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Physical and Mechanical Properties of Polyvinyl Alcohol-Coated Cotton Fiber as A Bio-Synthetic Fishing Gear Material

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Abstract**—** Ghost fishing caused by lost or abandoned fishing gear remains a major environmental issue because most fishing gear components are made from synthetic materials that degrade slowly in marine environments. This study evaluated the feasibility of polyvinyl alcohol (PVA)-coated cotton rope as a bio-synthetic fishing gear material. Cotton rope specimens were coated with a 10% PVA solution and tested for their physical and mechanical properties. The effect of seawater immersion on degradation behaviour and technical service life was assessed through a 10-week immersion experiment. PVA coating significantly improved the mechanical performance of cotton rope, increasing its breaking strength from 21.97 kgf to 42.68 kgf and elongation from 13.00% to 20.11%. The estimated technical service life of the coated rope reached 54 weeks, compared with 17 weeks for uncoated cotton rope. These findings demonstrate that PVA-coated cotton rope is a promising bio-synthetic material for trammel net components and may contribute to reducing ghost fishing impacts.

Keywords— cotton ropes, fishing gear, ghost fishing, polyvinyl alcohol, trammel net.

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I. INTRODUCTION

The phenomenon of ghost fishing refers to the loss of fishing gear in aquatic environments, which continues to capture fish and other aquatic organisms without control from fishermen [1] [2] [3]. [4] argues that there are three main impacts of ghost fishing: its effects on habitat, species mortality, and the economy. Most ghost fishing incidents are caused by passive fishing gear such as nets (gillnets and trammel nets) and traps (fish pots) [5] [2]. Ghost fishing occurs because most lost or abandoned fishing gear is difficult to degrade in the ocean, leading to the unintentional and continuous capture of fish [6].

The prolonged degradation time of lost fishing gear occurs due to the synthetic materials used in its components, which are difficult to decompose. Synthetic materials used in fishing gear construction possess high strength and resistance to environmental factors such as water [7]. Several examples of synthetic materials, such as polyamide (PA), polyester (PES), polyethylene (PE), polyvinyl chloride (PVC), and polyvinyl alcohol (PVA), are the most commonly used components in fishing gear [8] [3]. To mitigate the ghost fishing phenomenon, research on environmentally friendly fishing gear materials is crucial. One alternative material for sustainable fishing gear is natural fiber.

Natural fibers are a type of fiber obtained from living organisms, such as plants and animal hair [7]. Natural fibers have several advantages over synthetic fibers, including being lighter in weight and environmentally friendly, as they are renewable materials [9]. However, natural fibers have limitations in terms of moisture resistance and relatively lower tensile strength compared to synthetic fibers [10]. Based on their characteristics, plant-based fibers (vegetable fibers) are the most widely utilized type of natural fiber.

Plant fibers are natural fibers composed of cellulose. Examples of natural fibers include cotton, kenaf, linen, ramie, flax, and sisal [9]. One type of plant fiber with potential use as an environmentally friendly fishing gear material is cotton rope. Cotton rope is widely utilized by fishermen as a material for handline fishing [11] [12], the net body of purse seine gear [13], the net body of gillnets [14] [15], and as a component in fish aggregating devices [16].

Cotton rope is a cellulose-based fiber, which results in a relatively short technical lifespan. This short lifespan is caused by the decomposition process by cellulolytic bacteria capable of degrading cellulose substrates [17]. Therefore, efforts are needed to enhance the durability of cotton rope against decomposition and to improve its tensile strength. To achieve this, the cotton rope will be coated with polyvinyl alcohol (PVA). Polyvinyl alcohol is a synthetic polymer produced through the polymerisation of vinyl acetate with polyvinyl acetate [18]. Polyvinyl alcohol has characteristics that allow it to form a protective coating effectively; it is non-toxic, biocompatible, and biodegradable [19].

The coating process using polyvinyl alcohol is conducted because this material has several advantages, including high elasticity, transparency, non-toxicity, resistance to chemicals, and relatively low production costs [20]. The application of polyvinyl alcohol on cotton rope is expected to enhance its tensile strength and elongation, making it a potential substitute material for fishing gear components. The improvement in tensile

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strength and elongation of the cotton rope is achieved by sealing and coating its cavities and pores. This method also aims to slow down the degradation rate of the rope and extend its technical lifespan after being coated with polyvinyl alcohol.

