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Development of EVA Foam Using Corn Pith as a Sustainable Filler

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Abstract

This research explores the development of EVA (ethylene-vinyl acetate) foam incorporating corn pith as a filler material. EVA, a widely used thermoplastic elastomer derived from non-renewable petrochemical resources, raises environmental concerns due to its limited biodegradability. Corn pith, a lightweight and porous agricultural by-product, serves as a potential sustainable filler. This study investigates the effects of varying corn pith filler concentrations (10%, 20%, and 30%) on the mechanical and physical properties of EVA foam. The foam formulation involved mixing EVA, corn pith, and a physical blowing agent in a twin-screw extruder to ensure uniform material dispersion. The resulting compound was processed using compression molding, where heat and pressure facilitated expansion. Experimental results show that incorporating corn pith reduces EVA usage while enhancing foam flexibility and lightweight properties, as evidenced by decreased hardness and density compared to conventional EVA foam. Additionally, corn pith improves compression strength and expansion ratio, making the foam suitable for cushioning and lightweight applications. A filler percentage of 10% to 20% optimizes foaming properties while promoting material sustainability. This study demonstrates that corn pith is a viable filler, reducing reliance on synthetic polymers and promoting the use of agricultural waste in foam production.

Keywords

Ethylene-Vinyl Acetate, Corn Pith Filler, Compression Molding, Biodegradability, Sustainability

1. Introduction

The increasing environmental concerns linked to synthetic polymer-based foams have accelerated the search for more sustainable alternatives. Ethylene-vinyl acetate (EVA) foam, though widely used due to its desirable mechanical, thermal, and structural properties, is primarily derived from non-renewable petrochemical resources and involves energy-intensive production processes. To address these sustainability challenges, the incorporation of agricultural residues as natural fillers offers a promising solution by reducing the dependency on synthetic polymers and minimizing environmental impact. In this context, this study explores the use of chemically treated corn pith, a renewable agricultural by-product, as a sustainable filler in EVA foam. The aim is to reduce overall polymer content, lower production energy requirements, and enhance material sustainability, all while maintaining or improving the essential properties of the foam.

The incorporation of natural fibers and fillers into polymer matrices has been widely studied, with a focus on enhancing composite properties and addressing sustainability challenges. Ho *et al.* identified critical factors such as fiber-matrix interaction, chemical treatments, and manufacturing methods as essential for improving composite durability and mechanical performance. These principles are particularly relevant to overcoming issues like poor wettability and fiber/matrix interface degradation when incorporating corn pith into EVA foams [1]. Similarly, Bergeret and Benezet demonstrated that natural fibers such as hemp and coconut improve the mechanical strength, density, and water absorption of bio-foams when appropriately treated. These findings highlight the potential of corn pith as a filler in EVA foams, especially when combined with tailored processing and chemical treatments [2]. Corn stalks, a common agricultural residue, provide a sustainable source of fibers and fillers. Youngquist *et al.* saw that corn stalks, along with their soft inner part and tough outer layer, can be used to make composite materials [3], while Zhang *et al.* explained that the tough outer layer of maize stalks is strong and stiff, making it good for strengthening plastics [4]. Ekhuemelo further characterized corn stalk fibers, noting the unique properties of the pith and rind that make them valuable for industrial applications. Corn pith has also been explored in other elastomer applications [5]. Meng *et al.* highlighted its microporous structure and cushioning properties in a bio-based elastomer [6], while Zimmermann *et al.* Guo *et al.* and Jeremia *et al.* demonstrated the versatility of agricultural by-products in enhancing the functionality of EVA composites [7]-[9]. Chemical treatments are crucial to enhance compatibility between natural fillers and polymer matrices. Rosdi and Ahad demonstrated that treated corn stalk fibers exhibit improved surface morphology, reduced water absorption, and better hydrophobicity, addressing common challenges in natural fiber composites. Particulate fillers such as corn pith can significantly influence foam morphology and properties [10]. Kuan *et al.* reviewed the impact of particle size, volume fraction, and chemical treatments on polymer composites, emphasizing the need for optimization [11]. Rodrigue *et al.* studied natural fillers like wood flour and demonstrated their ability to improve foam homogeneity and cellular structure, insights that inform the development of corn pith-based EVA foams [12]. However, Anam khan *et al.* highlighted that these fibers have high moisture absorption and low thermal stability, which can weaken composite materials [13]. The effects of blowing agents and processing methods have also been explored extensively in foam manufacturing. Rodriguez-Perez *et al.* and Ries *et al.* emphasized the importance of optimizing blowing agent content and processing parameters to achieve desirable expansion ratios and foam structures [14] [15]. Sikora *et al.* highlighted the role of twin-screw extrusion in ensuring consistent foam quality [16], while Allen *et al.* provided a framework for predicting EVA expansion characteristics during molding processes [17]. These findings guide the manufacturing process for corn pith-based EVA foams. Sustainability is a key driver for integrating agricultural by-products into polymers. Bianchi *et al.* and Sai Aditya Pradeep [18] [19]. Evaluated the mechanical properties of recycled EVA and demonstrated its environmental and cost benefits, supporting the use of natural fillers like corn pith. Jianxin *et al.* showed that agricultural by-products such as hemp stem powder can reduce foam density and hardness while improving functionality, a parallel that highlights the potential of corn pith [20]. Furthermore, Liu *et al.* and Xiaoye Li *et al.* examined the mechanical properties of EVA foams under varying impact conditions, findings that align with the performance goals for corn pith-filled EVA foams [21] [22]. Research into the use of agricultural residues for polymer composites has further established corn pith's potential. Rodriguez-Perez *et al.* demonstrated the feasibility of EVA blends with natural fillers like cornstarch, showing improved density, compressive strength, and biodegradability [23]. Similarly, Petchwattana and Covavisaruch analyzed the impact of blowing agent particle size and concentration on foam properties, insights that guide the selection of processing parameters for corn pith-based EVA foams [24].

