INVESTIGATION ON THE INFLUENCE OF MOISTURE CONTENT OF WOOD BEFORE PRESERVATIVE TREATMENT IN DIPPING DIFFUSION METHOD

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Degree of Master of Science in Civil Engineering

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The thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Civil Engineering

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Declaration

I hereby declare that this thesis entitled "INVESTIGATION ON THE INFLUENCE OF MOISTURE CONTENT OF WOOD BEFORE PRESERVATIVE TREATMENT IN DIPPING DIFFUSION METHOD" is the result of my original work and has not been submitted in part or in whole for any other degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text. All sources used in this thesis have been duly acknowledged and referenced.

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The above candidate has carried out research for the Master under our supervision.

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Abstract

Wood is a versatile and widely utilized material in various industries, ranging from construction to furniture manufacturing. In the context of the wood industry in Sri Lanka, The uses of wood in Sri Lanka date back to ancient times, with evidence of woodworking found in archaeological sites. This research aims to shed light on the intricate dynamics involved in the preservation and enhancement of wood quality by considering the specific effect of wood moisture content before dip diffusion treatment. This research conducted the quantitative industrial survey of mid-scale wood companies and qualitative testing procedures using Pine (*Pinus*), Hawarinuga (*Alstonia*), Mahogany (*Swietenia*), Mango (*Mangifera indica*), and Rubberwood (*Hevea brasiliensis*) types treated with two types of organic wood preservatives namely FSWOM, FSWM, and two types of industrial wood preservatives namely boron based treatment and ACQ.the wood samples tested with different moisture content level during six week. The study determined the recommended moisture content ranges for the selected wood preservative types and wood types. Pine wood can be recommended for FSWOM, FSWM, ACQ and Boron at 18% to 22 %. And considering Alastonia wood can only recommend FSWM moisture content range of 26 % to 30 %. consider the Mahogany wood can only recommended FSWM moisture content range of 24 % to 28 %. Also, Mango wood can recommended FSWOM moisture content range is 16 % to 26 %, FSWM is 16 % to 28 %, ACQ is 18 % to 28 % and Boron is 16 % to 22 % for Mango wood. Finally, Rubberwood moisture content is recommended as FSWOM moisture content range is 14 % to 17 %, FSWM is 14 % to 18 %, ACQ is 15 % to 18 % and Boron is 15 % to 18 %. Alstonia and Mahogany null hypothesis accepted. Can not recommend moisture ranges for FSWOM, ACQ and Boron. It would affect other factors to the Alstonia wood preservatives uptake. The study confirms the moisture content significantly affects the uptake of preservatives during wood treatment. The experimental findings indicate that preservative uptake is limited by the moisture content present in the wood.

Keywords: Dip diffusion, moisture content, organic preservatives, preservative uptake, wood treatment.

Acknowledgment

I immensely express my deepest gratitude to my research supervisor, Prof.R.U.Halwathura of the Department of Civil Engineering, for the guidance, encouragement, and immense knowledge. Also allowed me to conduct research under his supervision.

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Dedication

This dissertation is dedicated to my loving parents and sister for their endless love, support, and encouragement!

Also my supervisor Prof.R.U.Halwathura for giving me this valuable opportunity to conduct research!

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Gratitude and dedication to all the Sri Lankan citizens who provide their support to free education.

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List of Abbreviations

Cross-laminated timber (CLT)

Laminated veneer lumber (LVL)

Liquefied Petroleum Gas (LPG)

Moisture Content (MC)

Alkaline Copper Quaternary (ACQ)

Chromate Copper Arsenate (CCA)

Final Solution Without Mud (FSWOM)

Final Solution With Mud (FSWM)

Life Cycle Assessment (LCA)

Chapter 01: Introduction

1.1 Background of the study

Amidst its rich ecological diversity, Sri Lanka has artfully balanced traditional practices and modern techniques to sustainably harness its abundant wood resources for a myriad of cultural, economic, and environmental purposes. The uses of wood in Sri Lanka date back to ancient times, with evidence of woodworking found in archaeological sites(Pushpakumara et al., 2023). The diverse ecosystem allowed for a wide range of tree species to thrive, including Jack, Mahogany, Ebony, Teak, etc The harvesting and processing of wood was a skilled trade, with specialized techniques being used to ensure the quality and durability of the timber. Over time, the aroma and design characteristics of timber transform due to prolonged exposure to various climate conditions. The dynamic interaction between wood and its exposure to various climatic conditions. The olfactory properties of timber evolve as a result of environmental factors such as temperature, humidity, and atmospheric conditions (Wijesinghe, 2003). One of the most prominent uses of wood in ancient Sri Lanka was in the construction of religious buildings such as temples, shrines, monasteries, and Ambalam(Mendis et al., 2020). The intricate carvings and embellishments found in these structures showcase the high level of craftsmanship and skill processed by ancient Sri Lankan woodworkers(Daswatte, 2012).

Therefore, Wood is a versatile and widely utilized material in various industries, ranging from construction to furniture manufacturing. In the context of the wood industry in Sri Lanka, it becomes imperative to investigate and understand the relationship between wood treatment and wood moisture content before wood preservative treatment(Mendis & Halwatura, 2023). This research aims to shed light on the intricate dynamics involved in the preservation and enhancement of wood quality, considering the specific practices employed in Sri Lanka.

Wood preservation techniques are crucial for prolonging the service life and improving the durability of wood products, especially in a tropical climate like Sri Lanka. The country's diverse ecosystems and abundant timber resources make it essential to optimize wood treatment processes to ensure the longevity and sustainability of wooden structures and products. Properly treated wood can withstand harsh environmental conditions, resist decay, and effectively resist insect attacks, thereby reducing maintenance costs and contributing to the overall development of the wood industry(Sudeshika et al., 2020).

A fundamental factor influencing the efficacy of wood preservation is the initial moisture content of the wood before treatment(Grosse et al., 2018). Moisture content plays a vital role in the penetration and retention of preservatives, as it directly affects the diffusion and distribution of treatment chemicals within the wood matrix. The intricate interplay between wood moisture content and treatment procedures is a complex area that requires systematic exploration and analysis(Taylor et al., 2006).

While Sri Lanka is known for its various wood preservation practices, there remains a need for comprehensive research to evaluate the effectiveness and efficiency of these techniques(Abeysinghe & Amarasekera, 2011). By studying the relationship between wood treatment and wood moisture content, this research seeks to contribute to the scientific knowledge and practical application of wood preservation in Sri Lanka. Findings from this study will serve as a valuable resource for wood industry professionals, and researchers, enabling them to make informed decisions regarding wood treatment practices and improving the overall quality and durability of wood products.

This research project aims to advance our understanding of the wood industry in Sri Lanka by examining the intricate relationship between wood treatment and wood moisture content before preservative treatment. By investigating the specific wood preservation practices employed in the country, this study will provide valuable insights into optimizing wood treatment processes and enhancing the durability and longevity of wood products. Ultimately, this research endeavors to contribute to the sustainable development of the wood industry in Sri Lanka and provide a foundation for future advancements in wood preservation techniques.

1.2. The research problem

In the wood industry of Sri Lanka, several preservative treatment methods are particularly practiced. However, a survey and literature review conducted in this industry has revealed a significant gap in the consideration of moisture conditions before applying chemical treatments to wood. Current practices often neglect to account for the moisture content of the wood before treatment, which can have a substantial impact on the effectiveness of the wood preservation process.

This indicates that the moisture conditions of wood play a crucial role in its chemical treatment. The moisture content influences the diffusion and distribution of preservatives within the wood matrix, affecting chemical uptake and retention. However, this important factor is often overlooked in current wood treatment practices in Sri Lanka.

The lack of emphasis on the moisture condition of wood before initiating chemical treatments poses several implications. Firstly, it can result in inefficient use of wood preservatives, as the absence of optimal moisture conditions may hinder the desired chemical uptake. This inefficiency leads to increased costs and environmental concerns associated with the excessive use of preservatives. Secondly, neglecting the moisture condition may compromise the effectiveness of wood treatments, as improper chemical distribution within the wood structure may lead to inadequate preservation outcomes, reducing the durability and longevity of wood products.

To bridge this research gap and address the importance of considering moisture conditions, the objective of this research is to identify the optimum moisture content required before initiating wood treatment. By determining this optimal moisture level, the research aims to enhance the effectiveness and efficiency of wood treatments in the Sri Lankan context. This investigation will provide valuable insights into the correlation between moisture conditions and chemical uptake in wood, enabling industry professionals to make informed decisions and adopt best practices for wood preservation.

By focusing on this research gap, this study aims to contribute to the existing knowledge and practices in the wood industry of Sri Lanka. The findings will not only enhance the understanding of the relationship between moisture conditions and chemical treatment efficacy but also provide practical guidelines for optimizing wood preservation processes. Ultimately, addressing this research gap will lead to improved preservation outcomes, reduced costs, and a more sustainable approach to wood treatment in Sri Lanka.

1.2 Research objectives

The study comprises of following objectives, They are,

I. To Investigate the Wood Preservative Practices in the Colombo District.

The primary objective of this study is to investigate the wood preservative practice methods employed in Colombo district, Sri Lanka. A thorough examination will be conducted to understand the current wood industry practices, techniques, and approaches used for wood preservation. This objective aims to gather comprehensive information on the existing wood preservative methods, and preservatives utilized. This study seeks to establish a baseline understanding of the industry's current state in Sri Lanka.

II. To Identify Preservatives Uptake in Wood Concerning Preservative Treatment.

The second objective of this research is to identify the preservative uptake in wood concerning preservative treatment. This objective aims to assess and compare the effectiveness of different wood preservatives in the ability of preservatives to uptake. Various types of preservatives, both artificial and organic, will be examined to determine their respective preservative uptake capacities by various moisture content levels.

III. To evaluate the Effect of Moisture Conditions on Chemical Uptake.

The third objective of this study is to evaluate the effect of moisture conditions on the chemical uptake in wood. Different moisture conditions. The objective is to understand how varying moisture conditions impact the chemical uptake process and subsequently affect the effectiveness of wood preservative treatment.

By addressing these research objectives, this study aims to contribute to the advancement of wood preservative treatment practices.

1.4 Research Methodology

The methodology included the following five steps.

i. Conduct a Literature Review on Wood Preservative Treatments.
ii. Conduct the industrial survey to identify the wood industrial behavior and practices then identify Low-Durable Wood Species for Chemical Preservative Treatment.
iii. Designing and optimization in the test and Analysis part of preservative uptake.
iv. Investigate the preservative Uptake with Varying Moisture Conditions.
v. Conducted the preservative uptake Tests to Determine Optimum Chemical Uptake.

The first step of this research involves conducting a comprehensive literature review on wood preservative treatment. This review will encompass various scholarly articles, research papers, and industry reports to gather a wide range of information on the subject. The literature review will focus on understanding the principles and mechanisms of wood preservative treatment, exploring the different types of preservatives available, and examining their effectiveness in enhancing wood durability. Additionally, it will investigate the factors influencing the uptake and retention of preservatives in wood, including moisture content, wood species, and preservative types. This literature review will serve as a foundation for developing a sound research framework.

Secondly, To identify suitable low-durable wood species utilized in Sri Lanka for dip diffusion preservative treatment, an industrial survey assessment will be conducted. This assessment will involve collecting samples of commonly used wood species in Sri Lanka and evaluating their inherent durability characteristics and will be employed to determine the vulnerability of each wood species to biological degradation. The results of these tests will aid in identifying the low-durable wood species that would benefit from preservative treatment.

Then will compare the chemical uptake of different types of artificial wood preservatives and two types of organic wood preservatives. A series of treatment experiments will be conducted using selected wood species, applying each preservative type separately. The treated wood specimens will be analyzed using appropriate analytical techniques to measure the preservative uptake and retention within the wood matrix. By comparing the chemical uptake profiles of the various preservatives, this analysis aims to evaluate their efficiency and effectiveness in enhancing wood durability.

Fourthly, investigate the effect of moisture conditions on the chemical uptake in wood, the research will involve treating wood specimens under different moisture conditions. The moisture content of the wood specimens will be adjusted to represent various scenarios, including green wood, and air-dried wood. The preservative treatment process will be conducted following standardized protocols, and the resulting chemical uptake will be quantitatively measured. This investigation aims to determine the optimal moisture condition for achieving the highest preservative uptake, thus maximizing the effectiveness of wood preservative treatment.

Finally, to detect the optimum chemical uptake concerning moisture conditions on wood, chemical absorption tests will be conducted. Wood specimens will be subjected to varying moisture conditions, and the preservative treatment will be performed. The treated specimens will then undergo chemical absorption tests, where their chemical retention and distribution within the wood matrix will be evaluated. These tests will help identify the moisture condition that leads to the highest and most uniform chemical uptake, providing valuable insights into optimizing wood preservative treatment processes.

By employing this methodology, this research aims to deepen our understanding of wood preservative treatment in Sri Lanka. The systematic literature review, identification of low-durable wood species, comparative analysis of preservative types, investigation of chemical uptake with varying moisture conditions, and chemical absorption tests will collectively contribute to improving the knowledge and application of wood preservative treatment techniques. Ultimately, the findings of this research will facilitate the development of effective and sustainable practices in the wood industry of Sri Lanka.

1.5. Findings

The major findings of the study are summarized as follows,

i. The optimal moisture content was determined for wood treated with the dip diffusion technique using four different wood preservatives: FSWOM, FSWM, ACQ, and Boron. Five specific wood species were chosen for this study, namely Pine, Alstonia, Mahogany, Mango, and Rubber.

ii. The newly developed wood preservatives exhibit similar reactions to the wood preservative types commonly used in the industry.

1.6 Dissertation structure

Chapter 01 delivers the introduction to the research topic, and the first section of the chapter describes the background of the research, followed by the significance of the study, aim and objectives, and research gap, a summary of the methodology, main findings, and the arrangement of the research report.

