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Sustainable Rice Husk Mixture Fibre–Stripe Polyethylene Film Composites: Effects of Recycling and Alkali Treatment on Water Absorption, Flammability, Density, and Mechanical Properties

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Abstract

The increasing accumulation of plastic and agricultural waste has intensified interest in sustainable polymer composites that combine improved material performance with environmental value. This study investigates the water absorption, flammability, density, hardness, and tensile strength of composites prepared from used and unused stripe polyethylene (PE) films and rice husk mixture fibres, with and without NaOH treatment. Water absorption testing showed that composites made with used PE exhibited the highest uptake, reaching 88.35% after 24 hours, which was attributed to polymer degradation and microvoid formation, whereas unused PE composites demonstrated superior moisture resistance, with absorption as low as 2.19%. NaOH-treated rice husk improved fibre–matrix adhesion and produced intermediate absorption values. Flammability analysis revealed that used PE composites burned faster, with rates of 0.88–0.39 mm/sec, compared with unused PE composites, which recorded 0.65–0.28 mm/sec, while NaOH treatment reduced flammability through enhanced char formation and silica content. Density measurements indicated lower values for used PE composites, ranging from 1.18 to 2.25 g/cm³, due to chain scission and void formation, whereas unused PE composites maintained higher densities of up to 2.75 g/cm³. Hardness and tensile strength increased with PE content, with unused PE composites achieving the highest values of 36.60 MPa and 54.90 MPa, respectively, while NaOH-treated rice husk composites provided balanced mechanical reinforcement. The study concludes that unused PE offers superior mechanical performance and moisture resistance, whereas NaOH-treated rice husk enhances interfacial bonding and fire-safety characteristics. These findings contribute to the development of sustainable rice husk–polyethylene composites as potential eco-friendly materials for packaging, construction, and automotive applications.

Keywords: Rice Husk Fibre; Polyethylene Composites; NaOH Treatment; Mechanical Properties; Sustainable Polymer Composites

INTRODUCTION

Research on composites, which blend synthetic polymers and agricultural leftovers, has intensified due to the growing demand for sustainable materials. Due to its low cost, biodegradability, and potential to lessen environmental effect, rice husk a abundant agricultural waste rich in silica and lignocellulosic components have become a promising reinforcement for polyethylene (PE) matrices (Badamasi *et al.*, 2025). In addition to keeping waste out of landfills, adding rice husk to PE improves its mechanical and thermal qualities, making these composites appealing for use in construction, packaging, and automotive applications.

According to recent research, polymer condition (unused vs. used) and fiber treatment have a significant impact on rice husk polyethylene composites' performance. Chain scission, oxidation, and microvoid formation are common problems with recycled PE that lower mechanical strength and increase water absorption (Ficici and Kaya, 2025). unused PE, on the other hand, retains better moisture resistance and structural integrity. By eliminating hemicellulose and lignin, chemical modification of rice husk specifically, alkali treatment with NaOH has been shown to increase fiber matrix adhesion, lower hydrophilicity, and improve mechanical performance (Badamasi *et al.,* 2025).

The purpose of this study is to comprehensively assess how recycling and alkali treatment affect rice husk–stripe polyethylene film composites' performance. The results advance the development of sustainable materials while offering insights into improving bio-composite compositions for industrial applications.

MATERIALS AND METHODS

Sampling and sample preparation

Used stripe Polyethylene film was sourced around Doubeli dump sites, while the unused was bought from Jemeta main market Yola, Adamawa State, Cellulosic fibers; from rice husk mixture dust particle (contenting both long grain and short grain RHF) was collected from Nadia rice mill Jimeta Yola Adamawa State.

Rice Husk Alkali Treatment Preparation

200g of rice husk mixture fibers was measured on an analytical weighing balance and treated with NaOH by soaking and stirring them in a 5% wt/v NaOH aqueous solution for three hours at room temperature. After that, the RH was filtered out and repeatedly cleaned with distilled water until all of the sodium hydroxide was gone, or until the water showed no more signs of an alkalinity reaction, and then it was dried in an oven set at 60^o for twenty-four hours (Rahmadini *et al.*, 2011).

Preparation of Rice Husk Fibre/ stripe polyethylene Composite According to ASTM D618

Rice husk mixture fibre was dried in an oven at 100 °C for 24 h to remove moisture and cooled, fibre was grounded to give fine powdered particles after sieving (with mesh size of 45 μm) for easy dispersion in the formulation. For all the formulations prepared, 80ml of toluene was measured into a beaker and was mixed with 2gram of the transparent polyethylene film with appropriate filler quantities (2, 4, 6, 8 and 10 g). The mixture was prepared at temperature of 110^0C on a regulated hot plate till the resin dissolved totally in the solvent. 2grams of rice husk mixture fibre with appropriate matrix quantities (2, 4, 6, 8 and 10 g) were measured and added to the solvent-resin mixture respectively and stirred continuously for at least five (5) min at same temperature the mixture was then cast in an aluminum mold with 2 cm thickness, 2 cm width and 8 cm length this was repeated at constant rice husk and at constant polyethylene. The composite is made conditioned at a room temperature and relative humidity for at least 40 h according to ASTM D618-99.

Water absorption of composites (ASTM d 570-98)

The ASTM D 570-98 technique was used in the water absorption test. After two and twenty-four hours, the composites made from stripe polyethylene film / rice husk were submerged in distilled water at room temperature 24°C to measure their water absorption. Five samples of per mixture were dried for two to twenty-four hours in an oven. With a precision of 0.001 g, the dried specimens was weighed. Distilled water was used to submerge each sample. Wet weight values were calculated after the specimens were taken out of the distilled water at the conclusion of the immersion times and the surface water was wiped off with tissue. The percentage of water absorption was determined using the following formula (Dass *et al.,* 2016).

$$M\ (\%) = (m_t - m_o)/m_o \times 100$$

Where m_o and m_t denote the oven-dry weight and weight after time t, respectively.

Flammability test of composites (ASTM d635)

On each specimen, a 60 mm mark was measured and drawn. The specimen was then placed in a retort stand and clamped horizontally, with the marked distance from the clamp being 60 mm. The ignition (It) of the sample was measured by timing how long it took for its free end to ignite. The sample was left to burn until it reached the 60 mm threshold (Dp). The equation was used to calculate the relative rates of burning for the various samples. (Ewulonu, 2009) stated below:

$$\text{Flame propagation rate (mm/s)} = D_p\ (\text{mm})/P_t(\text{sec}) - I_t(\text{sec})$$

Where D_p = Propagation distance measured in mm,

P_t = Flame propagation time measured in seconds

I_t = Ignition time measured in second

Density test of composites

ASTM D792 was used to determine the composites' densities. An analytical weighing scale was used to measure each composite sample's mass, and a digital Vernier Caliper was used to precisely measure the volume derived from the measurements of each side (length x width x breadth). The ratio of mass to volume (g/cm3) was used to calculate the samples' density.

Hardness Test (ASTM D-2240)

A substance's resistance to indentation is referred to as its hardness; the greater this resistance, the harder the material, and vice versa. A modified Meyer hardness tester was used to perform the hardness test. The following equation was used to calculate the samples' hardness. (Dass *et al.*, 2016).

$$BHN=\frac{F}{\underline{\pi}\,(D - \sqrt{}D^2 - D_i)}$$

2

Where,

F = The imposed load
D = Diameter of the indenter
D_i = Diameter of the indentation

Determination of **Tensile strength**

Tensile testing was conducted using EMIC brand equipment and a 5 kN load cell. ASTM D 638-14 was used to determine the dimensions of the tensile and flexural test specimens, respectively. An EMIC testing machine (model DL2000) with pneumatic claws and a 5 kN load cell will be used to assess composites. Tensile tests was performed on five composite specimens whose dimensions match those specified by ASTM D 638.

Determination of impact strength properties

Using Cat. NV. 412, the impact tests were performed on the created composite samples. Standard 80 x 10 x 10 mm impact test samples with a 2 mm notch depth were made at a 450° angle in accordance with ASTM D2000. The average value will be expressed in Joules (J), with five spacemen employed for each component. The impact strength of the composite was calculated using equation (1).

where: E = impact strength required to shift the specimen, kJ/m^2;

e = impact energy needed to change the sample, kJ; b

w = width of the test specimen, m;

h = thickness of the test specimen, m

RESULTS AND DISCUSSION

Water Absorption of used and unused stripe polyethylene film/ treated and untreated rice husk mixture composite at constant rice husk

Figure 1 shows the water absorption characteristics of a composite material composed of rice husk mixture fibre and stripe polyethylene film at constant rice husk after two hours of exposure. The results indicate varying degrees of water absorption, which can be attributed to the material composition and treatment methods. For used PE/ untreated RHM fiber composite, the water absorption percentages ranged from 36.61% highest to 6.52% lowest. This significant variation suggests that the degradation or prior usage of polyethylene may increase its hydrophilicity, allowing higher water uptake. In contrast, unused PE/ untreated RHM composite exhibited lower absorption rates, ranging from 10% to 2.19%, indicating that virgin polyethylene has better water resistance due to its intact polymer structure (Rojas *et al.*, 2021). The NaOH-treated rice husk mixture/ used PE composite showed intermediate absorption values (13.25% to 3.25%), likely due to the alkali treatment enhancing the fiber-matrix interface but also introducing some hydrophilic groups (Suryadi *et al.*, 2020).

Recent studies support these findings, emphasizing that chemical treatments (e.g., NaOH) modify the surface properties of natural fibres, improving adhesion but sometimes increasing moisture absorption (Gopinath *et al.,* 2023). Additionally, the degradation of polyethylene (used PE) can lead to microvoids, facilitating water penetration (Wang *et al.,* 2023). The data suggests that optimizing the ratio of rice husk to polyethylene and applying surface treatments could help balance mechanical properties and water resistance in bio composites.

