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Original Article

Effect of False Ceiling Materials: An Evaluation of Coconut Shell Powder Reinforced PLA with Various Fire Retardants

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Abstract *- It investigates using Coconut Shell Powder (CSP) composites reinforced with Polylactic Acid (PLA) as fire-resistant and environmentally friendly false ceiling materials. Out of these, PLA is a biodegradable thermoplastic, while CSP, which is made from agricultural waste, helps improve the material's mechanical strength and thermal stability. Using the TOPSIS approach, many composite formulations, both with and without fire retardants, have been compared against traditional ceiling materials based on a number of characteristics. Fire retardants containing CSP-PLA composites outperformed those containing ammonium polyphosphate and zinc borate, particularly those concentrating on mixed retardants (Ci=0.690) to maintain physical strength and effectiveness. The results showed that CSP-reinforced PLA with a combination of fire retardants was the top-performing option. It obtained the highest rank and a Closeness Coefficient (Ci) of 0.690. Further, making the intensity of CSP-PLA capacity to produce strong fire retardance thoroughly was the concentration of CSP-reinforced PLA with Ammonium polyphosphate (Ci=0.649) and CSP-reinforced PLA with Zinc Borate (Ci=0.587). Although CSP-PLA without retardants performed remarkably well in terms of cost and sustainability, fire retardants significantly improved overall performance, particularly in terms of fire safety. According to the results, CSP-PLA composites show promise as environmentally caring substitutes for interior building applications.*

Keywords *- Coconut Shell Powder (CSP), Fire Retardancy, False Ceiling, Polylactic Acid (PLA), TOPSIS Analysis.*

1. Introduction

The article examines that PLA-based green composites, reinforced with natural fibers, offer strong mechanical properties and eco-friendly benefits, constructing them sustainable alternatives to synthetic composites. However, experiments like high biopolymer costs and fiber-matrix compatibility need further research [1]. The article examines the natural fiber-reinforced PLA composites are fully bio-based materials with strong mechanical potential, but their presentation depends deeply on fiber properties like type, length, and adhesion to the matrix [2]. This study evaluates four common fillers for their fire-retardant effectiveness in biodegradable false ceiling materials. It concludes that fire retardancy can be assessed over metrics related to heat release rate, limiting oxygen index, and thermal gravimetric analysis, with fillers significantly enhancing thermal resistance [3]. The study highlights Coconut Shell Powder (CSP) as a low-cost, eco-friendly filler for biocomposites, helping reduce effluence and dependence on synthetic fibers. CSP composites demonstrate promising mechanical, thermal, and physical qualities, making them appropriate for sustainable and economical product applications. [4]. Coconut Shell Powder (CSP) is a promising natural filler for biodegradable composites due to its good thermal stability and cost-effectiveness. While CSP-reinforced composites are probably crosswise in several industries, further research is needed to enrich their properties and market viability through chemical changes and processing improvements [5]. This study shows that polyester composites reinforced with 10% Coconut Shell Powder (CSP) and Corn Husk Fiber (CHF) exhibit improved flexural strength and tensile modulus due to better interfacial bonding. While tensile strength initially decreases with added CHF, it improves at higher CHF contents (20–30%), making 10% CSP composites more efficient and economical than those with 5% CSP [6]. The study demonstrates the potential of biodegradable composites made from coconut shell powder and rice husk powder reinforced with vinyl ester matrices, showing promising tensile and flexural properties [7]. The study found that adding Coconut Shell Powder (CSP) as a filler in concrete improves splitting tensile strength but reduces compressive strength and workability due to high water absorption. The optimum CSP content was 2%, achieving a compressive strength of 33.1 MPa [8]. This article demonstrated that while untreated PLA/Coconut Shell (CS) biocomposites degraded faster in diastase enzyme solution, chemically treated biocomposites (via maleic acid and silanation) showed slower degradation due to improved interfacial adhesion. Despite reduced biodegradability, treated composites exhibited enhanced thermal stability and structural integrity over time. [9].This article discovered that adding Coconut Shell Powder (CSP) to PLA decreased tensile strength and elongation, boosting the composite modulus and thermal stability. 3-aminopropyltriethoxysilane (3-APE) treatment greatly increased mechanical and thermal properties because of the nucleating effects of CSP and better filler–matrix interaction [10]. This article focuses on Ammonium Polyphosphate (APP) and Aluminium Hydroxide (ALH), which effectively enhanced the thermal stability and fire resistance of flax fiber-reinforced polymer composites, with APP showing superior flame retardancy. Although both FRs reduced mechanical properties, ALH-treated composites retained better tensile strength and exhibited improved ductility, indicating potential for structural applications [11]. The study highlights novel macromolecular intumescent flame retardant (DT-M) and Phytic Acid-Intercalated Layered Double Hydroxides (PA-LDH) that were synthesized and incorporated into PLA, significantly enhancing its flame retardancy. The PLA composite with 14% DT-M and 1% PA–LDH achieved a UL-94 V-0 rating, a 38.9% LOI value, and a 63% reduction in peak heat release rate, demonstrating synergistic effects in both gas and condensed phases [12].