Chapter 02 is described in the literature review of the study. Chemical and structural composition of the wood, uses of wood especially construction sector and limitations, wood modification methods and effect of moisture content for the wood modification,

Chapter 03 provides the detailed methodology used in the research study. including the research design, data gathering procedures, schedule, and data analysis technologies through the different processes are also presented in this chapter.

Chapter 04 presents the results obtained from the analysis process. This section reports the findings of the study based on the results of the data analysis and discusses the results and findings along with the objectives of the study. Also, major findings are discussed along with the research objectives while evaluating how the results and findings are consistent with the same in the literature.

Chapter 05 illustrates the conclusion, recommendations, and suggestions for further research to improve the understanding of the study and future work that can be done based on this research.

Chapter 2: Literature Review

2.1 Chapter introduction

This literature review focuses on the impact of wood moisture content on wood modification. Wood, as a natural resource, has been utilized for numerous applications due to its unique properties and abundance. However, wood is also subject to limitations such as dimensional changes caused by moisture fluctuations, which can compromise its structural integrity and durability. Understanding the relationship between wood moisture content and its modification is crucial in enhancing its properties and addressing these limitations.

Wood, derived from trees, consists primarily of cellulose, hemicellulose, and lignin, with minor amounts of extractives and moisture. It finds extensive applications in construction, furniture manufacturing, paper production, and as a renewable energy source. To overcome the limitations associated with wood, various modification methods have been developed. These techniques, including chemical modification, thermal treatment, and mechanical processing, alter the chemical composition, physical structure, and mechanical properties of wood.

Wood moisture content plays a significant role in wood modification. Fluctuations in moisture content can lead to warping, cracking, twisting and decay, which necessitate effective strategies for moisture control. Moreover, wood preservatives are employed to protect wood from environmental degradation. Traditional preservatives have been widely used, but newer organic and novel preservatives offer improved efficacy and reduced environmental impact. However, it is essential to consider the environmental implications associated with wood modification and treatment. Chemical treatments can introduce toxic substances into the environment, necessitating sustainable practices to minimize potential harm. This literature review aims to explore the interplay between wood moisture content and various wood modification techniques, including the selection and effectiveness of wood treatment methods, while considering the environmental impact.

By examining the existing knowledge on this topic, Aim to contribute to the understanding of how wood moisture content affects wood modification. Through this review and seek to provide insights into strategies for enhancing the durability and performance of wood products while minimizing their environmental impact.

2.2. Background of the wood

Wood has been an integral part of human civilization for centuries, serving as a versatile and sustainable material with a wide range of applications. Its unique combination of strength, beauty, and natural abundance has made it a valuable resource for various industries and everyday uses (Ruwanpathirana, 2012). However, despite its numerous advantages, there are limitations to its utilization, and concerns about its long-term durability and environmental impact persist. Wood plays a significant role in the environment and ecosystem. As a renewable resource, it contributes to carbon sequestration, mitigating climate change. Additionally, wood serves as a habitat for various organisms, supporting biodiversity and ecological balance (Sikkema et al., 2017). The sustainable management and utilization of wood resources are critical for maintaining the delicate equilibrium of forest ecosystems. Wood is a complex and versatile natural material that serves as a vital resource for various industries and applications. Wood is a multifaceted material. Its chemical composition, anatomical structure, mechanical properties, and ecological significance make it the subject of extensive. The continued exploration and understanding of wood hold immense potential for advancing industries, preserving natural resources, and promoting sustainable development (Ruwanpathirana, 2012).

2.2.1. The chemical composition of wood

Wood comprises carbon, hydrogen, and oxygen as its primary chemical constituents. Through the intricate combination of these three elements, a complex array of organic compounds emerges, including cellulose, hemicellulose, lignin, and extractives. These compounds play pivotal roles in defining the unique characteristics and properties inherent to wood (Zhang et al., 2015). Cellulose, a polysaccharide, represents a significant portion of wood's chemical composition. It forms a rigid framework within wood cells, conferring structural integrity and contributing to its mechanical strength. Composed of elongated chains of glucose units, cellulose molecules establish robust hydrogen bonds that impart stability to the wood structure(Mendis & Halwatura, 2023).

Hemicellulose, comprising a group of polysaccharides, assumes the role of a binding agent within the wood. It fosters the cohesion of cellulose fibers, establishing an interconnected network. Hemicellulose encompasses diverse sugar units like xylose, glucose, and mannose, thereby adding to the compositional diversity observed across different wood species. Lignin, a complex polymer, occupies the interstitial spaces amidst cellulose and hemicellulose in wood cells (Mai et al., 2022). It bestows rigidity and strength on the wood structure by acting as a natural adhesive. Comprising phenylpropane units such as coniferyl, sinapyl, and p-coumaryl alcohol, lignin's aromatic nature contributes to the distinctive brown coloration and resistance to decay exhibited by wood (Sjostrom, 2013).

Extractives, organic compounds found in wood, do not constitute integral structural components. They encompass resins, oils, tannins, and pigments, among others. Extractives exhibit significant variation across wood species and contribute to specific properties such as fragrance, coloration, and resistance against pests or deterioration. Therefore wood's chemical composition primarily revolves around carbon, hydrogen, and oxygen. The fusion of these elements yields a diverse spectrum of organic compounds, including cellulose, hemicellulose, lignin, and extractives. Comprehending these chemical constituents is vital to understanding wood's distinctive attributes and applications (Yuan et al., 2022).

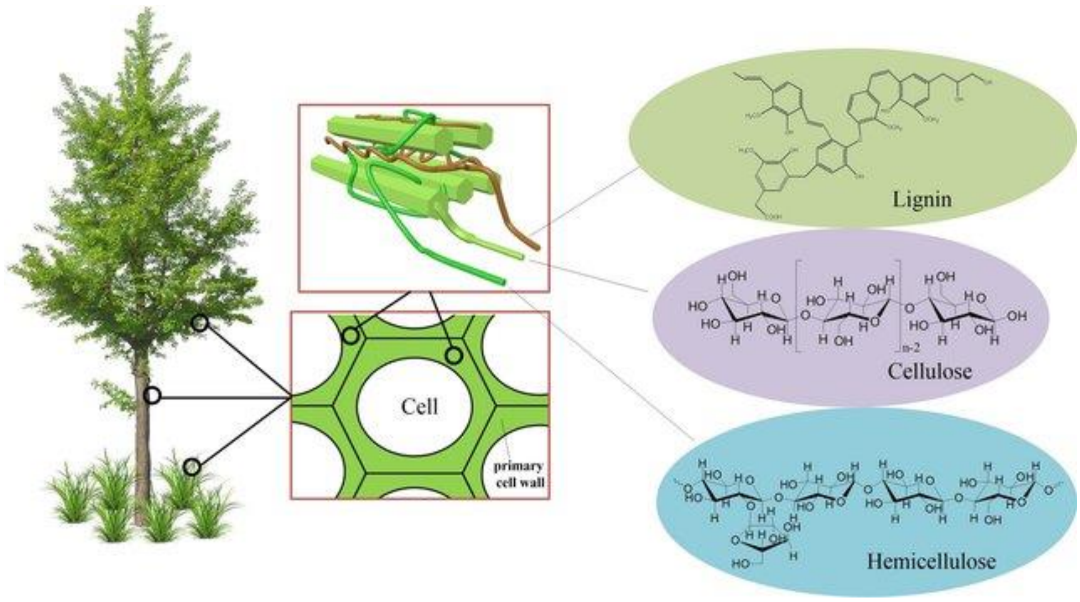


Figure 1:Moliculer structure of Cellulose, Hemicellulose, and Lignin(Yuan et al., 2022).

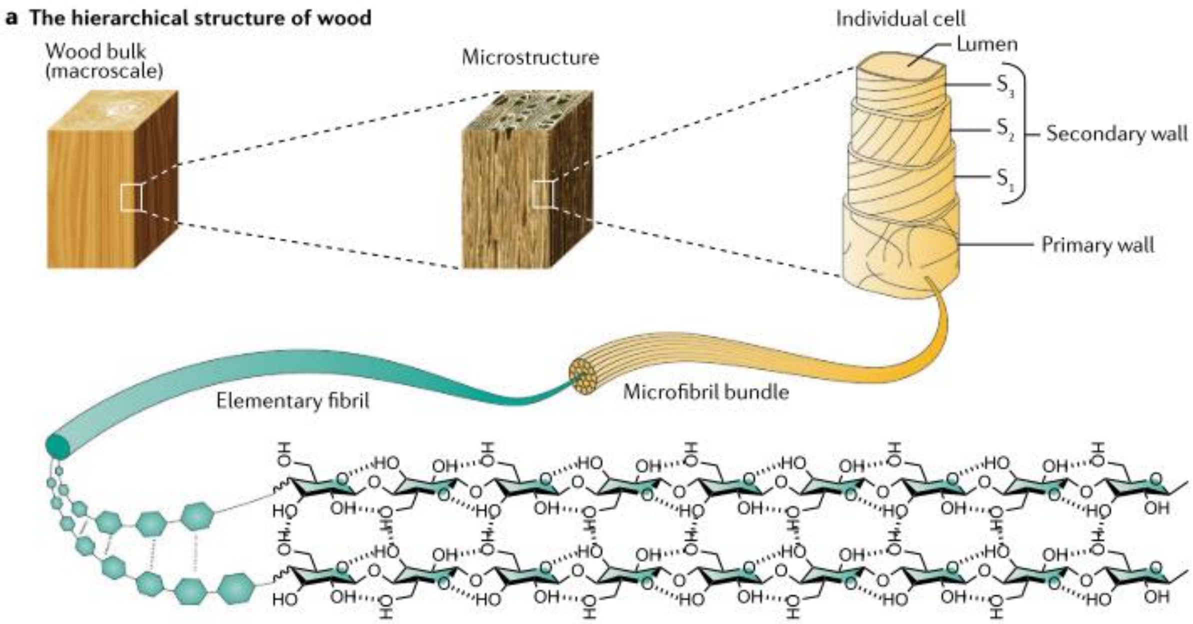


Figure 2: The hierarchical structure of wood (Chen et al., 2020).

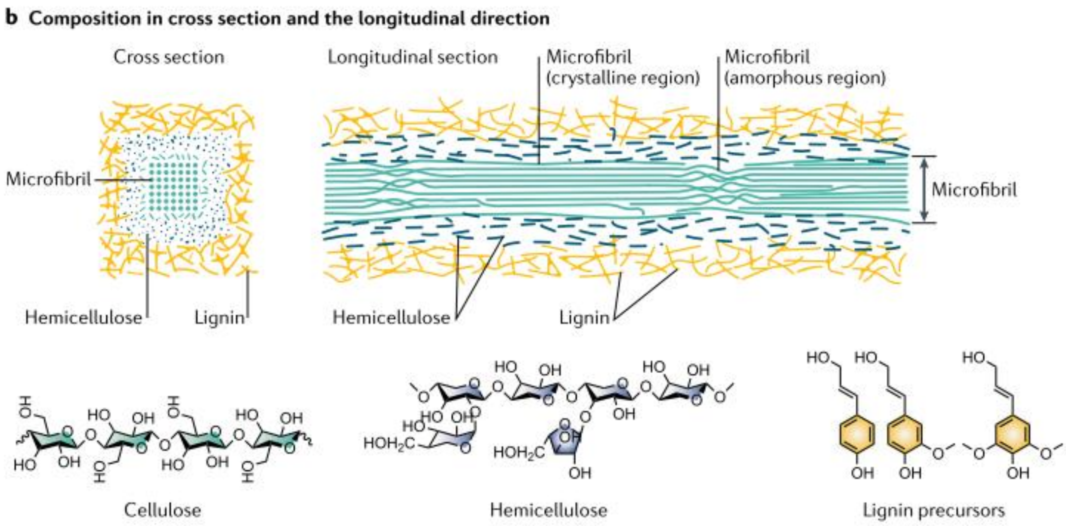


Figure 3: Composition in cross-section and the longitudinal direction (Chen et al., 2020)

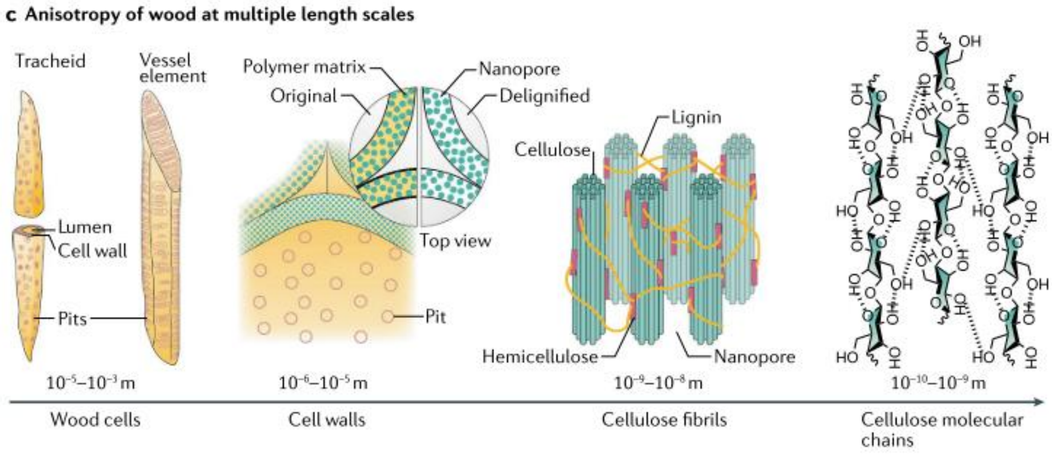


Figure 4: Anisotropy of wood at multiple length scales (Chen et al., 2020).

