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Eco-Flame Shield: Formulating a Hybrid Fire Retardant Coating Using Carbonized Rice Husk Ash, Carbonized Coconut Coir Ash, and Sodium Silicate

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Abstract
This research is a quasi-experimental study that experimented and tested the effectiveness of using carbonized rice husk ash (CRHA), carbonized coconut coir ash (CCCA), and sodium silicate (SS) in developing and formulating an eco-friendly hybrid fire retardant coating that slows down fire spread, provides a non-harmful alternative to conventional fire retardants, and promotes practical solutions and fire safety measures in various applications, benefiting the environment, community, and public safety. Through experimental tests, such as Time to Ignition, Flame Spread, and Flammability tests, the necessary data were collected, analyzed, and interpreted using a quantitative approach. The results concluded that treated wood Sample 3, formulated with 10% carbonized rice husk ash (CRHA), 15% carbonized coconut coir ash (CCCA), and 75% sodium silicate (SS), was the most effective formulation compared to the other treated wood samples (Sample 1 and Sample 2) and the untreated wood sample (Sample 4). The formulated fire-retardant coating demonstrated promising results as an effective solution, reducing waste and dependence on harmful chemicals. Its potential applications extended to textiles and construction, offering a cost-effective and environmentally friendly alternative. Further research was recommended to explore controlled application methods and to broaden the understanding of this eco-friendly hybrid fire retardant coating, promoting wider adoption and contributing to both environmental sustainability and economic viability.

Keywords: Hybrid Fire Retardant Coating, Eco-Friendly Fire Solution, Sustainable Fire Safety, Harm-Free Fire Measures, Non-Toxic Fire-Retardant Alternatives

Introduction

In an era where environmental sustainability has become a global priority, the need for eco-friendly solutions in all aspects of life is more pressing than ever. According to Xue *et al*. (2021) [14], eco-based fire retardants have a chance to take the lead in helping everyone reduce fire, given the increasing worldwide ban on traditional fire retardants.

A problem shared by all Filipino citizens is the occurrence of fires, which drives them into poverty. In the nation of the Philippines, a lot of people experience fires, and it takes them a long time to recover to their previous way of life. Many of them do not receive assistance when the fire breaks out, which leads to the fire spreading throughout their community. If it is not addressed, lots of people have already suffered, and a lot more will. According to Kurata *et al*. (2023) [6], the Philippines is one of the countries in Asia known to be vulnerable to the severe effects of fire disasters. All Filipinos must be ready for any fire that may break out in their lifetime, even if it isn't expected to occur.

Alongside this worldwide issue and threat, a large percentage of people in the Philippines consume fire extinguishers as a solution to prevent the spread of fire in their area. However, the extinguisher's contents ran out fast, and the fire that is destroying homes in other parts of the Philippines hasn't been completely put out yet. Because of the pressure needed to release the extinguisher chemical, fire extinguishers empty quickly. For the flame to be reached and put out, this pressure is required.

Fire safety, a critical concern in both residential and industrial settings, has traditionally relied on chemical-based fire retardants. According to Lu *et al*. (2021) [10], flame retardants are an efficient technique to stop a fire from spreading, particularly if char has formed on the surface. When the fire is not yet spreading, it is best to use a flame or fire retardant coating to help extinguish the fire. According to Lai *et al*. (2023) [8], it is more successful to put out a fire with fire retardant to prevent it from spreading to other areas.

Fire accidents are extremely dangerous for the environment, property, and people's lives. A fire retardant can help to reduce the fire threat to human life. However, traditional fire retardants often contain harmful chemicals that can have effects on human health (Feiteiro *et al*., 2021) [5]. While conventional chemical-based fire retardants are effective, these conventional products often pose significant environmental and health risks, contributing to pollution and potentially causing adverse health effects in humans. According to *UNEP - UN Environment Programme* (2024) [13], flame retardants that are included in the Stockholm Convention show POPs, such as high persistence, a strong propensity for bioaccumulation and biomagnification, and the ability to travel over great distances. There is proof that they are hazardous to wildlife, especially mammals. Adverse consequences have been observed for people, rats, mice, birds, fish, frogs, and soil organisms. They have also been connected to hormone disruption, cancer, and other negative health impacts. Additionally, according to Collaborative for Health & Environment (2020) [3], conventional fire retardants do not easily break down, remaining in the environment for years and bioaccumulating in people and animals over time.

As a result, the search for sustainable and eco-friendly alternatives has gained momentum, aiming to protect both lives and the environment. In order to prevent the harmful effects of other chemicals on human health, eco-friendly hybrid fire retardant coating have a chance to take the lead in today's society, where environmental sustainability is a priority.

