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AntifUEgo: Incorporating Chicken Eggshells and Oyster Shells in Jute Fabric as an Alternative Fire Retardant Textile

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ABSTRACT

The alternative fire -retardant textile AntifUEgo which is made up of jute cloth, oyster, and chicken eggshells is the focus of the study. Sustainable solutions are essential as fire accidents increase worldwide. Oysters and eggshells are investigated for their fire-retardant qualities since they contain an abundance of calcium carbonate ($CaCO_3$). The foundation fabric is of jute, renowned for its sustainability and toughness. This study assesses tensile strength, shrinkage, air permeability, and flammability by testing varying concentrations of eggshell and oyster shell solutions (Set A: 95%-5% and Set B: 90%-10%) on jute fabric against untreated jute fabric (Set C) and synthetic fire-retardant textile (Set D). The AntifUEgo solution is produced by mixing powdered shells with an acrylic copolymer binder and treated using a quantitative, quasi-experimental method using four set-ups with four trials on each test totaling 64 samples. The mentioned tests were done using the modified ASTM protocols. The data was analyzed using descriptive statistics and dependent and independent t-tests. Results show that Set A is better in all categories than Set B, which makes it the optimal ratio of the study. Against Set C, the optimal ratio significantly improves air permeability and flammability, with minor differences in shrinkage and tensile strength. Furthermore, against Set D, the optimal ratio shows negligible differences in shrinkage, air permeability, and flammability with a significant difference in tensile strength. The study achieves inference by creating a fire-retardant textile that is sustainable and cost-effective with a versatile application.

Keywords: fire-retardant textiles, agricultural waste, eggshells, oyster shells, jute fabric

The study by McNamee *et al.* (2019) brings attention to the global threat of fire-related fatalities and injuries, attributing these risks to resource scarcity, growing populations, and urbanization. Even industrialized regions such as the USA and Europe are not exempt from this danger, with most of the population residing in urban areas, a significant increase from 30% in 1950 to a projected 68% by 2050. Urbanization has intensified the risk of wildfires, particularly in emerging nations where regulations may be inadequate, leading to a rise in fire incidents, as exemplified by the Philippines' 21.1 percent increase in 2023 (Cariaso, 2024).

There is a growing reliance on fire-retardant materials, especially fabrics, to combat these issues. However, conventional options often involve carcinogenic fire-retardant chemicals, posing health risks (National Institute of Environmental Health Sciences, 2023). Hence, the crucial need for environmentally friendly alternatives. The study explores the potential of agricultural waste products, specifically egg (*Gallus gallus*) shells and oyster (*Crassostrea iredalei*) shells, as alternative fire retardants. Eggshells, composed principally of $CaCO_3$, can exhibit fire retardation properties when incorporated into fabrics (Yang *et al.*, 2023). Oyster (*C. iredalei*) shells, made up of 95% $CaCO_3$, can likewise provide a potential eco-friendly fire retardant (Ren, 2022).

In the search for fire-retardant fabrics, jute has been considered a potential fabric for its durability and biodegradability not to mention its other uses such as from clothing to household products (Nguyen, 2023). Jute is a plant-based material abundant in tropical countries like India and Bangladesh. This particular study combined jute fabric separately with eggshells and oyster shells and tested their features for potential as environmentally safe alternative fire-retardant textile. The results were similar to those of Farzana *et al*. (2022), showing the potential of jute fiber composites as an alternative to conventional fire retardants as shown by their cost-effectiveness, lightweight nature, and environmental friendliness.

The study aligns with the 12th Sustainable Development Goal of the United Nations (2024) which advocates that future processing and consumption of materials ensure sustainable patterns. In this study, food scraps such as seashells and eggshells, which end up in dumpsites and landfills, become sustainable source of $CaCO_3$ and used as a preventer and combatant against fire hazards. This study serves as an initiative in sustainable management and production and developing solutions for managing excess wastes common in urban and slum areas.

This research primarily aims to bridge existing gaps from Tseghai *et a.l*. (2019) and Silva *et al*. (2019) by exploring the application and combination of chicken (*G. gallus*) eggshells, oyster (*C. iredalei*) shells, and jute fabric as a potential alternative to conventional fire-retardant textiles. This innovative approach addresses health concerns associated with traditional fire retardants and aligns with the increasing preference for cost-effective, sustainable, and environmentally friendly materials in various industrial applications.