This review highlights recent advances in enhancing both flame retardancy and mechanical performance of Polylactic Acid (PLA) through diverse strategies, including surface-modified fibers, nanofillers, and macromolecular flame retardants. Integrating multifunctional additives and structural modifications has proven effective in addressing PLA's inherent flammability and brittleness, supporting its broader application in sustainable materials [13]. Ammonium Polyphosphate (APP) efficiently lowers flammability by up to 26% and improves char formation in bio-HDPE composites reinforced with pineapple leaf fiber. Flame retardancy, mechanical performance, and damping behaviour are all enhanced by an ideal APP content of 5%, which qualifies the composite for use in construction and automotive applications [14]. Increasing hydrophobicity, compatibility, and catalytic activity, functionalized Ammonium Polyphosphate (APP) flame retardants greatly improve the mechanical performance, fire safety, and smoke suppression of Epoxy Resin (EP) composites. Future studies must concentrate on industrial scalability and cost-effective processing for real-world applications with these developments [15].

Sawdust panels treated with magnesium hydroxide and zinc borate exhibit superior flame retardancy compared to coconut coir and rice husk panels, as evidenced by ASTM D365 and D3801 fire tests. These treated panels demonstrate the lowest burning rates, making them promising materials for enhancing fire safety in public-use products [16].

The present work examines the biodegradation behaviour of CSP/PLA bio-composites by adding fire retardants containing ammonium polyphosphate and zinc borate, especially those concentrating point to mixed fire retardants. Evaluations of the weight loss, chemical degradation, and thermal and morphological properties of the CSP/PLA composites after enzymatic degradation are also provided. The TOPSIS method is used to evaluate these materials based on several criteria, including fire retardancy, mechanical strength, cost-effectiveness, environmental impact, aesthetic appeal, ease of installation, availability of raw materials, and ease of recycling.

2. Methodology

TOPSIS is the Technique for Order of Preference by Similarity to the Ideal Solution. It is a multicriteria decision-making method. It senses the best supernumerary by result the shortest geometric distance from an ideal best solution and the longest distance from an ideal worst solution; considering numerous weighted criteria for calculation examined by Hwang and Yoon in 1981, TOPSIS deals with a structured decision-making method by ranking alternatives based on their closeness to an ideal solution and distance from a negative-ideal solution, enabling objective and effective multicriteria evaluation [17]. TOPSIS uses the geometric distance principle to find the alternatives that are closest to the ideal solution, which is the optimum option that maximizes the positive criteria and minimizes the negative ones, and the alternative that is furthermost from the negative ideal solution, which is the worst option possible in terms of all criteria. This dual goal guarantees that the selected option is the best one in terms of both benefits and downsides [18].

The TOPSIS method delivers a structured decision-making approach by calculating substitutes based on their distance from an ideal and a negative-ideal solution. It enables objective ranking through normalization, weighting, and separation metrics. [19-22]. Because of its simplicity of use, flexibility, and effectiveness in assessing various factors, TOPSIS is commonly used in industries such as supply chain management, healthcare, and environmental management. It is widely applicable due to its capability to achieve intricate decisions without necessitating criteria independence [23]. TOPSIS does have certain drawbacks, though. The approach makes the assumption that criteria weights are well-defined and known, which might continually match actual situations. Moreover, the reliability of the standings may be impacted if Euclidean distance is used as the separation measure because it may not always adequately reflect genuine dissimilarities [24]. TOPSIS approach, an effective multicriteria decision-making (MCDM) technique that rates alternatives according to their separation from ideal and anti-ideal solutions, is provided. It talks about TOPSIS's sensitivity to criteria weights, possible drawbacks, and its capacity to manage both qualitative and quantitative criteria.

Additionally, the publication provides detailed directions for putting the concept into practice. [25-26]. With an emphasis on TOPSIS and its popular variation, Modified TOPSIS, this article tackles the problem of choosing an effective MADM approach when several good ones are available. It contrasts the two approaches using in-depth simulations and mathematical analysis to elucidate their distinctions and provide guidance on how best to apply them to address MADM challenges [27]. The Best–Worst Method and TOPSIS are used in this work to present a hybrid Multicriteria Decision-Making (MCDM) approach for assessing stock performance in the Saudi Stock Market. Financial metrics, including ROE, ROA, net profit margin, and asset turnover, are used in the research to show how well the banking industry is performing. The suggested method facilitates well-informed investing choices and lays the groundwork for further stock market analysis study [28]. The five main steps that comprise the TOPSIS technique's process of selecting the best option are detailed below and shown in Figure 1.