The reviewed literature highlights the feasibility and advantages of using natural fillers like hemp stem powder, wood flour, and coconut powder in polymer composites. By leveraging their lightweight, reinforcing properties and blending them with EVA, sustainable and high-performance foams can be produced. Blowing agents further enhance the structure and properties of these foams, making them suitable for diverse applications, including automotive, packaging, and thermal insulation. This study aims to evaluate how the incorporation of corn pith filler at varying concentrations (10%, 20%, and 30%) affects the hardness, density, compression strength, expansion ratio, and biodegradability of corn pith–EVA-based foams compared to conventional EVA foam, contributing to the development of eco-friendly materials that reduce reliance on non-renewable resources and promote the utilization of agricultural waste.

2. Materials and Methods

2.1. Materials

In this study, corn pith was used as a filler material. It was sourced from a local farmer in Rammanagudem, India. As shown in **Figure 1**, Corn pith is a soft, spongy material that is found in the stalk of corn. It possesses a foamy characteristic and is elastic. It has a porous structure, is light in weight, and exhibits good compression strength and insulating properties [3] [6]. The density of corn pith ranges from 0.04 to 0.08 g/cm^3, and its thermal degradation temperature is approximately 220˚C - 250˚C [4]. These properties render it a suitable filler material for EVA foam.

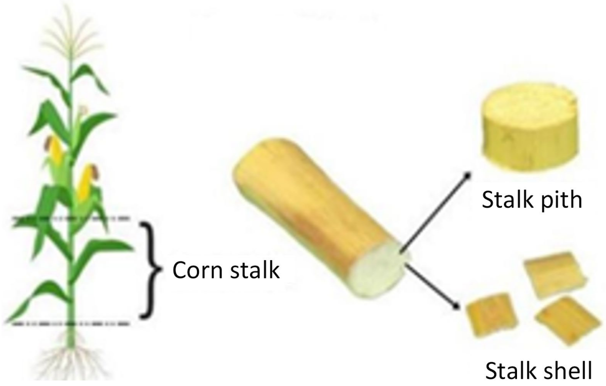


Figure 1. Corn plant with stalk and pith.

Ethylene Vinyl Acetate (EVA 28%) is a copolymer composed of 28% vinyl acetate. It is a thermoplastic elastomer widely used in foaming applications [20]. EVA 28% has a melting point of 75˚C and a melt flow rate of 5 - 6 g/10 min. Its Vicat softening temperature is at 46˚C, which allows it to be easily processed into foam. Corn pith filler can be added to EVA as it does not thermally degrade within the processing temperature range of EVA, making it a suitable bio-filler for enhanced material properties.

Expancel®930 MB is a physical blowing agent composed of thermoplastic microspheres that encapsulate a gas. Upon heating, the microspheres undergo expansion due to an increase in pressure from the gas within, resulting in a foaming effect. This expansion occurs without a chemical reaction, differentiating it from chemical blowing agents that release gases through decomposition. The primary rationale for employing this blowing agent is its ability to expand without undergoing a chemical reaction, thereby preserving the integrity of the filler material, corn pith, and avoiding thermal degradation. This expansion occurs within a temperature range of 150˚C to 180˚C, which is below the thermal degradation temperature of corn pith filler material.

2.2. Extraction of Fibers

Corn pith is located inside the corn stalk, as shown in **Figure 2**, surrounded by an outer skin and fibrous layers. To extract the pith, the outer skin of the corn stalk is removed to access the inner pith material. The pith is then separated from the stalk and cut into small pieces to facilitate further processing, as shown in **Figure 3**.

2.3. Alkali treatment

As shown in **Figure 4**, the extracted corn pith pieces underwent alkali treatment

Figure 2. Corn stalk.

Figure 3. Corn pith.

to enhance their properties and improve compatibility with polymer matrices, improve mechanical properties (increased fiber strength), enhance interfacial adhesion with polymer matrices, and remove impurities such as lignin and hemicellulose from the fiber surface to enhance interfacial adhesion [25]. The corn pith pieces were immersed in a 4% potassium hydroxide (KOH) solution for 4 hours. After treatment, the fibers were thoroughly washed with distilled water to remove residual alkali solution and dried at room temperature for 5 days. Subsequently, as shown in Figure 5, the fibers were dried at 40˚C in an oven to remove moisture before further processing.

2.4. Grinding

Following the alkali treatment, the corn pith fibers were subjected to a grinding process to reduce them into fine powder. Size of 150 to 600 microns. As shown in Figure 6.

2.5. Design of Experiments

Six formulations were prepared by varying EVA, blowing agent (BA), and corn pith filler (FILL) to optimize the foaming properties of EVA-based composites. The formulations are summarized in Table 1.

Figure 4. Alkali treatment.

Figure 5. Treated corn pith.

Figure 6. Corn pith powder.

Table 1. Design of experiments.

Samples	EVA (%)	BA (%)	FILL (%)
S1	95	5	-
S2	92.5	7.5	-
S3	90	10	-
S4	80	10	10
S5	70	10	20
S6	60	10	30

The first three samples (S1 - S3) were prepared with varying BA concentrations to determine the optimal foaming conditions. S3 (90% EVA, 10% BA) exhibited superior foaming properties in terms of hardness, density, and expansion ratio. Based on these results, the next three samples (S4 - S6) were formulated by keeping BA constant at 10% while progressively increasing corn pith filler content (10% - 30%) and adjusting EVA accordingly. This approach helped evaluate the effect of filler on foam characteristics, providing insights into the most suitable composition for enhanced material performance.

2.6. Compounding

The material was prepared using compositions from the experiments' design. All three materials EVA, blowing agent, and corn pith filler were mixed in a Kneader (**Figure 7**) for a blending time of 5 minutes to ensure uniform dispersion of the components [14]. The temperature was maintained between 90˚C and 100°C during the mixing process. After thorough mixing, the resulting compound material (**Figure 8**) was fed into a granulator to convert the mixture into fine granules, as shown in **Figure 9**. This step ensures that the materials are evenly distributed, making the compression molding process smoother and more efficient.