REVIEW OF RELATED LITERATURE AND STUDIES

Jute Fabric. Several industrial applications have found favor with jute's tenacity and robustness, as the Sewport Support Team (2019) has noted. The inherent biodegradability of jute textiles, resulting from their cellulose content, is highlighted in Nguyen's study (2023). This exceptional quality highlights the fabric's eco-sustainability and increases its longevity because it can be easily included in composting procedures. In spite of its vulnerability to fire just like other current materials, jute is still preferred because it is ecofriendly, biodegradable since it is made from plant as well as strong and readily available.

Chicken Eggshells. According to Butcher and Miles (2019), good-quality eggshells comprise 95% $CaCO_3$ with phosphorus, magnesium salt, and potassium traces. Other factors that affect the quality of eggshells are strength, thickness, size, and the hen's age. Waheed *et a.l*. (2020) suggested that eggshell waste, often considered a pollutant, can be utilized and applied in various ways like as fertilizers and as source of calcium as a nutritional requirement. Moreover, the mechanochemical treatment of eggshells can increase their applications, mitigate waste, and reduce environmental concerns (Balaz *et a.l.*, 2021). Additionally, its application is limited to the medical field and the textile industry, as a study conducted by Tseghai *et a.l.* (2019) showed the potential of chicken (*G. gallus*) eggshells to reduce the flammability of synthetic fire-retardant cotton fabric. These studies present the versatility and benefits of repurposing chicken (*G. gallus*) eggshells across different fields.

Oyster Shells. Ruslan *et al*. (2022) mentioned that oyster (*C. iredalei*) shell waste, which constitutes 90% of the total oyster mass contributed to 300,000 tons of waste in the last five years. The study pointed out the harmful effect of improper disposal of oyster shell waste on soil and water, especially noting the non-biodegradable nature of oyster (*C. iredalei*) shells and the release of toxic gases such as ammonia during decay, all of which can lead to health risks from environmental contamination. Silva *et al*. (2019) emphasized how promising $CaCO_3$ is as a vital raw material in various industries which can be sourced from numerous sources such as crustaceans and bivalve shells. Hapinat (2019) pointed to further use of discarded oyster (*C. iredalei*) shells for extinguishing small fires.

Tensile Strength. Yalcin (2021) defined tensile strength as the maximum amount of stress that a material can withstand before it breaks. Tensile testing involves application of a controlled tension on the sample until it breaks (Kumar, 2024). Materials with high tensile strength are preferably used in construction because of their durability and resistance to force. Tensile strength is important in material selection and improving product design. Steelfab (2020) stated that tensile strength refers to the maximum amount of stress a material can withstand without breaking or failing, and a material with high tensile strength tends to exhibit increased durability, malleability, and ductility.

Air permeability. As stated by Kiron (2012), Air permeability refers to the rate at which gas or liquid flows through a porous material. For textiles, it is essential for maintaining comfort by facilitating the movement of air, water, and vapor. This characteristic is an important measure of fabric quality and is often a deciding factor for manufacturers and buyers in the textile industry.

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Shrinkage. Shrinkage in fabric is the dimensional changes in length, width, or thickness of the fabrics, occurring in both positive and negative directions (Kiron, 2022). This affects garment fit, causing issues like seam puckering and torquing, making shrinkage testing important. Testing involves marking and washing a fabric sample to measure dimensional changes, with acceptable shrinkage typically under 5%, though it varies by buyer standards. Managing shrinkage is vital in textile manufacturing to ensure garment quality and consumer satisfaction.

Flammability. Safeopedia (2017) defines flammability as the ability of materials to ignite and the speed with which this occurs. Many materials are highly flammable, as long as certain conditions are met, which is why there is a need to conduct flammability testing where the samples are set up and are carefully exposed to controlled flames. In this test, researchers observe the speed in which the material ignites (Elmore, 2024). Different standardized tests are used to determine the flammability of materials. The Vertical Burn Test (ASTM D6413) is commonly used in textiles and fabrics which involves placing a sample vertically and subjecting it to a controlled flame to evaluate its capability to self-extinguish and resist the spread of flames ("The Importance of Flammability Testing in Ensuring Product Safety," 2023).