Recently, there has been a growing interest in utilizing waste and by-products from various sectors, particularly agriculture. When rice husk is burned, it produces around 20% ash, the main component of which is silica, which is usually amorphous when burned properly (Farid & Zaheer, 2023) [4]. Rice husk, a byproduct of rice milling, is burned to produce rice husk ash (RHA), which contains 85–95% amorphous silica. Silica is a crucial component in eco-friendly fire retardants due to its ability to slow heat transfer and impede flame spread.

Meanwhile, according to Hasan *et al*. (2021) [7], coconut coir, derived from the outer husk of coconuts, is a renewable and versatile material increasingly used in sustainable biocomposites. Coir fibers are valued for their strength, stiffness, and high lignin content (40-50%). Lignin in coir contributes to its thermal stability and flame retardancy by forming a protective char layer that reduces flame spread. Modified coconut coir can thus serve as an effective bio-based flame retardant, enhancing its utility in fire protection applications.

Additionally, sodium silicate, often known as water glass, is a non-harmful and non-toxic chemical that is a versatile and significant industrial chemical having numerous applications in a range of industries. Sodium silicate is water resistant, which is one reason or way to improve the effectiveness of hybrid fire retardant coatings (Li *et al*., 2020) [9]. Moreover, sodium silicate has the advantage of creating foam, which protects an object against fire and improves the effectiveness of fire retardant coating.

The student researchers observed that while there are previous and published research studies on fire retardants, there is a lack of studies on the combination of bio-based materials, like rice husk ash (RHA) and coconut coir, in the production of fire retardant and the development of fire retardant coating. This presents a unique opportunity to develop a product or output that not only mitigates fire hazards but also aligns with environmental principles. Thus, the purpose of this research study is to present two less widely used bio-based materials, rice husk ash and coconut coir, and a non-harmful chemical, which is sodium silicate, and investigate how they perform in terms of reducing or minimizing fire risks or hazards and preventing combustion. The major objective is to evaluate the suitability and effectiveness of carbonized coconut coir ash, carbonized rice husk ash, and sodium silicaten as the main components of an environmentally friendly hybrid fire retardant coating. This approach highlights the advantages of utilizing natural or nontoxic, eco-friendly materials instead of conventional chemical fire retardants, which may be hazardous to the environment and public health. Lastly, natural materials exhibit greater sustainability.

Objectives of the Study

This study aims to investigate and explore the effectiveness of utilizing carbonized rice husk ash, carbonized coconut coir ash, and sodium silicaten as the main components of an eco-friendly hybrid fire retardant coating. Specifically, it aims to (1) determine the essential materials needed to develop an effective and eco-friendly hybrid fire retardant coating; (2) determine the step-by-step procedures required to develop an eco-friendly hybrid fire retardant coating using carbonized rice husk ash, carbonized coconut coir ash, and sodium silicate; (3) determine how feasible and effective is the development of a rice husk ash and coconut coir-based fire retardant coating in terms of: A. Time to Ignition Test, b. Flame Spread Test, c. Flammability Test; and (4) determine the effectiveness of using carbonized rice husk ash, carbonized coconut coir ash, and sodium silicate as the primary components or materials in developing an eco-friendly hybrid fire retardant coating.

Methods and Materials

The student researchers utilize quantitative research, specifically the quasi-experimental research design. Quantitative research is the process of gathering and evaluating numerical data in order to characterize, predict, or control significant variables. This kind of study supports prediction-making, investigating or testing causal relationships between variables, and generalizing findings to larger populations. Quantitative research aims to test a theory or hypothesis and, depending upon the findings, to either accept or reject it. When researchers want to understand data sets across time and spot trends, they apply quantitative data analysis (Sreekumar, 2024) [11].

This research focuses on developing and formulating an eco-friendly hybrid fire retardant coating using carbonized coconut coir ash, carbonized rice husk ash, and sodium silicate. To effectively study the alternative materials of this coating, a clear understanding of the population and sampling methods are important. According to Thomas (2022), a quasi-experimental design seeks to demonstrate a cause-and-effect link between an independent and dependent variable, just like a real experiment does. But a quasi-experiment doesn't depend on random assignment like a real experiment does. Rather, non-random criteria are used to assign participants to groups.

As an alternative for modern fire retardant coating, the researchers are focusing on environmentally safe materials to support agricultural products. When choosing populations and materials, non-randomized sampling techniques are employed to prevent biases. Because of its inherent advantages, the components of the environmentally friendly fire retardant coating will be chosen. The researchers will employ non-randomized sampling, which is equivalent to quasi-experimental sampling, to obtain the evaluation needed to determine how effective the environmentally friendly components that will be utilized for making the fire retardant coating are.