This study aimed to evaluate the feasibility of polyvinyl alcohol (PVA)-coated cotton rope as a bio-synthetic fishing gear material. Specifically, the study investigated its physical and mechanical properties, assessed the effect of seawater immersion on its degradation behavior and technical service life, and evaluated its potential application in trammel net fisheries as an environmentally friendly alternative to conventional synthetic materials.

Although previous studies have investigated biodegradable fishing gear materials and the application of PVA in packaging and biomedical fields, studies evaluating PVA-coated cotton ropes as bio-synthetic fishing gear materials remain very limited. This study is the first to comprehensively evaluate the physical characteristics, mechanical performance, degradation behaviour, and practical application of PVA-coated cotton ropes for trammel net components as a strategy to mitigate ghost fishing.

II. Method

The research was conducted at the Fishing Gear Laboratory and the Integrated Laboratory, Department of Fisheries Resource Utilization, Faculty of Fisheries and Marine Sciences, IPB University, from August to November 2024. The equipment used in the research included a portable stove, scissors, a digital scale, a ruler, a container box, a measuring glass, a thermometer, an aquarium pump, plastic containers, an aluminum pot, Olympus SZ61 zoom stereo microscopes, a Hung Ta HT-2402 universal testing machine, Microsoft Excel 2021, and Statistical Product and Service Solution (SPSS) software version 25. The materials used in the research were 3 mm diameter cotton rope, polyvinyl alcohol powder, glycerin solution, and seawater.

A. *Research Procedures*

The research began with the stages of specimen preparation, polyvinyl alcohol solution preparation, specimen coating, specimen immersion, physical property observation, and mechanical property observation using a Universal Testing Machine (UTM).

a. *Specimen Preparation*

Cotton ropes were cut into 400 mm. A total of 330 specimens were divided evenly into two groups: coated and uncoated. Each group underwent physical and mechanical tests with 11 replications (15 specimens each), following SNI ISO 1805 (2010), which requires a minimum of 10 specimens per test. The specimens used in this study consisted of 15 specimens per replication.

b. *Preparation of Polyvinyl Alcohol Solution*

The process of preparing the polyvinyl alcohol solution was carried out by making a 10% concentration polyvinyl alcohol solution. A 10% PVA solution was prepared by mixing 10 g of PVA powder with 100 ml of water at 60–90°C until homogeneous. Glycerin (100 ml) was added as a plasticizer to enhance coating flexibility by reducing intermolecular interactions and increasing elasticity. The plasticizer is a non-volatile substance that functions as a softener to improve the mechanical properties of the coating by altering the dimensional structure of the coating, reducing the inter-protein chain bonding, and filling the empty spaces within the coating material [21] [22]. The plasticizer used in the preparation of the polyvinyl alcohol solution is glycerin. The glycerin compound ($C_3H_8O_3$) is used as a plasticizer to produce a flexible and non-brittle polyvinyl alcohol coating (Andiati et al. 2022).

c. *Specimen Coating*

The cotton ropes were immersed in the PVA solution for 48 hours to allow deep penetration into the fiber structure. Post-immersion, the ropes were air-dried in a shaded indoor area. According to the guidelines stated in SNI ISO 1805 (2010), the immersion process for threads and ropes in a treatment must be carried out for at least 12 hours.

d. *Immersion of Specimens in Seawater*

Specimens were submerged in a circulating seawater tank to simulate marine conditions. Immersion lasted 10 week. The aim was to analyze the degradation rate and durability under prolonged exposure. The seawater used as the immersion medium maintained its salinity level and was not replaced throughout the study. The specimen immersion process lasted for 10 weeks. The duration of the immersion was based on the research by [23], which stated that cotton ropes begin to degrade within a period of 9 to 11 weeks after immersion.

e. *Physical Property Observation*

Physical characteristics such as diameter and mass were recorded. The mass of the specimens was measured using a digital scale in grams. Diameter was measured by wrapping the rope around a cylindrical object and dividing the wrap length by the number of coils [24].

f. *Mechanical Property Observation*

Mechanical tests assessed breaking strength and elongation using UTM, based on SNI ISO 1805 (2010). Specimen length between grips was set between 250–500 mm, with pulling speeds between 250–500 mm/min. The testing machine (UTM) used is equipped with a load cell capacity of 250 kN (kilo Newton). The testing device is also fitted with a graph recorder to monitor the increase in load and elongation until the rope breaks.