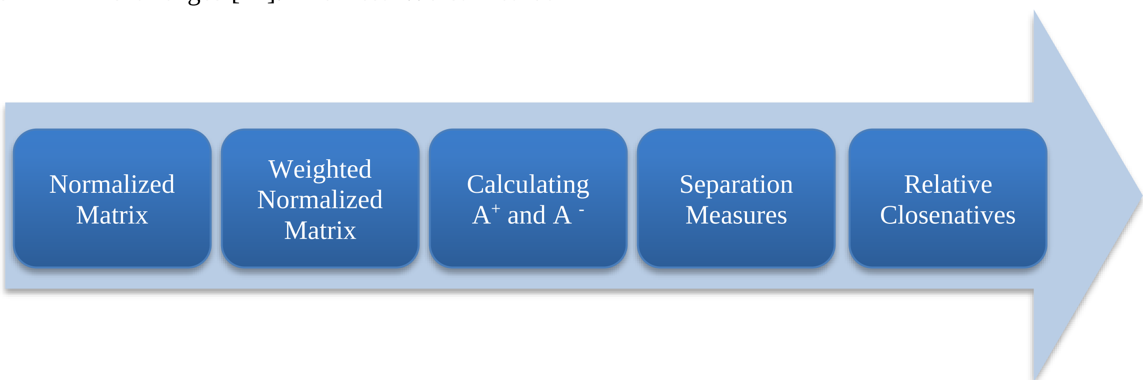

Fig. 2 TOPSIS technique's process

The special additives added have a major impact on how fire-resistant Coconut Shell Powder (CSP) is reinforced with Poly Lactic Acid (PLA). CSP-reinforced PLA is prone to fast ignition and rapid flame spread in the absence of fire retardants. Introducing when magnesium hydroxide is heated, it issues water vapour, which effectively delays combustion and increases fire resistance. Likewise, water molecules that make a barrier beside flames are released by zinc borate and boric acid. In addition to releasing ammonia, ammonium polyphosphate makes a barrier that prevents fire from spreading. The overall effectiveness of fire protection can be improved by combining these fire retardants. The composition and fire resistance of commercially available fake ceiling materials vary greatly, and these additions are frequently used to satisfy safety requirements. When choosing materials for applications like false ceilings, where fire safety is crucial, it is imperative to perform thorough testing on variables like ignition time, flame spread rate, and smoke output. A number of crucial criteria in the areas of material selection and product design influence both operational effectiveness and customer attractiveness. Higher Fire Retardancy (FR) values specify stronger fire resistance, which is crucial for safety in manufacturing and construction. FR measures a material's capacity to withstand ignition and restrict fire spread. The ability of a material to bear applied stresses without deforming or failing is measured by its Mechanical Strength (MS); higher MS values show stronger structural integrity, which is essential for durability in various applications. The economic efficiency of materials or solutions is assessed by Cost-Effectiveness (CE), which weighs the long-term advantages against the upfront expenditures. Options that balance eminence and cost are more economically viable when their CE values are higher. The ecological footprint of materials or processes is measured by Environmental Damage (EI), where higher EI values correspond to greater environmental damage.

Reducing EI is crucial for applying maintainable practices and meeting permitted requirements—non-benefit metrics, instead of taking into account logistical and subjective features. A product's visual attractiveness is measured by its Aesthetic Appeal (AA), wherever higher values indicate better visual appeal. Lower values indicate easier implementation. Ease of Installation (EOI) measures how easy and efficient an installation is. While Ease of Recycling (ER) looks at how readily materials can be recycled, Availability of Raw Materials (ARM) assesses how easy it is to source resources. All of these issues work together. To inform varieties that maximize product performance, increase market acceptability, and encourage environmental responsibility.

3. Analysis and Discussion

Table 1 presents a comparison of different false ceiling materials enhanced with Coconut Shell Powder (CSP) and Polylactic Acid (PLA), both with and without fire retardants. Initially, CSP-reinforced PLA without fire retardant determines strong performance in mechanical strength (MS), Cost-Effectiveness (CE), Environmental Impact (EI), Aesthetic Appeal (AA), ease of Installation (EI), availability of Raw Materials (ARM), and Ease of Recycling (ER).

Table 1. Comparison of various false ceiling materials

Alternative	FR	MS	CE	EI	AA	EI	ARM	ER
M1	3	8	9	8	7	8	9	9
M2	7	7	7	7	6	7	8	8
M3	8	7	6	6	6	7	7	7
M4	7	6	7	6	6	7	8	7
M5	9	6	5	5	6	7	6	6
M6	10	5	4	4	5	6	5	5
M7	8	8	3	3	8	9	9	4

M1: CSP reinforced PLA without fire retardantM2: CSP reinforced PLA with Magnesium HydroxideM3: CSP reinforced PLA with Zinc BorateM4: CSP reinforced PLA with Boric AcidM5: CSP reinforced PLA with Ammonium polyphosphateM6: CSP reinforced PLA with the combination of fire retardantsM7: Commercially available false ceiling materials. Fire Retardancy (FR), Mechanical Strength (MS), Cost-Effectiveness (CE), Environmental Impact (EI), Aesthetic Appeal (AA), Ease of Installation (EI), Availability of Raw Materials (ARM) and Ease of Recycling (ER)

However, the introduction of fire retardants modifies these characteristics. CSP reinforced PLA with Magnesium Hydroxide shows enhanced Fire Retardancy (FR) but slightly lower scores in other categories compared to the non-retardant version.

Similarly, PLA with Zinc Borate or Boric Acid adjusts FR levels while keeping efficient MS and CE ratings. In contrast, CSP-reinforced PLA with Ammonium polyphosphate, either alone or combined, prioritises FR at the expense of MS, CE, and AA.

Meanwhile, commercially available false ceiling materials deal with variable FR and MS capabilities but tend to have drawbacks in CE and EI despite advantages in AA and ease of installation.