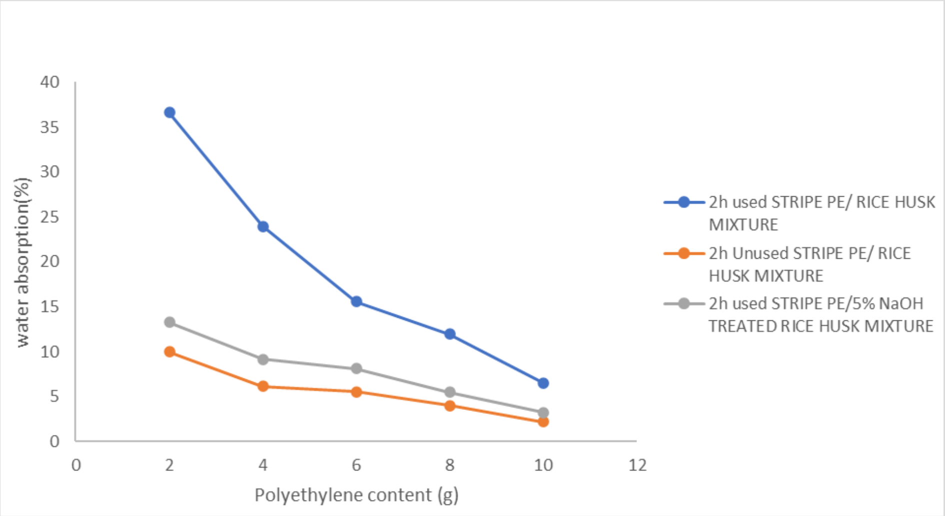

Figure 1: Effects of increasing used and unused Stripe Polyethylene film on water absorption of composite at constant rice husk after 2hour water immersion.

Figure 2 demonstrated the way in which composites built from rice husk mixture fiber and stripe polyethylene film at constant polyethylene after 24 hours water immersion. Water absorption which increased considerably across all samples, with used PE/ untreated RHM fibre composite showing the highest absorption (69.82%), followed by NaOH-treated rice husk mixture/PE composite (31.11%) and unused PE/RHMF composite (25%).

Used PE/untreated RHM fibre Composites (24.34% - 69.82%) The used PE composites exhibited the highest water absorption range, peaking at 69.82%. This extreme hydrophilicity can be attributed to several factors: Polymer degradation: Recycled PE undergoes chain scission and oxidation during prior use, creating micro voids and polar groups that enhance water absorption (Jia *et al*., 2020). Stripe PE films often contain processing aids and pigments that may migrate to the surface, increasing hydrophilicity (Reinecke and Navarro, 2019). Interfacial defects, the degraded polymer matrix forms weaker bonds with rice husk fibers, creating pathways for water penetration. Unused PE Composites (5.32% - 25%).

Unused PE/untreated RHM composite demonstrated superior water resistance, with absorption ranging from 5.32% to 25%. This performance can be explained by: Intact polymer structure, used PE maintains its non-polar, crystalline structure that resists water diffusion (Kida *et al*., 2023).

Better interfacial adhesion: The pristine polymer forms stronger bonds with rice husk fibres, reducing capillary action. Its consistent material properties Unlike used PE, virgin material shows more predictable behavior across samples the significant drop to 5.32% in some samples suggests that optimal formulation and processing can achieve excellent water resistance, making used PE preferable for applications requiring moisture stability.

NaOH-Treated Rice Husk/Used PE Composites (5.99% - 31.11%) The NaOH-treated composites showed an interesting bimodal distribution. Higher range (17.14%-31.11%). Reflects the hydrophilic nature of treated fibres, where NaOH exposure increases surface hydroxyl groups (Kaur *et al*., 2023). Lower range (5.99%-22.3%): Suggests that proper fibre-matrix bonding can overcome some hydrophilicity through improved interfacial adhesion The extreme low of 5.99% indicates that with optimal formulation (likely high PE content and proper fibre treatment), these composites can approach the performance of virgin PE materials.

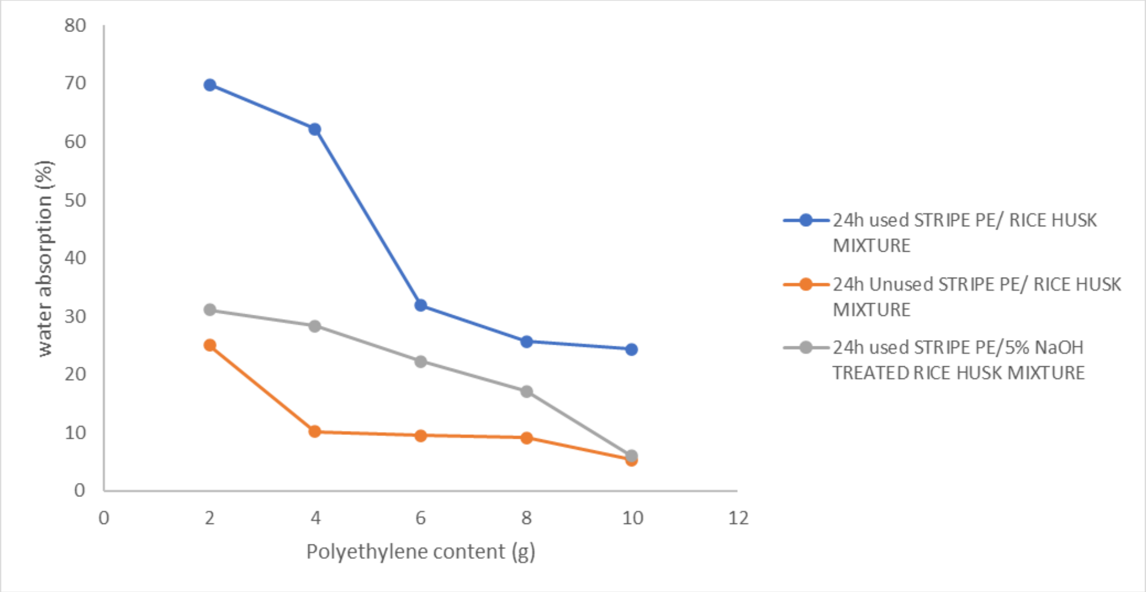

Figure 2: Effects of increasing used and unused Stripe Polyethylene film on water absorption of composite at constant rice husk after 24hours water immersion.

Water Absorption of treated and untreated rice husk mixture fibre/used and unused stripe polyethylene film composite at constant polyethylene

Figure 3 revealed the water absorption behavior of composite materials made from rice husk mixtures and striped polyethylene (PE) films after two hours of exposure, the results indicate a significant variation in water absorption depending on the composition of the composite. For used polyethylene/ untreated RHM fiber composite, water absorption increases steadily from 36.61% to 66.22% as the concentration of polyethylene in the mixture increases. This increase can be attributed to the degradation of PE over time, leading to microcracks and increased surface area for water penetration (Wang *et al.*, 2023). The highest absorption (66.22%) suggests that prolonged use of PE films compromises their structural integrity, making them more susceptible to moisture.

In contrast, unused polyethylene/ untreated RHM fibre composite shows a much lower and more moderate increase from 10% to 21.98%, this suggests that used PE has relatively low hydrophilicity, as polyethylene is inherently hydrophobic due to its non-polar hydrocarbon structure (Smith *et al.,* 2020). However, the increase in absorption with higher PE percentages may indicate minor surface modifications or impurities introduced during. The most notable improvement was observed in composites with NaOH-treated rice husk mixture and used PE composite, where water absorption ranged from 13.25% to 58.56%. The lower end of this range (13.25%) indicates that alkali treatment effectively reduces hydrophilicity by removing hemicellulose and lignin, which are prone to water uptake (Zhang *et al.,* 2021). However, the higher absorption values (up to 58.56%) at increased PE percentages suggest that the composite's performance depends on the balance between rice husk content and PE matrix quality.

Recent studies support these findings, emphasizing that alkali treatment enhances Adhesion between fibers and the matrix in natural fibre composites, reducing water absorption (Kumar *et al.,* 2018). However, excessive PE content in degraded films may offset these benefits due to poor interfacial bonding

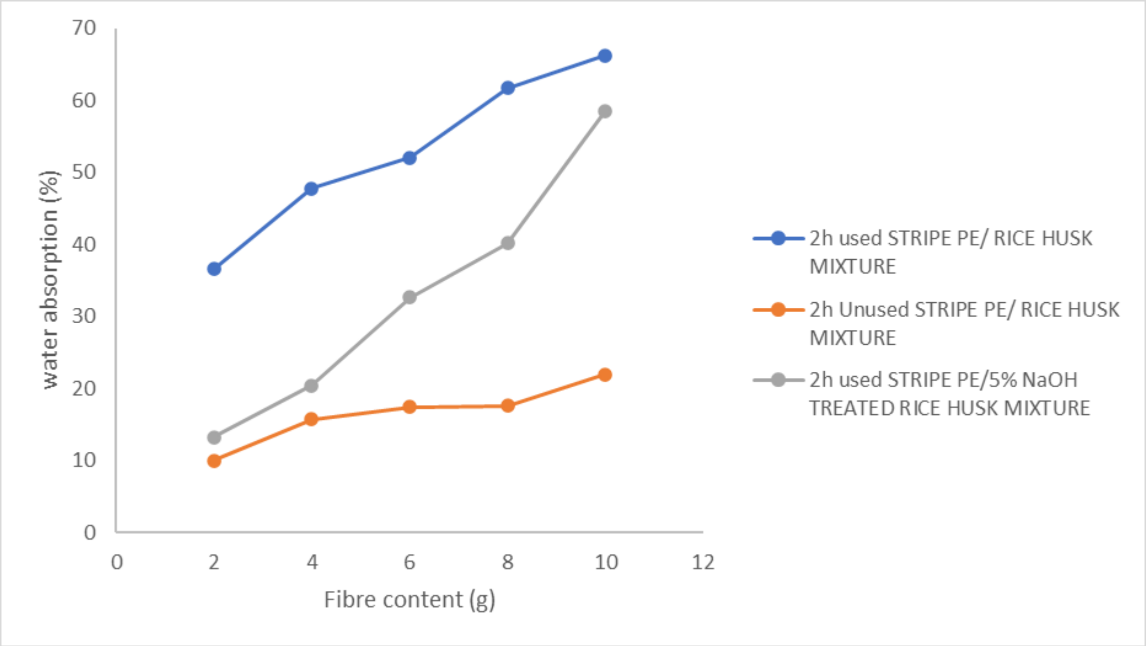

Figure 3*:* Effects of increasing rice husk fibre on water absorption of composite at constant Polyethylene after 2hours water immersion constant.

