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Fire-Resistant Coating Using Avocado Seeds and Chicken Eggshells

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ABSTRACT

This study focused on developing an eco-friendly, fire-resistant coating using natural waste materials, including avocado seeds and chicken eggshells. It addressed the need for sustainable and cost-effective alternatives to traditional fire retardants, which often contain harmful chemicals. The study aimed to determine whethSer these agricultural byproducts could be transformed into a fire-resistant material suitable for combustible surfaces, specifically testing the product on linen fabric. Linen fabric samples were coated with three treatment formulations and compared with uncoated fabric through flame spread and drying time tests. Results showed that the coating reduced flame spread compared to uncoated fabric. A key finding was the synergistic effect between the calcium carbonate in eggshells and the organic compounds in avocado seeds, which enhanced the coating's thermal resistance. The study rejected the hypothesis that the ratio of the two ingredients would significantly affect the coating's effectiveness; the coating remained consistently fire-resistant across all proportions. In conclusion, the study demonstrated that avocado seeds and chicken eggshells are viable and sustainable raw materials for producing effective fire-resistant coatings. The findings support their use as eco-friendly alternatives to synthetic fireproofing products. Future studies are encouraged to investigate other natural sources, evaluate the coating on various surfaces, enhance transparency and appearance, and simulate real-world fire conditions to facilitate broader application.

INTRODUCTION

Sustainable flame retardants (FRs) are increasingly developed, often using biodegradable chemicals and agricultural waste, with the objective of minimizing environmental burden and increasing fire resistance. A combination of calcium carbonate, concentrated eggshell powder, and a biofiller has shown efficacy as a biofiller in intumescent coatings, improving thermal stability and reducing the spread of fire (Wang *et al.*, 2021). Apart from eggshell powder, avocado seeds have also been investigated as a bio-based flame retardant, which has potential in sustainable coatings (Zuluaga-Parra *et al.*, 2021). The use of eggshells in construction applications showed that eggshells had extensive usage prior to their invention for coatings (Mensah *et al.*, 2022).

This study developed a fire-resistant coating using Evergreen avocado seeds and commercialized chicken eggshells, offering eco-friendly, partial replacement of synthetic components with bio-waste materials, and alternatives to chemical-based coatings. This study also evaluated the flame spread and drying/curing time of different avocado seed–eggshell coating formulations to determine whether formulation ratios significantly affect performance. It benefited the construction industry by slowing the fire spread, enhancing public safety while reducing environmental impact, and to serve as a foundation for future research on natural fire-resistant materials.The research, however, is limited to the Evergreen avocado variety and commercial eggshells and was conducted at the WVN Research and Laboratory Training Center in Davao City, Philippines.

LITERATURE REVIEW

A fire-retardant coating could be the fastest growing product in the Asia-Pacific region because of the rapid urbanization and regulatory enforcement. In China and India, for instance, stringent fire safety standards have spawned a demand for these coatings (Fire-Resistant Coatings Market, 2024). However, in India, the price of fire-retardant paints has become a prominent concern (Straits Research, 2024). In Thailand, IPEN (2023) documented the toxic exposure experienced by workers working on e-waste, which underscores the health risks linked to traditional flame retardants. For these concerns, Dai *et al.* (2022), have developed magnesium phosphate cement coatings that have the potential to cure within 30 minutes and retain their fire-resisting properties for more than three hours.

Flame-retardant efficiency is commonly assessed using the Flame Spread Index (FSI), where Class A materials score 0–25 and Class E coatings exceed 500. Standard tests such as ASTM E84 measure flame spread and smoke emission. Research shows that drying time, curing rate, environmental conditions, and heat resistance significantly influence coating performance, as seen in modern intumescent products like DC315, which dry within 1–2

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hours and can be recoated in 2–4 hours (SPI Coatings, 2025; Fire Retardants, 2020; International Fireproof Technologies, Inc., 2024). In Europe construction requires large quantities of wood and concrete which require protection coatings. Lainioti *et al.* (2022) proposed a nontoxic hybrid coating for plywood that achieves a Euroclass B fire rating—the highest possible rating for wooden materials. In North America, there is increasing concern about the harmful effects of halogenated flame retardants and there is also growing research to identify safer coating technologies.