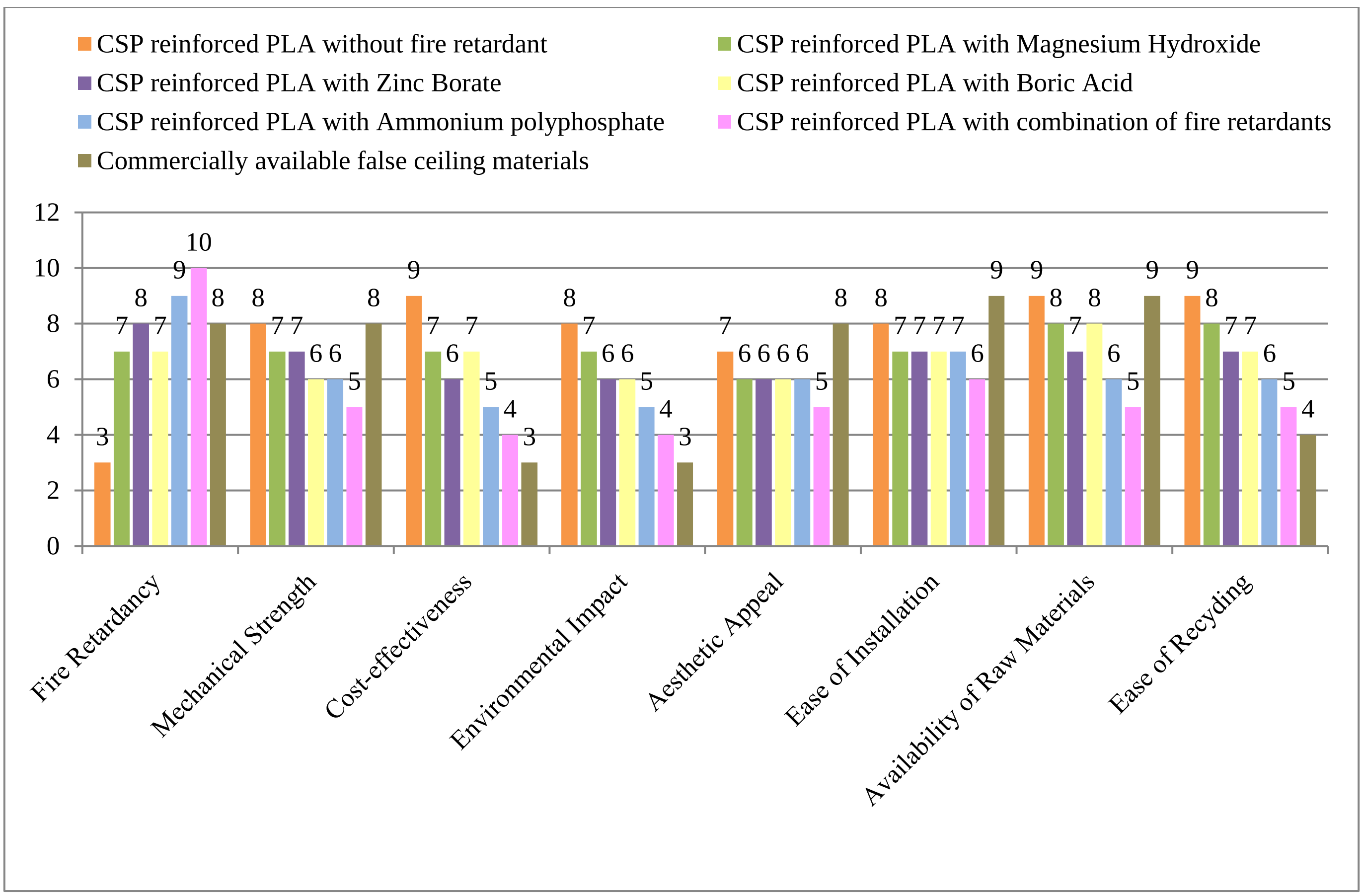

Fig. 2 Comparative analysis of different false ceiling material

Figure 1 offers a comparative analysis of different false ceiling materials strengthened with Coconut Shell Powder (CSP) and Poly Lactic Acid (PLA), with and without fire retardants. Initially, CSP-reinforced PLA without fire retardant demonstrates robust performance in Mechanical Strength (MS), Cost-Effectiveness (CE), environmental impact (EI), Aesthetic Appeal (AA), Ease of Installation (EI), Availability of Raw Materials (ARM), and Ease of Recycling (ER). However, the introduction of fire retardants alters these properties. CSP reinforced PLA with Magnesium Hydroxide enhances Fire Retardancy (FR) but shows slightly lower scores in other areas compared to the non-retardant version. Similarly, PLA with Zinc Borate or Boric Acid adjusts FR levels though sustaining competitive MS and CE ratings. In contrast, CSP-reinforced PLA with Ammonium polyphosphate, whether used alone or in combination, prioritizes FR at the expense of MS, CE, and AA. Meanwhile, commercially available false ceiling materials exhibit varied FR and MS capabilities but typically have CE and EI limitations despite AA benefits and ease of installation.

Table 2. Normalized Data Using the TOPSIS Method for False Ceiling Materials

Material	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
M1	0.1471	0.3922	0.4413	0.3922	0.4168	0.4764	0.5359	0.5359
M2	0.3432	0.3432	0.3432	0.3432	0.3573	0.4168	0.4764	0.4764
M3	0.3922	0.3432	0.2942	0.2942	0.3573	0.4168	0.4168	0.4168
M4	0.3432	0.2942	0.3432	0.2942	0.3573	0.4168	0.4764	0.4168
M5	0.4413	0.2942	0.2451	0.2451	0.3573	0.4168	0.3573	0.3573
M6	0.4903	0.2451	0.1961	0.1961	0.2977	0.3573	0.2977	0.2977
M7	0.3922	0.3922	0.1471	0.1471	0.4764	0.5359	0.5359	0.2382

M1:M7 represent different false ceiling materials. Criteria 1:8 represents the evaluation factors considered in the TOPSIS analysis.