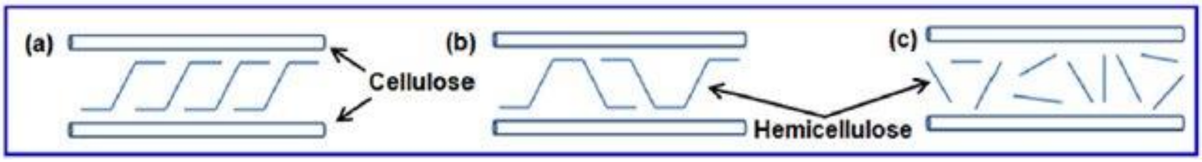


Figure 5: The schematic representations of three different binding modes of hemicellulose chains to the cellulose microfibrils: (a) bridge, (b) loop, and (c) random scattering(Zhang et al., 2015).

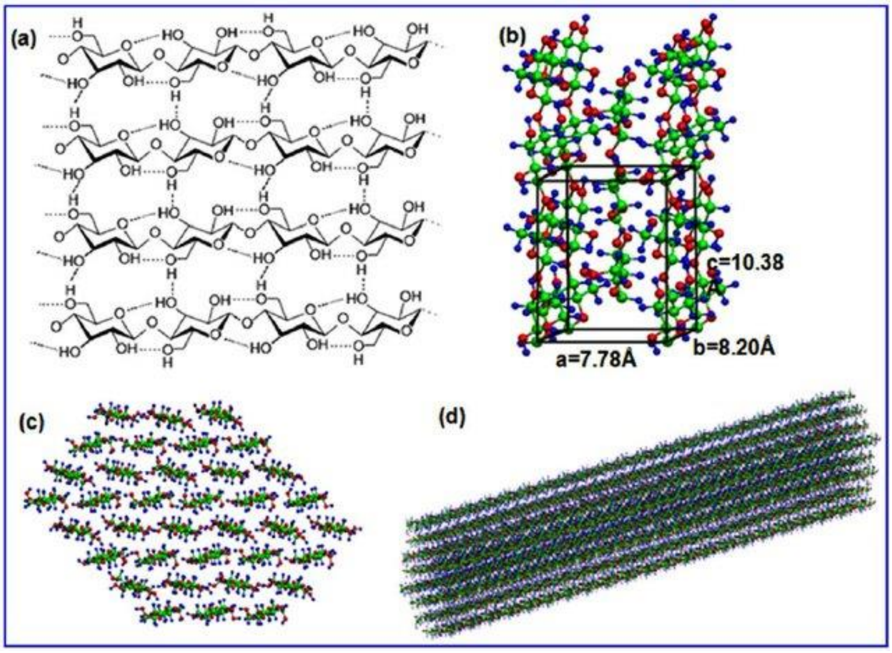


Figure 6:(a) The network of hydrogen bonds in cellulose microfibrils; (b) Crystalline structure of a unit cell of cellulose; (c) Cross-sectional view and (d) 3D view of a cellulose microfibril bundle(Zhang et al., 2015).

2.2.2 The anatomical structure of wood

Consider the anatomic structure of conifers and angiosperm plants have different variations but the role of axial and ray parenchyma is combined in every two groups (Carlquist, 2018). The anatomical structure of wood consists of various cell types and these have unique functions such as transportation, storage, and support 20 x magnification makes it easy to identify different types of cells in hardwood and softwood types, including vessels, fibers, and parenchyma cells (Richter, 2015). Vessels, responsible for water conduction, are hollow cylindrical structures that form a network throughout the wood. Fibers, elongated and thick-walled cells, contribute to the mechanical strength of wood by providing tensile and flexural properties. Parenchyma cells, often found in storage tissues, aid in nutrient storage and transport.

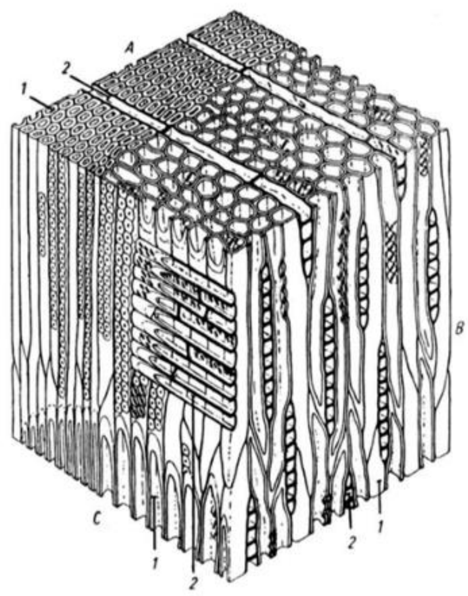


Figure 7: Microscopic structure of softwood. A Cross section, 1 tracheid, B tangential section, 2 wood rays, and C radial section (Richter, 2015).

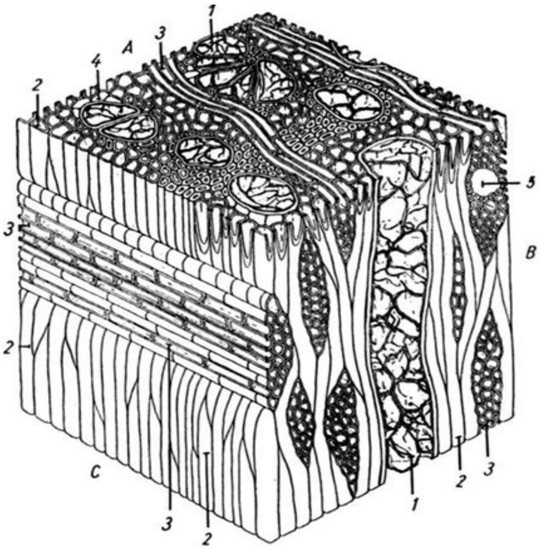


Figure 8: Microscopic structure of hardwood, A Cross section, 1 vessel with tylosis, B tangential section, 2 libriform fi bers, C radial section, 3 wood rays, 4 longitudinal parenchyma (Richter, 2015).

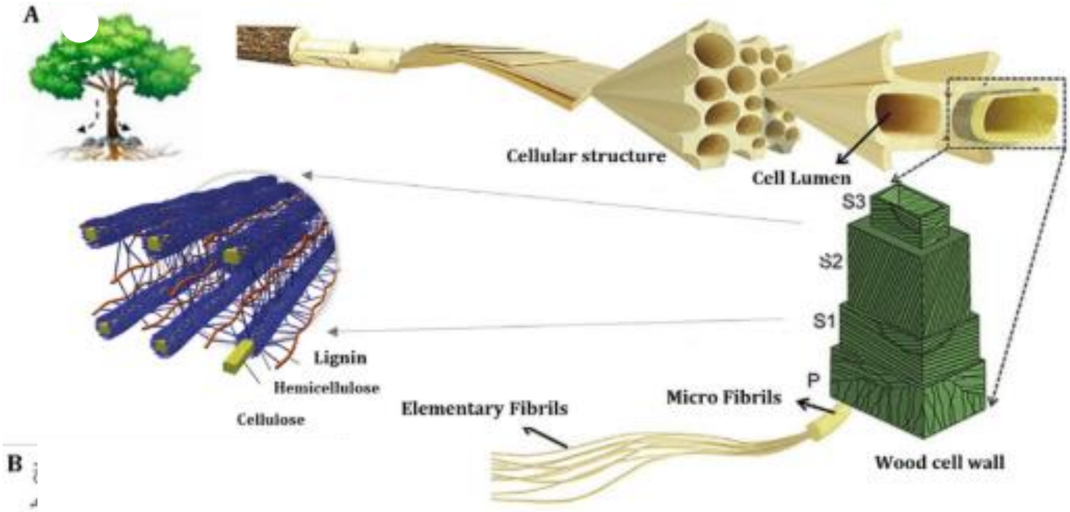


Figure 9: Cell Structure, Cell Lumen, Wood cell wall, Micro Fibrils, Elementary Fibrils (Mendis & Halwatura, 2023).

2.2.3 The mechanical properties of wood

Wood is described as an orthotropic material because wood has unique and independent mechanical properties in the directions of three mutually perpendicular axes, such as longitudinal, radial, and tangential. The longitudinal is parallel to the fiber, the radial axis is normal to the growth rings and the tangential axis is perpendicular to the gain. Mechanical properties are elastic properties, strength properties, vibration properties, etc. (Kretschmann, 2010). The mechanical properties of wood are influenced by its microstructure and composition. It possesses a remarkable strength-to-weight ratio, making it suitable for construction and engineering applications. The anisotropic nature of wood, exhibiting different mechanical properties along different grain orientations, adds to its complexity. Understanding the mechanical behavior of wood is crucial for designing structures, predicting their performance, and ensuring their safety and reliability (Lian et al., 2022).

2.3 Wood as Construction Material

Throughout human history, wood has been a crucial resource due to its versatility, durability, and natural beauty, making it highly sought after for diverse applications.

(Altaner, 2022*)*. The demand for specific wood properties is influenced by social, economic, and environmental factors, all of which contribute to determining its value and significance in various industries. From construction to furniture making, wood's unique combination of strength, durability, and aesthetic appeal has cemented its position as a preferred material for countless applications (Wegner et al., 2010). This provides an in-depth analysis of the uses of wood and its contributions to various industries and the following describes several main uses of wood. Considering these factors wood can be used as,

Table 1:vairiuse industry of wood

Industry	uses
Construction	building materials (Pramreiter et al., 2023), structural properties (Mendis et al., 2020)
Furniture and Interior Design	furniture manufacturing (Nyrud et al., 2014), (H.Amarsekera,W.C.Dheerasekera, 2007)
Packaging and Pallets	transportation and storage of goods (Weththasinghe et al., 2022), (Singh et al., 2010)
Energy Production	the primary source of heat energy (Srivastava et al., 2023), (Brostow et al., 2010)
Paper and Pulp Industry	raw material (Ashwath et al., 2023), (Mishra & Singh, 2023)

Wood in Manufacturing	veneers, plywood, particleboards, and fiberboards (Ruwanpathirana, 2016), flooring producers, manufacturers of wood-based panel products, and carving businesses (Perera et al., 2022)

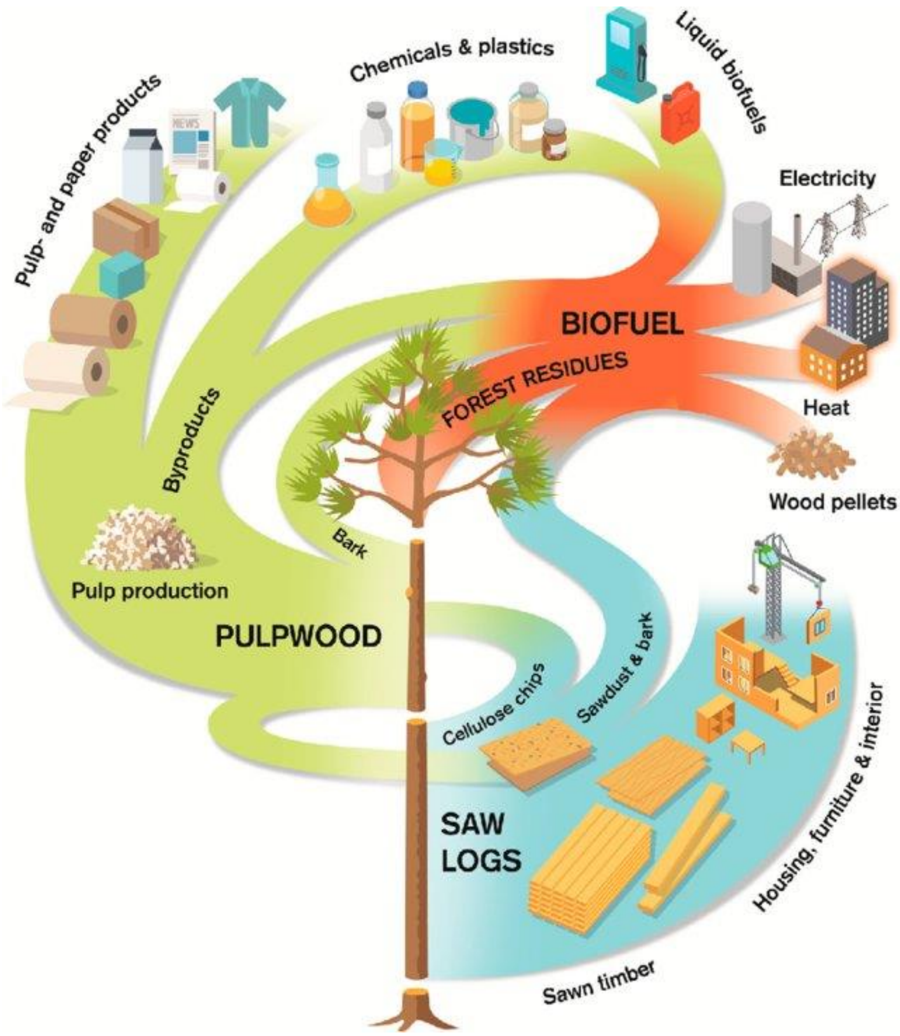


Figure 10: The efficient use of harvested wood (Sikkema et al., 2017).

The demand for specific wood properties is influenced by social, economic, and environmental factors, all of which contribute to determining its value and significance in various industries. From construction to furniture making, wood's unique combination of strength, durability, and aesthetic appeal has cemented its position as a preferred material for countless applications.

The shift towards creating environmentally sustainable cities has sparked a renewed interest in wood as a renewable construction material. To avoid potential shortages of raw materials in the future, prioritizing the use of wood in durable, resource-efficient engineered wood products and structures is crucial (Pramreiter et al., 2023). Wood has great potential as a building material because the wood is lightweight, used as an environmentally friendly sustainable material, and can be used in prefabricated buildings. And also wood changes the building code from steel and concrete. wood has been used to build a shelter for many thousand years (Wimmers, 2017). And also construction due to its structural properties such as Temples, Ambalam, Tampita, Dewala, Towers, and bridges. Over the years, construction timber has undergone a transformation from traditional usage to the development of "engineered wood," which offers significantly enhanced strength and stability compared to regular wood.

Figure 11 Temples, Ambalam, Tampita (Mendis et al., 2020).