B. *Data Analysis*

The data analysis employed in this study consists of several methods, each serving a distinct function. Descriptive statistics were used to present physical and mechanical characteristics. Data normality was assessed using the Shapiro-Wilk test, followed by ANOVA to detect significant differences between treatments. A Completely Randomized Design (CRD) was applied for treatment comparisons.

III. Results and Discussion

A. *Characteristics of the Physical and Mechanical Properties of Cotton Rope as a Bio-Synthetic Fishing Gear Material*

The physical characteristics of cotton rope as a bio-synthetic fishing gear material are determined based on observations and examinations of the tested specimens, while the mechanical properties are obtained through prior testing. In detail, the physical and mechanical characteristics of cotton rope as a bio-synthetic fishing gear material are as follows.

a. Physical Characteristics of Cotton Rope

The specimens used in both treatments had an S-twist direction. Based on the type of twist, they belong to the 'soft' twist group as they have a twist angle of 35° (<40°). The twist direction of the cotton rope used can be seen in Figure 1.

The cotton rope without polyvinyl alcohol coating (control) has a diameter of 3 mm (±0.1 mm). Meanwhile, the diameter of the cotton rope coated with polyvinyl alcohol (treatment) ranges between 3.67–4.00 mm, with an average diameter of 3.83 mm. Based on the ANOVA test results, the P-value obtained is 6×10^{-3} (<0.05), indicating that the coating of the cotton rope with polyvinyl alcohol has a significant effect on increasing the rope's diameter.

The research results indicate that the control cotton rope exhibits a light cream color, tending toward white. The whitish light cream color of the cotton rope without polyvinyl alcohol coating originates from the natural fiber color surrounding the cotton boll, which serves as the raw material for cotton rope production [25] [26]. In contrast, the treated cotton rope has a darker cream color with a slight yellowish hue. This color change occurs because the polyvinyl alcohol layer permeates the cotton rope's pores and dries, resulting in a darker appearance of the coated cotton rope.

The control cotton rope has a smooth and soft surface texture with slight stiffness, whereas the treated cotton rope exhibits a rougher and stiffer texture. The difference in surface texture between the two specimens is attributed to the effect of the polyvinyl alcohol coating. In the treated rope, the polyvinyl alcohol material covers the entire rope surface and hardens, imparting a rigid texture to the cotton rope. The surface texture of the cotton rope is also significantly influenced by the twist density, fiber type, and fiber pattern [27]. The differences in physical characteristics, including color, stiffness, tactile sensation, diameter, and twist direction, are presented in Figure 2.

b. Mechanical Characteristics of Bio-Synthetic Fishing Gear Material

The mechanical characteristics of bio-synthetic fishing gear material ropes are measured based on breaking strength, tensile stress, and elongation. Breaking strength is the maximum load a rope can withstand just before it breaks [28]. A more detailed comparison of the breaking strength of cotton ropes coated with polyvinyl alcohol (treatment) and those without the coating (control) can be seen in Figure 3.

The normality test results using the Shapiro-Wilk method indicate that both polyvinyl alcohol-coated and uncoated cotton ropes follow a normal distribution, with P-values of 0.258 and 0.141, respectively (>0.05). The ANOVA (Analysis of Variance) results show that the breaking strength of polyvinyl alcohol-coated and uncoated cotton ropes differs significantly (P-value 4.33×10^{-9} (<0.05)). The average breaking strength of the polyvinyl alcohol-coated cotton rope is 42.68 kgf, whereas the uncoated cotton rope has a breaking strength of 21.97 kgf. The application of polyvinyl alcohol coating increases the breaking strength of the cotton rope by 94.26%. Meanwhile, a study conducted by [29] reported that the average breaking strength of synthetic ropes, such as polyethylene ropes with the same diameter, is 76.45 kgf.