Fire Retardant. Riedel (2019) described chemical treatment of fire-retardant materials in order to prevent fires and flames. The American Chemistry Council's North American Flame Retardant Alliance (2019) refers to these substances as fire retardants that are capable of lessening heat release and preventing the spread of fire. These substances have been extensively used since the 1970s and are found in electronics, furniture, and building supplies. There is current research on these materials because of potential environmental and human health risks (National Institute of Environmental Health Services, 2023). Leveraging on their endothermic breakdown, inorganic substances such as $CaCO_3$ can function as gas-phase fire-retardants (Pondelak *et a.l.*, 2021).

Theoretical Framework

Previous studies show that tensile strength, shrinkage, air permeability, and flammability are all critical physical characteristics of fire-retardant fabrics. Velling (2020) referred to tensile strength as the material's ability to resist tension. Fabrics with greater tensile strength, therefore, are stronger and capable of withstanding force and pressure providing these fabrics with more versatile applications. Vaughn (2024) described shrinkage as the reduction in a textile's dimensions after exposure to washing or heat. Minimal shrinkage is critical for maintaining precise textile dimensions, so that fabric quality and longevity are ensured. Khan (2019) referred to air permeability as the volume of air that can pass through a fabric. Tighter fibers reduce air permeability, reducing oxygen exposure subsequently enhancing fire retardancy. Lastly, flammability is the tendency of a fabric to ignite, combust, and propagate flames. Tseghai *et al*. (2019) found that $CaCO_3$ from eggshells improved the fire-retardant properties of cotton, a typically flammable fabric.

This study looked into $CaCO_3$ as a key variable in fire retardancy. Han *et al.* (2023) showed the effectiveness of CaCO3, a non-combustible biomineral that is abundant in natural resources such as eggshells and oyster shells. The potential of $CaCO_3$ as a fire-retardant substitute is attributed to its release of carbon dioxide at very high temperatures in the process reducing the availability of oxygen. Hernandez *et al.* (2022) added that cooling and diluting combustible gases further reduce fire effectiveness. The combustion of $CaCO_3$ releases carbon dioxide gas ($CO2(g)$) and a white powder calcium oxide ($CaO(s)$) (Science Learning Hub, 2012). $CaCO_3$ enhances the fire-retardant properties of various materials such as concrete, paint, and textiles.

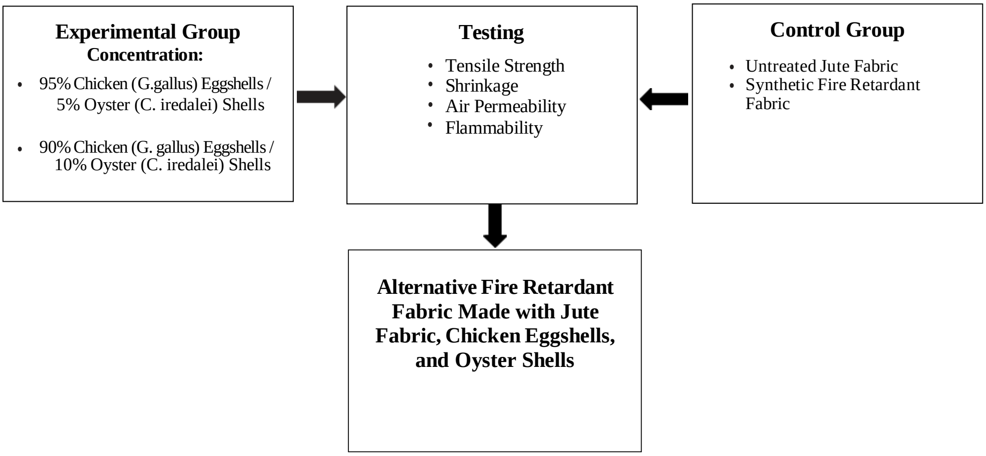
This study focused on the calcium carbonate content of eggshells and oyster shells because of its high melting point contributing to its fire retardant properties. Such characteristic of $CaCO_3$ merged with the jute fabric's biodegradability and toughness contribute to a potential alternative fire retardant fabric that can be accessible and sustainable.