Figure 7. Kneder.

Figure 8. Compounded material.

Figure 9. Granules.

2.7. Compression Molding

Once the granules were prepared, they were placed in a hot press as shown in **Figure 10**. The compression molding process involved applying a temperature of 180˚C and a pressure of 5 bar for 2 minutes to ensure proper melting and uniform distribution of the material in the mold. During this time, the granules melted and filled the entire mold cavity. Once the pressure was released, the blowing agent caused the material to expand, forming the foam structure. The foam was allowed to cool and solidify before being carefully removed from the mold, resulting in the final expanded foam product as shown in **Figure 11**. And the size of the mold is 100 mm × 100 mm × 4 mm (**Figure 12**).

Figure 10. Compression molding.

Figure 11. Corn pith foam.

Figure 12. Mold.

2.8. Test Equipment and Test Parameters

2.8.1. Tensile Test

Tensile tests were conducted to evaluate the behavior of materials under tension. The tests were performed according to the DIN EN ISO 527 standard [26], using a Zwick

Roell universal testing machine, as shown in Figure 13. The crosshead speed was set to 5 mm/min. Young's modulus was determined within the strain range of 0.05% to 0.25%. Five specimens of each composite material were tested, and the average values were recorded. During the course experiment, the specimen's force and displacement were meticulously monitored to facilitate the construction of comprehensive stress-strain curves. As shown in Figure 14, the specimens, cut from the panel to standard dimensions, were precisely measured to be 10 mm × 8 mm × 100 mm.

Figure 13. Tensile test equipment.

Figure 14. Tensile test specimens.

2.8.2. Compression Test

Compression tests were conducted to evaluate the behavior of foam materials under compressive loads. The tests were performed by the DIN EN ISO 604 standard, using a Zwick Roell universal testing machine. A constant crosshead speed of 5 mm/s was applied, and a maximum load of 80 N was used during the test. Compressive strength was determined at 25% deformation of the specimen. Five specimens of each foam material were tested, and the average values were recorded. Throughout the experiment, the force and displacement of the specimens were carefully monitored to construct detailed stress-strain curves. The dimensions of the tested specimens were precisely measured to be 5 mm × 5 mm × 8 mm, ensuring accurate evaluation of the foam's ability to withstand compressive forces and maintain structural integrity under compression.

2.8.3. Hardness

The Shore hardness test was conducted on the foam by ASTM D2240 and ISO 48-4 standards, which define the method for determining the indentation hardness of rubber, elastomers, and plastics. The test measures the foam's resistance to indentation, indicating its firmness and surface hardness. A durometer from the company Zwick was used, as shown in **Figure 15**. The Shore A scale, commonly used for flexible materials such as foams, elastomers, and rubbers, was applied with a 1 kg load on specimens ≤6 mm thick. Hardness measurements were taken at multiple areas on the foam.

Figure 15. Hardness test.

2.8.4. Density

Density is a key property of foam, with an ideal foam being lightweight and having low density. The Archimedean immersion method, the most common technique for density calculation, was used in this test [27]. Conducted with the KERN AES A01 test device (KERN & Sohn GmbH, Balingen, Germany), the method determines density by measuring the weight loss of an object when suspended in a fluid of known density, allowing the calculation of its volume and density.

2.8.5 Water Absorption Test

The water absorption test was conducted to measure the amount of water absorbed by the foam under specified conditions, following the ASTM D570-98 standard [28]. The percentage of water absorption was calculated using the equation 1

$$\text{Water absorption}\left[\%\right]=\frac{w_2-w_1}{w_1}\times 100 \qquad \text{Equation. 1}$$

where W_2 is the weight of the wet sample and W_1 is the weight of the dry sample. Test specimens were first dried in an oven at 90˚C for 24 hours, then cooled and weighed using a digital balance. Each specimen was submerged in a salt and distilled water solution at 25˚C for 24 hours, as shown in **Figure 16**. then retrieved, wiped with a tissue, and immediately reweighed to record any weight gain. This process was repeated for 240 hours for all compositions of EVA and corn pith foams.

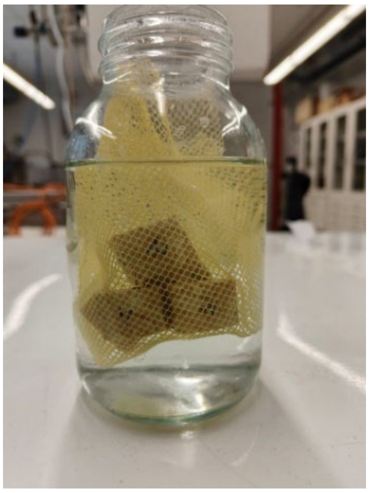


Figure 16. Water Absorption test.

3. Results and Discussion

3.1. Tensile Strength

The tensile strength of EVA foam decreases with the addition of a blowing agent and corn pith filler. As shown in **Figure 17**, the highest tensile strength was observed in sample 3 (1.8 MPa), which contains no filler, indicating that the EVA foam with 10% blowing agent has strong tensile properties in its baseline composition. Upon adding 10% corn pith filler (sample 4), the tensile strength dropped significantly to 0.391 MPa, a decrease of approximately 78% compared to sample 3. This suggests that the introduction of corn pith filler disrupts the EVA matrix, reducing its ability to withstand tensile forces. As the filler content increased to 20% (Sample 5) and 30% (sample 6), the tensile strength slightly improved to 0.414 MPa and 0.454 MPa, respectively. This represents a modest increase of 5.9% from sample 4 to Sample 5 and 9.7% from Sample 5 to Sample 6. This may be due not only to better bonding between the filler and matrix, but also to the fibrous nature of the filler, which can help reinforce the foam and reduce damage at higher amounts.