The increase in breaking strength of the cotton rope coated with polyvinyl alcohol occurs because the polyvinyl alcohol layer fills the cavities within the cotton rope's pores, forming hydrogen bonds between the polyvinyl alcohol and the cotton fibers. These hydrogen bonds form due to the hydroxyl (-OH) groups in polyvinyl alcohol, which interact with the hydroxyl groups of cellulose in the cotton fibers [30]. The resulting hydrogen bonds enhance the adhesion between the polyvinyl alcohol layer and the cotton fibers, thereby increasing the breaking strength of the coated cotton rope

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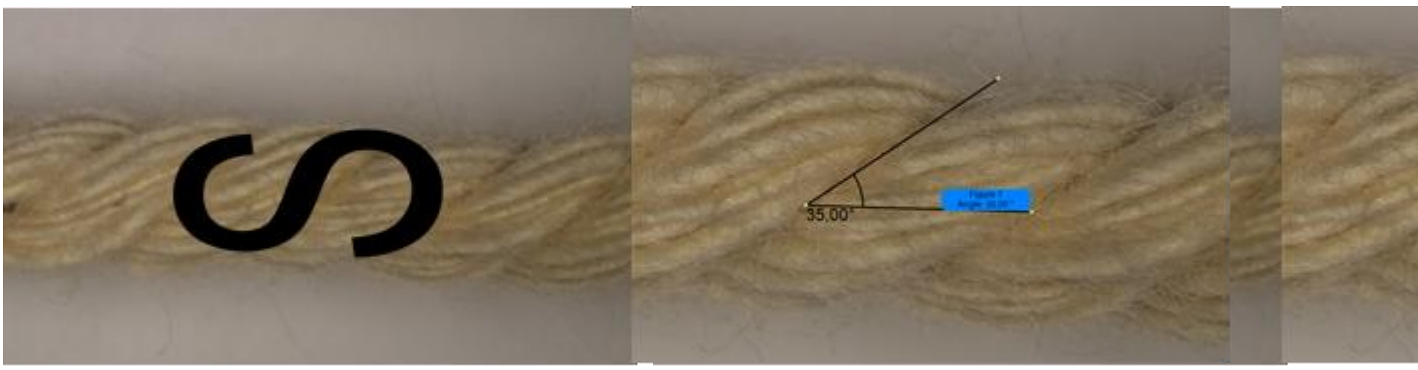

Figure 1 Twist direction and twist angle of the cotton yarn

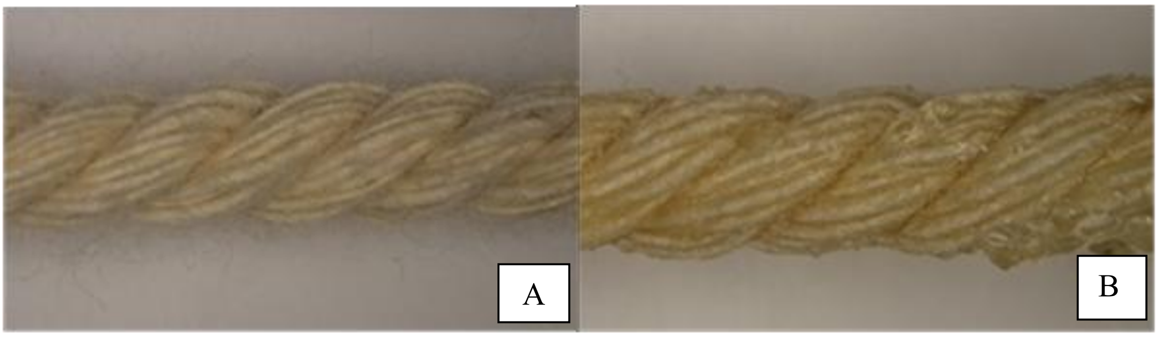

Figure 2 Physical form of bio-synthetic fishing gear material (a. treated, b. control)

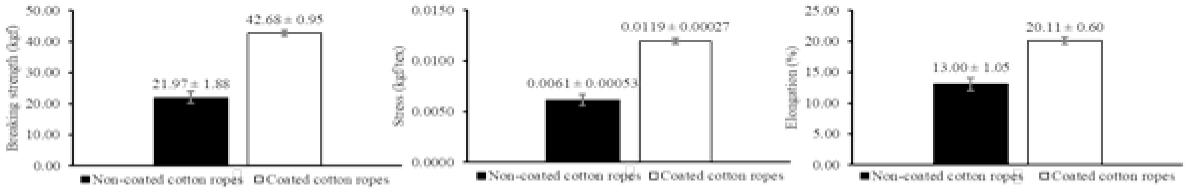

Figure 3 Mechanical Characteristics of Bio-Synthetic Fishing Gear Material

Stress refers to the deformation of an object caused by an external force acting upon it [1]. The magnitude of stress in a material is influenced by the rate of deformation of the tested rope [31]. Statistically, the stress values of polyvinyl alcohol-coated and uncoated cotton ropes differ significantly (P-value 4.26×10^{-9}, <0.05). The average stress of the polyvinyl alcohol-coated cotton rope is 0.0119 kgf/tex, whereas the stress of the uncoated cotton rope is only 0.0061 kgf/tex.