Conceptual Framework

Figure 1 shows the experimental set-up and the control set-up that were tested for tensile strength, shrinkage, air permeability, and flammability. The experimental set-up involved two combinations with varying concentrations of chicken eggshells and oyster shells. The control set-up involved a commercially available fire-retardant fabric and an untreated jute fabric. The two set-ups were compared for tensile strength, shrinkage, air permeability and flammability. The results were analyzed to determine an alternative fire retardant fabric that can be developed from jute fabric, chicken eggshells and oyster shells.

Figure 1

Conceptual Framework



Objectives of the Research

The general objective of the research is to determine the possibility of developing an alternative fire retardant that is made up of jute fabric combined with eggshells and oyster shells.

The specific objectives include the following.

1. To determine the differences in tensile strength, shrinkage, air permeability and flammability of jute fabric combined with differing proportions of chicken eggshells and oyster shells
2. To compare the jute fabric with the combination that obtained optimum results in tensile strength, shrinkage, air permeability and flammability with untreated jute fabric
3. To compare the jute fabric with the combination that obtained optimum results in tensile strength, shrinkage, air permeability and flammability with the commercially available synthetic fire-retardant textile in terms of the same parameters

Significance of the Study

The study which aims to develop a fire-retardant textile from sustainable materials, such as jute fabric, oyster (*C. iredalei)* shells, and chicken (*G. gallus)* eggshells, to combat the frequent fire events that occur in the Philippines hopes to contribute to the improvement of food waste management and to reduction of fire risk in crowded regions with subpar electrical and structural materials. Communities may improve safety and cultivate a sustainable future by incorporating alternative fire-retardant materials into their homes.

Scope and Delimitation of the Study

The research focused on incorporating different formulas (95%-5% and 90%-10%) of shells as a fire-retardant coating in jute fabric to create an alternative fire-retardant textile. The shells were limited to chicken (*G. gallus*) eggshells and oyster (*C. iredalei*) shells. In contrast, the jute fabric was chosen simply as a base textile for the study due to its sustainability and durability. Other factors such as the jute fabric's components and build were not addressed in the study. The mentioned shells were used only for their $CaCO_3$ content as an additive, to improve the quality and fire retardancy of the jute fabric. The solution was created at one of the researcher's homes in Meycauayan, Bulacan. Subsequently, the textile underwent thorough testing at the University of the East-Caloocan Engineering Building. The study was completed in three months from January to April 2024 with a budget of P7,000.00 covering the expenses for materials, equipment, tokens, personnel and other expenses.

The study focused on features of an effective alternative fire-retardant textile, such as its tensile strength, shrinkage, air permeability, and flammability. These features contribute to the structural integrity and efficacy of the alternative fire-retardant textile. Other relevant parameters like heat release rate and smoke toxicity were excluded because of limited equipment, time facility, and funding.

MATERIALS AND METHOD

Research Design

This study used a quantitative and quasi-experimental research design to determine how the amount of oyster (*C. iredalei)* shells and chicken (*G. gallus)* eggshells in the jute fabric—affect tensile strength, shrinkage, air permeability, and flammability.