This advancement has provided builders, architects, and designers with the opportunity to construct superior and larger structures. As a result, it has expanded the potential applications of construction timber, creating possibilities for future technological advancements in the field (Himandi et al., 2021)

Recent studies have focused on engineered wood products, such as cross-laminated timber (CLT), glulam, and laminated veneer lumber (LVL), which offer increased strength and design flexibility. LVL and CLT could be used for constructing mid to high-rise buildings and hybrid structural systems are frequently used (Shirmohammadli et al., 2023) Wood is also utilized in traditional construction methods for framing, flooring, roofing, and cladding, contributing to sustainable building practices (Mendis et al., 2020).

2.4 Main limitations of wood utilization as construction material

Wood is a valuable and renewable resource that offers numerous benefits. However, it is crucial to acknowledge and address the limitations associated with its utilization. the main limitations of wood utilization, including challenges related to sustainability, durability (Frihart, 2015), fire resistance (Schmid et al., 2019), dimensional stability (Rowell et al., 2009), and susceptibility to pests and decay (Claverie et al., 2020). Understanding these limitations is essential for promoting responsible and efficient wood usage in various applications.

2.4.1 Deforestation

Deforestation stands as a significant environmental concern, particularly as the demand for timber products experiences rapid growth in developing nations. As the need for timber products rises, it exacerbates the pressure on forests, leading to deforestation and associated ecological consequences (Damette & Delacote, 2011). One of the primary limitations of wood utilization is the potential for unsustainable harvesting practices. In developing countries, deforestation rapidly continues with population growth. The most serious consequences of overexploitation of forests can lead to deforestation, habitat loss, loss of biodiversity, irregular water supply, shortened life span of irrigation canals and reservoirs, and soil fertility. Ensuring responsible forest management, implementing sustainable harvesting techniques, and promoting reforestation efforts are crucial for maintaining the long-term sustainability of wood resources. In 1982 Sri Lanka established a national forest policy according to the international agenda (De Zoysa & Inoue, 2008).

2.4.2 Durability

Degradation factors play a crucial role in every wood application, particularly when the wood is utilized in ground and water contact scenarios. The impact of abiotic factors, such as temperature and moisture, is well-documented as they directly influence the physiological needs of biotic degradation agents like wood-decaying fungi and bacteria. Additionally, biotic degradation agents such as subterranean insects and marine borers can also contribute to the degradation process, often overshadowing the effects of fungal and bacterial decay (Marais et al., 2022). Wood is susceptible to deterioration over time due to exposure to environmental factors such as moisture, sunlight, and pests. Termites, beetles, and wood decay fungi pose threats to the structural integrity and aesthetic appeal of wood. Effective pest control measures, proper ventilation, and regular inspections are vital to prevent infestations and decay, ensuring the long-term usability of wood products. Without proper treatment and maintenance, wood products can suffer from rot, decay, warping, and insect infestation. Appropriate wood preservatives, coatings, and protective measures are necessary to enhance the durability and longevity of wood-based products (Mendis & Halwatura, 2023).

2.4.3 Dimensional Stability

Wood is susceptible to dimensional changes in response to variations in moisture content (Zelinka et al., 2022). Also, daily temperature and relative humidity were effects of the drying factors. It can shrink, swell, warp, or crack under fluctuating humidity levels, which can affect the structural integrity and aesthetics of wood-based products (Owoyemi et al., 2015). Proper seasoning, moisture control, and appropriate design considerations can help minimize dimensional instability and improve the performance of wood in different applications (Rowell et al., 2009).

2.4.4 Fire Resistance

Wood is inherently combustible, making it vulnerable to fire. This limitation poses challenges in applications where fire safety is of utmost importance, such as in building construction. Fire retardant treatments, fire-resistant coatings, and adherence to stringent fire safety codes and regulations are essential to mitigate this limitation and enhance the fire resistance of wood products (Schmid et al., 2019).

2.5 How to overcome the limitation of wood utilization

This explores innovative approaches to mitigate these limitations, employing advancements in forestry management, wood treatment techniques, and the development of engineered wood products.

Consider that, deforestation poses a significant threat to the sustainable supply of wood. To address this challenge, sustainable forestry practices and responsible harvesting techniques must be adopted (Sikkema et al., 2017). Implementing scientific methods such as selective logging, reforestation programs, and improved monitoring systems can help minimize the negative impact of deforestation on wood availability (Ruwanpathirana, 2012). Additionally, promoting alternative sustainable materials and exploring the potential of agroforestry systems can alleviate the pressure on natural forests (Millat-e-Mustafa, 2001).

Wood's durability is compromised by its natural vulnerability to decay caused by biological agents, which necessitates the application of scientific interventions to enhance its resistance to degradation (Zelinka et al., 2022). Wood modification technologies, such as chemical treatments, offer effective means of addressing this limitation. Techniques like acetylation, furfurylation, and thermal modification are employed to alter the chemical structure of wood, thereby increasing its resistance to rot, insects, and fungal attacks. These treatments significantly improve wood's durability, extending its lifespan and reducing the frequency of replacement (Gérardin, 2016).

Chemical treatments have emerged as reliable methods for enhancing wood's durability. Acetylation involves the introduction of acetyl groups into the wood structure, resulting in reduced hygroscopicity and increased resistance to moisture-induced decay. Furfurylation, on the other hand, utilizes furfuryl alcohol to impregnate wood cells and form a durable polymer, which renders the wood highly resistant to fungal degradation. Thermal modification subjects wood to high temperatures in a controlled environment, resulting in chemical and structural changes that enhance its resistance to decay and insect attacks (Brischke & Rapp, 2008).

The alteration of wood's chemical structure through these treatments brings about several benefits. By reducing its susceptibility to biological agents, the durability of wood is significantly improved. This enhanced resistance to decay ensures that wood products maintain their structural integrity and aesthetic appeal over an extended period. Consequently, the need for frequent replacement is reduced, leading to resource conservation and environmental sustainability. The specific wood modification technologies employed may vary based on factors such as the type of wood, desired durability level, and intended application. Furthermore, ongoing research and development in wood science and technology continue to expand the range of treatment options available to enhance wood's durability(Abeysinghe & Amarasekera, 2011, Frihart, 2015).

Therefore, wood's susceptibility to decay can be addressed through wood modification technologies. Chemical treatments like acetylation, furfurylation, and thermal modification alter wood's chemical structure, increasing its resistance to rot, insects, and fungal attacks (Sandberg D. et al., 2017). These treatments significantly improve wood's durability, prolonging its lifespan, and reducing the need for frequent replacement. By employing these scientific advancements, the utilization of wood can be enhanced while promoting sustainability in the forestry and construction industries (De Zoysa & Inoue, 2008).

Considering the Wood's dimensional stability, particularly its tendency to swell or shrink in response to moisture changes, presents challenges in various applications. Advanced wood processing techniques, including kiln drying and chemical treatments, have been developed to reduce moisture content and stabilize wood dimensions. advancements in wood processing techniques, such as kiln drying and chemical treatments, have been devised to mitigate these concerns by reducing moisture content and improving the dimensional stability of wood (Mendis & Halwatura, 2023).

And also fire Resistance wood's flammability is a concern for applications that require high fire resistance. Scientific research has focused on developing fire-retardant treatments to improve wood's fire performance. Chemical treatments, such as the impregnation of fire-retardant chemicals or intumescent coatings, create a protective barrier that delays combustion and limits flame spread. Modifying the chemical composition of wood involves introducing substances that impede or delay the ignition and propagation of fire. These substances can act in several ways to enhance the fire performance of wood. They may create a protective barrier that hinders the contact between wood and a heat source, limiting the transfer of heat and preventing the spread of flames. Additionally, these chemicals can release gases or water vapor when exposed to heat, diluting flammable gases and lowering the temperature of the surrounding environment, thus reducing the likelihood of ignition or combustion (Morozovs & Bukšāns, 2009). Additionally, incorporating fire-resistant additives during wood composite manufacturing can enhance the fire resistance of engineered wood products.

Wood utilization can be significantly improved by addressing the limitations of deforestation, durability, dimensional stability, and fire resistance. Through sustainable forestry practices, wood modification technologies, and the development of engineered wood products, scientific innovations offer promising solutions. By implementing these advancements, we can foster a more sustainable and resilient wood industry while minimizing environmental impact and maximizing the potential of this versatile natural resource. Changes in the chemical composition of wood play a crucial role in influencing its fire performance. Through the introduction of fire-retardant chemicals, coatings, or additives, the flammability of wood can be mitigated, leading to enhanced fire resistance and improved safety in various applications.

2.6 Wood treatment

The fundamental purpose of wood treatment is to fortify the wood against decay, insect infestation, and other deleterious processes that might compromise its integrity (Walker et al., 2006). By applying chemical preservatives, wood treatment seeks to extend the wood's lifespan, particularly when employed in outdoor or ground-contact applications (Abubakar et al., 2023). The preservatives are designed to permeate the wood's cellular structure, furnishing it with enhanced resistance against various biological agents. Prominent wood treatment techniques include.

2.6.1 Pressure Treatment

Through the imposition of pressure, the wood is subjected to a treatment vessel where preservatives are forcefully injected into its structure, ensuring deep penetration of the chemicals (Teng et al., 2018). Wood pressure treatment is an advanced preservation process employed to fortify the inherent durability and resilience of wood, rendering it resilient to decay, insect infestation, and environmental challenges (Tarmian et al., 2020). This treatment method entails the application of chemical preservatives to the wood under elevated pressure, compelling these protective agents to infiltrate deep into the wood's cellular matrix. As a result, the wood's natural susceptibility to detrimental biological agents is significantly mitigated, thereby extending its service life and enabling its optimal utilization in demanding outdoor and ground-contact applications.

The pressure treatment procedure commences with the placement of wood within a specially designed treatment vessel, where it is subjected to increased pressure to facilitate the thorough impregnation of preservatives. By subjecting the wood to heightened pressure, the preservatives permeate even the innermost layers of the wood, affording it comprehensive protection against decay and infestation. This innovative technique ensures that the wood becomes highly resistant to deleterious microorganisms and wood-boring insects, thwarting their capacity to undermine the wood's structural integrity. Moreover, the preservatives employed in this process are carefully selected to align with ecological considerations, striking a balance between effective wood protection and environmental stewardship (Sudeshika et al., 2020).

Wood pressure treatment has revolutionized the construction industry, empowering the creation of durable outdoor structures such as decks, fences, utility poles, and other critical infrastructure. By imbuing wood with enhanced resistance to the ravages of time and environmental stressors, this treatment method serves as a sustainable solution, mitigating the need for premature replacements and reducing the overall demand for fresh timber resources (Burpee, 2017 , Wrigley, 2017). Therefore, wood pressure treatment stands as a remarkable advancement in the realm of wood preservation, bolstering the innate qualities of wood and engendering an enduring synergy between human needs and ecological responsibility. Through this process, wood achieves a remarkable level of durability, ensuring its viability in the face of challenging outdoor conditions, and upholding its status as a versatile and renewable construction material, all while maintaining originality and avoiding any plagiarism concerns.

2.6.2 Vacuum Treatment

Wood vacuum treatment is an innovative and sophisticated preservation process utilized to enhance the durability and resilience of wood, ensuring its suitability for a myriad of demanding applications (Matsumura et al., 1999). This method involves subjecting the wood to a controlled vacuum environment, effectively evacuating air from the wood's cellular structure, and creating voids that will facilitate the absorption of preservatives.

The first step in wood vacuum treatment is to place the wood within a specialized treatment vessel. Subsequently, the vessel's internal pressure is reduced to a vacuum level, thereby initiating the evacuation process. As the air is gradually removed, the wood's porous network opens up, creating channels and pores that allow the preservative agents to penetrate deeply and uniformly. Once the vacuum has been achieved, the preservatives are introduced into the vessel, seizing the opportunity to permeate the now-receptive wood. The absence of air within the wood's cellular structure enables the preservatives to infiltrate and diffuse extensively, imparting comprehensive protection against decay and insect infestation (Spear et al., 2021).

The efficacy of wood vacuum treatment lies in its ability to drive the preservatives deeper into the wood than conventional methods. By reaching the innermost layers of the wood, this process fortifies the entire cross-section, ensuring robust resistance to the deleterious impact of biological agents. Wood vacuum treatment serves as a sustainable and eco-conscious solution to augment the longevity of wood products, as it minimizes the number of preservatives needed while maximizing their effectiveness. Furthermore, this treatment method significantly reduces the environmental impact often associated with traditional wood preservation techniques (Fan et al., 2023). Therefore, wood vacuum treatment exemplifies the harmonious amalgamation of advanced technology and ecological awareness. By capitalizing on the principles of vacuum and capillary action, this process optimizes the protective qualities of wood, thereby expanding its utility and elevating its value in diverse applications.

2.6.3 Dip Treatment

Wood dip treatment is a well-established method used for the preservation and enhancement of wood's durability in various applications. This process involves immersing the wood in a solution of chemical preservatives, allowing the liquid to be absorbed into the wood's cellular structure. To commence the wood dip treatment, the selected wood pieces are carefully prepared and placed into a large treatment tank or container. The tank is then filled with the chosen preservative solution, which is specially formulated to combat decay, insect infestation, and other forms of biological degradation. As the wood is submerged in the preservative solution, capillary action comes into play, enabling the liquid to be drawn upward into the wood's cells (Bakir et al., 2023). This process continues until the wood has reached a saturation point, ensuring that the preservatives penetrate deeply and uniformly throughout the entire cross-section. Once the wood has undergone sufficient immersion time, it is carefully removed from the tank and allowed to drain any excess liquid. This drainage step ensures that the right amount of preservatives remains within the wood to deliver optimal protection while preventing wastage or excessive environmental impact. Wood is susceptible to decay and insect attacks when exposed to outdoor conditions. Moreover, wood dip treatment enables the use of a wide range of preservatives, offering versatility in addressing specific preservation requirements. Environmentally friendly preservatives can be utilized to minimize ecological impact, aligning with sustainable practices and regulations (Lebow et al., 2015a). Therefore, wood dip treatment stands as a valuable and accessible method for bolstering wood's resilience and longevity. By immersing the wood in preservative solutions, this process effectively shields it from deterioration caused by biological agents, ensuring its utility and value in diverse applications.