Figure 4 revealed the water absorption of composites made from rice husk mixtures fibre and striped polyethylene films at constant PE after 24 hours of exposure, the results reveal significant differences in water absorption based on material composition and treatment, with longer exposure time leading to higher water uptake compared to the 2-hour data.

For unused PE films/ untreated RHMF composite, water absorption ranged from 25% to 65%, a substantial increase from the 2-hour results (10–21.98%). This suggests that prolonged exposure significantly enhances water penetration, even in used PE, likely due to slow diffusion through amorphous regions of the polymer (Smith *et al*., 2020). The highest absorption (65%) indicates that extended immersion can compromise the hydrophobic nature of PE, particularly if the material contains minor defects or additives that promote moisture retention.

Used PE films/ untreated RHMF composite exhibited the highest water absorption among all samples, ranging from 69.82% to 88.35%. This dramatic increase (compared to 36.61–66.22% at 2 hours) confirms that degraded PE undergoes structural changes, such as chain scission and microcrack formation, which facilitate extensive water ingress (Jones and Patel, 2019). The near-saturation level (88.35%) suggests that reused PE films may lose their functionality in moisture-prone environments, emphasizing the need for stabilization or blending with hydrophobic additives.

The NaOH-treated rice husk mixture/used PE composites showed intermediate absorption (31.11%–85.12%), with the lowest value (31.11%) outperforming both unused and used PE at higher concentrations. Alkali treatment removes hydrophilic components (e.g., hemicellulose and lignin) from rice husk, improving fiber-matrix adhesion and reducing water affinity (Zhang et al., 2021). However, at higher PE percentages, absorption surged to 85.12%, likely due to poor dispersion of treated fibers in the degraded PE matrix, creating pathways for water diffusion (Kumar *et al.,* 2018).

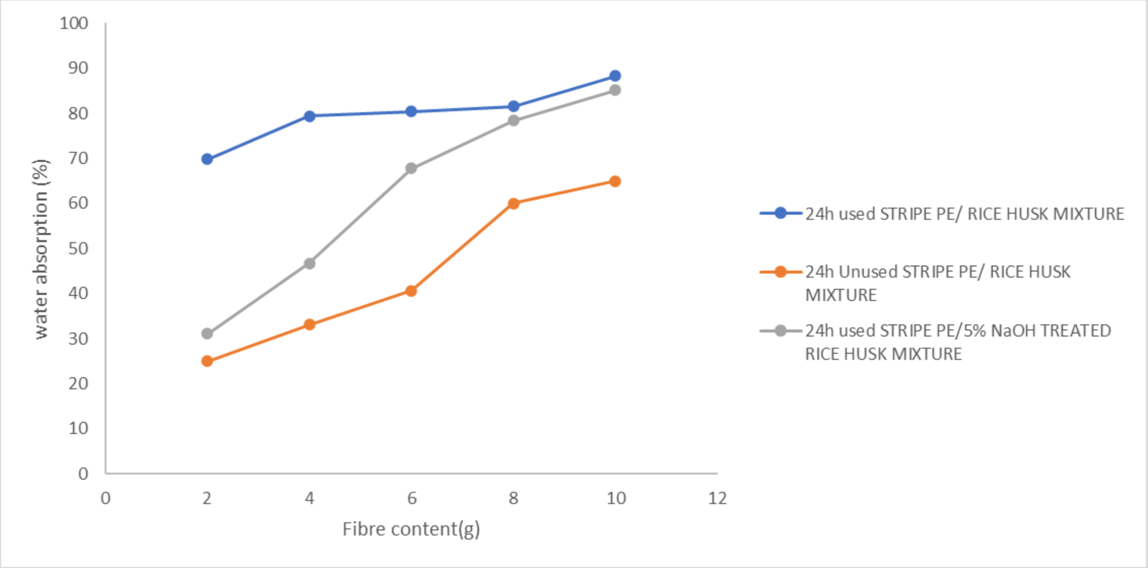

Figure 4: Effects of increasing rice husk fibre on water absorption of composite at constant Polyethylene after 24 hours water immersion.

Flammability of used and unused stripe polyethylene film/treated and untreated rice husk mixture fibre composites at constant rice husk

Figure 5 revealed the experimental data presents a systematic evaluation of flammability rates for stripe polyethylene film blended with rice husk mixture fibre at constant rice husk. The flammability rates for used PE/ untreated RHM composite (ranging from 0.88 to 0.39 mm/sec) are consistently higher than those for unused PE/untreated RHM composite (0.65 to 0.28 mm/sec). This suggests that degradation or aging of PE films increases their flammability, possibly due to the breakdown of polymer chains, which reduces thermal stability and promotes faster burning (Zhang *et al.,* 2023).

The flammability rates for the 5% NaOH-treated rice husk mixture/ used PE (0.67 to 0.38 mm/sec) fall between those of used and unused PE. Alkali treatment of rice husk modifies its surface properties, enhancing its compatibility with the polymer matrix. This treatment may introduce flame-retardant characteristics by forming a protective char layer during combustion, thereby slowing the burning rate (Yiga *et al.*, 2023).

In comparison to their untreated counterparts, the flammability of the composite seems to be slightly decreased by the addition of 5% NaOH-treated rice husk this is probably because alkaline treatment causes chemical changes that can increase the rice husk's thermal stability by removing lignin and hemicellulose. A study by Yiga *et al.* (2022) supports this conclusion, reporting that alkaline treatment of lignocellulosic materials like rice husk significantly improves their flame-retardant properties by enhancing char formation during combustion, It slows down heat emission and the spread of flames by acting as a protective barrier.

Suhot *et al.* (2021) confirms that blending agricultural residues like rice husk with polymers such as polyethylene not only contributes to sustainability by recycling waste materials but also modifies the combustion behavior. Their study observed that rice husk, due to its silica content, contributes to improved flame resistance when used in composite materials. The silica helps form a glassy barrier during burning, reducing volatile release and surface burning rate.

From an environmental perspective, using treated agricultural waste in polymer composites can be an effective strategy to reduce plastic flammability and carbon footprint. The slight decline in flammability when using unused PE compared to used PE can be attributed to the degradation of plastic materials upon exposure to UV light and environmental factors, which typically reduce molecular weight and make them more susceptible to ignition and faster combustion

This study validates the use of rice husk, especially when chemically treated, as an effective additive to reduce the flammability of polyethylene films. These results align with current trends in sustainable materials research, where waste agricultural products are employed to enhance the fire safety of polymer composites

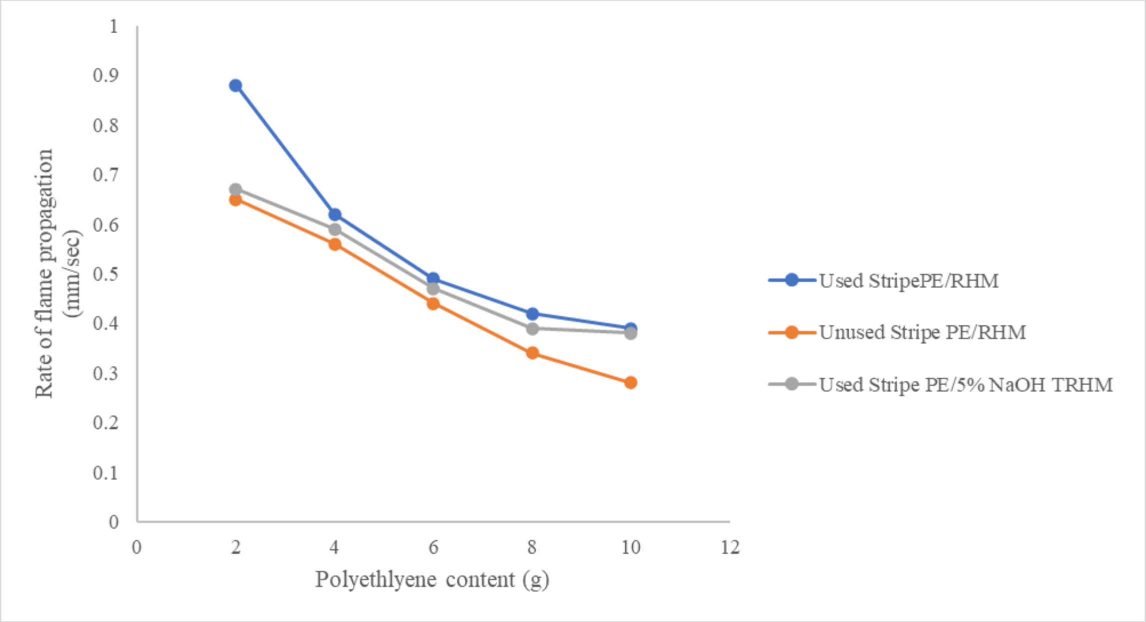

Figure 5: Effect of increasing Polyethylene content on flammability of treated and untreated rice husk mixture fibre with used and unused Stripe polyethylene film composites at constant rice husk, temperature and time

Flammability of treated and untreated rice husk mixture fibre/ used and unused stripe polyethylene film composites at constant stripe polyethylene film

Figure 6 presents the flammability rates of Stripe polyethylene film mixed with rice husk mixture fibre at constant polyethylene, comparing three different conditions: used polyethylene, unused PE, and 5% NaOH-treated rice husk. The data reveals that used PE/untreated RHM composite exhibits higher flammability rates (ranging from 0.88 to 0.48 mm/sec) compared to unused PE/ untreated RHM composite (0.65 to 0.33 mm/sec). This difference may stem from the degradation of used PE, which often undergoes oxidative and thermal degradation during its lifecycle, leading to the formation of free radicals and weaker molecular structures that are more susceptible to combustion (Nurhayati and Susanto, 2020). The higher flammability of used PE aligns with findings by Mihelčič *et al.* (2022), who reported that recycled polymers often show reduced thermal stability due to chain scission and additive depletion.