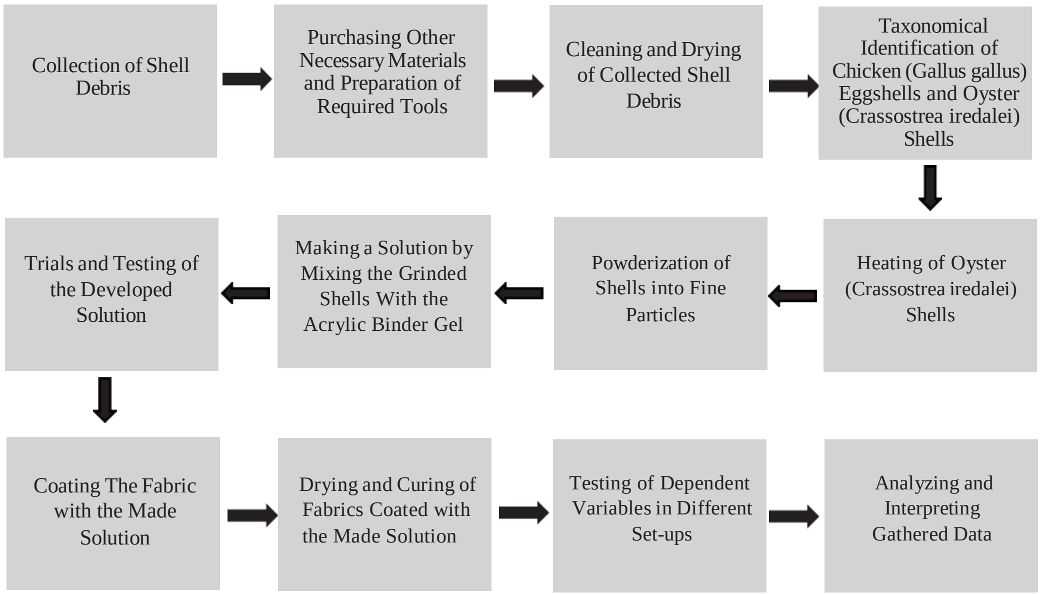
Samples

A total of 64 samples were used. Textile qualities such as tensile strength, shrinkage, air permeability, and flammability were compared across various setups representing different combinations of eggshells and oyster shells. The jute samples measured 5 cm by 20 cm except for the test on tensile strength where the samples were smaller following the protocol of Tseghai *et al.* (2019) Varying contents of oyster (*C. iredalei)* shells, chicken (*G. gallus)* eggshells, untreated jute fabric, and synthetic fire-retardant fabric were used. Four replicates for each test and set up were used to reduce bias and increase reliability following Slutz and Hess's (2017) methodology.

Experimental Setup and Materials

Figure 2 below outlines the step-by-step procedure, starting from gathering shell debris to data processing and interpretation.

Figure 2
Flowchart of the Procedure



Powderization. Collected chicken (*G. gallus*) eggshells and oyster (*C. iredalei*) shells were cleaned with water to remove unnecessary substances such as dirt and blood stains on the egg shells before sun-drying. The washed oyster (*C. iredalei*) shells were heated in an oven for 200°C for an hour to make them brittle (Hamester *et al*., 2012). The next step involves pulverizing the chicken (*G. gallus)* eggshells and oyster (*C. iredalei)* shells into fine particles using a blender with a coffee grinder attachment for about 3-5 minutes, using a fine flour mesh to sift large particles until the shell waste achieves a powdery or talc-like consistency.

AntifUEgo Solution. The powdered chicken (*G. gallus)* eggshells and oyster (*C. iredalei)* shells were placed in a small, dry container, with a ratio of 100g of powder per 100ml of acrylic copolymer binder measured using a weighing scale in modification of Tseghai's (2019) study. These shell components are manually mixed with an acrylic copolymer binder throughout the process. After mixing, it was stored in a plastic container in a dark room at room temperature.

Table 1
Fire-Retardant Solution Formulations

SET-UPS	Formulation		Amount of Eggshell Powder	
		Acrylic Binder	Chicken Eggshells	Oyster Shells
A	F1	100ml	95% (95g)	5% (5g)
B	F2	100ml	90% (90g)	10% (10g)
Control				
C	C1		Untreated Jute Fabric	
D	C2		Kevlar Fabric	

Table 1 shows the various setups used in the study. Based on the advice of experts from the UE College of Engineering and the Caloocan Fire Department, the solutions, for two distinct concentrations of chicken (*G. gallus)* eggshells and oyster (*C. iredalei)* shells were Set A consisting of 95 g eggshells and 5 g oyster shells and Set B consisting of 90 g of eggshells and 10 g of oyster shells. On the other hand, Set C and Set D which are controls did not contain any acrylic binder and shells.

Fabric Samples. The fabric used in the study is jute fabric, also known as a burlap sack. The researchers chose this fabric instead of other textiles due to its durability and ability to be used in industrial applications (Sewport Support Team, 2019). The jute fabric was cut into 16 pieces per set-up, totaling 48 pieces. The standard size of each sample is 20x20 cm (Tseghai *et a.l.*, 2019). Subsequently, the sample sizes were modified per experimental protocols. Moreover, each sample side was stitched to avoid tearing and unraveling. Lastly, the commercialized fire-retardant fabric was also cut and stitched into 16 pieces for experimentation, using the exact measurements and modifications mentioned above.