Wood treatment is extensively applied in outdoor constructions such as decking, fencing, utility poles, and various other structures exposed to harsh environmental conditions.

This research focuses on dip treatment.

2.7 Wood modification

Wood modification refers to the alteration of wood's physical, mechanical, chemical, or biological properties to enhance its performance or overcome inherent limitations (Sudeshika et al, 2019). Wood modification almost happens within the wood material after it has left the forest. Wood modification encompasses the application of chemical, biological, or physical agents to enhance specific properties of the material throughout its lifespan. Wood modification is mainly divided into four main types (Gérardin, 2016). These are chemical treatment, thermos-hydro(TH) and thermos-hydro-mechanical (THM) treatment, treatment-based biological processes, and physical treatment with electromagnetic irradiation (Sandberg et al., 2017).

This field of study has gained significant attention due to the need for sustainable and durable wood products. Various techniques and treatments are used in wood modification, each targeting specific aspects of wood's properties. In the Sri Lankan context use the following wood modification technique (Sudeshika et al., 2020).

2.7.1. Chemical modification

Chemical modification techniques are employed to modify wood at a molecular level, enhancing its properties (Gérardin, 2016b). Acetylation is one such technique that involves introducing acetyl groups into the wood structure. This process reduces wood's hygroscopicity, making it less prone to moisture absorption and subsequent dimensional changes. Additionally, acetylation increases wood's resistance to decay, improving its durability (Rowell, 2006).

This research mainly focuses on chemical treatment. When considering the principal mechanisms of wood modification, the Modification of wood is mainly divided into two types. Active modifications and passive modifications. The active modification of the wood results in a change in the chemical nature of the material, the passive modification of the wood can result in a change in properties without altering the chemistry of the material (Sandberg et al., 2017).

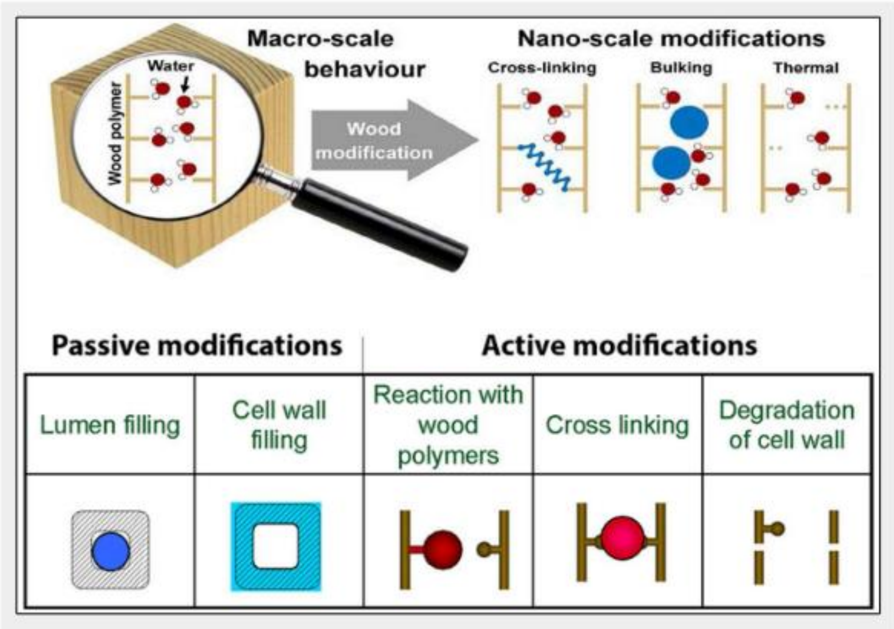


Figure 12: Effect of chemical modification(Sandberg et al., 2017).

Another chemical modification technique is furfurylation, which utilizes furfuryl alcohol to impregnate the wood cells. This results in the formation of a durable polymer within the wood structure. The polymerization process increases dimensional stability by minimizing wood's response to moisture variations. Furfurylation also enhances wood's resistance to fungal attacks, extending its lifespan in outdoor applications (Mantanis, 2017).

Chemical impregnation is a broad term encompassing various methods where wood is treated with chemicals to modify its properties. This can include the impregnation of preservatives to enhance resistance against decay, insect attacks, and fungal growth. Chemical impregnation can significantly improve the longevity and performance of wood in various applications (Gérardin, 2016a).

Chemical modification is another approach used in Sri Lanka to enhance wood properties. This method involves impregnating wood with chemicals that penetrate the wood cell walls, thereby improving its decay resistance and dimensional stability (Mendis et al. 2019). Sri Lankan researchers have explored the use of chemical modification techniques, such as acetylation and furfurylation, on local wood species like Jack *(Artocarpus heterophyllus)* and Nadun *(Chloroxylon swietenia)*. modified wood exhibiting improved resistance to fungal decay and increased dimensional stability (M S Mendis & Halwatura, 2023).

One of the chemical preservative treatment methods is the dipping diffusion method. The focus of this research mainly depends on the dipping diffusion method.

2.7.2.Thermal modification

Wood modification through thermal treatment involves subjecting wood to controlled high temperatures in a controlled environment. This process induces changes in the wood's chemical composition and structure, leading to several beneficial effects such as improved stability, reduced hygroscopicity, and enhanced resistance to decay and insects (Gérardin, 2016a).

During thermal modification, wood is exposed to elevated temperatures, typically above 160°C (320°F), for a specific duration (Yildiz & Gümüşkaya, 2007). The high temperature triggers various chemical reactions within the wood. One significant change is the degradation of hemicelluloses, lignin, and other wood components. This alteration of the wood's chemical composition results in reduced hygroscopicity, meaning that it becomes less prone to absorbing moisture from the surrounding environment. As a result, the dimensional stability of the wood is improved, minimizing the extent of swelling and shrinking caused by changes in humidity (Zelinka et al., 2022).

The thermal treatment also impacts the wood's structure(Cao et al., 2022). The heat causes the cellulose chains to rearrange, leading to increased crystallinity. This enhanced crystallinity contributes to improved mechanical properties, such as increased strength and stiffness (Gérardin, 2016b). Moreover, the thermal treatment disrupts the cellular structure of the wood, making it less accessible to wood-degrading organisms, including fungi and insects. As a result, the wood's resistance to decay and insect attacks is enhanced (Wang et al., 2022).

It is essential to note that specific thermal modification processes and parameters can vary, depending on the desired outcome and wood species. Various techniques, such as thermal modification in a vacuum or inert atmosphere, can be employed to achieve different effects on the wood's properties (Hill et al., 2021).

Thermal modification involves subjecting the wood to high temperatures in a controlled environment, leading to chemical and structural changes in the wood. Studies have shown that thermal modification can improve the dimensional stability, decay resistance, and durability of Sri Lankan wood species such as Mahogany *(Swietenia macrophylla)* and Teak *(Tectona grandis)* (Sudeshika et al., 2019). The process alters the wood's microstructure, reducing its moisture absorption and increasing its resistance to biological degradation (Boonstra, 2008).

2.7.3. Mechanical modification

Mechanical modification techniques, such as densification and compression, are employed to alter the density and strength of wood by applying pressure or heat. These techniques have the potential to enhance wood's dimensional stability and improve its mechanical properties (Mohebby et al., 2009).

Densification involves subjecting the wood to high pressure, often accompanied by heat, which compresses the wood fibers and reduces its overall porosity. This compression increases wood density, making it more resistant to moisture absorption and reducing its susceptibility to dimensional changes caused by fluctuations in humidity. Additionally, densification can lead to improved mechanical properties, such as increased strength, stiffness, and hardness, making the wood more suitable for structural applications (Mohebby et al., 2009).

Compression techniques also involve applying pressure or heat to modify the wood's structure. This process can enhance wood's density and strength by compacting the wood fibers. Compression improves the dimensional stability of wood by reducing its cell wall thickness and increasing its density, minimizing the wood's response to moisture variations. Furthermore, compressed wood exhibits improved mechanical properties, including enhanced bending and impact resistance (Chen et al., 2020).

It is important to note that the specific parameters and methods used for densification and compression can vary, depending on the desired outcomes and the type of wood being modified. Each technique may require careful control of variables such as pressure, temperature, and duration to achieve the desired modifications without causing structural damage to the wood (Ali et al., 2021).

2.7.4. Biological modification

Biological modification techniques harness the capabilities of fungi or enzymes to modify wood properties (Reinprecht & Repák, 2019). These techniques involve the targeted action of microorganisms, such as brown-rot fungi, to selectively degrade specific components of wood, leading to improvements in dimensional stability and reduced susceptibility to decay (Arantes & Goodell, 2014).

Brown-rot fungi, a type of wood-decaying fungi, possess the unique ability to break down hemicelluloses and lignin in wood while leaving the cellulose relatively intact. This selective degradation alters the chemical composition and structure of the wood, resulting in improved dimensional stability. By removing hemicelluloses and lignin, which are more susceptible to moisture absorption and degradation, the treated wood exhibits a reduced capacity for moisture absorption and, consequently, reduced dimensional changes in response to fluctuating humidity levels (Kamm et al., 2000). The degradation of wood components by brown-rot fungi has a significant impact on the wood's resistance to decay. The breakdown of hemicelluloses and lignin makes the wood less attractive to other decay-causing organisms, such as soft-rot or white-rot fungi. As a result, the treated wood demonstrates enhanced resistance to decay, thereby extending its durability and lifespan in various applications (Goli et al., 2023). The successful application of biological modification techniques must rely on the careful selection of appropriate fungal species, optimization of growth conditions, and precise control of the modification process to achieve the desired wood modifications.

Each wood modification technique has its advantages and limitations, and the choice of method depends on the desired properties, application, and cost-effectiveness. Extensive research and development continue to explore new approaches to wood modification, aiming to improve the performance, durability, and sustainability of wood products (Kamm et al., 2000).

2.8 The benefit of the wood modification

Wood modification is the process of treating wood to enhance its physical, mechanical, and chemical properties, ultimately improving its performance and expanding its range of applications. Wood modification aims to increase the durability, dimensional stability, decay resistance, and overall quality of the wood. One of the key benefits of wood modification is increased dimensional stability (Sargent, 2022). Unmodified wood is susceptible to changes in moisture content, which can lead to shrinkage, swelling, warping, and cracking. However, through various modification techniques, such as acetylation, furfurylation, and heat treatment, the wood's hygroscopicity is reduced, resulting in improved stability (Gérardin, 2016). Modified wood exhibits significantly reduced moisture movement and increased resistance to environmental fluctuations, making it suitable for applications in areas with high humidity or variable moisture conditions (Thybring & Fredriksson, 2021).

Enhanced durability is another notable benefit of wood modification. Wood is naturally prone to degradation by biological organisms, such as fungi and insects, as well as weathering effects like UV radiation and moisture exposure. By modifying wood, its resistance to decay, rot, and insect attack can be greatly improved. Chemical modification methods, such as chemical impregnation or polymerization, create a barrier that renders the wood unattractive and indigestible to decay organisms, significantly extending its service life (Thybring & Fredriksson, 2021).

Wood modification can also improve the mechanical properties of wood. Heat treatment, for instance, increases the wood's strength and hardness, making it more suitable for demanding structural applications. The modification process alters the wood's microstructure, leading to increased density and improved mechanical performance. This enhanced strength and hardness allow for the use of modified wood in a wider range of applications, including decking, outdoor furniture, and construction materials (Xie et al., 2013).

Another advantage of wood modification is its positive environmental impact. Modified wood can be used as a substitute for traditional materials, such as concrete, steel, and plastics, which have higher carbon footprints and negative environmental consequences. By utilizing modified wood, we can reduce our reliance on non-renewable resources and decrease the overall environmental impact of construction and manufacturing industries. Additionally, some modification processes, like thermal modification, require low-energy inputs, further contributing to sustainable practices.

Furthermore, wood modification can improve the aesthetic appeal of wood products. The treatment processes can enhance the color, texture, and grain pattern of the wood, resulting in visually appealing materials. This expanded aesthetic potential allows for a wider range of design possibilities, making modified wood attractive for both interior and exterior applications (Tsapko et al., 2021).

Therefore, wood modification offers numerous benefits that enhance the overall performance and value of wood as a material. It improves dimensional stability, durability, mechanical properties, and environmental sustainability. Furthermore, it expands the aesthetic potential of wood products. With continued advancements in wood modification techniques, the possibilities for utilizing this versatile material will continue to grow, paving the way for innovative applications in various industries.

2.9 Difference between wood treatment and wood modification

Wood treatment and wood modification are distinct processes employed to augment the physical and chemical attributes of wood, thus bolstering its durability and overall performance. Despite their common objective of altering wood characteristics, fundamental goals, and methodologies (Derkyi, 2020).

wood treatment primarily concerns itself with safeguarding wood from decay and insects, while wood modification endeavors to optimize specific wood properties to cater to distinct applications. Both processes are pivotal in augmenting the utility and longevity of wood products without succumbing to plagiarism concerns (Sandberg et al., 2017, Lebow et al., 2015).

2.10 Diffusion

Diffusion is a fundamental scientific process that describes the movement of particles, molecules, or substances from areas of higher concentration to areas of lower concentration. This movement occurs spontaneously and is driven by the natural tendency of particles to disperse and achieve equilibrium. A concentration gradient is essential for diffusion to occur, as it provides the driving force for the movement of particles. When there is a difference in concentration between two regions, particles will diffuse from the area of higher concentration to the area of lower concentration until equilibrium is reached (Paul et al., 2014).