The statistical test results indicate that the polyvinyl alcohol coating process significantly affects the stress of the cotton rope. The coating process increases the stress of the cotton rope by 95.08%. Compared to the findings of [29], the average stress of synthetic ropes, such as polyethylene ropes with the same diameter, is 0.0214 kgf/tex. A comparison of the stress values between polyvinyl alcohol-coated and uncoated cotton ropes can be seen in Figure 3.

The application of polyvinyl alcohol also affects the elongation of cotton rope. Elongation refers to the increase in the length of the rope specimen after testing [28] [31]. The elongation of polyvinyl alcohol-coated and uncoated cotton ropes shows a statistically significant difference (P-value 1×10^{-3} (<0.05)) based on the Mann-Whitney test. The statistically significant difference confirms that the coating process with polyvinyl alcohol has a substantial impact on the elongation properties of cotton rope.

The cotton rope coated with polyvinyl alcohol exhibits an average elongation of 20.11%, whereas the uncoated cotton rope has an average elongation of 13%. The results indicate that the application of polyvinyl alcohol coating on cotton rope increases its elongation by 54.69%. In comparison, the average elongation of synthetic ropes, such as polyethylene ropes with the same diameter, is 0.84% [29]. The elongation of both the control and treated cotton ropes is presented in Figure 3.

The increase in elongation of the cotton rope coated with polyvinyl alcohol is presumed to be influenced by the elastic properties of polyvinyl alcohol after being mixed with a glycerin solution, which acts as a plasticizer. The addition of glycerin loosens the polymer molecular chains in polyvinyl alcohol, thereby enhancing its ductility [32].

A. Effect of Immersion on the Service Life of Cotton Rope as a Bio-Synthetic Fishing Gear Material

The immersion of cotton rope specimens, both coated with polyvinyl alcohol and uncoated, was conducted in seawater to evaluate its effect on the technical lifespan of the rope. The technical lifespan of fishing gear materials can be influenced by both internal and external factors. Internal factors include the chemical composition and material characteristics, while external factors involve environmental conditions such as currents, waves, catch load, and decomposing microorganisms [1].

The study shown, the cotton rope specimens were immersed for ten weeks in a container box filled with circulating seawater. The seawater was left unchanged to observe the degradation rate over time. This treatment aimed to assess the technical lifespan of polyvinyl alcohol-coated and uncoated cotton ropes. The determination of the technical lifespan was conducted by testing the breaking strength of the cotton rope. The graph illustrating the breaking strength of the specimens during immersion (per week) is presented in Figure 4.

The initial breaking strength of the polyvinyl alcohol-coated cotton rope before immersion in seawater was 45.15 kgf. As the immersion period increased, the breaking strength of the coated cotton rope fluctuated, although the overall trend showed a decline. By the 10th week of immersion, the breaking strength of the polyvinyl alcohol-coated cotton rope was recorded at 39.24 kgf. In contrast, the initial breaking strength of the uncoated cotton rope before immersion was 35.03 kgf. Compared to the coated cotton rope, the breaking strength of the uncoated cotton rope showed a significantly steeper decline. By the 10th week, its breaking strength had decreased to 15.81 kgf.