Coating, Drying, and Curing. The finished solution that contains chicken (*G. gallus*) eggshells and oyster (*C. iredalei*) shells were incorporated into a jute cloth using a roller forming machine by running through the machine only once. The distance between the two rollers of a roller forming machine is designed to be lower than the thickness of the working material to be manufactured (Ikumapayi *et* a*l*., 2020). Following a modified version of Tseghai *et al*.'s (2019) method, the cloth was submerged in water, then in the solution, and rolled to ensure even distribution. After sun-drying for approximately three days, a caliper was used to measure fabric thickness consistency.

METHODS

Tensile Strength. The tensile strength of the fabric is assessed using an ASTM D5034-21 modified grab test, where a bucket filled with weight is attached to the fabric until it breaks. The force exerted by the bucket is calculated using Equation 1.

Equation 1: Force

$$F = (mass/kg)\ (9.8m/s^2)$$

The fabric's area is determined by multiplying its length and width, measured with a caliper. Calculating tensile strength is done by dividing the force by area, yielding units of Newton per square meter (N/m^2) or Pascals (Pa) using equation 2.

Equation 2: Tensile Strength

$$tensile\ strength = \frac{Force}{Area}$$

Shrinkage Test. The textile was initially marked with a 10 cm by 10 cm rectangle. Following treatment, as per modified ASTM D7983-17 guidelines, the rectangle was remeasured to calculate the shrinkage percentage. Shrinkage was determined by comparing sixteen pre- and post-treatment area differences presented as percentages (Tseghai *et a.l.*, 2019).

Equation 3: Percent Shrinkage

$$\% \, shrinkage = \frac{Original Size - Final \ Size}{Original Size} \, x \, 100$$

Air Permeability. The test protocol ASTM D737 is modified to assess fabric breathability by measuring air permeability. The test is modified with an enclosed box featuring a 15x15 cm opening facing an electric blower. An anemometer measures wind velocity in feet per minute before and after placing 16 samples to cover the opening. Air permeability is calculated as the amount of air passing through a square foot of cloth in cubic feet per minute (CFM). Air permeability can be determined by repeating the test under different pressure conditions or comparing results to a reference fabric (Kiron, 2012). The formula is wind velocity (ft/min) multiplied by the opening area (ft^2), yielding CFM.

Equation 4: Air Permeability

$$air \, permeability = (wind \ velocity)(area)$$

Flammability. ASTM D6413, used for quality control and assessing material reaction to heat and flame, is modified in this study. Testing involves exposing the material to at least 150°C temperature using a butane torch regulated by a pyrometer. The test specimen is held 2 inches above the flame for 12 seconds. Data are collected on char length post-flame exposure, where the weakened area from burning is measured using a caliper.

Data Analysis

The study used the following tests to analyze the results in order to respond to the three objectives of the study.

The study used descriptive statistics to determine the optimal ratio of the alternative fire-retardant textile through the parameters of the study. Through descriptive statistics, the study compares the mean and standard deviation (SD) of Set-up A and Set-up B.

A dependent t-test was used to compare the optimal ratio identified in the first objective with and Set-up C. An independent t-test was used to compare the optimal ratio of the alternative fire-retardant textiles with synthetic fire-retardant textiles (Set-up D) sold commercially.

The raw data taken from comprehensive tests conducted in the Laboratory Department of the College of Engineering of UE Caloocan was inputted in Google Sheets after every trial, which serves as the database of the study. Every parameter of each set-up consists of 4 trials (e.g. Set-up A | Flammability Trial 1 - Trial 4), where the mean was obtained.

Equation 5: Average

$$average = \frac{Trial\,1 + Trial\,2 + Trial\,3 + Trial\,4}{4}$$

A separate sheet was made for data collected for each specific parameter. The curated data from the database was inserted in Jamovi which is a statistics-centered application. In this application, a sheet is made for every set-up and its parameters (e.g. Sheet 1: Set-Up A | Tensile Strength. The sheets were organized and comparisons were made using predetermined functions of the application such as descriptive and t-tests. The output created by the application contained graphs, interpretation, and visualization appropriate for the specific test used. The p-value was used to analyze the data against the null hypothesis and determining the statistical significance of observed differences in properties like tensile strength, shrinkage, air permeability, and flammability. An alpha level below 0.05 provides strong evidence against the null hypothesis (Singh, 2013).

The following reference was used in making conclusions.