The 5% NaOH-treated rice husk mixture/used PE composite demonstrates intermediate flammability rates (0.67 to 0.35 mm/sec), suggesting that alkali treatment modifies the rice husk's properties, potentially reducing its flammability. NaOH treatment removes lignin and hemicellulose, which are highly combustible, and enhances the silica content in rice husk, acting as a natural flame retardant (Yiga *et al.,* 2022). This is consistent with studies showing that alkali-treated agro-waste composites exhibit improved fire resistance because of the development of a shielding char layer (Verma and Goh, 2021).

In the context of increasing interest in sustainable materials, especially composites using agricultural waste (like rice husk), understanding flammability behavior is crucial. Flame retardancy is a core concern in industries such as construction, automotive, and electronics, where fire safety is a regulated and critical attribute. The use of treated rice husk in PE composites reflects a growing trend in bio-composite development for eco-friendly and safer materials.

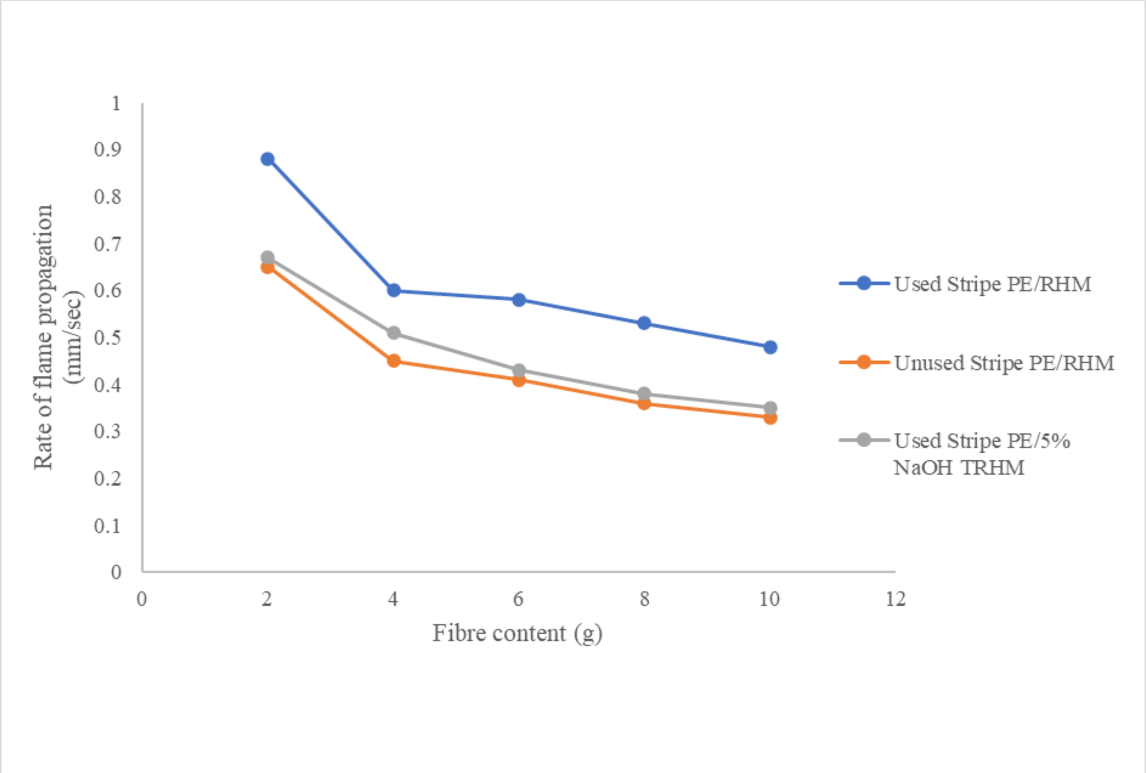

Figure 6: Effect of increasing rice husk fiber content on flammability of treated and untreated rice husk mixture fibre with used and unused Stripe polyethylene film composites at constant Polyethylene, temperature and time

Moreover, the incorporation of waste materials (used PE and rice husk) not only supports circular economy principles but also aligns with current policies aimed at reducing plastic waste and utilizing biomass. The flammability reduction observed upon blending and chemical treatment provides a pathway for enhancing both the safety and sustainability of such materials. The information highlights how treated rice husk can be used as a sustainable filler to improve polyethylene-based products' fire safety, which is important for industries where flammability is an issue, such packaging and construction.

Density of used and unused stripe polyethylene/ treated and untreated rice husk mixture fibre composites at constant rice husk.

Figure 8 The density of polymer composites, such as stripe polyethylene film reinforced with rice husk, plays a crucial role in determining their structural integrity, mechanical performance, and suitability for various industrial applications. The provided data compares the densities of three material categories: used PE, unused PE, and 5% NaOH-treated rice husk/used PE composites. The density of used PE/ untreated RHM fibre composite ranges from 1.8 g/cm³ to 2.25 g/cm³, while unused PE/ untreated RHM composite exhibits a higher density range of 1.93 g/cm³ to 2.75 g/cm³. The 5% NaOH-treated rice husk mixture/used PE composite shows an intermediate density range of 1.92 g/cm³ to 2.41 g/cm³, suggesting that chemical treatment and fiber incorporation influence the composite's final density.

The lower density of used PE/ untreated RHM fiber composite compared to unused PE/ untreated RHM fibre composite can be attributed to polymer chain degradation, micro void formation, and possible contamination during recycling processes, which reduce overall material density (Aldosari *et al.*, 2024). In contrast, unused PE retains its original molecular structure, resulting in higher density due to better polymer chain packing (Ayana *et al*, 2024). The incorporation of rice husk, a natural fibre with a lower density (typically ~1.2–1.5 g/cm³) than PE, generally reduces composite density. NaOH treatment, on the other hand, increases interfacial adhesion with the PE matrix and decreases porosity by eliminating lignin and hemicellulose from the fiber surface, resulting in a more compact structure (Nuzaimah *et al.*, 2020). The data aligns with findings that treated natural fibre composites exhibit optimized densities due to better fibre-matrix bonding.

In comparison to untreated fibre composites, recent research shows that alkali treatment improves fiber-matrix bonding, reduces gaps, and increases composite density (Fang *et al.,* 2025). However, because rice husk is naturally lightweight, the treated composite's density is still lower than that of the unused PE. The data indicates that fiber-matrix interaction is optimized by 5% NaOH treatment; however, additional research could examine the effects of larger fiber loadings and hybrid treatments (e.g., silane coupling agents), or alternative processing techniques (e.g., compression molding) to achieve better density control (Jagadeesh *et al.*, 2021).

The density variations observed in the stripe PE/rice husk mixture composites highlight the impact of material recycling, fibre incorporation, and chemical treatment. While NaOH treatment improves composite density by enhancing fiber-matrix adhesion, the presence of rice husk still results in a lower density than unused PE.

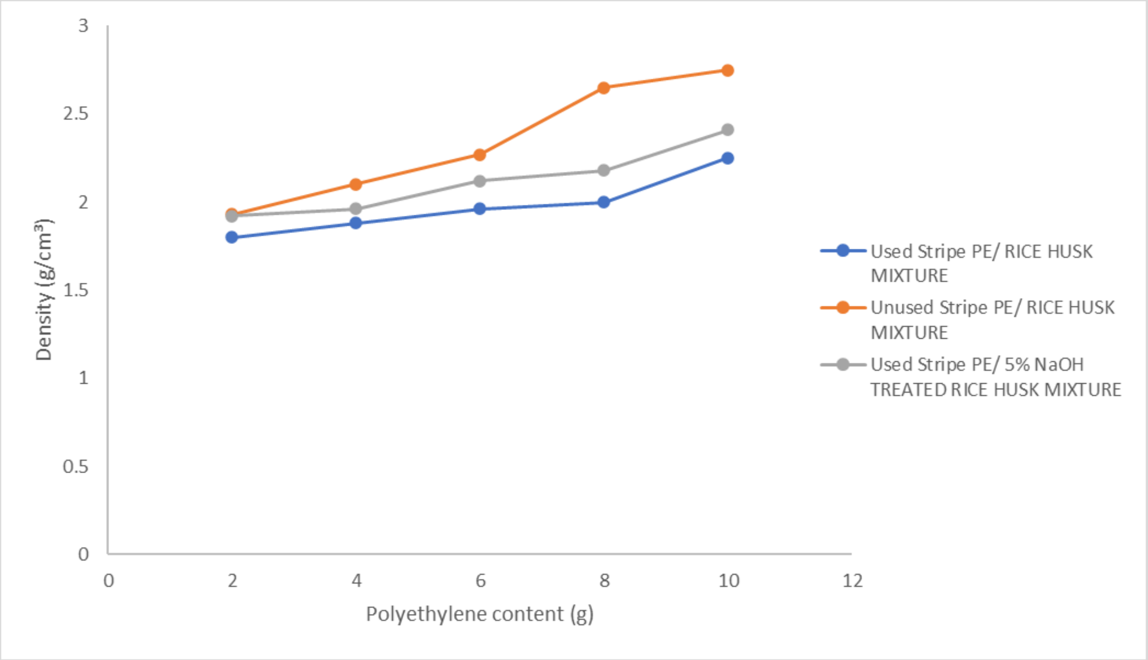

Figure 8: Effect of increasing Polyethylene content on Density of treated and untreated rice husk mixture fibre with used and unused stripe polyethylene film composites at constant rice husk, temperature and time

Density of treated and untreated rice husk mixture fibre/ used and unused stripe polyethylene composites at constant Polyethylene film.