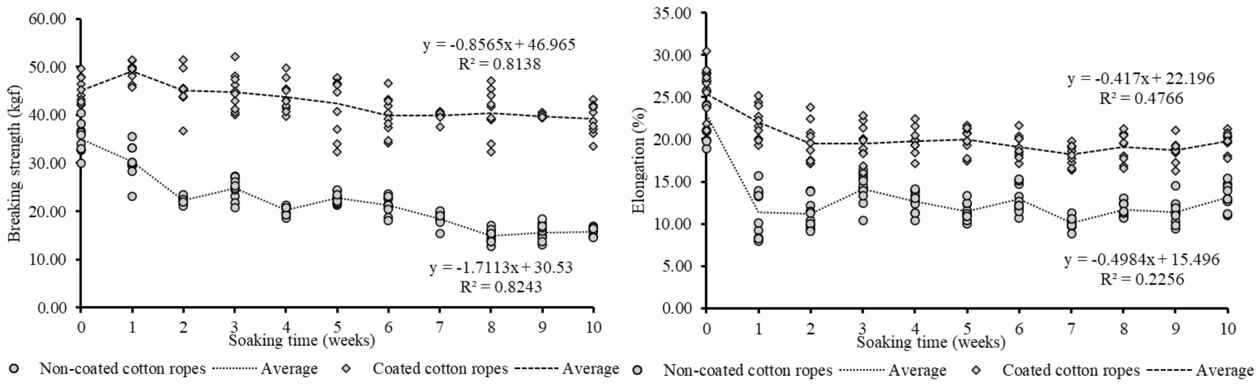

Figure 4 Effect of Immersion on the Service Life of Cotton Rope as a Bio-Synthetic Fishing Gear Material

Based on the regression equation between the immersion duration and the breaking strength, the regression equation for polyvinyl alcohol-coated cotton rope is $Y = -0.8565x + 46.965$, with a coefficient of determination (R^2) of 0.8138. This equation predicts that the coated cotton rope will fully degrade after 54 weeks (13 months) of immersion. Meanwhile, the regression equation for the uncoated cotton rope is $Y = -1.7113x + 30.53$, with a coefficient of determination (R^2) of 0.8243. According to this model, the uncoated cotton rope is expected to fully degrade after 17 weeks (4 months) of immersion.

The breaking strength of the polyvinyl alcohol-coated cotton rope is higher than that of the uncoated cotton rope. This higher breaking strength in the coated cotton rope is due to the ability of the polyvinyl alcohol layer to inhibit cellulolytic bacteria, which can degrade the cellulose substrate in the cotton rope. Visually, the water in the immersion container of the polyvinyl alcohol-coated cotton rope appeared murkier compared to the water in the container of the uncoated cotton rope. This turbidity in the immersion medium is suspected to result from the gradual natural degradation of the polyvinyl alcohol layer on the cotton rope.

The elongation of polyvinyl alcohol-coated cotton rope fluctuates over time during immersion. However, in aggregate, its elongation tends to remain constant, especially after the second week of immersion. The uncoated cotton rope exhibits more fluctuating elongation compared to the polyvinyl alcohol-coated rope. The elongation of uncoated cotton rope undergoes a significant decline after being subjected to immersion in seawater.

Before immersion in seawater, the polyvinyl alcohol-coated cotton rope had an elongation of 25.39%. After immersion, its elongation decreased. However, it remained relatively stable from the second week until the tenth week. The stable elongation during immersion indicates that the polyvinyl alcohol coating on the cotton rope helps prevent deformation (shape changes) when submerged in seawater or when used as a fastening component in fishing gear.

The uncoated cotton rope exhibited an elongation of 22.92% before being immersed in seawater. However, after undergoing immersion, its elongation experienced a drastic decline. Despite this, the elongation of the uncoated cotton rope tended to remain stable in the following weeks. This condition indicates that seawater immersion does not significantly alter the structure of the cotton rope.

The reduction in elongation of the uncoated cotton rope is suspected to be due to the degradation of its fiber structure. According to [33], this degradation process occurs due to the hydrophilic nature of natural fibers, which absorb water, leading to fiber swelling and the formation of gaps within the structure. Additionally, the degradation process is influenced by the activity of marine organisms present in seawater, which further contributes to the significant decrease in elongation of the uncoated cotton rope. A more detailed comparison of the effects of immersion on the elongation of both rope types can be seen in Figure 4.

The regression equation analysis between elongation and immersion time was conducted for each treatment. The regression equation for polyvinyl alcohol-coated cotton rope is $Y = -0.417x + 22.196$, with a coefficient of determination (R^2) of 0.4766. Meanwhile, the regression equation for uncoated cotton rope is $Y = -0.4984x + 15.496$, with a coefficient of determination (R^2) of 0.2256. Based on the coefficient of determination values in both treatments, it can be concluded that seawater immersion does not directly influence the changes in elongation experienced by the cotton rope.