The gradual increase with higher filler content may indicate improved filler-matrix interaction or better distribution of the filler at higher percentages, though the tensile strength remains significantly lower than the filler-free sample. However, the foam remains much weaker than pure EVA, making it more suitable for lightweight and cushioning applications rather than high strength uses.

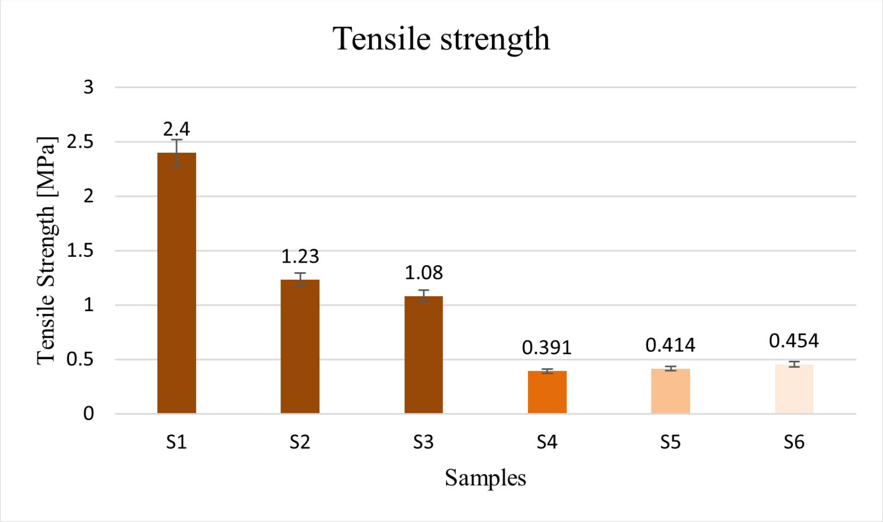


Figure 17. Tensile strength.

3.2. Young's Modulus

The Young's modulus of EVA foam increases with higher blowing agent and filler content. **Figure 18** shows that sample 3 (no filler) had a young's modulus of 6.88 MPa, indicating moderate stiffness. With the addition of 10% filler, sample 4, the young's modulus decreased to 4.54 MPa, a reduction of 34%. This suggests that the initial addition of corn pith filler makes the foam less stiff, likely due to the filler's softer, porous nature. However, as the filler content increased to 20% (sample 5) and 30% (sample 6), the young's modulus increased significantly to 11.5 MPa and 14.7 MPa, respectively. This represents a 153% increase from sample 4 to sample 5 and a 27.8% increase from sample 5 to sample 6. The trend indicates that higher filler content enhances the stiffness of the foam, likely due to the reinforcing effect of the corn pith filler, which has a hollow, fibrous structure that contributes to increased rigidity at higher concentrations.

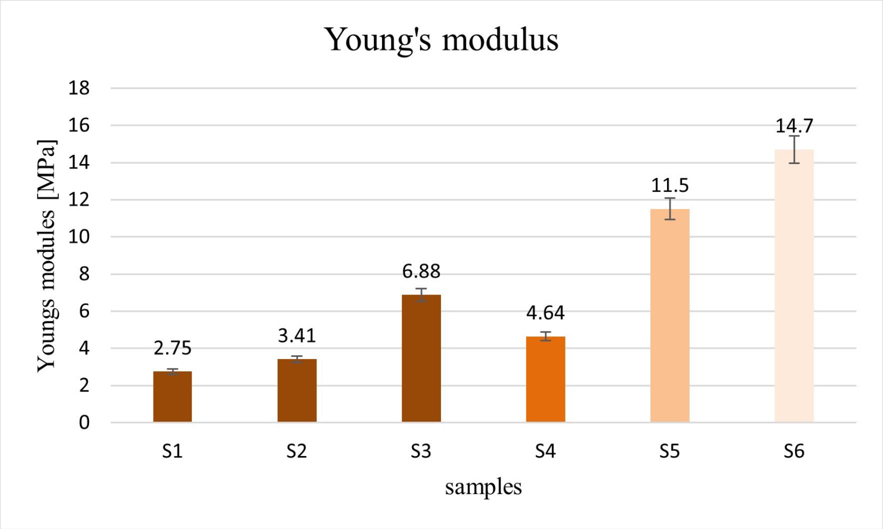


Figure 18. Young's modulus.

3.3. Compression Strength

The compression strength of the foam decreases with an increase in the blowing agent but improves with a higher filler content. As seen in **Figure 19**, among the filler-free samples, sample 1 (5% BA) had the highest compression strength at 38.4 MPa. As the blowing agent content increased to 7.5% (sample 2) and 10% (sample 3), the compression strength decreased to 21.1 MPa and 17.7 MPa, respectively, representing a 45% drop from sample 1 to sample 2 and a 16.1% drop from Sample 2 to sample 3. this indicates that increasing the blowing agent reduces the foam's ability to withstand compressive loads, likely due to the increased formation of bubbles and voids. With the addition of 10% filler (Sample 4), the compression strength remained the same as sample 3 at 17.7 MPa, showing no immediate change with the initial filler addition. at 20% filler (sample 5), the compression strength increased significantly to 33.8 MPa, a 90.4% improvement over sample 4. This suggests that 20% filler content provides an optimal reinforcement effect, enhancing the foam's ability to resist compressive forces. However, at 30% filler (sample 6), the compression strength decreased to 25.93 MPa, a 23.3% reduction from sample 5. This indicates that beyond 20% filler, the foam's compressive properties decline, possibly due to excessive filler disrupting the foam structure and reducing its uniformity.