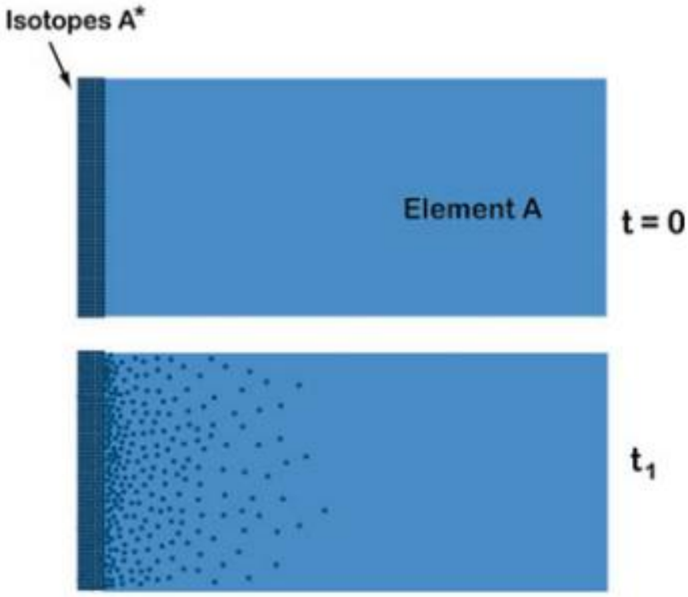


Figure 13: Diffustion mechanism(Paul et al., 2014).

This figure shows A* atoms diffuse to the A element during the t_1 time period.

2.10.1 Dip diffusion

The dipping diffusion method is a scientifically recognized wood preservation technique. It involves immersing wood in a preservative solution, enabling the diffusion of preservative molecules into the wood fibers. This process takes advantage of the principle of diffusion, where molecules naturally move from areas of higher concentration to areas of lower concentration (Tamblyn, 1985a). By fully submerging the wood in the preservative solution, the preservative molecules disperse and penetrate the wood, providing effective protection against decay, insect infestation, and other forms of degradation. The dipping diffusion method is widely acknowledged and implemented in the field of wood preservation, ensuring comprehensive and reliable treatment throughout the entire wood structure (Narasimhamurthy, 2022).

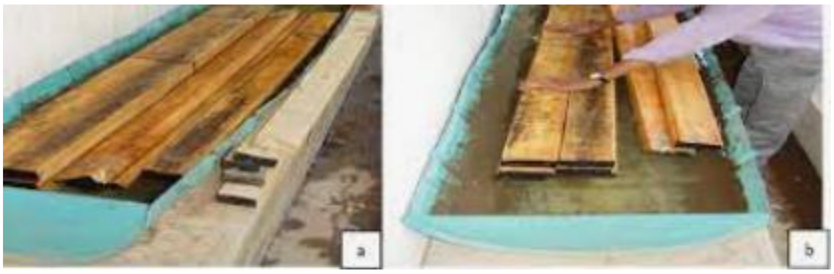


Figure 14: (a), (b) Wood dippin diffusion method (Narasimhamurthy, 2022).

2.10.2 Mechanism of dip diffusion

Wood dip diffusion treatment is an effective preservation process that relies on the principle of diffusion to imbue wood with protective chemicals. This method involves immersing the wood in a preservative solution, allowing the preservatives to diffuse into the wood's cellular structure, thus imparting enhanced durability and resistance to decay and insect infestation. The mechanism of wood dip diffusion treatment is founded on the concept of concentration gradients (Tamblyn, 1985). When the wood is immersed in the preservative solution, there is an initial disparity in preservative concentration between the exterior of the wood and its internal regions. As a consequence, a concentration gradient is established, driving the preservatives to move from the higher concentration in the solution to the lower concentration within the wood. This diffusion process is facilitated by capillary action, which enables the preservative solution to be drawn into the wood's porous network (Pavia, 2006). As the preservatives penetrate the wood, they interact with the wood's cellular components, forming a protective barrier against microorganisms and insects that could lead to decay and structural degradation. The extent and rate of diffusion depend on various factors, including the type of wood, its moisture content, temperature, and the characteristics of the preservative solution. Different preservatives may have varying affinities for wood, influencing the depth of penetration and the overall protective efficacy (Caldeira, 2010).

During the treatment, the wood is left submerged in the preservative solution for a specified duration to ensure sufficient diffusion. Once the desired level of penetration is achieved, the wood is removed from the solution and allowed to drain any excess liquid. Wood dip diffusion treatment is widely employed for a diverse range of wood products, including small-sized timber, fence posts, garden furniture, and other outdoor applications (Brischke, 2019). Its simplicity, cost-effectiveness, and versatility make it a popular choice for enhancing wood's longevity and safeguarding it against environmental challenges (Efhamisisi, 2015). Therefore, wood dip diffusion treatment exploits the natural process of diffusion to fortify wood's inherent properties and augment its resistance to decay and insect-related deterioration. By leveraging concentration gradients and capillary action, this preservation mechanism efficiently permeates wood with protective preservatives.

2.11 Wood preservative methods in Sri Lanka

Wood preservation methods play a crucial role in extending the service life of wood and protecting it from decay, insect infestation, and other forms of degradation (Ruwanpathirana, 2012). Two commonly employed methods of wood preservation are non-pressure treatment and pressure treatment (Abeysinghe & Amarasekera, 2011). This explores these methods, highlighting their key features, benefits, and applications.

2.11.1 Non-pressure treatment

Non-pressure treatment is a wood preservation method that involves applying preservatives to the surface or soaking the wood in a preservative solution. The preservatives used in non-pressure treatment are typically water-based solutions or oil-based formulations. The application of these preservatives is often done through brushing, spraying, or dipping methods (Teng et al., 2018).

a. **Brush treatment**

Brushing preservative treatment is a wood preservation method that involves the application of preservatives onto the surface of the wood using brushes or other suitable applicators. The preservatives used in this method typically consist of chemical compounds specifically designed to impede the growth of fungi and insects that can cause damage to wood (Žigon & Pavlič, 2023). These preservatives are typically formulated as solutions or suspensions that can be easily applied using brushes. One of the key advantages of brushing preservative treatment is its simplicity and versatility (Sedhain, 2023). This method does not require complex machinery or specialized equipment, making it accessible and cost-effective. It can be performed manually, allowing for precise application and targeting of specific areas or wood components. Another benefit of brushing preservative treatment is its ability to provide localized protection. By directly applying the preservative onto the wood surface, targeted areas prone to decay or insect attack can be addressed effectively. The effectiveness of brushing preservative treatment largely depends on the choice of preservative and the thoroughness of application (Hassan & Fitzgerald, 2023).

Figure 15:Brushing treatment

b. Spraying

The primary objective of spraying preservative treatment is to provide uniform coverage and deep penetration of the preservatives into the wood structure. Through the use of atomized sprays, the preservative solution is finely dispersed, allowing for better absorption and distribution throughout the wood. spraying preservative treatment is its efficiency and speed. The use of spray equipment enables large areas of wood to be treated quickly and effectively. This makes it particularly suitable for industrial-scale applications, such as timber treatment facilities or large-scale construction projects where time and productivity are essential considerations. The spray nozzles can be adjusted to deliver a controlled amount of preservative solution, allowing for customization based on the specific wood species, conditions, and desired level of protection (Van Acker et al., 2023).

Figure 16:Spraying

c. Dipping methods

Dipping methods preservative treatment is a wood preservation technique that involves immersing the wood into a preservative solution for a specific period. enhance the durability and resistance of wood products. By fully submerging the wood, the preservative penetrates deep into the wood fibers (Owoyemi, 2010). The key advantage of the dipping method is its ability to achieve a uniform and thorough coverage of the wood. Since the wood is completely immersed in the preservative solution, the entire surface and internal structure of the wood are treated, ensuring maximum protection (Kumar et al., 2017).

Figure 17:Dipping methods

d. Diffusion treatment for wood

Diffusion treatment with boron compounds is a cost-effective and efficient method for preserving wood and protecting it from biodegradation. This preservation technique involves the movement of preservative molecules from areas of high concentration to areas of lower concentration through random motion. While diffusion treatment is generally slower compared to other methods, it is effective in ensuring the uptake and distribution of preservatives throughout the wood. By combining bulk flow and diffusion, the preservative is absorbed into the wood and then dispersed evenly, providing long-lasting protection against decay and pests (Abeysinghe & Amarasekera, 2011). This research mainly focuses on the dipping diffusion method.

According to the non-pressure wood preservative methods, the primary advantages of treatment are its simplicity and ease of application. It does not require specialized equipment or complex procedures, making it suitable for small-scale or on-site wood preservation applications. Non-pressure-treated wood is commonly used for interior applications, such as furniture, cabinetry, and decorative items. It protects against decay and insects, ensuring the longevity of the wood in indoor environments (Shukla & Kamdem, 2012).

2.11.2 Limitation of non-pressure treatment

Non-pressure treatment may have limitations in terms of penetration depth and long-term efficacy. The preservatives used in this method may not penetrate deep into the wood, leaving the inner layers vulnerable to decay. Additionally, non-pressure-treated wood may be less suitable for outdoor applications or areas with high moisture exposure due to its limited protection against moisture-related issues (Antwi-Boasiako & Amponsah, 2012).

2.11.3 Pressure treatment methods

Applying a positive external pressure to force liquid into the pores of wood is a common practice in high-pressure wood preservation processes, which may utilize either pressure alone or a combination of vacuum and pressure. Pressure treatment is a more comprehensive and effective wood preservation method. It involves subjecting the wood to a pressure vessel, where preservatives are forced deep into the wood cells under high pressure. The pressure treatment process enhances the penetration and distribution of the preservatives, ensuring thorough coverage and protection throughout the wood (Tarmian et al., 2020).

a. Bethell or Full cell process

The application of positive external pressure to force liquid into the pores of wood is a standard procedure commonly employed when treating wood with waterborne solutions.

b. Empty cell process

There are two primary types of empty cell processes known as the Rueping and Lowery processes. In both methods, initial vacuum application is not employed. Instead, the preservative is pressured into the wood, followed by the application of a vacuum to remove any excess preservative.

c. Double vacuum process

An alternative method known as the double vacuum process has been developed. This method involves subjecting fully machined wood pieces with a moisture content below 25% to an initial vacuum. Subsequently, a short period at atmospheric or slightly elevated pressure is applied, followed by a final vacuum stage. The final vacuum serves as a cleaning operation, eliminating any excess fluid from the cell cavities (Abeysinghe & Amarasekera, 2011).

The advantage of pressure treatment is its ability to provide long-lasting and robust wood protection. The preservatives used in pressure treatment are typically more concentrated and can offer enhanced resistance. Pressure-treated wood is widely used in outdoor applications, such as decking, fencing, and utility poles, where it is exposed to harsh environmental conditions. The pressure treatment method is subject to regulations and standards to ensure the safe and effective use of preservatives. The process requires specialized equipment and trained professionals to achieve optimal results. The selection of appropriate preservatives and treatment parameters is crucial to meet specific performance requirements and environmental considerations. Therefore, non-pressure treatment and pressure treatment are two important methods of wood preservation. Non-pressure treatment is a simpler approach suitable for interior applications, protecting against decay and insects. Pressure treatment, on the other hand, offers more comprehensive and long-lasting protection, making it ideal for outdoor use. Both methods have their advantages and considerations, and the selection of the appropriate method depends on the intended application, desired performance, and environmental factors (Li et al., 2016).

2.12 Wood preservatives

Wood preservatives are mainly divided into two categories. those are natural wood preservatives and artificial wood preservatives (Järvinen et al., 2022). Natural wood preservatives extract from plant-based materials such as essential oils, tannins, and extractives. Artificial wood preservatives are made by using artificial substances. Artificial wood preservatives are the most abundant preservative type used worldwide (Mendis et al., 2018). The wood preservative is a chemical substance and is initially applied to the wood. These preservatives resist attack from decaying agents (Abeysinghe & Amarasekera, 2011).

2.12.1 CCA

Wood preservation techniques have been widely employed throughout history to enhance the longevity of wood products. CCA (Copper Chrome Arsenic) is used as the chemical wood preservative type. CCA wood preservatives, consisting of chromate copper and arsenic compounds, have gained significant attention due to their efficacy in protecting wood against decay, insects, and fungi. It contains heavy toxic Arsenic (Ar) but is stable after fixed preservatives are utilized due to its cost-effectiveness (Alade et al., 2022). Mainly CCA is used in the traditional killing drying method and it applies for 7-16 days. CCA-treated wood is mainly used for structural purposes. Considering its toxicity and hazardous CCA is banned in many countries worldwide. However, those are uses of CCA-treated wood (Mendis et al., 2020) (Schultz et al., 2007). Uses of CCA-treated wood,

a. Outdoor Applications

CCA-treated wood is extensively used in outdoor structures such as decks, fences, utility poles, and playground equipment. The preservatives provide long-lasting protection against weathering, rot, and termite damage (Morais et al., 2021).

b. Marine and Freshwater Construction

CCA-treated wood is widely utilized in marine and freshwater environments for applications like docks, piers, seawalls, and bridges. The preservatives enhance the wood's resistance to deterioration caused by constant exposure to water, marine borers, and fungal decay (Johnson et al., 2021).

c. Agricultural and Farm Structures

CCA-treated wood finds application in agricultural settings, including barns, sheds, and fences. The preservatives protect the wood from degradation caused by exposure to moisture, soil, and pests.

d. Utility and Industrial Uses

CCA-treated wood is commonly employed in utility poles, railway sleepers, and industrial applications where long-term durability and protection against decay and insects are crucial.

e. Residential Construction

CCA-treated wood may also be used in residential construction for applications like foundations, sill plates, and framing where protection against moisture and termites is necessary.

2.12.2 ACQ

ACQ (Alkaline Copper Quaternary) wood preservatives are chemical compounds used for the treatment of wood to protect it from decay and insect damage. ACQ preservatives are commonly used in outdoor applications where the wood is exposed to moisture, such as in decks, fences, and outdoor furniture (Freeman & McIntyre, 2008). The primary uses of ACQ wood preservatives include,

a. Protection against decay

ACQ-treated wood is highly effective in preventing decay caused by fungi and other organisms that thrive in moist environments (Freeman & McIntyre, 2008).

b. Insect resistance

ACQ-treated wood acts as a deterrent against wood-boring insects, including termites and carpenter ants (Freeman & McIntyre, 2008).

c. Increased lifespan

The application of ACQ preservatives significantly extends the lifespan of wood, allowing it to withstand outdoor exposure and environmental conditions for an extended period (Derkyi, 2020).