Tensile Strength: The value of mean farther from 0 is better.
Shrinkage: The closer value of mean approaching 0 is better.
Air Permeability: The closer value of mean approaching 0 is better.
Flammability: The closer value of mean approaching 0 is better.

Ethical Consideration

The proposal was reviewed and approved by the Ethics Review Board of the Basic Education Department of UE Caloocan. Consent was obtained from stores and homes from where the eggshells and the oyster shells were collected. Protective personal equipment such as lab coats and gloves were used during the experiments (Hurrish, 2023). After the flammability test, the burnt fabric samples were cooled in water before disposal in the general waste bins, ensuring safety and responsible waste management (Toowoomba Region, 2024).

RESULTS AND DISCUSSION

Results of the study are shown in the following tables. Table 1 shows a comparison of the AntifUEgo fabric with different concentrations (90%/10% (set B) and 95%/5% set A) of eggshells and oyster shells solution based on tensile strength, shrinkage, air permeability, and flammability.

With an average tensile strength of 8.713 and a standard deviation of 0.790, Set-up A exhibits greater strength than Set-up B, whose strength is marginally lower at 8.185 and an SD of 0.456. With a mean of -2.139 and an SD of 4.285, Set-Up A exhibits an expansion or less shrinkage than Set-Up B, which has a mean of 0.195 and an SD of 1.587. Drying shrinkage is the change in a fabric's dimensions caused by the 'deswelling' of fibers, threads, and structural parts during the drying process. The laws of drying physics cause the structure to compress inward (Kiron, 2022). The air permeability in both configurations is 0.000 meaning both are airtight. With a mean of 1.150 and an SD of 0.191, Set-Up B exhibits greater flammability than Set-Up A, which has a mean of 0.685 and an SD of 0.282. Set-Up A exhibits similar air permeability, superior tensile strength, reduced shrinkage, and better flammability.

To summarize, Set-Up A exhibits similar air permeability, superior tensile strength, reduced shrinkage, and flammability meaning it can withstand greater stress and minimize fabric deformation, which are critical for long-term durability of the product. Thus, through these findings, set-up A is the best and optimal ratio of the alternative fire-retardant textile. Finding the ideal fire-retardant textile set-up that enhances flammability, durability, and shrinkage is significant. These changes are essential for sectors including construction, firefighting, and automobile manufacturing.

Table 2 shows the comparison of untreated jute fabric and the optimal concentration of the AntifUEgo fabric in terms of tensile strength, air permeability, shrinkage, and flammability.

Table 2.
Comparison of Set-up A and Set-up B in terms of different dependent variables

Test	Set-ups	Mean	SD
Tensile Strength (MPa)	A	8.713	0.790
	B	8.185	0.456
Shrinkage (%)	A	-2.139	4.285
	B	0.195	1.587
Air Permeability (CFM)	A	0.000	0.000
	B	0.000	0.000
Flammability (m)	A	0.685	0.282
	B	1.150	0.191

Set-up A was found to have the optimum concentration of chicken eggshells and oyster shells and was henceforth considered the treated sample that was eventually compared with the untreated samples. There were no discernible variations between the two setups for either tensile strength (t-value of 1.407 and corresponding p-value of 0.254) or shrinkage (t-value of 0.998 and p-value of 0.392). However, a t-value of 6.175 and a p-value of 0.009 comparing the treated to untreated samples showed considerably lower air permeability, and a t-value of 33.214 and a p-value of less than 0.001 showed significantly decreased flammability.

According to Kiron (2012), a fabric's air permeability has a direct impact on its comfort since it dictates how easily air flows through it. Materials with high air permeability offer limited wind protection, whereas fabrics with low air permeability restrict breathability. Fabrics with lower air permeability are better since they permit less oxygen entry and can therefore serve as better fire retardant. Eliminating one element from the fire triangle, such as oxygen, can cause the fire to be extinguished (Fire Action, 2017). In the flammability test, which included three degrees of freedom, a significant difference was found, with a high test value of 33.214 and a p-value of less than 0.001 indicating the rejection of the null hypothesis.

Set-up A solution therefore improved the jute fabric's flammability and air permeability suggesting that it is a more effective flame-retardant material than untreated textiles.