In the current study, the student researcher will go through a step-by-step process to gather and collect the data required for the current study. The student researcher will conduct experiments as the research instruments. These experiments and tests are tools or methods used to collect, measure, or analyze data. According to Cheng *et al.* (2020) [2], experimentation is one of the most important steps in developing an environmentally friendly fire retardant coating. Student researchers must experiment in order to efficiently develop the final output. Continuous experimentation allows them to see whether the product is effective or not. An experiment also involves the systematic manipulation of variables to test hypotheses and generate data that can be analyzed to draw conclusions about cause-and-effect relationships.

The student researchers will apply and utilize quantitative data analysis methods to evaluate the effectiveness of their hybrid fire retardant coating formulation. It will begin by conducting a series of controlled experiments to measure the fire retardant properties of the developed coating. Data will be collected on various parameters, such as the time taken for flames to extinguish, the flame spread, and the time taken for the treated and untreated wood to ignite. These measurements will be recorded systematically, and the researchers will use statistical methods to analyze the data collected or gathered.

Results and Discussion

To clarify the following terms, here is their detailed meaning:

- CRHA – Carbonized Rice Husk Ash
- CCCA – Carbonized Coconut Coir Ash
- SS – Sodium Silicate.

Table 1: Flammability Test Data Table

Sample ID	Material Percentage	Ignition Time (s)	Burn Time (s)	Char Length (cm)	Flame Spread Behavior	Self Extinguishing (Yes/No)	Ashing (Yes/No)	Other Observations	Ranking
1	CRHA – 15% CCCA – 10% SS – 75%	12.81 s	00.00 s	4 cm		Yes	No	formed a white-grayish foam or bubbles on the wood surface, it only glowed and didn't form a flame, self-extinguished after removing the flame source	1
2	CRHA – 12.5% CCCA – 12.5% SS – 75%	6.00 s	00.00 s	4 cm		Yes	No	it only glowed and didn't form a flame, formed a white-grayish foam or bubbles on the wood surface, self-extinguished after removing the flame source	2
3	CRHA – 10% CCCA – 15% SS – 75%	4.66 s	00.00 s	4 cm		Yes	No	formed a white-grayish foam or bubbles on the wood surface, it only glowed and didn't form a flame, self-extinguished after removing the flame source	3
4	No fire retardant coating	11.20 s	173.28 s	8 cm	Rapid	No	Yes	continues to burn after removing flame source, the wood becomes weak after being burned, both sides are charred	

In performing the flammability test, the student researcher pointed the butane torch at the middle or center of the wood surface. The flammability test results indicate that the treated wood samples (Samples 1, 2, and 3) exhibited significantly better fire retardancy compared to the untreated wood (Sample 4). All treated samples self-extinguished after the ignition source was removed and showed no flame spread, while the untreated sample continued to burn with rapid flame spread, greater charring, and structural weakening.

Among the treated samples, Sample 1 (CRHA 15%, CCCA 10%, SS 75%) demonstrated the highest retardancy, with the longest ignition time, and was ranked as the most effective fire retardant mixture in performing the flammability test, followed by Sample 2 and Sample 3. The treated samples also formed a protective white-grayish foam or bubbles on the wood surface, which likely contributed to their flame retardancy.

In conclusion, the fire-retardant mixtures or combinations of carbonized rice husk ash, carbonized coconut coir ash, and sodium silicate are effective in improving wood's fire retardancy by preventing sustained burning and promoting self-extinguishing behavior. Sample 1, with the highest percentage of carbonized rice husk ash (CRHA), was the most effective formulation, suggesting that a higher proportion of CRHA may enhance fire retardant properties. The untreated wood (Sample 4) was the least fire-resistant, emphasizing the protective advantage provided by the fire retardant coatings.

Table 2: Time to Ignition Test Data Table

Sample ID	Material Percentage	Time to Ignition (s)	Visible Smoke (Yes/No)	Type of Ignition (Flame/Glow)	Surface Changes Before Ignition	Ignition Duration (s)	Other Observations	Ranking
1	CRHA – 15% CCCA – 10% SS – 75%	9.38 s	No	Glow	forms a white-grayish foam or bubbles on the wood surface	00.00 s	formed a white-grayish foam or bubbles	3
2	CRHA – 12.5% CCCA – 12.5% SS – 75%	10.56 s	No	Glow	forms a white-grayish foam or bubbles on the wood surface	00.00 s	formed a white-grayish foam or bubbles	2
3	CRHA – 10% CCCA – 15% SS – 75%	12.47 s	No	Glow	forms a white-grayish foam or bubbles on the wood surface	00.00 s	formed a white-grayish foam or bubbles	1
4	No fire retardant coating	4.96 s	Yes	Flame	forms charring	140.30 s	the wood becomes weak after being burned	