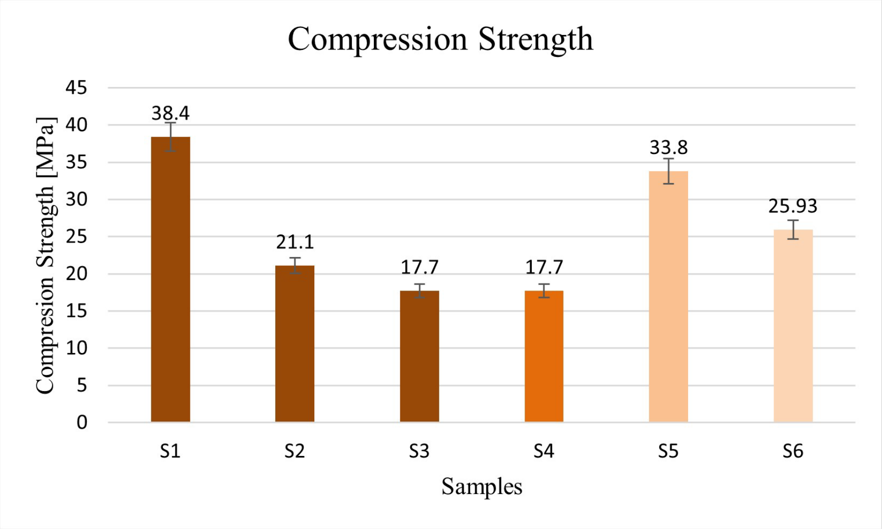


Figure 19. Compression strength.

3.4. Hardness

The hardness of foam is influenced by both the blowing agent and filler content. as **Figure 20** shows, sample 3 (no filler) had the highest hardness at 45.62, indicating a relatively firm foam. With the addition of 10% filler (sample 4), the hardness decreased to 39.75, a 12.9% reduction compared to sample 3. This suggests that the corn pith filler, with its softer and more porous structure, reduces the overall rigidity of the foam.

As the filler content increased to 20% (sample 5), the hardness increased to 43,

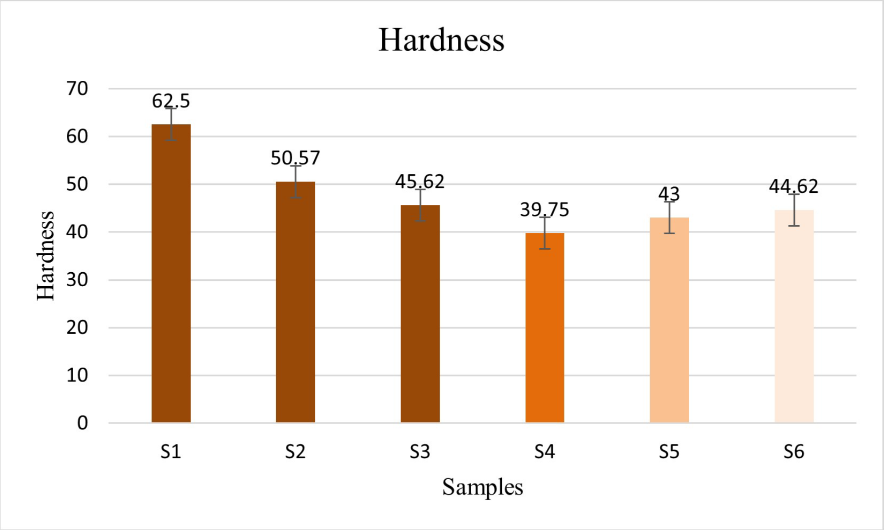


Figure 20. Hardness.

an 8.2% improvement over sample 4. At 30% filler (Sample 6), the hardness further increased to 44.62, a 3.8% increase from sample 5, approaching the hardness of sample 3 (only 2.2% lower). This trend indicates that while the initial addition of filler softens the foam, higher filler content begins to restore hardness, possibly due to the increased stiffness contributed by the filler at higher concentrations.

3.5. Density

The density of foam is influenced by the blowing agent and filler content. As shown in **Figure 21**, Sample 3 (no filler) had the highest density at 0.348 g/cm^3, reflecting the denser structure of the EVA foam with 10% blowing agent. With the addition of 10% filler (Sample 4), the density decreased significantly to 0.2511 g/cm^3, a 27.8% reduction compared to sample 3. This indicates that the porous, lightweight nature of corn pith filler reduces the overall density of the foam, making

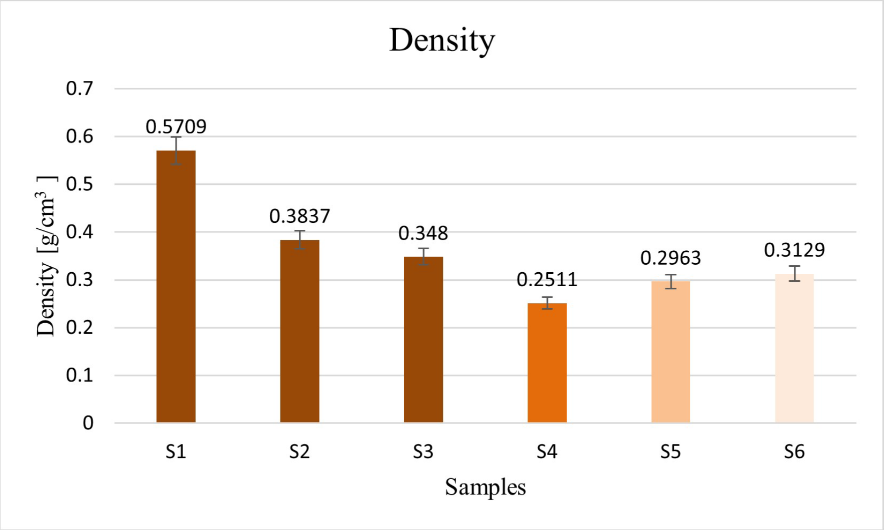


Figure 21. Density.

it more suitable for applications requiring low-density materials.