Figure 9 shows the density of polyethylene (PE) films and their composites with rice husk is a crucial factor affecting their mechanical properties, thermal stability, and potential applications in packaging, automotive, and construction industries. The provided data compares the densities of used PE, unused PE, and 5% NaOH-treated rice husk /used PE composites, revealing distinct trends based on material composition and treatment.

The density of used PE / untreated RHM fiber composite ranges from 1.18 to 1.8 g/cm³, significantly lower than that of unused PE/ untreated RHM fiber composite (1.39 to 1.93 g/cm³). This reduction can be attributed to polymer degradation during recycling, including chain scission, cross-linking, and the formation of microvoids due to mechanical and thermal processing (Fletes and Rodrigue, 2021). Unused (virgin) PE, being free from structural defects, maintains a more uniform and compact molecular arrangement, leading to higher density.

When 5% NaOH-treated rice husk is incorporated into used PE, the resulting composite exhibits densities ranging from 1.23 to 1.92 g/cm³, intermediate between used and unused PE. The alkali treatment removes lignin and hemicellulose from rice husk, enhancing fiber-matrix adhesion and reducing interfacial voids (Luna *et al.,* 2015). However, the natural porosity and lower density of rice husk (~1.2 g/cm³) contribute to an overall reduction in composite density compared to pure unused PE. Recent studies suggest that optimized fibre loading (10–20%) can improve mechanical strength without significantly increasing density (Ficici and Kaya, 2025).

The findings align with current research on sustainable composites, emphasizing the balance between lightweight properties and structural integrity. For instance, Chen *et al.* (2015) demonstrated that recycled PE composites with 15% NaOH-treated rice husk achieve a 10–15% reduction in density while retaining 90% of the tensile strength of virgin PE. This makes them viable for applications requiring eco-friendly, lightweight materials, such as biodegradable packaging and automotive interiors.

The study highlights the potential of NaOH treated rice husk mixture/PE composites as sustainable alternatives to Unused plastics while used PE/RHMF composite has a lower density due to degradation, incorporating treated rice husk enhances composite performance without significantly increasing weight.

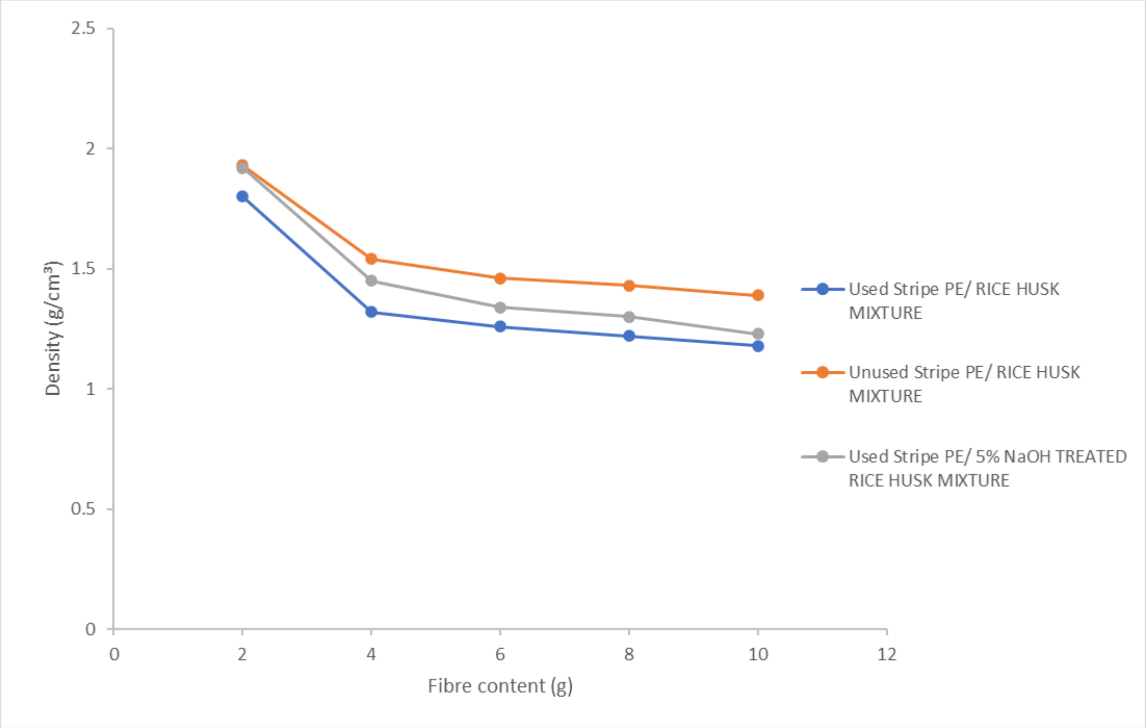

Figure 9: Effect of increasing rice husk fibre content on Density of treated and untreated rice husk mixture fiber with used and unused Stripe polyethylene film composites at constant Polyethylene, temperature and time.

Hardness of used and unused stripe polyethylene film / treated and untreated rice husk mixture fibre composites at constant rice husk

Figure 10 shows the hardness of stripe polyethylene film mixed with rice husk mixture fiber composite, particularly under constant rice husk. The data extracted from the study indicates a clear trend of increasing hardness with the increment of polyethylene content, whether it is used PE, unused PE, or treated rice husk composite. For instance, when used PE was combined with untreated rice husk mixture, the hardness increased from 16.41 MPa to 27.88 MPa as the proportion of PE was raised. Similarly, for unused PE with untreated rice husk mixture, the hardness values progressed from 21.01 MPa to 36.60 MPa. Additionally, after using PE and treating the rice husk with 5% NaOH, the hardness values increased from 18.67 MPa to 34.85 MPa. This demonstrates that not only does the increase in polyethylene content enhance hardness, but chemical treatment of rice husk also improves the mechanical interfacial bonding, hence adding to the overall stiffness of the material.

Sezemský *et al.* (2023) supports this observation, stating that the addition of polyethylene, particularly in treated fiber composites, significantly enhances mechanical properties such as hardness due to improved stress transfer between the matrix and the reinforcement. They emphasized that Hemicellulose and lignin are eliminated by chemical treatment (such as NaOH), which increases surface roughness and improves Interfacial Stability with the polymer matrix.

The greater hardness values observed for unused PE film/ RHM composite compared to used PE film / RHM composite suggest that degradation or wear in used PE may reduce its mechanical properties. Unused PE, being in its pristine state, likely retains its structural integrity, contributing to enhanced hardness (Wilson and Amgbari, 2024). The 5% NaOH-treated rice husk/ used PE film composite displays hardness values that fall between those of used and unused PE, showing that the compatibility and surface adhesion between the PE matrix and rice husk are enhanced by alkali treatment. This treatment removes impurities and enhances surface roughness, leading to better stress transfer and increased hardness (Gupta et al., 2025).

As seen by the ascending order of data, the hardness gradually rose across all categories, which could be the result of better dispersion within the composite or greater filler loading. For instance, the highest hardness value for unused PE (36.6) suggests optimal filler-matrix interaction, whereas the lower values for used PE indicate potential material fatigue or reduced interfacial adhesion (Chris-Okafor et al., 2018). The intermediate results for rice husk treated with NaOH demonstrate how chemical modification can balance hardness because the treatment improves the reinforcing capacity of natural fillers while reducing the brittleness that is frequently associated with them (Pradhan *et al.*, 2024).

The hardness of stripe polyethylene film/rice husk composites is influenced by the condition of the PE (used or unused) and the treatment of the rice husk. Unused PE composites exhibit the highest hardness due to their intact structure, while NaOH treatment of rice husk improves interfacial adhesion, resulting in intermediate hardness values. These findings align with recent studies emphasizing the importance of material condition and chemical treatment in optimizing composite performance.