B. *Recommended Application of Cotton Rope as a Bio-Synthetic Fishing Gear Material in Trammel Nets*

The breaking strength and elongation of cotton ropes coated with polyvinyl alcohol showed promising results. Cotton ropes coated with polyvinyl alcohol exhibited higher breaking strength and more stable elongation compared to uncoated cotton ropes. The application of polyvinyl alcohol-coated cotton ropes in trammel nets can be implemented as the lower riser line, sinker line, and the connecting line between the lower riser and sinker lines. The use of polyvinyl alcohol-coated cotton ropes in these parts is expected to reduce the negative impact of ghost fishing in the event that the trammel net is lost and becomes ghost gear. Cotton ropes coated with polyvinyl alcohol will degrade in a relatively shorter period compared to polyethylene multifilament or polyamide multifilament ropes. An illustration of the use of polyvinyl alcohol-coated cotton ropes in trammel nets is shown in Figure 5.

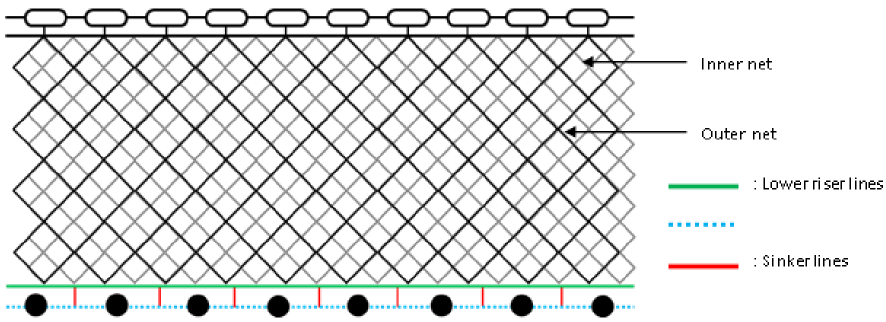

Figure 5 Design for the implementation of polyvinyl alcohol-coated cotton ropes in trammel net fishing gear

The installation of polyvinyl alcohol-coated cotton ropes on the trammel net as the lower riser line is illustrated in green in Figure 5, while the blue lines in Figure 5 represent the use of polyvinyl alcohol-coated cotton ropes as the sinker line, and the red lines illustrate the connecting lines. Consequently, if the deployed trammel net is lost and becomes ghost gear, the net body will float to the surface because the bio-synthetic fishing gear materials degrade faster than the other components. This allows lost trammel nets to be more easily detected for retrieval, thereby helping to mitigate the impact of ghost fishing.

C. Comparison of the Price of Polyvinyl Alcohol Coated Cotton Rope with Synthetic Rope

The most commonly used material for the ropes in trammel net fishing gear is synthetic material, such as polyethylene (PE) multifilament rope [34]. Components like the bottom riser rope, sinker rope, and the tying rope between the bottom riser and the sinker rope can be substituted with bio-synthetic fishing gear materials, such as polyvinyl alcohol-coated cotton rope. From an economic perspective, polyvinyl alcohol-coated cotton rope has a lower production cost compared to polyethylene rope.

The total cost of producing 1000 meters of polyvinyl alcohol-coated cotton rope with a diameter of 3 mm is Rp249,500.00. This cost includes Rp200,000.00 for purchasing cotton rope, Rp13,500.00 for polyvinyl alcohol powder, and Rp36,000.00 for glycerin solution. In comparison, the price of synthetic rope such as polyethylene with a diameter of 3 mm is Rp800.00 per meter, amounting to Rp800,000.00 for 1000 meters. Polyvinyl alcohol-coated cotton rope is 68.81% cheaper to produce than polyethylene rope, with a cost difference of Rp 550,500.00.

IV. Conclusion

The polyvinyl alcohol-coated cotton rope exhibited a darker cream color, increased stiffness, and a rougher texture compared to the control. The coated rope had a diameter of 3.83 – 4.00 mm with an S-twist, while the control had a diameter of 3 mm with the same twist. The coated rope had an average tensile strength of 42.68 kgf and an elongation of 20.11%, whereas the control had a tensile strength of 21.97 kgf and an elongation of 13%. Seawater immersion resulted in a gradual decline in tensile strength and elongation over time. The coated cotton rope degraded completely in approximately 54 weeks (13 months), while the control degraded in 17 weeks (4 months). The use of bio-synthetic fishing gear material in trammel nets can help mitigate ghost fishing. The coated cotton rope is suitable for use as the lower riser line and sinker line in trammel nets. If the net is lost, the bio-synthetic material will degrade faster than other components, reducing long-term environmental impact.

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