As the filler content increased to 20% (sample 5), the density increased to 0.2963 g/cm³, an 18% increase from sample 4 at 30% filler (sample 6), the density further increased to 0.3129 g/cm³, a 5.6% increase from sample 5, though still 10.1% lower than sample 3. this trend suggests that while the initial addition of filler reduces density, higher filler content adds more mass to the foam, counteracting the lightweight properties of corn pith to some extent.

3.6. Expansion Ratio

The expansion ratio is determined by comparing the foam thickness to the mold size. As shown in **Figure 22**, sample 3 (no filler) had an expansion ratio of 2.07, indicating moderate expansion due to the 10% blowing agent. With the addition of 10% filler (sample 4), the expansion ratio increased to 2.55, a 23.2% improvement over Sample 3. this suggests that the corn pith filler, with its larger size (180 – 550 μm) compared to the bubbles, enhances the foam's ability to expand by occupying space between the bubbles. as the filler content increased to 20% (sample 5), the expansion ratio decreased to 2.28, a 10.6% reduction from sample 4. at 30% filler (sample 6), the expansion ratio further decreased to 2.06, nearly returning to the level of sample 3 (a 9.6% decrease from sample 5). This trend indicates that while the initial addition of filler enhances expansion, higher filler content (beyond 10%) starts to hinder the expansion process, possibly due to the filler particles interfering with bubble formation and growth.

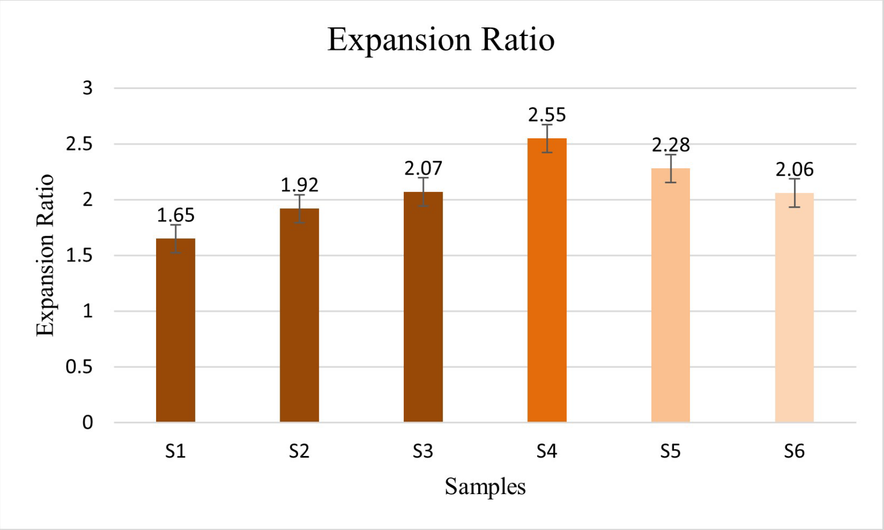


Figure 22. Expansion ratio.

3.7. Water Absorption

Water absorption was measured over 240 hours, with readings taken every 24 hours. as shown in **Figure 23**, the water absorption capacity increased with the addition of corn pith filler, with sample 6 (30% filler) showing the highest absorption at 9% after 240 hours, compared to sample 3 (no filler) at 2.5%. This represents a 260% increase in water absorption for sample 6 compared to sample 3. The trend across all samples shows a steady increase in water absorption over time, with the rate of absorption being higher for samples with more filler. This is attributed to the porous structure of corn pith (pore sizes of 2 - 6 microns), which allows greater water retention. The filler-free samples (s1 - s3) absorbed significantly less water, indicating that EVA foam without filler is more water-resistant. However, the increased hydrophilicity caused by the filler may reduce the material's suitability for use in humid or wet environments, where moisture resistance is important.