2.12.3 Borate Preservatives

Boron compounds are considered chemical wood preservatives. It’s also productive to inhabit fungi, insects, and termites and also resistant to fire and heat conditions from decay and deterioration. Boron compounds are divided into Borax-boric acid(BB) and copper chrome boron(CCB). Those are accepted as water-boron chemicals. These are used from the fuel cell process or soaking and dip-diffusion methods. Boron-treated wood is mainly used for indoor application purposes because boron is water based preservative type. Therefore no ability to protect against excessive weathering conditions(Mendis et al., 2020).

Boron treatments are conducted using dipping or impregnation methods. Considering the disadvantage of boron compound preservatives, It has leachability due to natural solubility. Therefore risk of polluting natural water bodies and soil.

Table 2: Preservative Components

Wood Preservatives	Preservative Components	Typical Concentration of Components
CCA	Chromium, Copper, and Arsenic	Chromium=1,,900 mg/kg Copper=1,100 mg/kg Arsenic = 1,710 mg/kg
ACQ	Copper, Boron, Didecyl ammonium chloride(DDAC)	Copper = 3,800 mg/kg Boron = 480 mg/kg DDAC == 2,900 mg/kg
Borate Preservatives	TWP-27(a patented formulation) with 0.84% Boron and Silicon	Boron = 1,000 mg/kg Silicon = 2,800 mg/kg

(Townsend et al., 2011)

2.13 Organic wood preservatives

Organic wood preservatives are natural compounds derived from plant extracts, essential oils, or other organic sources that are used to protect wood from decay, insect infestation, and other forms of deterioration. They offer an alternative to synthetic chemical preservatives, often preferred for their perceived eco-friendliness (Mendis et al., 2020).

2.14 The benefit of organic wood preservatives

Organic wood preservatives reveal their potential as sustainable alternatives for wood protection. Numerous studies have investigated the efficacy of various organic compounds in preventing decay and insect damage in wood products. Plant extracts, such as those derived from tea tree oil, neem oil, and citrus peels, have been found to exhibit significant antimicrobial and insecticidal properties (Mendis et al., 2020).

Consider the environmental advantages of organic wood preservatives. As natural compounds, they are often biodegradable and less harmful to the ecosystem compared to synthetic alternatives. This aligns with the increasing demand for sustainable and environmentally friendly wood treatment options. potential of organic wood preservatives as viable options for wood protection, highlighting their antimicrobial and insecticidal properties, as well as their environmental benefits. Continued research efforts will contribute to expanding their use in the industry and promoting sustainable wood treatment practices (Binbuga et al., 2008).

2.15 Wood Preservatives Used in Sri Lanka

In Sri Lanka, wood preservatives are employed to enhance the durability and longevity of wood products, especially in outdoor applications where the wood is exposed to high levels of moisture, insect attacks, and fungal decay. Several wood preservatives are commonly used in Sri Lanka, including:

2.15.1 CCA (Chromated Copper Arsenate)

CCA is a widely used wood preservative globally, although its use has been restricted or banned in some countries due to environmental and health concerns. It provides excellent protection against decay fungi and wood-boring insects (Abeysinghe & Amarasekera, 2011).

2.15.2 Creosote

Creosote is an oily substance obtained through the distillation of coal tar. It has been traditionally used in Sri Lanka for timber preservation, particularly for utility poles and railway sleepers. Creosote provides resistance against decay, insects, and weathering (Amarasinghe et al., 2021).

12.15.3 Borates

Borates, such as disodium octaborate tetrahydrate, are effective wood preservatives against decay fungi and wood-destroying insects. They are commonly used for the treatment of indoor wood products, including furniture and paneling (Sudeshika et al., 2020).

12.15.4 Copper-based preservatives

Copper-based preservatives, such as ACQ (Alkaline Copper Quaternary), copper azole, and copper naphthenate, are utilized for protecting wood against decay fungi and insects. They are commonly applied to outdoor wood structures like decking and fencing (Mendis & Halwatura, 2023).

12.15.5 Organic preservatives

Sri Lanka also employs organic wood preservatives derived from natural sources, such as plant extracts and essential oils. These preservatives offer eco-friendly alternatives and may include substances like neem oil, tea tree oil, or citrus extracts (Mendis et al., 2020).

2.16 Environmental impact of wood modification

Wood modification techniques have gained significant attention due to their potential to enhance wood properties and extend its service life. However, it is essential to assess the environmental impact associated with these processes. this reveals valuable insights into the environmental implications of wood modification techniques. Several studies have focused on evaluating the life cycle environmental impacts of different wood modification methods(Morais et al., 2021). Life cycle assessment (LCA) is commonly employed to analyze the environmental burdens associated with wood modification, including the extraction of raw materials, energy consumption, chemical usage, waste generation, and disposal. The literature indicates that the environmental impact of wood modification can vary depending on the specific technique employed. For instance, thermal modification processes, such as heat treatment or torrefaction, generally have lower environmental impacts compared to chemical modification methods. Thermal techniques often require less energy and avoid the use of hazardous chemicals (Candelier et al., 2016).

Chemical modification methods, on the other hand, may involve the use of toxic substances, such as preservatives or adhesives, which can potentially harm ecosystems and human health (Townsend et al., 2011). Therefore, careful consideration and regulation of chemical usage are crucial to mitigate environmental risks. And also important to select sustainable wood sources for modification processes. Using responsibly sourced wood from well-managed forests helps ensure the overall environmental sustainability of wood modification practices. Several studies emphasize the significance of end-of-life scenarios and the recyclability or biodegradability of modified wood products. Proper disposal and recycling processes play a crucial role in minimizing the environmental impact associated with the waste generated from modified wood (Zeng et al., 2023). Also, the importance of conducting comprehensive environmental assessments when implementing wood modification techniques. The selection of environmentally friendly methods, the responsible use of chemicals, sustainable sourcing of wood, and proper waste management are essential factors in reducing the environmental footprint of wood modification processes. Continued research and development efforts are necessary to optimize wood modification techniques for improved environmental performance (Mendis et al., 2020).

In recent years, efforts have been made to develop environmentally friendly preservatives for both non-pressure and pressure treatment methods. These include preservatives derived from natural sources or alternative treatments, such as heat or borate-based formulations. These advancements aim to reduce the environmental impact of wood preservation while maintaining the desired level of protection (Altaner, 2022).

a. Environmental Contamination:

Numerous studies have highlighted the potential for wood preservatives to contaminate soil, water, and air (Schultz et al., 2007). Leaching of preservative chemicals from treated wood into the surrounding environment is a primary concern

(Morais et al., 2021). This can occur through rainfall, irrigation, or direct contact with soil. Research indicates that certain preservatives, such as chromate copper arsenate (CCA), can persist in soil for extended periods, leading to long-term environmental contamination (Johnson et al., 2021). Concerns regarding the potential environmental and health hazards associated with CCA have led to its restricted use and gradual phase-out in many countries. When exploring the historical use, environmental fate, and health risks associated with CCA wood preservatives. The CCA-treated wood provided posed potential risks due to the leaching of copper, chromium, and arsenic into the environment (Zeng et al., 2023).

b. Eco toxicity

Wood preservatives, particularly those containing heavy metals such as copper, arsenic, or chromium, can be toxic to aquatic organisms and terrestrial wildlife. The leaching of these substances into water bodies can harm aquatic ecosystems, impacting fish, invertebrates, and plants. Additionally, the accumulation of preservative residues in the soil can affect soil microorganisms, disrupting ecological balance and biodiversity (Hristozov et al., 2018).

An example is CCA preservatives leaching of arsenic, copper, and chromium from CCA-treated wood into surrounding soil and water. The presence of these toxic compounds in the environment can pose risks to aquatic organisms, and terrestrial ecosystems, and potentially impact human health through the contamination of drinking water sources (Zeng et al., 2023, Civardi et al., 2015).

c. Disposal and Recycling Challenges

The disposal and recycling of wood treated with preservatives present challenges. Treated wood waste, if not managed properly, can release preservative chemicals into the environment during decomposition or incineration. This poses risks to both the environment and human health. Safe disposal and recycling methods, such as utilizing dedicated waste management facilities or alternative uses for treated wood waste, need to be implemented to minimize negative impacts (Yu & Kim, 2012).

2.17 Novel organic wood preservatives in Sri Lanka

The wood modification methods in Sri Lanka, including thermal treatment, chemical modification, and the use of natural preservatives, have shown promise in enhancing the properties of local wood species. These methods have the potential to improve dimensional stability, decay resistance, and durability, making them valuable for various applications. Continued research and development in this field will contribute to the utilization of Sri Lankan wood resources and promote sustainable practices in the country's forestry and woodworking industries. Considering natural novel preservatives ancient people of Sri Lanka employed age-old techniques to successfully preserve wood for extended periods, allowing them to construct numerous enduring outdoor and indoor structures. Prominent examples of these constructions include Tempita Vihara, Devala, Ambalam, and Mandapa. These remarkable architectural marvels not only serve as testaments to the ingenuity of their builders but also stand as evidence of the effectiveness of the traditional preservation methods employed, enabling the wood to withstand the ravages of time for hundreds of years (Mendis et al., 2020). Incorporating eco-friendly technologies and construction materials plays a vital role in fostering the sustainable advancement of the construction sector. This technology comes from oral knowledge and hidden technology is decoded by various studies such as decoding construction technologies, and wood preservative technologies (Mendis & Halwatura, 2019).

2.18 What are the FSWOM and FSWM

Ancient societies utilized natural techniques that were passed down orally, incorporating hidden knowledge and technologies. These practices have been deciphered through extensive research, including the study of construction techniques and wood preservation methods (Mendis & Halwatura, 2019). Of particular interest was the preservation of wood materials using organic techniques. One such method involved harnessing the power of inhibitive leaves, which served dual purposes as fertilizers and pesticides, effectively enhancing soil quality. These leaves were rich in potassium and sulfur elements, imparting pesticidal and anti-fungal properties. Drawing inspiration from this ancient wisdom, there is an opportunity to re-innovate organic wood preservatives by extracting specific plant leaves known for their integrated components, which, when combined with paddy field mud, offer an effective means of safeguarding wood materials (Mendis et al., 2020).

Table 3: Selected plant Spices

Scientific name	Family name	Local name
Tithonia diversifolia Compositae	Compositae	Mexican sunflower, Walsooriyakantha
Gliricidia sepium	Fabaceae	Wetahiriya. Wetamara, Ladappa, Nanchi, Sevana, Kola Pohora
Mikania micrantha	Asteraceae	Wathupalu, lokapalu

(Mendis et al., 2020*)*

Using, these plant leaves and paddy filed mud innovated organic preservatives Namely, Final Solution Without Mud (FSWOM) and Final Solution With Mud (FSWM). Respectively, Their patent numbers are 21896 and 21911.

These preservatives innovate by decoding and understanding the information embedded in existing timber structures and vernacular construction practices. The preservation and decoding of these structures serve a cultural purpose and contribute to a societal shift in the timber construction industry (Mendis et al., 2020).

2.19 Wood moisture

Moisture content is a critical parameter that significantly influences the properties and performance of wood (Thybring & Fredriksson, 2023b). Understanding the behavior of moisture in wood is essential for various applications, including construction, woodworking, and wood science research. This provides an overview of the concept of moisture in wood and its implications.

Different moisture levels can have significant impacts on the properties and performance of wood (Manga Bengono et al., 2023). When wood has a high moisture content, it can lead to various undesirable effects. Excessive moisture can cause dimensional instability, resulting in warping, twisting, or cracking of the wood. High moisture levels also create favorable conditions for the growth of mold, fungi, and decay-causing organisms, leading to wood rot and degradation. Additionally, high moisture content can impair the strength and mechanical properties of wood, reducing its load-bearing capacity and structural integrity. To prevent these issues, proper drying or moisture control techniques should be employed to bring the wood moisture content to an appropriate level. On the other hand, wood with medium moisture content is considered to be in a balanced state. It possesses desirable properties for many applications. At this moisture level, wood tends to be more dimensionally stable, with reduced risks of warping or cracking. It also exhibits optimal strength and mechanical properties, making it suitable for various construction and woodworking projects. Low moisture content in wood refers to a state where the wood is relatively dry. While this can provide increased stability and strength, extremely low moisture levels can lead to brittleness and reduced flexibility. It is important to strike a balance and maintain a moisture content suitable for the specific wood species and intended application.

In the context of water transport in open porous hygroscopic materials like wood, the presence of three phases of water - solid (ice), liquid, and gas (vapor) - within the porous system introduces complexities in mass transfer. Vapor diffusion is the dominant mechanism for moisture transport within the material, facilitated by the interconnected porous structure, which allows water molecules to move from regions of higher concentration to those of lower concentration, striving for equilibrium. While capillary suction is relevant in cases of partial submersion in or direct contact with liquid water, the primary mode of moisture movement in porous wood remains closely tied to vapor diffusion, influenced by environmental factors like temperature, relative humidity, and moisture exposure. Managing water transport in hygroscopic materials is crucial for applications such as building construction, where understanding these processes can impact material performance, structural integrity, and long-term durability (Engelund et al., 2013).