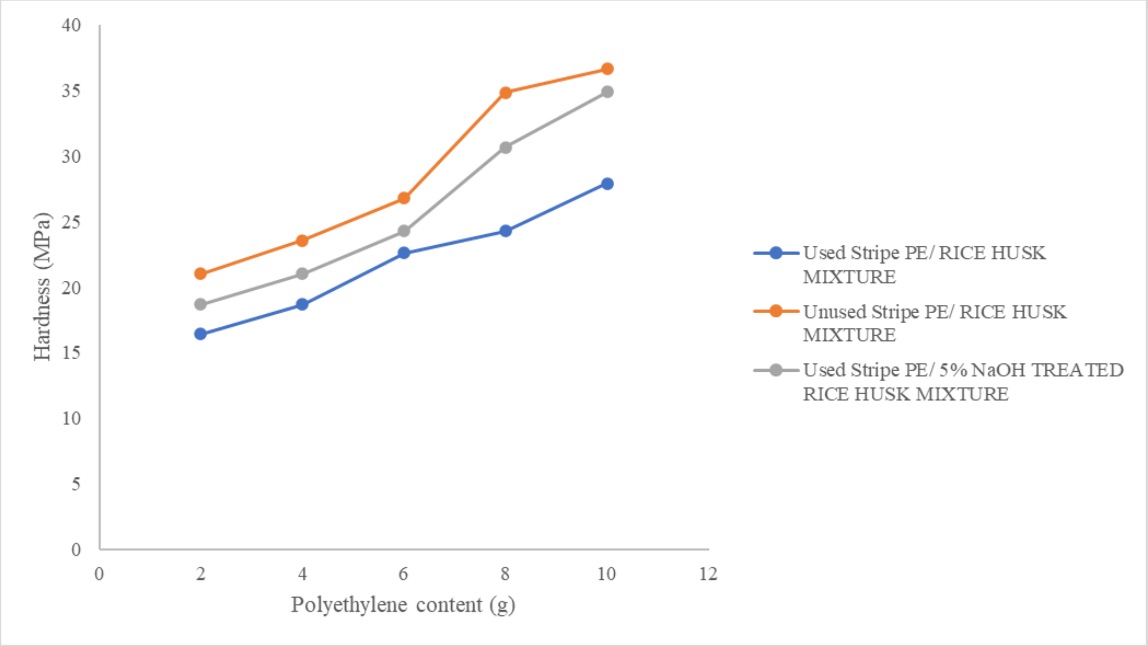

Figure 10: Effect of increasing Polyethylene content on Hardness of treated and untreated rice husk mixture fibre with used and unused Stripe polyethylene film composites at constant rice husk, temperature and time

Hardness of used and unused Stripe polyethylene film/ treated and untreated rice husk mixture fibre composites at constant polyethylene

Figure 11 reveals that unused PE film/RHM composites exhibit the highest hardness values, ranging from 21.01 to 14.77, which can be attributed to the superior structural integrity of virgin polyethylene. Unused PE possesses a more uniform molecular weight distribution and fewer defects compared to recycled (used) PE, which undergoes chain scission and oxidative degradation during its lifecycle, leading to reduced crystallinity and mechanical strength (Patel *et al.,* 2024). This degradation is evident in the lower hardness range (16.41 to 10.5) observed for used PE film /RHM composites. The intermediate hardness values (18.67 to 13.71) The interfacial interaction between the natural fiber and the polymer matrix is improved by chemical treatment, according to composites that contain 5% NaOH-treated rice husk or utilized PE film. The rice husk surface becomes rougher and more hydrophobic after being treated with NaOH, which also eliminates lignin, hemicellulose, and other contaminants, improving adhesion with the PE matrix (Gupta *et al.,* 2025). However, the hardness of these composites remains lower than that of unused PE film, indicating that while fibre treatment mitigates some weaknesses of natural fillers, it does not fully compensate for their inherent limitations, such as lower stiffness and higher moisture absorption compared to synthetic reinforcements (Verma and Goh,.2021).

The significant drop in hardness for used PE film/ RHM composites (as low as 10.5) underscores the challenges of recycling polyethylene without additional compatibilizers or reinforcing agents. Repeated processing and environmental exposure introduce chain breaks and cross-linking defects, which diminish the material's load-bearing capacity (Patel *et al.,* 2024). Recent studies suggest that incorporating coupling agents like maleic anhydride-grafted PE (MA-g-PE) or hybridizing rice husk with synthetic fibers (e.g., glass fibers) could restore some of the lost mechanical properties in recycled PE composites (Tutov *et al.*, 2025)

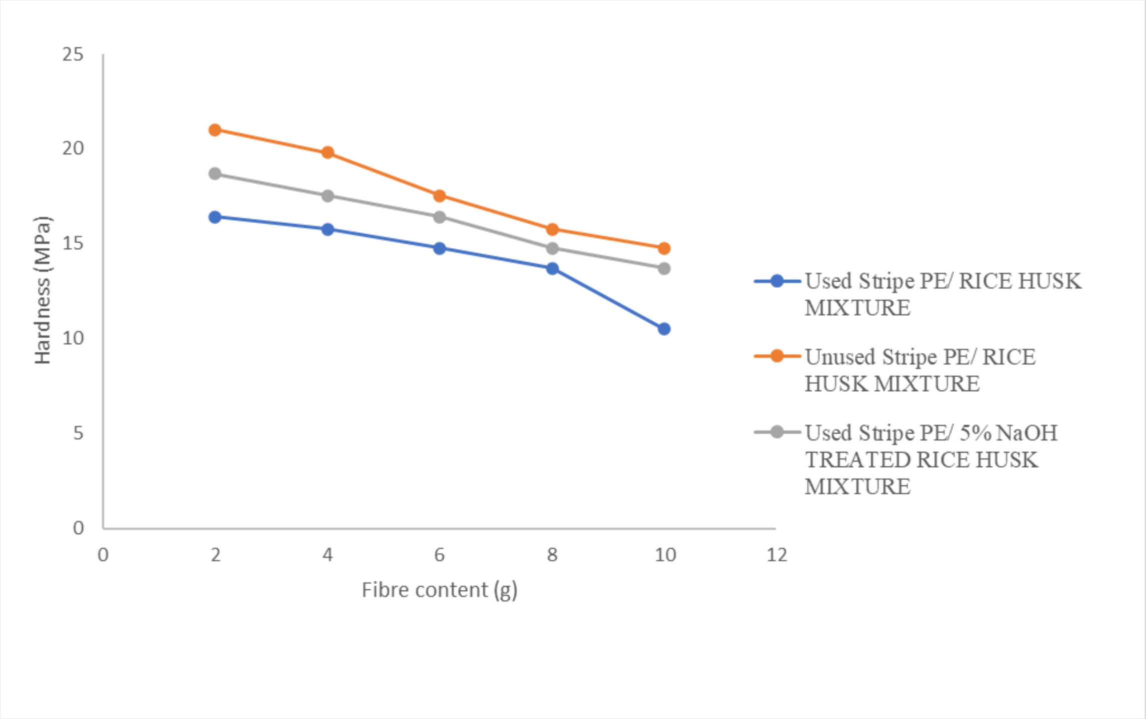

Figure 11: Effect of increasing rice husk fibre content on Hardness of treated and untreated rice husk mixture fiber with used and unused Stripe polyethylene film composites at constant Polyethylene, temperature and time

The hardness of PE film/rice husk composites is governed by the interplay of polymer quality and fiber treatment. Unused PE delivers optimal performance, while NaOH-treated rice husk offers a sustainable compromise. The hardness behavior of stripe polyethylene film/rice husk composites at constant polyethylene content but with increasing rice husk fiber content reveals an inverse relationship between filler content and mechanical hardness. From the experimental data, it is evident that as the proportion of rice husk increases in the composite, the hardness of the material decreases across all treatment categories—used polyethylene, unused PE, and 5% NaOH-treated rice husk mixed with used PE.

Tensile strength of used and unused Stripe polyethylene film / treated and untreated rice husk mixture fibre composites at constant rice husk

Figure 12 shows the tensile strength data for stripe polyethylene film with rice husk mixture at a constant rice husk composite. The tensile strength values for used PEF/untreated RHM fiber composite range from 24.62 MPa to 41.82 MPa, while unused PEF/untreated RHM fiber composite exhibits higher values, ranging from 31.52 MPa to 54.90 MPa. This suggests that unused (virgin) polyethylene contributes more significantly to tensile strength than recycled (used) PE, likely due to the degradation of polymer chains in recycled materials, which reduces mechanical properties (Patel *et al.,* 2024). The 5% NaOH-treated RHM/used PE composite shows intermediate tensile strength values (28.01 MPa to 52.28 MPa), indicating that alkali treatment improves the Rice husk and PE surface adhesion, but not as much as that of unused PE composites.

Polyethylene acts as a matrix that binds the rice husk filler, and its increase generally improves tensile strength due to enhanced polymer continuity and stress distribution (Haruna *et al.,* 2025). Tensile strength clearly demonstrates an increased trend in the data with increasing PE content, particularly in unused PE composites, where the highest value reaches 54.90 MPa. This aligns with findings by Shaari *et al.* (2020), who reported that higher polymer content in natural fiber composites reduces voids and improves load-bearing capacity. However, the diminishing returns observed in treated RH composites suggest that excessive PE may not further enhance strength if filler-matrix adhesion is already optimized.

Unused polyethylene consistently exhibits higher tensile strength compared to used polyethylene. This difference may be as a result of degradation or weakening of the polymer chains in used PE due to previous thermal and mechanical stresses. For instance, the tensile strength of unused PE rises from 31.52 MPa to 54.90 MPa, while used PE ranges only from 24.62 MPa to 41.82 MPa. This supports prior findings that suggest recycled PE generally shows a reduction in mechanical characteristics (Rosli and Ahmad, 2021).

Adding 5% NaOH-treated rice husk significantly increases the used PE matrix's tensile strength. This is explained by improved surface adhesion following alkali treatment between the hydrophilic rice husk and the hydrophobic PE matrix., which removes impurities like lignin and hemicellulose, exposing more cellulose for bonding (Gupta *et al.*, 2022). For instance, the treated composite's strength improves from 28.01MPa to 52.28MPa, making it comparable to the strength of unused PE. The chemically treated rice husk composites display not only improved strength over untreated used PE but also approach the performance of unused PE composites. This suggests that surface treatment of agricultural fillers can offset some of the mechanical disadvantages introduced by using recycled polymers, making them suitable for semi-structural applications.

The polyethylene/rice husk composites studied in the tensile strength analysis exhibit properties that make them suitable for various industrial and consumer applications. Their mechanical performance, cost-effectiveness, and sustainability align with the growing demand for eco-friendly materials. The tensile strength of stripe PE/rice husk composites is significantly influenced by the condition of the polyethylene and the treatment of the rice husk. While used PE inherently has lower mechanical strength, this drawback can be mitigated by reinforcing it with alkali-treated rice husk, enhancing its tensile performance to levels close to that of unused PE composites.