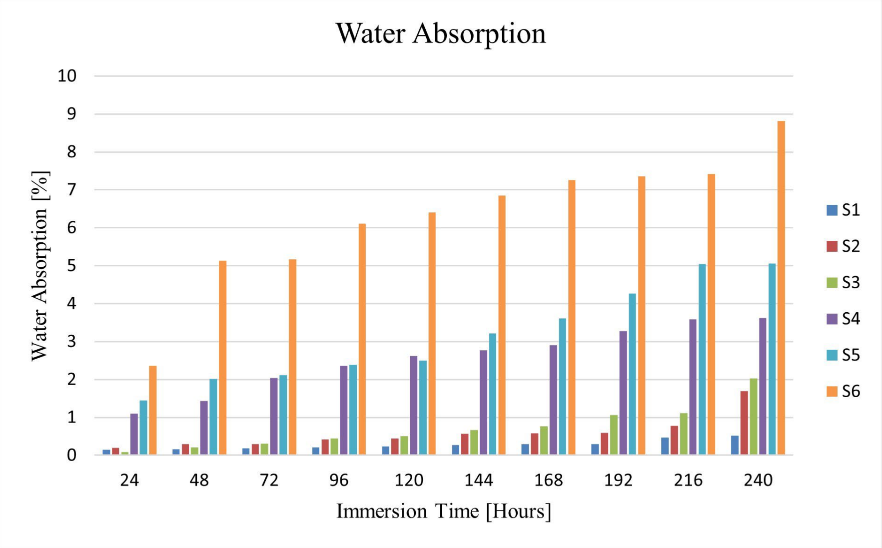
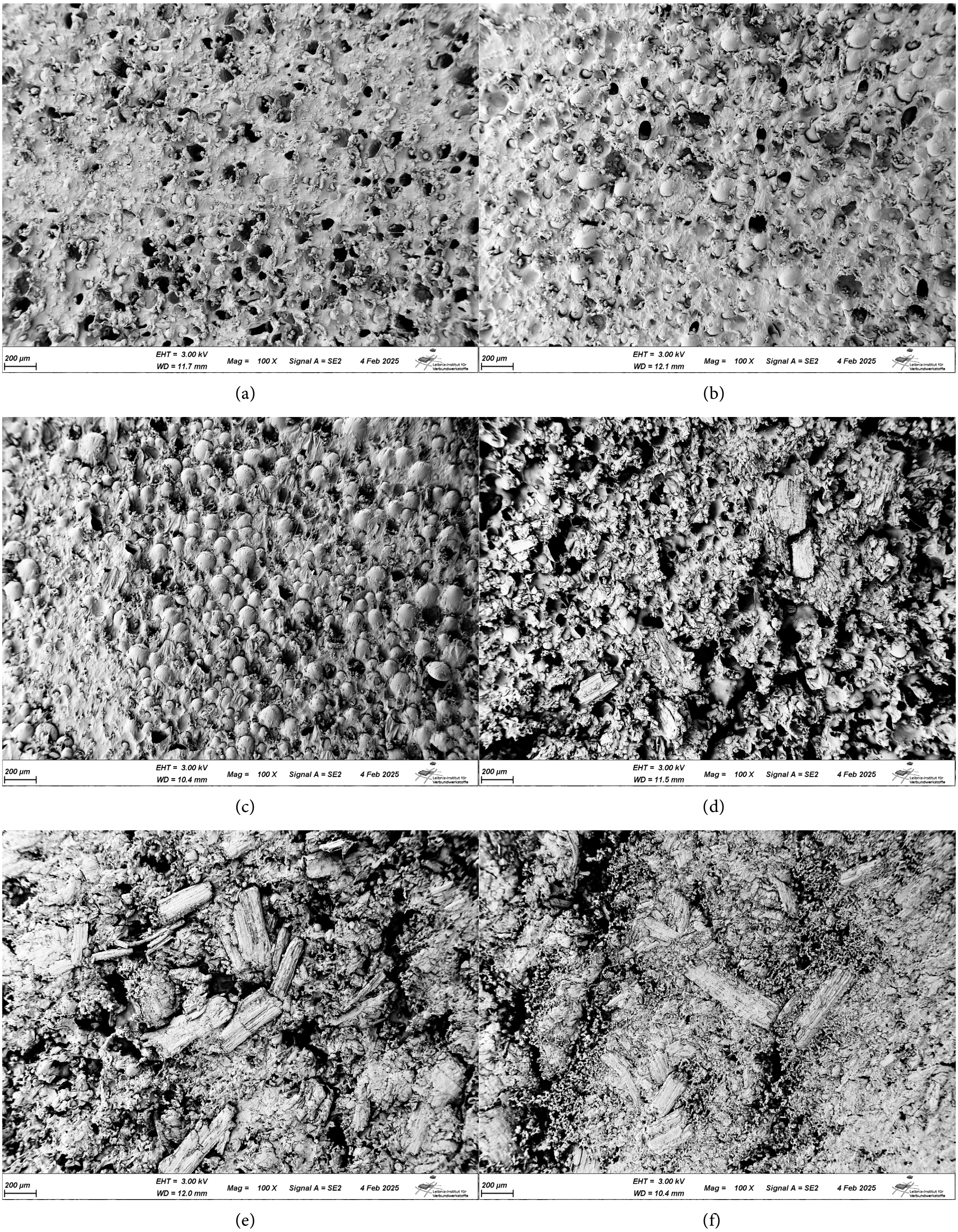


Figure 23. Water absorption.

3.8. Scanning Electron Microscopy (SEM)

Scanning electron microscopy was employed to investigate the of structural elements. To improve surface conductivity and imaging quality, all samples were sputter-coated with gold and palladium cellular morphology of corn pith EVA foam, focusing on voids, bubble formation, filler dispersion, interfacial bonding, and dimensional characteristics before analysis.

The above figures present representative SEM micrographs of selected samples. The unfilled EVA foam samples (samples 1 - 3) exhibited distinct microstructural features that influenced their mechanical and physical behavior. Sample 1 from **Figure 24** (a) revealed a structure dominated by voids (approximately 70%) and minimal bubble formation (10%), with void sizes ranging from 20 to 100 µm as seen in **Figure 25** (g). The high void content correlated with limited foam expansion and higher density, contributing to a firmer texture. Sample 2 as seen in **Figure 24** (b) exhibited a more balanced morphology, with roughly 50% voids and 50% bubbles. The void dimensions ranged from 40 to 110 µm, and the overall structure appeared more open and flexible compared to sample 1, yielding a softer and lighter foam. Sample 3, as seen in **Figure 24** (c) chosen as the baseline for filler addition, demonstrated a highly foamed architecture with 90% bubbles and only

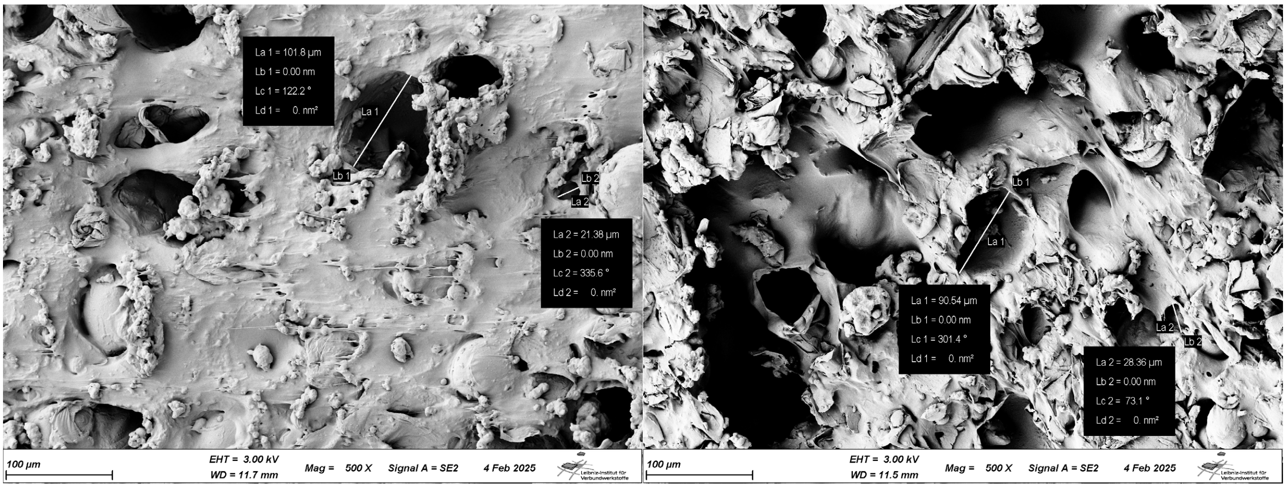


(a) (b)

