow-enhancing substances may be eliminated as the concentration of alkali rises, while intermolecular connections may be reinforced, increasing viscosity. This consequence implies that whereas alkalization increases adhesion, it also limits the mobility of polymer chains, which impacts the material's processability.

The findings show that the flow characteristics of rPP composites reinforced with Biduri fibers are influenced by the addition of fiber and the alkalization process. The melt flow rate (MFR) falls with increasing fiber content and alkali concentration, which is consistent with the results of (Soleimani et al., 2006). According to earlier research, alkali treatment improves fiber-matrix adhesion, which in turn improves the mechanical properties of composites (Zhang et al., 2011). Better stress transmission inside the composite as a result of this increased adhesion can be advantageous for structural applications, although processability and mechanical performance must be balanced through optimization.

CONCLUSION

This study investigated the effects of potassium hydroxide (KOH) concentration on the mechanical and rheological characteristics of recycled polypropylene (rPP) composites during the alkali treatment of *Calotropis gigantea* (biduri) fibers. The results showed that the alkali treatment greatly increased the interfacial bonding between the rPP matrix and the biduri fibers, which resulted in improved mechanical performance. In particular, compared to composites with untreated fibers, the impact strength of rPP composites rose by 19.8% and 54.95%, respectively, when biduri fibers were treated with 2.5% and 5% KOH solutions. At a 5% KOH concentration, the composites' tensile strength also approached the benchmark of 18.276 MPa for side mirror covers made of polypropylene, at 17.275 MPa. These findings imply that additional fiber treatment condition and composite formulation adjustment may be necessary to attain the required mechanical performance.

Improved fiber-matrix adhesion and improved load transfer within the composite are made possible by the alkali treatment procedure, which efficiently eliminates lignin, hemicellulose, and contaminants from the fiber surface. The melt flow rate (MFR) decreased from 12.183 g/10 min for pure rPP to 5.430 g/10 min for composites including fibers treated with 5% KOH, indicating that this treatment also increased the viscosity of the composite material. Although better fiber-matrix bonding is reflected in this drop in MFR, processing and manufacturing issues could arise.

In conclusion, improving the mechanical characteristics of rPP/biduri fiber composites through alkali treatment with KOH is a promising technique. A precise balance between fiber content, fiber treatment conditions, and processability is required to achieve optimal performance. To further improve the mechanical characteristics and manufacturability of these composites for structural applications, future research should concentrate on improving fiber-matrix compatibility and adjusting the KOH concentration. These results are in line with earlier research that found that alkali treatment enhanced the mechanical characteristics of natural fiber-reinforced composites. For example, an evaluation of the effects of different chemical treatments on biofibers found that, in comparison to untreated fiber composites, chemical treatment with a 5% NaOH concentration improves the composites' mechanical, thermal, and physical qualities.

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