Table 2 presents normalized data using the TOPSIS method to judge different false ceiling materials reinforced with CSP and PLA, with and without fire retardants. Normalization adjusts values to a scale from 0 to 1, where larger values indicate improved performance in each criterion. Initially, CSP-reinforced PLA without fire retardant achieved moderate scores crosswise all standards, mostly excelling in mechanical strength (MS), cost-effectiveness (CE), and ease of installation (EI). The introduction of fire retardants significantly modifies these scores. For example, CSP-reinforced PLA with Magnesium Hydroxide improves fire retardancy (FR) but diminishes in MS and CE. Similarly, PLA with Zinc Borate or Boric Acid achieves varying degrees of FR effectiveness while keeping reasonable MS and CE ratings. Conversely, CSP-reinforced PLA with Ammonium polyphosphate, whether used alone or in combination, prioritises FR at the overhead of other sides, resulting in lower scores for MS, CE, and Aesthetic Appeal (AA). Meanwhile, commercially available false ceiling materials generally show lower overall scores, mostly in CE and Environmental Impact (EI), despite competitive FR and MS ratings.

Table 3. Even Distribution of Weights for TOPSIS Analysis of False Ceiling Materials

Material	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
M1	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125
M2	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125
M3	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125
M4	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125
M5	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125
M6	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125
M7	0.12	0.12	0.12	0.12	0.125	0.125	0.125	0.125

Each criterion is assigned an equal weight of 12.5% (0.125) for fair assessment across all eight evaluation criteria. M1 to M7 represent different false ceiling materials.

Table 3 employs an even distribution of weights (0.125 or 12.5% for each) across a range of criteria to assess different false ceiling materials strengthened with Coconut Shell Powder (CSP) and Poly Lactic Acid (PLA), with or without fire retardants. It evaluates every selection with CSP reinforced PLA without fire retardant, various combinations with fire retardants, and commercially available choices based on Fire Retardancy (FR), Mechanical Strength (MS), Cost-Effectiveness (CE), Environmental Impact (EI), Aesthetic Appeal (AA), Ease of Installation (EI), Availability of Raw Materials (ARM), and Ease of Recycling (ER). This systematic approach offers an unbiased calculation of these materials, considering their performance across critical aspects for ceiling applications. The table enables a fair comparison by assigning equal weight to each criterion, illustrating each material alternative's comparative strengths and weaknesses.

For example, fire retardant-enhanced variants may demonstrate superior FR capabilities but could potentially score lower in MS, CE, and AA compared to non-retardant options. Conversely, commercially available materials influence shine in areas like ease of installation and visual demand but might trail in terms of EI and ER.

Table 4 illustrates weighted normalized data using the TOPSIS method, providing insight into the performance of diverse false ceiling materials reinforced with CSP and PLA across several criteria. CSP reinforced PLA without fire retardant demonstrates moderate scores through most factors, with notable strengths in Ease of Installation (EI), availability of Raw Materials (ARM), and Ease of Recycling (ER), exemplified by values like 0.0595 for EI and 0.0670 for both ARM and ER. This shows its competitive position in practical installation and workable material usage.

Table 4. Weighted Normalized Data Using the TOPSIS Method for False Ceiling Material

Material	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
M1	0.0184	0.049	0.0552	0.049	0.0521	0.0595	0.067	0.067
M2	0.0429	0.0429	0.0429	0.0429	0.0447	0.0521	0.0595	0.0595
M3	0.049	0.0429	0.0368	0.0368	0.0447	0.0521	0.0521	0.0521
M4	0.0429	0.0368	0.0429	0.0368	0.0447	0.0521	0.0595	0.0521
M5	0.0552	0.0368	0.0306	0.0306	0.0447	0.0521	0.0447	0.0447
M6	0.0613	0.0306	0.0245	0.0245	0.0372	0.0447	0.0372	0.0372
M7	0.049	0.049	0.0184	0.0184	0.0595	0.067	0.067	0.0298

M1:M7 represent different false ceiling materials. The values are obtained by multiplying the normalized data (Table 2) with the equal weights (Table 3) using the TOPSIS method.

The introduction of fire retardants alters these positions. For example, CSP-reinforced PLA with Magnesium Hydroxide achieves a higher Fire Retardancy (FR) score of 0.0429 but shows relatively lower Mechanical Strength (MS) values and other non-fire retardant criteria. Similarly, PLA variants with Zinc Borate, Boric Acid, and Ammonium polyphosphate prioritize FR while compromising on MS and Cost-Effectiveness (CE) features. Commercially available false ceiling materials show strengths in MS and FR but demonstrate significant weaknesses in CE and Environmental Impact (EI), reflected in their low scores of 0.0184. This highlights probable sustainability issues and larger costs associated with these materials.

Table 5. Optimal best (A+) and worst (A-) values derived using the TOPSIS

Optimal Values	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
A^+	0.0613	0.049	0.0552	0.049	0.0372	0.0447	0.0372	0.0298
A^-	0.0184	0.0306	0.0184	0.0184	0.0595	0.067	0.067	0.067

A^+ (Ideal Best Solution): The best possible values for each criterion, representative of the optimal performance.
A^- (Ideal Worst Solution): The worst possible values for each criterion, representing the least desirable performance.

Table 5 illustrates the optimal best (A+) and worst (A-) values derived using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for assessing false ceiling materials across several criteria. Within the TOPSIS framework, A+ signifies the values that represent the most desirable outcomes, with minimized scores observed for FR (0.061), CE (0.055), EI (0.049), and ER (0.030), and maximized scores for MS (0.049), AA (0.037), EI (0.045), and ARM (0.038). These figures outline the ideal benchmarks materials should aim to achieve across these metrics.