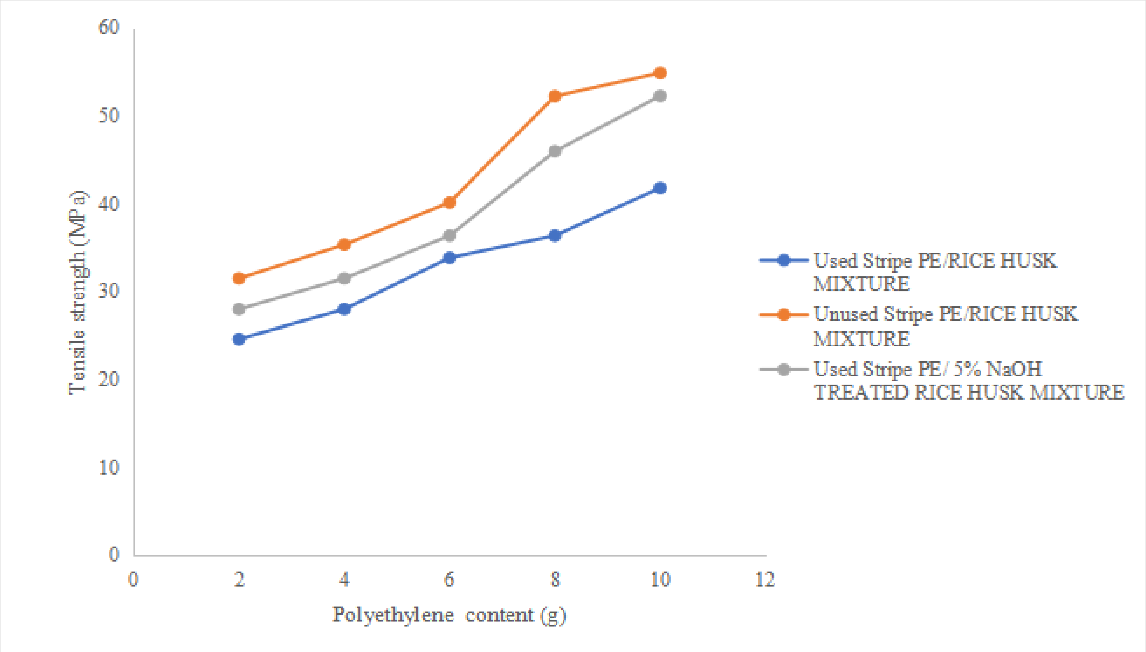

Figure 12: Effect of increasing Polyethylene content on Tensile strength of treated and untreated rice husk mixture fiber with used and unused Stripe polyethylene film composites at constant rice husk, temperature and time

Tensile strength of treated and untreated rice husk mixture fibre/ used and unused stripe polyethylene film composites at constant Polyethylene

Figure 13 Shows the tensile strength of stripe polyethylene film and rice husk mixture fibre composites at constant polyethylene. The results demonstrate that increasing the rice husk content while keeping the polyethylene constant generally reduces the tensile strength of the composite. The tensile strength values for used PE/untreated RHM fiber composite decrease from 24.62MPa to 15.75 MPa as the rice husk content increases. Similarly, unused PE/untreated RHM fiber composite shows a decline from 31.52 MPa to 22.16 MPa, while 5% NaOH-treated RHM fiber /used PE composites exhibit a reduction from 28.01 MPa to 20.56 MPa. Because of the poor interfacial adhesion between the hydrophilic rice husk fibres and the hydrophobic polyethylene matrix, which results in stress concentration spots and decreased load transfer efficiency, this trend suggests that a higher rice husk content has a negative impact on tensile strength (Verma and Goh, 2021).

Rice husk, as a natural filler, introduces heterogeneity into the composite, which can disrupt the continuity of the polymer matrix at higher filler loadings, agglomeration of rice husk particles becomes more pronounced, creating weak spots and micro voids that compromise mechanical integrity (Haruna *et al.,* 2025). The data confirms this, as the tensile strength consistently decreases with increasing rice husk content across all composite types. This aligns with findings by Thimmegowda *et al.* (2025), who observed that excessive natural fibre content in polymer composites leads to diminished mechanical properties due to fibre clustering and inadequate wetting by the polymer matrix. The data reveals that unused PE composites consistently exhibit higher tensile strength than used PE composites, regardless of rice husk content. This is because virgin (unused) polyethylene has intact polymer chains and has better mechanical qualities than recycled (used) PE where chain scission and degradation may occur during prior use (Din, 2023).

Interestingly, the alkali-treated rice husk mixed with used PE exhibits better tensile strength than used PE alone. This enhancement can be attributed to the NaOH treatment, which removes lignin, hemicellulose, and other surface impurities, leading to better interfacial bonding between the hydrophilic rice husk fibres and the hydrophobic polyethylene matrix. Several studies confirm that Alkali treatment increases the mechanical characteristics of the composite by improving fiber-matrix adhesion. (Bachtiar *et al.,* 2025).

This finding has significant implications for sustainable material design, especially in the context of reducing environmental impact by reusing waste polyethylene and agricultural by-products like rice husk. While unused PE remains the strongest in pure form, the treated rice husk composite offers a viable compromise between sustainability and mechanical performance, especially for non-load-bearing or semi-structural applications.

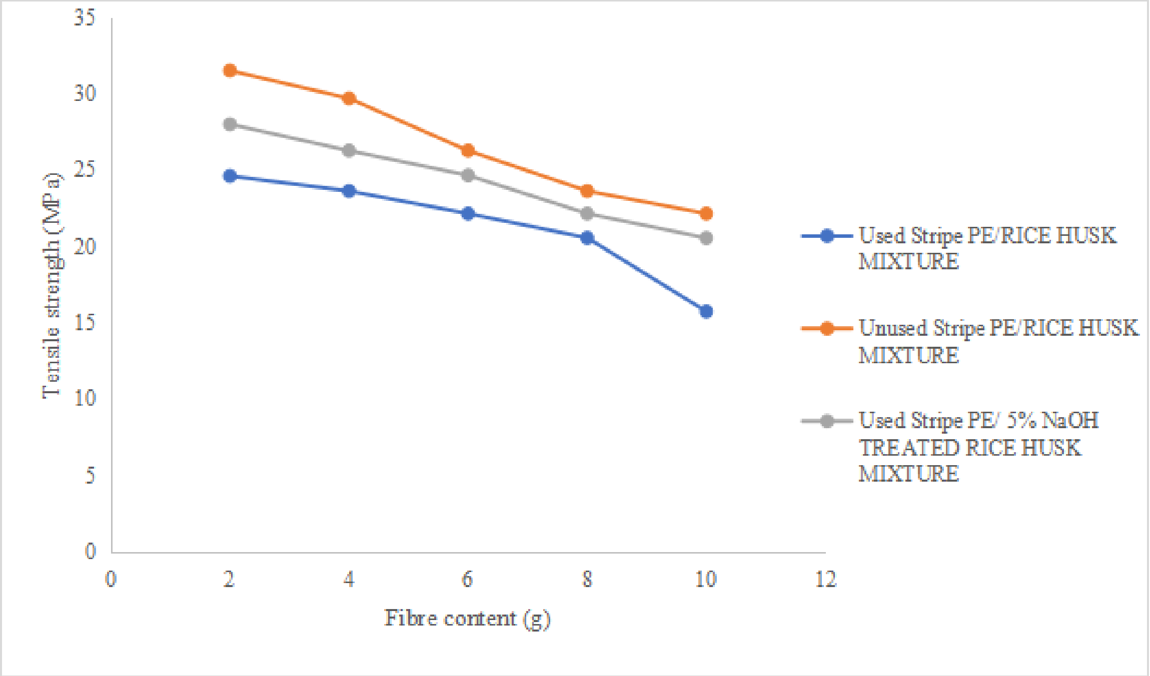

Figure 13: Effect of increasing rice husk fibre content on Tensile strength of treated and untreated rice husk mixture fibre with used and unused Stripe polyethylene film composites at polyethylene, temperature and time

Impact strength of used and unused stripe polyethylene film / treated and untreated rice husk mixture composites at constant rice husk

Figure 14 shows the effect of increasing polyethylene on the impact strength of a composite material at constant rice husk content. The impact strength values range from 0.95 to 1.14KJ/m^2, indicating variations influenced by material composition and treatment. The data suggests that increasing polyethylene content, while keeping rice husk content constant, leads to a gradual improvement in impact strength. For instance, in the Used PE/untreated RHM fiber composite, the impact strength increases from 0.95KJ/m^2 to 1.1 KJ/m^2. Similarly, the Unused PE/untreated RHM fibre composite category shows an increase from 1.03KJ/m^2 to 1.14KJ/m^2. This trend aligns with findings by Zhou et al. (2020), who reported that higher polyethylene content enhances the ductility and energy absorption capacity of composites, thereby improving impact resistance. The polyethylene matrix acts as a binder, distributing stress more evenly and reducing crack propagation (Zhang et al., 2022).

The Unused PE/untreated RHM fiber composite samples consistently exhibit higher impact strength (1.03–1.14 KJ/m^2) compared to the Used PE/untreated RHM fibre composite samples (0.95–1.1 KJ/m^2). This difference may be attributed to the degradation of used polyethylene, which can lead to reduced molecular weight and weaker interfacial adhesion with the rice husk filler (Morales *et al.*, 2021). Unused polyethylene retains its structural integrity, providing better reinforcement.