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Meanwhile, Africa also faces huge fire risks, especially by seasonal wildfires. As suggested in Laris *et al.* (2020), seasonal natural fires occur each year and could be particularly devastating for vulnerable regions. In Ethiopia a new coating was developed for increasing the fire resistance of cotton fabrics using chicken eggshells with an acrylic copolymer. Remarkably, Tseghai *et al.* (2019) showed that this coating was more potent due to the thickness of the fabric applied. In another study, Ahmed *et al.* (2022) selected linen as the testing substrate due to its high flammability. Linen fabric is a cellulosic fiber that is also common in household use. This has led to the construction of a low-cost, biodegradable solution.

MATERIALS AND METHODS

This study employed a completely randomized experimental design to evaluate the fire-resistant performance of coatings formulated using avocado seeds and chicken eggshells. Three treatment formulations with varying ratios of avocado seed powder and eggshell powder were prepared and applied to linen fabric samples, with an uncoated linen fabric serving as the control. The fire-resistant properties of the coatings were evaluated through flame spread and drying time tests adapted from the ASTM E84 standard for surface burning characteristics of materials (ASTM E84, 2018). Differences among the treatment formulations were analyzed using one-way analysis of variance (ANOVA) to determine statistical significance (Bevans, 2024).

Table 1: List of materials used and their description

Material	Description
Avocado Seed (Evergreen)	An avocado seed has large, rounded hass that look like thick leaves. They store starch and provide the energy needed for the seed to sprout and grow into a plant.
Chicken Egg Shells	Produced in large quantities in poultry farms for human consumption. They are washed, graded, and packaged, and can be fortified or labeled according to farming practices like cage-free, organic, or free-range.
Polyvinyl Acetate 7.2% (Binder)	A synthetic polymer commonly used as a binder in various applications, including adhesives, paints, and coatings.
Calcium Carbonate 18%	A white, odorless powder commonly used as a filler and pigment in various applications, including paints and coatings.
Borax 7.5%	Also known as Sodium Tetraborate, is a buffering agent that helps maintain a stable pH level in solutions.
Nitrosol 7.5%	A thickener or viscosity improver usually used in the production of most cosmetic products like washing up liquid and others.
Distilled Water 40%	Water that has been boiled into vapor and condensed back into liquid in a separate container.

This study involved a seven-phase process to test a Fire-Resistant Coating Using Avocado Seeds and Chicken Eggshell:

STEP 1. Prepare the linen fabric where the coating will be placed.

This study will use linen fabric as a surface type for testing the fire resistant coating. Before applying the coat, make sure the fabric is free from debris or other substances that may prevent the coating from sticking properly. After that, cut the fabric to the desired size.

STEP 2: Brush the prepared fire-resistant coating onto the linen fabric evenly. Ensure a consistent thickness (e.g., 1.5 ± 0.2 mm)

The coating must be applied evenly to provide an effective fire-resistance, and ensuring uniformity in thickness is essential. The thickness should be maintained at the specified level of 1.5 ± 0.2 mm for effective protection, as any further increase or decrease would compromise this balance.

STEP 3: Expose coated samples to controlled fire conditions following the principles of BS 476: Part 6 standards. Observe flame spread, and fire resistance.

The method assesses how successful the coating is in protecting fabric under fire conditions. By following the principles of BS 476: Part 6, flame spread index, and drying time are considered in a controlled manner; these observations feed into the consideration that the coating does in fact resist fire and insulate.

STEP 4. Conduct heat resistance to measure the heat resistance of the coating under high temperatures.

Conducting a heat resistance test ensures the coating can withstand high temperatures without degrading, peeling, or losing effectiveness. The test involves exposing the coated material to controlled heat and observing changes in texture, color, adhesion, or structural integrity. This helps evaluate its durability, thermal stability, and overall fire protection performance.