Contrariwise, A- represents the values indicating the least desirable outcomes, with minimized values for AA (0.060) and maximized values for FR (0.018), MS (0.031), CE (0.018), EI (0.018), and ER (0.067). These metrics highlight attributes that should ideally be minimized or avoided when selecting materials. Using TOPSIS, decision-makers can evaluate how carefully each material aligns with the A+ values (ideal best) and deviates from the A- values (ideal worst).

Materials that strictly approach the A+ benchmarks are considered more favorable choices, while those closer to the A- benchmarks indicate less preferable options. This method facilitates a structured comparison based on quantitative data, enabling the identification of the most suitable false ceiling material based on predefined norms. TOPSIS provides a comprehensive estimate framework that enhances informed decision-making in material selection processes by addressing both the optimal and suboptimal performance benchmarks.

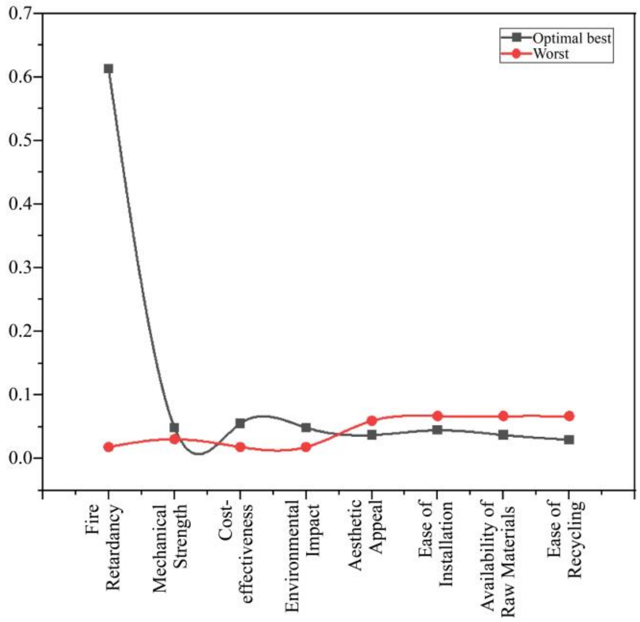

Fig. 3 Optimal best (A+) and worst (A-) values determined using the TOPSIS

Figure 2 presents the optimal best (A+) and worst (A-) values determined using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for evaluating false ceiling materials across various criteria. In the TOPSIS framework, A+ denotes the values representing the most desirable outcomes, with minimized scores observed for FR (0.061), CE (0.055), EI (0.049), and ER (0.030), and maximized scores for MS (0.049), AA (0.037), EI (0.045), and ARM (0.038). These figures establish the ideal performance benchmarks that materials should strive to achieve across these metrics. Conversely, A- reflects values indicating the least desirable outcomes, with minimized values for AA (0.060) and maximized values for FR (0.018), MS (0.031), CE (0.018), EI (0.018), and ER (0.067). These metrics underscore attributes that ideally would be minimized or avoided when selecting materials. By employing TOPSIS, decision-makers can assess how closely each material aligns with the A+ values (ideal best) and separates from the A- values (ideal worst). Materials that closely approximate the A+ benchmarks are considered more favorable choices, whereas those closer to the A- benchmarks suggest less preferable options.

Table 6. Separation of each alternative from the ideal solution (Si+) and the negative-ideal solution (Si-)

Alternative	Si Plus	Si Negative
CSP reinforced PLA without fire retardant	0.0587	0.0315
CSP reinforced PLA with Magnesium Hydroxide	0.0363	0.0385
CSP reinforced PLA with Zinc Borate	0.0292	0.0415
CSP reinforced PLA with Boric Acid	0.0323	0.0372
CSP reinforced PLA with Ammonium polyphosphate	0.0255	0.0471
CSP reinforced PLA with a combination of fire retardants	0.0256	0.0571
Commercially available false ceiling materials	0.0398	0.0482

Table 6 illustrates the separation of each alternative from the ideal solution (Si+) and the negative-ideal solution (Si-) using the TOPSIS methodology to assess false ceiling materials. A lower Si+ indicates closer proximity to the ideal solution, while a lower Si- signifies better divergence from the negative ideal solution. CSP-reinforced PLA without fire retardant achieves a Si+ of 0.0587 and a Si- of 0.0315. This suggests it is relatively further from the ideal solution but closer to the negative ideal solution associated with other alternatives, implying it may not shine in all criteria but avoids some negative characteristics. Alternatives incorporating fire retardants exhibit variability: CSP-reinforced PLA with Ammonium polyphosphate shows the lowest Si+ (0.0255), indicating it is closest to the ideal solution across evaluated criteria. However, it also has a relatively high Si- (0.0471), indicating greater divergence from the negative ideal result compared to other options. Commercially available false ceiling materials display a Si+ of 0.0398 and a Si- of 0.0482, suggesting they offer a balanced performance across the assessed criteria. They neither excel as the ideal solution nor exhibit significant drawbacks as the negative ideal, indicating moderate separation from both benchmarks. In an instantaneous manner, considering these separations aids in choosing the most suitable false ceiling material based on specific criteria, weighting, and priorities.