The 5% NaOH-treated rice husk/used PE composite samples show intermediate impact strength values (0.99–1.12KJ/m^2) compared to the untreated samples. NaOH treatment removes lignin and hemicellulose from rice husk, improving its compatibility with the polyethylene matrix (Hwang *et al.,* 2023). However, the impact strength does not surpass that of the unused PE composites, suggesting that while chemical treatment enhances filler-matrix interaction, the quality of the polyethylene remains a dominant factor.

The study demonstrates that increasing polyethylene content enhances the impact strength of PE/RHMF composites, with unused polyethylene yielding superior results due to its undegraded structure. NaOH treatment of rice husk improves filler-matrix adhesion but does not compensate for the inferior properties of used polyethylene. These findings are consistent with recent research emphasizing the importance of matrix quality and filler treatment in composite performance (Hwang *et al.*, 2018)

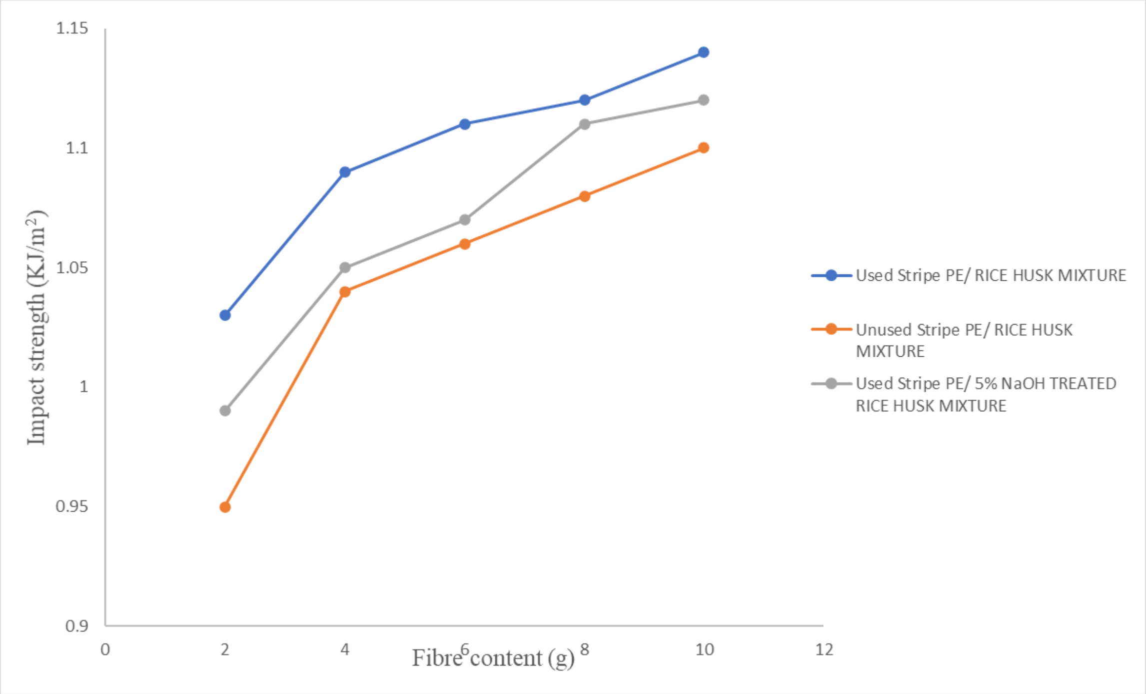

Figure 14: Effect of increasing Polyethylene content on Impact strength of treated and untreated rice husk mixture fibre with used and unused Stripe polyethylene film composites at constant rice husk, temperature and time

Impact strength of treated and untreated rice husk mixture /used and unused stripe polyethylene film composites at constant Polyethylene

Figure 15 shows the effect of increasing rice husk fiber content on Impact strength of treated and untreated rice husk mixture fibre with used and unused Stripe polyethylene film composites at constant Polyethylene. The provided data reveals a clear trend: as RHF content increases, impact strength declines across all sample categories—used PE/untreated RHMF composite, unused PE/untreated RHMF composite, and 5% NaOH-treated RHMF/used PE composite.

The data shows a consistent reduction in impact strength as RHMF composite content increases. For instance, in the Used PE/untreated RHMF composite, the impact strength drops from 0.95 KJ/m^2 to 0.55KJ/m^2. Similarly, the Unused PE/untreated RHMF composite samples exhibit a decline from 1.03 MPa to 0.64KJ/m^2, while the 5% NaOH-treated RHMF/used PE composite samples decrease from 0.99 KJ/m^2 to 0.57KJ/m^2. This trend aligns with findings by Mulenga *et al.* (2025), who reported that excessive natural fiber loading in thermoplastic composites introduces stress concentration points, leading to reduced impact resistance. The brittle nature of RHMF, combined with poor interfacial adhesion, exacerbates this effect. which negatively impacts the mechanical performance of composites. Poor interfacial adhesion between rice husk fibers and polymer matrices exacerbates this issue by creating weak bonding sites that reduce load transfer efficiency and promote defects. (Bisht *et al.*, 2020).

The untreated RHMF composites exhibit lower impact strength compared to the NaOH-treated samples, though the difference narrows at higher fiber loadings. NaOH treatment removes lignin and hemicellulose, improving fiber-matrix adhesion (Bisht and Gope, 2020). However, even with treatment, the impact strength remains lower than that of pure PE, suggesting that fiber loading is the dominant factor. The untreated RHMF composites suffer from weak interfacial bonding, leading to micro voids and crack propagation under impact (Gupta *et al.,* 2025).

Research indicates that natural fiber composites often exhibit a threshold beyond which mechanical properties deteriorate. For RHMF/PE composites, this threshold appears to be around 10–20 wt% (Dev *et al.,* 2023). Beyond this point, fibre agglomeration and poor dispersion dominate, further reducing impact strength. The data supports this, showing a steep decline in impact strength as RHMF content increases, particularly in the untreated samples. The Unused PE/untreated RHMF composite samples consistently outperform the Used PE/untreated RHMF composite samples, likely due to the degradation of used PE, which compromises its ability to bond with RHF. This degradation reduces the matrix's ductility and energy absorption capacity (Patel *et al.*, 2024). The NaOH-treated RHMF composites, despite using used PE, show intermediate performance, highlighting the importance of fiber treatment in mitigating matrix deficiencies.

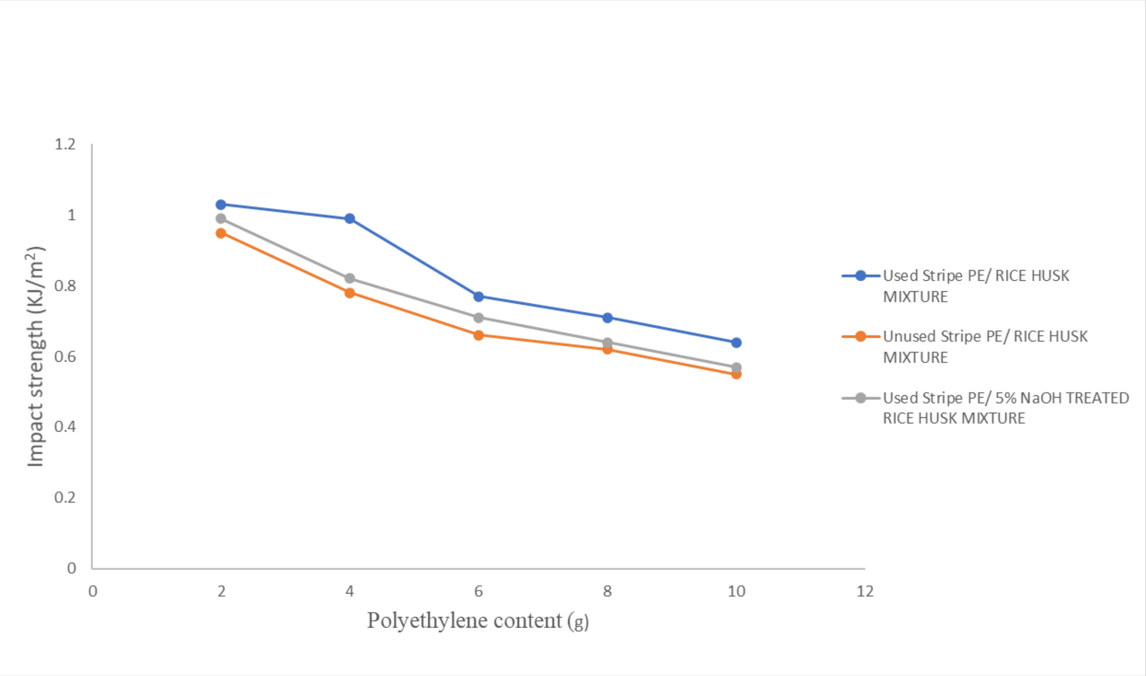

Figure 15 Effect of increasing rice husk fiber content on Impact strength of treated and untreated rice husk mixture fiber with used and unused Stripe polyethylene film composites at constant Polyethylene, temperature and time

CONCLUSION

The study emphasizes how polymer condition and fiber treatment have a significant impact on the structural and functional performance of stripe polyethylene film/rice husk fiber composites. When compared to recycled polyethylene, which has flaws brought on by deterioration, virgin polyethylene continuously showed better resistance to water absorption, reduced flammability, higher density, hardness, and tensile strength. Rice husk fibers treated with NaOH had better mechanical qualities, decreased porosity, and increased fiber–matrix adhesion; however, these advantages were lessened in deteriorated films with high polyethylene content. While NaOH-treated rice husk provided a sustainable alternative for recycled polyethylene composites, unused polyethylene composites generally had the best mechanical and moisture-resistant performance. These results validate that agricultural waste can be used as an efficient filler to enhance mechanical strength and fire safety in polymer composites, thereby promoting the development of environmentally friendly materials. Compatibilizers and hybrid reinforcements should be the main focus of future studies in order to improve recycled polyethylene composites for use in industrial settings.

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