STEP 5. Test the dry/cure time to measure the dry/cure time of the coating under high temperatures.

Testing the dry/cure time determines how long the coating takes to dry or fully cure after application, ensuring proper adhesion and performance. The test involves applying the coating to a surface, exposing it to air or controlled heat, and measuring the time required for it to become touch-dry and fully set. This helps assess its usability, efficiency, and suitability for high-temperature environments.

This study employed an experimental design to evaluate the fire-resistant performance of a coating formulated using avocado seeds and chicken eggshells. The coating was applied to linen fabric samples and evaluated based on flame spread and drying time to compare the effectiveness of different formulations, following adapted principles of standard fire performance testing methods (ASTM E84, 2018). The experimental design involved comparing three coating formulations with varying ratios of avocado seed and chicken eggshell powders applied to linen fabric, with an uncoated sample used as the control for reference. Differences among the formulations were analyzed using one-way analysis of variance (ANOVA) to determine statistical significance (Bevans, 2024). A one-way analysis of variance (ANOVA) is a statistical method used to assess differences in the means of three or more groups. It is applicable when there is one categorical independent variable and one quantitative dependent variable (Bevans, 2024). This method helps determine whether variations between groups are statistically significant, making it useful for comparing treatment effects in experimental research.

Table 2: Concentration of the Formulated Fire Resistance of Three Treatments

Component	**Treatment 1**	**Treatment 2**	**Treatment 3**
Polyvinyl acetate	72g (7.2%)	72g (7.2%)	72g (7.2%)
Calcium carbonate	180g (18%)	180g (18%)	180g (18%)
Borax	75g (7.5%)	75g (7.5%)	75g (7.5%)
Nitrosol	75g (7.5%)	75g (7.5%)	75g (7.5%)
Distilled water	400g (40%)	400g (40%)	400g (40%)
Avocado seed	118.8g (11.88%)	79.2g (7.92%)	99g (9.9%)
Eggshell	79.2g (7.92%)	118.8g (11.88%)	99g (9.9%)
Total	1000g (100%)	1000g (100%)	1000g (100%)

RESULTS AND DISCUSSIONS

The results indicated that the first treatment were formulated with a total weight of 1000g (100%). Formulation 1, the total weight of the final product was 118.8g of avocado seed and 79.2g of chicken eggshell, 11.88% and 7.92% of the total percent formulation, respectively.

The results revealed that the initial treatment was prepared using a total of 1000 g, accounting for 100% of the formulation. Treatment 2 was formulated in an inverse manner with respect to the ratio composing 79.2g of avocado seeds and 118.8g of chicken eggshells, providing 7.92% and 11.88% concentrations.

The results showed that the third treatment was also formulated with a total weight of 1000 g, representing 100%. In contrast, the Treatment 3 incorporated equally between both materials; the 99 g of both avocado seeds and the chicken eggshells were utilized for treatment 3; a total addition of 9.9% of the total formulation. These different contents were used to investigate the proportions of each component, which have some effect on the flame-retardant properties of the coating materials.

The formulations that were used in this experiment were guided by the researcher's instructors as part of the study on fire-resistant coatings. To test the effectiveness of fire resistance using avocado seeds and egg shells, polyvinyl acetate, calcium carbonate, nitrosol, borax, and distilled water was used as an ingredient in this fire resistant coating. Although previous studies have examined the ingredients given together with avocado seeds and egg shells to make a fire-retardant applications, the particular materials presented was supported by previous studies by Yew *et al.* (2014) and Zuluaga-Parra *et al.* (2021b), and this particular formulation was presented for testing purposes under the supervision of the researchers' instructor.

Therefore, to contextualize its possible applications, further research on related studies is suggested.