Figure 3 depicts the separation of each alternative from the ideal solution (Si+) and the negative-ideal solution (Si-) using the TOPSIS methodology for evaluating false ceiling materials. A lower Si+ indicates closer proximity to the ideal solution, while a lower Si- indicates better divergence from the negative ideal solution. CSP-reinforced PLA without fire retardant achieves a Si+ of 0.0587 and a Si- of 0.0315. This suggests it is situated further from the ideal solution but closer to the negative-ideal solution compared to other alternatives, indicating it may not excel across all criteria but avoids some negative characteristics. Alternatives incorporating fire retardants show variability: CSP-reinforced PLA with Ammonium polyphosphate achieves the lowest Si+ (0.0255), indicating it is closest to the ideal solution among the evaluated criteria. However, it also exhibits a relatively high Si- (0.0471), indicating greater divergence from the negative-ideal solution compared to other options. Commercially available false ceiling materials exhibit a Si+ of 0.0398 and a

Si- of 0.0482, suggesting they offer a balanced performance across the evaluated criteria. They do not excel as the ideal solution nor demonstrate significant drawbacks as the negative ideal, indicating a moderate separation from both benchmarks.

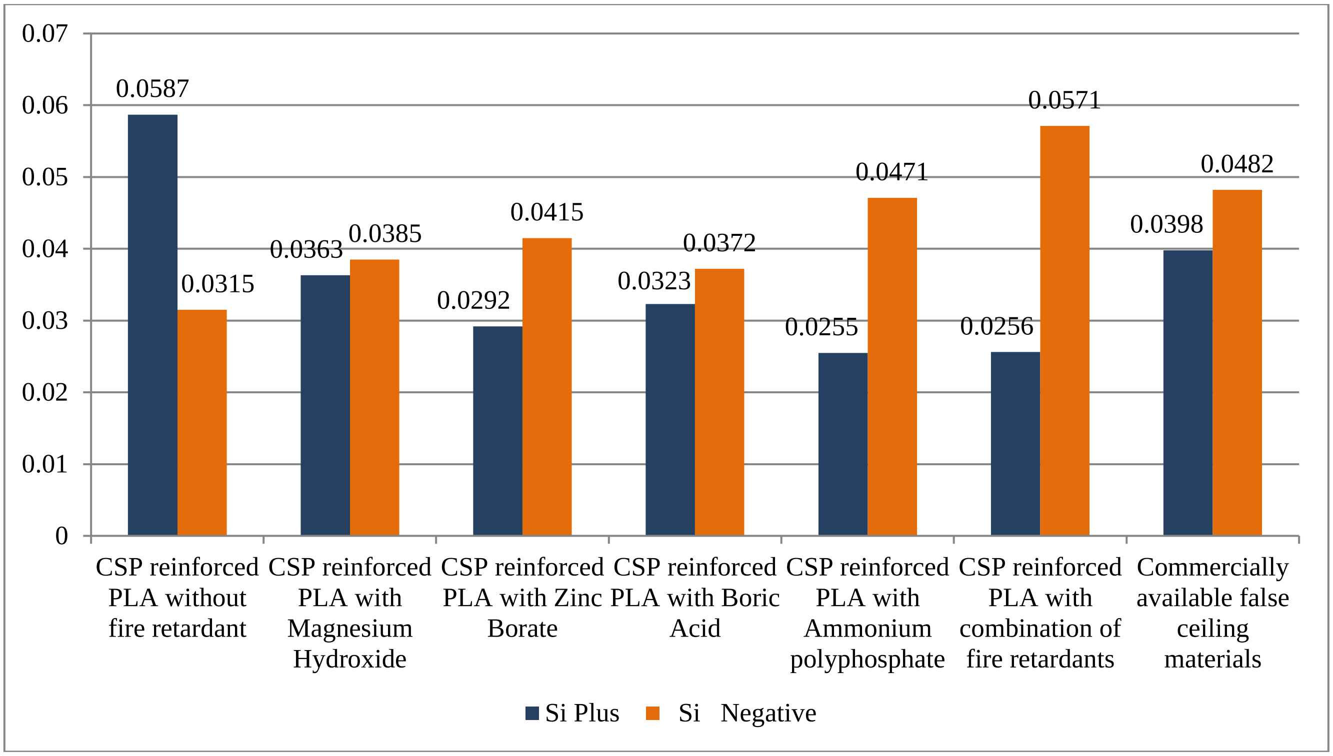

Fig. 4 Separation of each alternative from the ideal solution (Si+) and the negative-ideal solution (Si-)

Table 7. Results of the TOPSIS method

Alternative	Ci	Rank
CSP reinforced PLA without fire retardant	0.349418966	7
CSP reinforced PLA with Magnesium Hydroxide	0.514443362	6
CSP reinforced PLA with Zinc Borate	0.586577807	3
CSP reinforced PLA with Boric Acid	0.535221151	5
CSP reinforced PLA with Ammonium polyphosphate	0.648562695	2
CSP reinforced PLA with a combination of fire retardants	0.690374338	1
Commercially available false ceiling materials	0.547475822	4

Table 7 presents the results of the TOPSIS method, displaying Closeness Coefficient (Ci) values and ranks for various false ceiling materials. These Ci values indicate the proximity of each alternative to the ideal solution based on the assessment criteria, with minor values representing closer alignment.

The top-ranking option is CSP-reinforced PLA with a combination of fire retardants, achieving a Ci of 0.690 and securing the highest rank of 1. This shows its greater performance across the selected criteria. Next in line is CSP-reinforced PLA with Ammonium polyphosphate, which attains a Ci of 0.649 and ranks second.

Despite its concentration on fire retardancy, this option determines strong overall performance compared to other alternatives. CSP reinforced PLA with Zinc Borate follows closely with a Ci of 0.587, placing third and showcasing competitive performance across the evaluated criteria.