Table 3 shows the comparison between Set-up D (commercial fire retardant) and Set-up A in terms of tensile strength, air permeability, shrinkage, and flammability using independent T-test.

Table 3

Comparison of Set-up C and Set-up A using Dependent T-test

Test		**Set C**	**Set A**	**p*a*[a]**	**Remarks**
Tensile Strength	(MPa)	11.785	8.713	0.254	Not Significant
Shrinkage	(%)	0.000	-2.139	0.392	Not Significant
Air Permeability	(CFM)	0.529	0.000	0.009	Very Significant
Flammability	(m)	14.037	0.685	< .001	Highly Significant

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$; α= alpha level of 0.05

Results reveal notable variations in the tensile strength between the two textiles, with a t-value of 5.096 and a p-value of 0.014 indicating that synthetic fire retardant fabric has higher tensile strength than the treated jute fabric. Although the synthetic fire retardant fabric far exceeds the AntifUEgo Textile in terms of tensile strength, the AntifUEgo solution increased the tensile strength of untreated jute fabric, unlike other synthetic solutions, which were previously noted in Faysal *et al.* (2022) study which showed that synthetic chemicals not only reduce a fabric's tensile strength but also make it costly, hazardous to health and environment, and time-consuming.

Table 4 shows the outcomes of t-tests on independent samples, which were employed to evaluate the dependent variables of setup D (Kevlar) and A (optimal ratio).

Table 4

Comparison of Set-up D and Set-up A using Independent T-test

Test		**Set D**	**Set A**	**p*a*[a]**	**Remarks**
Tensile Strength	(MPa)	44.45	8.713	0.014	Very Significant
Shrinkage	(%)	0.00	-2.139	0.392	Not Significant
Air Permeability	(CFM)	0.000	0.000	0.000	No Difference
Flammability	(m)	1.20	0.685	0.062	Not Significant

Note. $H_a\ \mu_{\text{Measure 1 - Measure 2}} \neq 0$; *a*

a Levene's test is significant (p < .05), suggesting a violation of the assumption of equal variances

To summarize, Set-up D exhibited significantly higher tensile strength compared to Set-up A. Both set-ups however showed no significant difference in air permeability. On the other hand, the difference in data regarding shrinkage and flammability is insignificant. In terms of tensile strength, Set-up D is significantly higher than Set-up A in terms of shrinkage, air permeability, and flammability, there is no significant difference between Set-up A and Set-up D which means that Set-up A can offer a more environmentally friendly and possibly safer substitute for synthetic textiles.

These findings draw attention to the trade-offs between sustainability and performance, which are critical for sectors looking for environmentally friendly textile solutions, making Set-up A, a good alternative for a fire retardant textile.

CONCLUSION

Set-up A (95% eggshells and 5% oyster shells) exhibited better values throughout the tests than Set Up B (90% eggshells and 10% oyster shells). Set-up A was therefore deemed to show the optimal ratio. Compared to the untreated jute fabric, the optimal ratio showed a significant increase in air permeability and flammability whilst having no significant difference in tensile strength and shrinkage. Set-up A exhibited no significant difference in shrinkage, air permeability, and flammability compared to the commercially available fire-retardant fabric. But the commercially available fire-retardant fabric showed a better and more significant difference in tensile strength.

The study showed the potential of developing an alternative fire retardant textile from jute fabric mixed with chicken *(G. gallus)* eggshells and oyster *(C. iredalei)* shells. The sustainability, versatility, accessibility, and cost-effectiveness of this alternative were also described. Results from this study show that in addition to cotton, copolymer binder and eggshells that were previously worked on by Tseghai *et al.* (2019), oyster shells that contain $CaCO_3$ can be added to the list of alternatives that show potential as fire retardant and cause minimum environmental harm (Silva *et al.* 2019).

This study contributes knowledge to the growing interest in advancing sustainable textile production and solidifying the foundation for further improvements in natural fire-retardant treatments. Further studies may be needed to understand the mechanisms involved in improving flammability and tensile strength of treated natural fibers like jute (Set-up A). In developing alternatives, there are features that are non-negotiable such as flammability, air permeability, and shrinkage in favor of tensile strength. Sustainable fire-retardant textiles manufacturers should consider eco-friendly, adaptable treatments, including hybrid materials composed of natural and synthetic solutions and tested in the real world.

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