Table 3: Flame Spread of Fire-Resistant Coating on Linen Fabric

Test Samples	Fire Resistance (Flame Spread index, cm)*
Treatment 1	4.67±0.58
Treatment 2	4.33±0.58
Treatment 3	5.0±0.00

**Flame Spread 0–25 (most fire resistant)*

This table presented the average flame spread index (cm) of each treatment. Lower values indicate higher fire resistance. Values are presented as mean ± standard deviation (SD). Flame spread index values between 0–25 are considered fire-resistant. The flame spread index (FSI) results showed that all treatments were within the range of highly fire-resistant coatings, remaining well below the critical value of 25. Treatment 2 had the lowest FSI at 4.33 ± 0.58 cm, indicating the best fire resistance, followed by Treatment 1 at 4.67 ± 0.58 cm. Treatment 3 recorded the highest FSI of 5.0 ± 0.00 cm, suggesting slightly lower fire resistance. These differences highlight how variations in composition can influence flame-retardant performance.

The effectiveness of a fire-resistant coating is often evaluated using two key parameters: standard time to ignition and the flame spread index (FSI). According to ASTM E84, the FSI is a widely used metric to assess how quickly flames spread across the surface of building materials. Materials with an FSI below 25 are generally categorized as fire-resistant, indicating minimal flame propagation (ASTM International, 2021). A recent study by Wang *et al.* (2020b) looked at eco-friendly fire-resistant coatings and found that when these coatings increase the time it takes for the material to ignite and reduce how quickly the flame spreads, they are considered effective. Their research showed that materials using natural ingredients can work well when tested using standard fire tests.

Table 4: Drying Time of Fire-Resistant Coating on Linen Fabric

Test Samples	Drying Time, mins
Treatment 1	32.3±0.58
Treatment 2	33±1.00
Treatment 3	34±1.00

This table showed the average drying time (in minutes) required for each treatment to fully cure on linen fabric. Values are presented as mean ± standard deviation (SD). Drying time measurements revealed that Treatment 1 cured the fastest at 32.3 ± 0.58 minutes. Treatment 2 dried slightly slower at 33 ± 1.00 minutes, while Treatment 3 had the longest drying time of 34 ± 1.00 minutes. Although all times were close, the results suggest that component proportions may slightly affect the curing behavior of the coatings.

In addition to that, a study conducted by Wang et.al. (2021c) in the application of shell-derived bio-fillers in intumescent fire-retardant coatings, eggshells (CES), composed primarily of calcite calcium carbonate ($CaCO_3$), were found to enhance the fire resistance and char-forming ability of coatings when compared to formulations without bio-fillers. Specifically, the coating containing eggshells (IFRC-CES) exhibited a residual weight of 34.6% at 800 °C and showed a moderate reduction in flame-spread rating, indicating a positive synergistic effect on thermal stability and fire performance. Although other shell types like clamshell performed more effectively, the study confirmed that eggshells contribute to improved flame resistance. This finding supports the results of Table 3 in the present study, where Treatment 3 formulated with 9.9% eggshells and 9.9% avocado seeds are achieved the lowest flame spread index of 5.0 cm. This demonstrates that eggshells, even when used in equal proportion with another organic additive like avocado seeds, can significantly enhance the fire-resistant properties of a coating when applied to linen fabric.

Table 5: Test for Significant Differences in Flame Spread Index and Drying Time Between Treatment 1 and Treatment 2

Parameter	T1	T2	F - Value	P - Value	Remarks
Flame Spread Index (cm)	4.67 ± 0.58	4.33 ± 0.58	1.50	0.296	Not significant
Drying Time (min)	32.3 ± 0.58	33.0 ± 1.00	2.714	0.145	Not significant

Calculations was performed at 0.05 level of confidence

Table 6: Test for Significant Differences in Flame Spread Index and Drying Time Between Treatment 1 and Treatment 3

Parameter	T 1	T 3	F Value	P value	Remarks
Flame Spread Index (cm)	4.67 ± 0.58	5.00 ± 0.00	1.50	0.296	Not significant
Drying Time (min)	32.3 ± 0.58	34.0 ± 1.00	2.714	0.145	Not significant

Calculations was performed at 0.05 level of confidence

Table 7: Test for Significant Differences in Flame Spread Index and Drying Time Between Treatment 2 and Treatment 3