Meanwhile, CSP-reinforced PLA with Magnesium Hydroxide and CSP-reinforced PLA with Boric Acid achieve Ci values of 0.514 and 0.535, respectively, positioning them in the middle ranks (6^{th} and 5^{th} respectively). Commercially available false ceiling materials achieve a Ci of 0.547 and rank fourth overall. This suggests they provide a reasonable balance across the criteria assessed but do not surpass the top-performing alternatives.

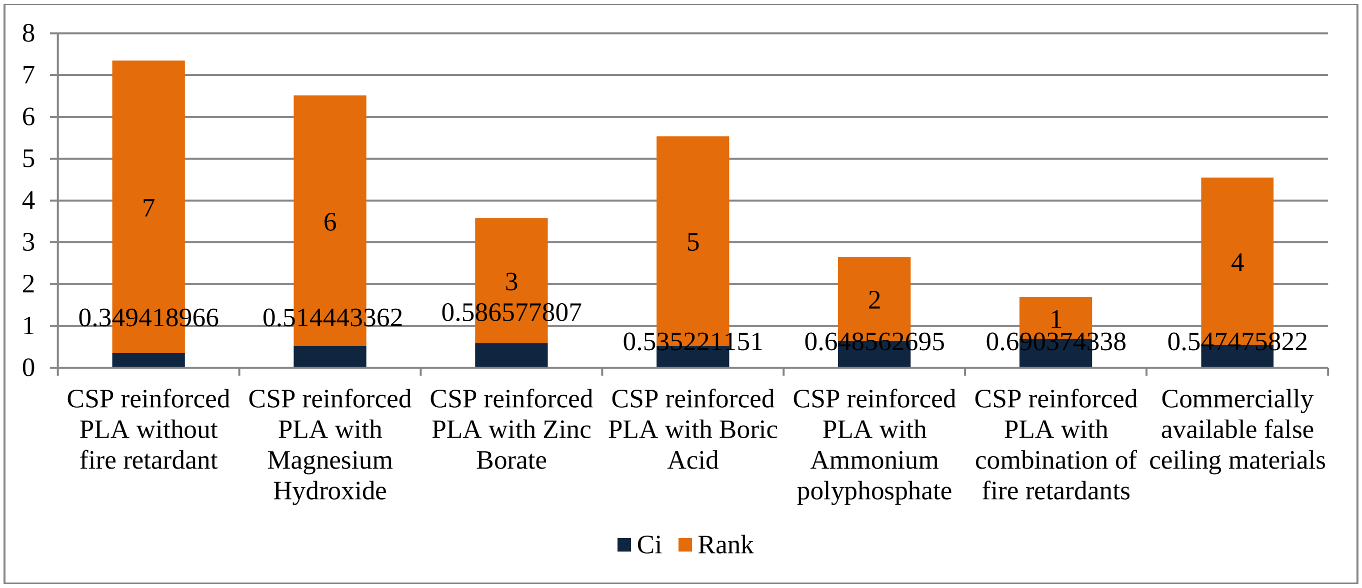

Fig. 5 Result of TOPSIS method CSP reinforced PLA with a combination of fire retardants

According to the results from Figure 4 using the TOPSIS method, CSP-reinforced PLA with a combination of fire retardants emerges as the top choice, achieving the highest rank (1) and a Closeness Coefficient (Ci) of 0.690. This specifies its closest alignment with the ideal solution as defined by the evaluation criteria, which contain aspects such as fire retardancy, mechanical strength, cost-effectiveness, environmental impact, aesthetic demand, and ease of installation. Following closely is CSP-reinforced PLA with Ammonium polyphosphate, which secures the second rank with a Ci of 0.649. Despite its prime emphasis on fire retardancy, this option demonstrates strong total performance across the assessed criteria. CSP-reinforced PLA with Zinc Borate takes the third position with a Ci of 0.587, demonstrating competitive performance, particularly in fire retardancy and other evaluated aspects. In contrast, CSP-reinforced PLA with Magnesium Hydroxide and CSP reinforced PLA with Boric Acid achieve lower rankings, indicating they provide less optimal solutions compared to the top-ranked alternatives. Commercially available false ceiling materials rank fourth overall with a Ci of 0.547, indicating a balanced performance across the criteria but without excelling in any specific category compared to the top-performing options.

4. Conclusion

This study explores the potential of Coconut Shell Powder (CSP) composites reinforced with Poly Lactic Acid (PLA) as environmentally friendly and fire-resistant materials for false ceiling applications. An agricultural waste high in cellulose and lignin, CSP improves thermal stability and mechanical strength. PLA, a biodegradable thermoplastic derived from renewable resources, has excellent mechanical qualities and is environmentally benign. The TOPSIS method was used in the study to evaluate several CSP-PLA formulations, both with and without fire retardants, in order to evaluate performance in terms of fire retardancy, mechanical strength, cost-effectiveness, environmental impact, aesthetic appeal, ease of installation, availability of raw materials, and recycled material.

The best-performing material among the evaluated materials was CSP-PLA with a fire retardant blend (Ci = 0.690), which combined outstanding fire resistance with well-balanced performance in other areas. Ammonium polyphosphate-containing CSP-PLA came in second (Ci = 0.649), providing robust fire protection. Traditional false ceiling materials came in fourth, and the formulation, including zinc borate, came in third. Due to insufficient fire safety, CSP-PLA without fire retardants ranked lowest despite having great cost and environmental factors. These results show that CSP-PLA composites can be used as efficient substitutes for conventional ceiling materials, especially when combined with fire retardants. According to the findings, these environmentally friendly, fire-safe bio composites should be developed further and used in sustainable building methods.

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