(c) (d)

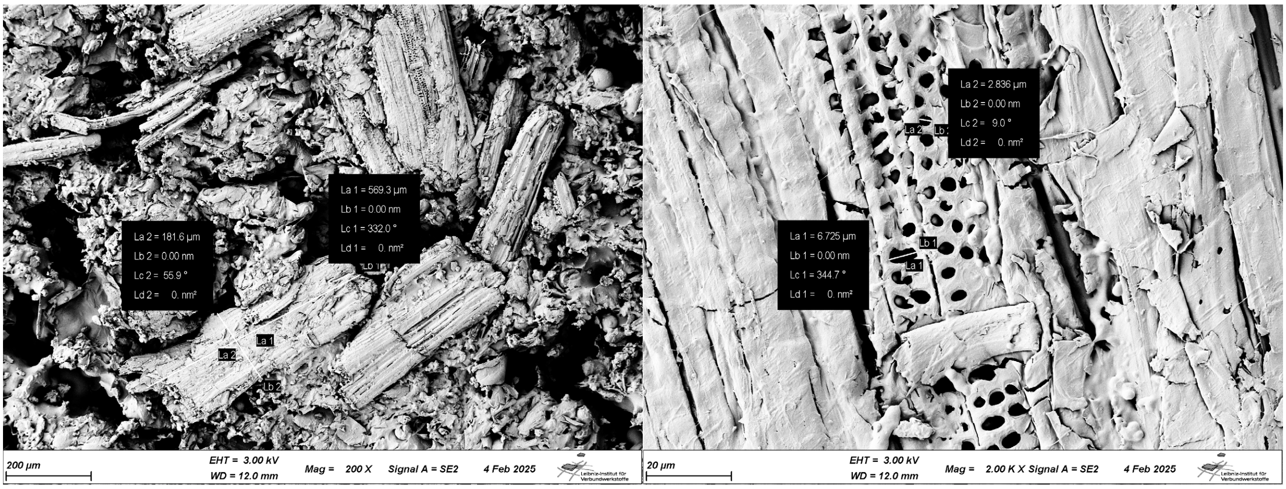
(e) (f)

Figure 24. SEM images at 100x magnification (a) S1-EVA/5% BA (b) S2-EVA/7.5% BA (c) S3-EVA/10% BA (d) S4-EVA/BA/10%FILL (e) S5-EVA/BA/20% FILL (f) S6-EVA/BA/30% FILL.



(g) (h)

Figure 25. SEM images at 500x magnification (g) S1-EVA/5% BA (h) S4-EVA/BA/10% FILL.



(i) (j)

Figure 26. SEM images (i) show filler size at 200x (j) pore sizes of corn pith fiber at 2000x.

10% voids, making it the softest and least dense among the three. This composition provided an optimal framework for subsequent filler incorporation.

Samples 4, 5, and 6 incorporated corn pith filler at 10%, 20%, and 30% loading, respectively. The filler particles, with sizes ranging from 180 to 550 µm, significantly altered the microstructure of the EVA foams. At 10% filler (Sample 4) as seen in Figure 24 (d), the SEM images revealed well-dispersed filler particles positioned between and along the foam cell walls. The presence of the filler at this concentration contributed to increased nucleation, forming relatively uniform, though slightly smaller, cells compared to the unfilled foam. With increasing filler content (Samples 5 and 6) as seen in Figure 24 (e and f), the micrographs showed a rise in filler agglomeration and an observable reduction in cell uniformity. The expansion ratio decreased as the filler volume increased, primarily due to the larger filler size and poor dispersion, which hindered cell growth and created localized regions of structural collapse. Filler particles were often found embedded within or penetrating cell walls, restricting expansion and leading to higher foam density and hardness.

Moreover, the moisture retention and extractives within the corn pith may have contributed to irregular cell shapes and occasional voids caused by pressure imbalances during gas release and condensation. This effect was more pronounced at higher filler concentrations, where the composite matrix became more viscous and less capable of uniform expansion. The use of a free-expansion pressure method further favored the formation of vertically elongated or elliptical cells, particularly in samples with poor filler dispersion. **Figure 26** (i) represents the filler size of 150 to 600 µm, while (j) represents the pore sizes of 2-6 µm. In corn pith, it states that corn pith is a hollow fiber.

4. Conclusions

In conclusion, the incorporation of corn pith filler into EVA/BA foam significantly influences its mechanical, physical, and water absorption properties. Corn pith is a sustainable and effective filler material for EVA foam, providing an environmentally friendly alternative in foam production. Research indicates that a filler content of 10% to 20% offers an optimal balance: 10% filler maximizes expansion ratio, while 20% filler provides the best compressive strength. Within this range, moderate filler levels promote nucleation and cellular integrity, as confirmed by SEM analysis. However, increasing filler content beyond 20% leads to diminishing returns, with decreases in density, hardness, and overall foam quality. Excessive filler (e.g., 30%) disrupts structural uniformity and expansion efficiency. Therefore, corn pith filler at 10% - 20% concentration offers a promising solution for sustainable EVA foam applications, provided its use is optimized to maintain performance and quality.

It is important to note that these findings are specific to the selected EVA grade and the compression molding process used in this study; results may vary with different polymers or manufacturing methods.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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