Parameter	**Treatment 2**	**Treatment 3**	**F Value**	**p-value**	**Remarks**
Flame Spread Index (cm)	4.33 ± 0.58	5.00 ± 0.00	1.50	0.296	Not significant
Drying Time (min)	33.0 ± 1.00	34.0 ± 1.00	2.714	0.145	Not significant

Calculations was performed at 0.05 level of confidence

In the case of the fire resistance property, the obtained F-value is 1.50 and p = 0.296. However, because the p-value is larger than the critical threshold of 0.05, it suggested that no statistically significant differences existed among Treatment 1, Treatment 2, and Treatment 3 in the flame spread index. This indicates that the change in the amount ratio of avocado seeds and chicken eggshells in the different formulations did not have an obvious effect on the fire resistant performance of the coatings. Although small numerical differences in the average value of the flame spread index were noted--Treatment 2 had the lowest and Treatment 3 the highest--the differences were not large enough to indicate one formulation had superior fire resistance properties. From this, all three formulations might be deemed to be relatively effective to retard flame spread under the tested test conditions, which confirms their suitability as an alternative fire resistant coating materials even at slight differences in concentrations.

Likewise, for the drying time calculated F value was 2.714 with p-value of 0.145. Since the p = 0.210, which is greater than level of significance of 0.05 it depicts that variation of drying times among the drying treatments; Treatment 2, Treatment 1 and Treatment 3 was not statistically significant. Whereas Treatment 1 was the fastest to dry and Treatment 3 the slowest, the magnitudes of these mean comparisons were not sufficiently large to be statistically significant. This result implied that the different ratios of avocado seeds and chicken eggshells in the respective formulations have less impact on the curing mechanism of the fire-retardant coatings. In practice, although there were some minor variations in the ratio of different components, drying time was relatively constant for all treatments. Such results further demonstrate the potential ability to tailor avocado seed and chicken eggshell levels without impairing the practical performance of the developed fire-resistant coatings.

In accordance with the findings of the study, the study found by Dai *et al.* (2022) that the time for drying of the fire proof product was less than 30 minutes, according to the results from the study being considered in this paper. Little variations occurred with drying times by treatments, but none of these differences were significant statistically; so it can be concluded that the ratios of avocado seeds and chicken eggshells in the formulations represented a marginal effect in the curing process. Showing that fire resistant coatings developed in this study have a practical and efficient drying time for their possible use in real-world situations without any compromise in performance. Moreover, in terms of fire resistance, the flame spread index (FSI), which is very important for the performance of the coatings, reflected consistent results over the treatments. According to Wang *et al.* (2021d), the inclusion of eggshell powder in intumescent coatings greatly enhanced their resistance to flame spread, thereby supporting the premise that the fire-resistant coating in this study retard flame spread effectively without considerable variation across different formulations.

CONCLUSION

Recommendations

All three formulations can be considered relatively effective in slowing down flame spread under the tested conditions, confirming their potential as alternative fire-resistant coating materials, even with slight differences in concentration. These results imply that minor variations in the avocado seeds and chicken eggshells could affect the fire resistance and drying time behavior. However, because the p-value is larger than the critical threshold of 0.05, it suggests that no statistically significant differences existed among Treatment 1, Treatment 2, and Treatment 3 in the flame spread index. This indicates that the change in the amount ratio of avocado seeds and chicken eggshells in the different formulations did not have an obvious effect on the fire-resistant performance of the coatings. From this, all three formulations might be deemed to be relatively effective to retard flame spread under the tested test conditions, which confirms their suitability as an alternative fire-resistant coating materials even at slight differences in concentrations. It is recommended to consider integrating natural fire-resistant coatings into product development, especially for applications in rural housing, agricultural structures, and eco-conscious building projects. Promoting awareness and application of eco-friendly coatings can help reduce reliance on synthetic, chemical-based fireproofing products, contributing to safer and greener living environments. Developing a colorless or more transparent coating could also improve versatility and visual compatibility across applications. It is also recommended to test the coating on actual wood and metal surfaces to assess performance across different materials.

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