In performing the time to ignition test, the student researcher pointed the butane torch at the side-end or edge of the wood. The results indicate that the fire-retardant coatings made from rice husk ash (CRHA), coconut coir char (CCCA), and sodium silicate (SS) provide varying levels of effectiveness in delaying ignition and preventing flame spread. Sample 3 (CRHA – 10%, CCCA – 15%, SS – 75%) was the most effective, with the longest time to ignition (12.47 seconds) and no flame spread, indicating that it successfully delayed ignition and prevented sustained burning. Sample 2 (CRHA – 12.5%, CCCA – 12.5%, SS – 75%) followed closely, showing a slightly shorter ignition delay (10.56 seconds) but still preventing flames from spreading. Sample 1 (CRHA – 15%, CCCA – 10%, SS – 75%) ranked third, with a time to ignition of 9.38 seconds, but was still effective in forming a protective foam that stopped further flame spread. In contrast, Sample 4 (no fire retardant coating) ignited almost immediately, with rapid flame spread, high ignition duration, and extensive burn time, highlighting its lack of fire-retardant properties. These findings demonstrate that the combination of CRHA, CCCA, and SS in varying proportions can effectively delay ignition and prevent fire spread, with Sample 3 offering the highest level of protection.

Table 3: Flame Spread Test Data Table

Sample ID	Material Percentage	Time to Ignition (s)	Visible Smoke (Yes/No)	Type of Ignition (Flame/Glow)	Flame Spread Distance (cm)	Ignition Duration (s)	Total Burn Time (s)	Other Observations	Ranking
1	CRHA – 15% CCCA – 10% SS – 75%	9.38 s	No	Glow	forms a white-grayish foam or bubbles on the wood surface	00.00 s	00.00 s	formed a white-grayish foam or bubbles	3
2	CRHA – 12.5% CCCA – 12.5% SS – 75%	10.56 s	No	Glow	forms a white-grayish foam or bubbles on the wood surface	00.00 s	00.00 s	formed a white-grayish foam or bubbles	2
3	CRHA – 10% CCCA – 15% SS – 75%	12.47 s	No	Glow	forms a white-grayish foam or bubbles on the wood surface	00.00 s	00.00 s	formed a white-grayish foam or bubbles	1
4	No fire retardant coating	4.96 s	Yes	Flame	forms charring	140.30 s	246.13 s	the wood breaks after being burned	

In performing the flame spread test, the student researcher pointed the butane torch at the side-end or edge of the wood. Based on the observed time to ignition, type of ignition, and surface changes, Sample 3 (CRHA – 10%, CCCA – 15%, SS – 75%) is the most effective in terms of delaying ignition and preventing visible flame, followed by Sample 2 and Sample 1. Sample 4, with no fire retardant coating, is the least effective, as it ignites very quickly and leads to more significant surface damage.

In conclusion, the combination of carbonized rice husk ash (CRHA), carbonized coconut coir ash (CCCA), and sodium silicate (SS) can significantly improve the fire retardant properties of wood. Among the samples tested, Sample 3 demonstrated the most effective fire retardant properties, delaying ignition and preventing flames, while Sample 4, with no coating, allowed rapid ignition and flame spread and caused severe damage to the wood.

Conclusion

In conclusion, the formulation of rice husk ash, coconut coir, and sodium silicate demonstrates an efficient fire retardant coating, with Sample 3, formulated with 10% carbonized rice husk ash (CRHA), 15% carbonized coconut coir ash (CCCA), and 75% sodium silicate (SS), being the most effective among the treated samples. This hybrid formulation not only enhances fire retardancy but also utilizes agricultural byproducts, promoting environmental sustainability and reducing waste. The coating has potential applications in various industries, including textiles and construction, offering an affordable and eco-friendly alternative to traditional fire retardants, which are usually formulated with harmful and toxic chemicals. With continued research, its performance can be further improved, making it a more practical solution for widespread fire safety applications. Ultimately, this could benefit the environment, community, and public safety. The findings of this study suggest that materials like coconut coir, rice husk ash, and sodium silicate, which are readily available and sustainable, could serve as simple yet highly effective components for creating an eco-friendly fire retardant coating. This study aligns with research by Aramwit *et al*. (2023) [1] that rice husk ash and coir can provide a sustainable source for developing composites to build fire-retardant coatings. Coir provides excellent strength increase, and rice husk has good thermal retardancy, which is suggested to be used for making an eco-based fire retardant coating.

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