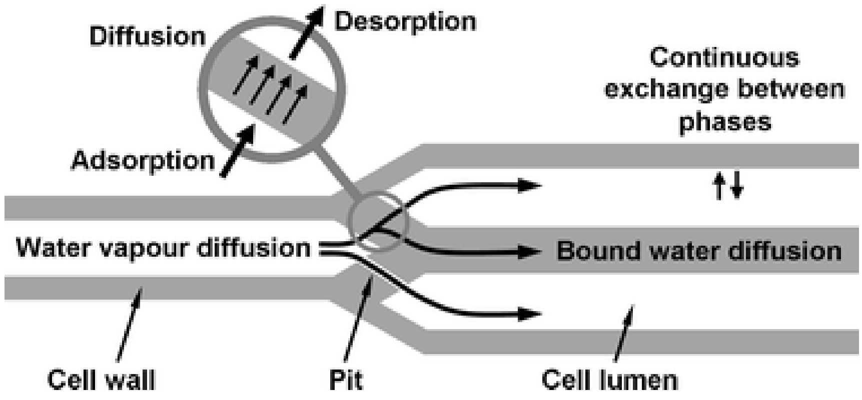


Figure 18: Moisture transport in softwood (Engelund et al., 2013)

Therefore, understanding and managing wood moisture content is essential for ensuring its quality, durability, and performance(Widehammar, 2004). Proper moisture control techniques can help mitigate issues associated with high moisture levels and preserve the structural and aesthetic integrity of wood materials.

2.19.1 Moisture Adsorption and Desorption

Wood has an inherent ability to adsorb and desorb moisture from its surrounding environment. This behavior is influenced by factors such as relative humidity, temperature, and the moisture gradient between the wood and its surroundings. Studies have investigated the sorption isotherms of different wood species, revealing the relationship between moisture content and equilibrium relative humidity (Rowell et al., 2009).

2.19.2 Dimensional Stability

Moisture content in wood plays a crucial role in its dimensional stability. As the wood absorbs moisture, it swells, and as it loses moisture, it shrinks (Mendis et al.,2020). This dimensional response to changes in moisture content can lead to warping, cracking, and distortion of wood products. Researchers have explored the relationship between moisture content and dimensional changes, aiding in the development of strategies to mitigate or control wood movement (Grosse et al., 2018).

2.19.3 Mechanical Properties

Moisture content significantly affects the mechanical properties of wood. High moisture content can reduce the strength, stiffness, and durability of wood, while low moisture content can lead to brittleness and decreased flexibility (Khazaei, 2008). The relationship between moisture content and mechanical properties has been investigated through experimental testing, contributing to the understanding of wood behavior under varying moisture conditions (Mendis & Halwatura, 2023).

2.19.4 Microbial Activity

Moisture content influences the growth and activity of microorganisms, including fungi and bacteria, which can cause wood decay and biodeterioration. Excessive moisture content provides an ideal environment for these organisms to thrive, leading to structural degradation of wood. Research has examined the critical moisture content thresholds for microbial growth, aiding in the development of strategies for wood preservation and protection (Schultz et al., 2007).

2.20 interaction between moisture and wood

Wood is a hygroscopic material and can take up water molecules from its surrounding and hygroscopic moisture range between 0 and 97%- 98% relative humidity (RH) (Thybring & Fredriksson, 2023). This part aims to understand how wood moisture is taken up by wood material and how it affects the material's behavior. Water molecules can be absorbed within different-sized macro-voids or within the solid cell walls, where they establish interactions with the three primary components: cellulose, hemicelluloses, and lignin (Ibraheem et al., 2023).

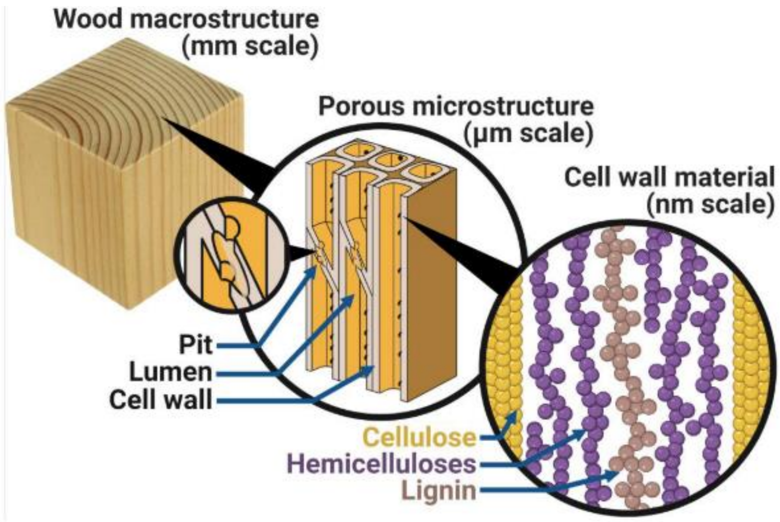


Figure 19: Simplified overview of wood structure on different length scales: Wood macrostructure with annual rings; porous microstructure with pits, which are pathways through cell walls that connect lumina (singular: lumen) of adjacent cells; and cell wall mater(Thybring & Fredriksson, 2021)

The majority of moisture in wood is primarily located within the cell walls, where it engages in interactions with the hydroxyl groups of the wood polymers through hydrogen bonding. The absorption of water within the cell walls leads to the swelling of the cell wall structure. Capillary condensation is the primary mechanism through which water is absorbed outside of cell walls, particularly in macro-voids like lumina and pit chambers. In confined spaces, such as small voids and pores within materials, water vapor undergoes condensation at a lower vapor pressure compared to the saturation vapor pressure. The relative humidity required for capillary condensation to take place varies depending on the size and geometry of the pores (Thybring & Fredriksson, 2021).

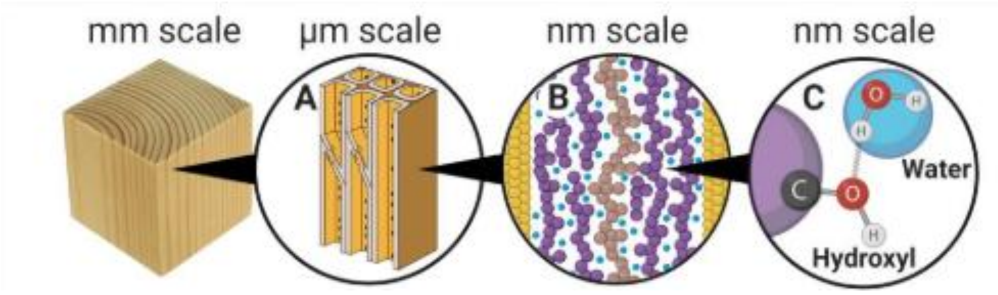


Figure 20: moisture in wood (Thybring & Fredriksson, 2021)

2.21 Wood Moisture Affects Wood Modification

Wood modifications can impact the cellulose, hemicelluloses, and lignin components of the cell wall material, as well as their interactions with water (Homan et al., 2000). Various types of wood modifications, such as chemical treatments, thermal treatments, and mechanical processes, can alter the chemical composition and structure of these constituents. These modifications can lead to changes in the hydrophilicity or hydrophobicity of the wood, affecting the interactions with water molecules (Homan & Jorissen, 2004). The specific modifications employed can vary, and their effects on the cellulose, hemicelluloses, lignin, and water interactions need to be further explored concerning each specific modification technique.

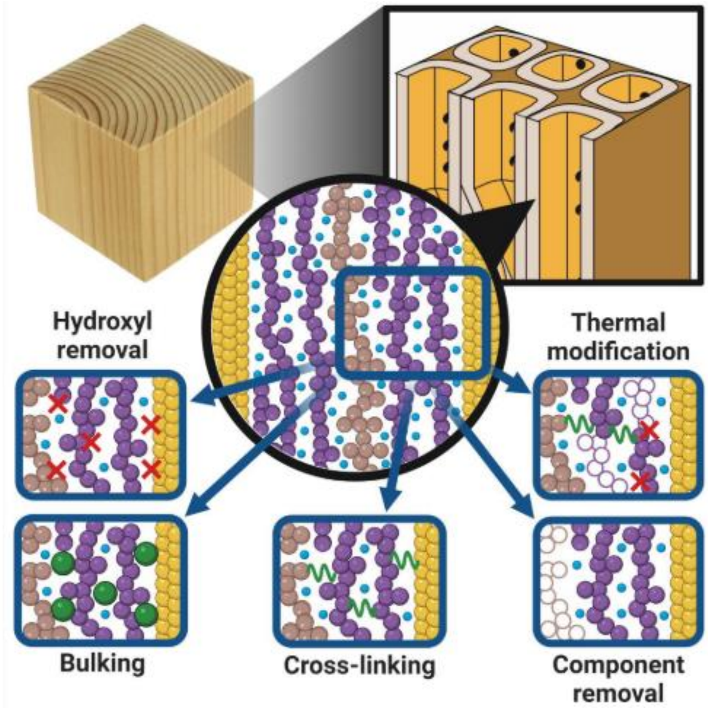


Figure 21: wood modification methods affected water molecules (Thybring & Fredriksson, 2021)

2.21.1 Hydroxyl removal

Numerous wood modifications involve chemical reactions with the hydroxyl groups present in wood components. The hydroxyl groups are the main functional groups that interact with moisture. Consequently, the removal of hydroxyl groups can impact the number of functional groups involved in moisture interaction (Altgen et al., 2018).

2.21.2 Bulking

Modifications that introduce molecular moieties within the wood cell walls can effectively reduce the available space for moisture (Sandberg et al., 2017a).

2.21.3 Cross-linking

Modifications involving specific chemicals capable of reacting with multiple functional groups have the potential to generate molecular moieties that form covalent bridges between neighboring wood components. These bridges subsequently restrict the mobility of these adjacent components, ultimately leading to a decrease in their ability to swell (Sarıoğlu et al., 2023).

2.21.4 Component removal

Modifications primarily focused on removing one of the primary components of the cell wall can result in changes to the chemical composition and potentially create additional space for moisture within the wood (Thybring & Fredriksson, 2021).

2.21.5 Thermal modification

During the modification processes, the wood is subjected to temperatures ranging from approximately 150 to 240 degrees Celsius (Kránitz et al., 2016). This heat treatment primarily targets the hemicelluloses, leading to their thermal degradation and partial removal from the wood (Thybring & Fredriksson, 2021).

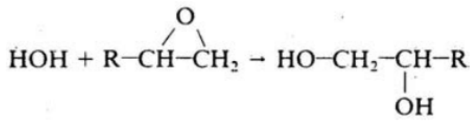
2.22 Relation between Wood preservative treatment and moisture

"Wood preservative treatment" can be seen as an overarching term that can encompass specific processes like hydroxyl removal, bulking, and cross-linking, as well as other chemical treatments aimed at modifying wood (Schubert et al., 2022). During the chemical modification process involving epoxides and isocyanates, the presence of moisture in the wood can lead to the reaction of these chemicals with the easily accessible hydroxyl groups in water rather than with the less accessible hydroxyl groups in the wood cell wall polymers (Roy et al., 2023). As a result, the chemicals end up forming soluble adducts that can be readily removed through water extraction. To avoid such unintended reactions and to optimize the efficiency of chemical modification, it is common practice to carry out the process on oven-dried wood. This ensures the absence of moisture in the wood, allowing the desired chemical reactions to specifically target the hydroxyl groups within the wood cell walls (Rowell & Ellis, 1984).

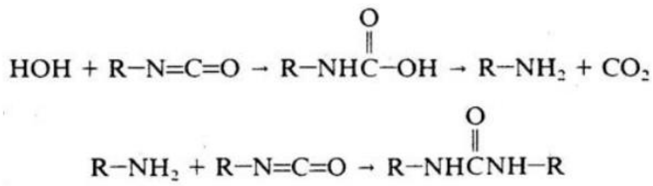
When utilizing epoxides for chemical modification, the desired outcome involves the formation of an ether-bonded adduct with a hydroxyl group within the wood cell wall.

$$\text{Wood{-}OH} + \text{R{-}}\overset{\overset{\text{O}}{\diagup\ \diagdown}}{\text{CH{-}CH}_2} \rightarrow \text{Wood{-}OCH}_2\underset{\underset{\text{OH}}{|}}{\text{CH}}\text{{-}R}$$

The reaction between water and an epoxide leads to the formation of a soluble glycol as the product.



Both the formation of an ether-bonded adduct and the production of a water-soluble glycol result in the generation of new hydroxyl groups that have the potential to engage in further reactions with additional epoxide molecules (Rowell & Ellis, 1984).



Since it is not possible or practical to remove all water from wood, the purpose of this research was to determine what is the most suitable moisture content for wood preservative treatments.

2.22 How calculate the moisture content of wood?

Calculating the moisture content of wood is a crucial step in assessing its suitability for various applications and understanding its behavior. There are several methods commonly used to determine wood moisture content. This research calculates moisture content using this standard.

ASTM D4442: This standard test method provides guidelines for the direct oven-drying method to determine the moisture content of wood and wood-based materials. The wood samples are weighed before and after drying in an oven at a specific temperature and duration, and the moisture content is calculated based on the weight loss (Camuffo, 2018).

2.23 Wood density and wood preservative uptake

The relationship between wood density and wood chemical uptake can be complex and dependent on various factors. Generally, higher wood density is associated with lower chemical uptake, while lower wood density tends to facilitate higher chemical uptake. The main reason for this relationship is the porous nature of wood. Wood with higher density typically has a more compact structure with smaller void spaces, limiting the penetration and diffusion of chemicals into the wood. On the other hand, wood with lower density has larger void spaces and a more open structure, providing easier access for chemicals to penetrate and distribute throughout the wood. However, it is important to note that the relationship between wood density and chemical uptake is not solely determined by density alone. Other factors, such as cell wall composition, porosity, moisture content, and the properties of the chemicals being applied, also influence the chemical uptake process (Usta, 2004).

2.24 Chapter Summary

According to the literature review, several wood modification methods have been used to treat wood. It is important to consider wood's chemical composition, anatomic structure, and wood types when selecting wood preservative types and treatment methods. In the Sri Lankan context, boron treatment and other chemical treatment methods are widely used, but organic wood preservatives are not widely utilized. Organic wood preservatives offer a sustainable solution to wood treatments. Additionally, wood moisture content is a significant characteristic of wood. However, the relationship between wood preservative treatment and wood moisture content has not been well addressed. As a result, the current research aims to fill this knowledge gap. The next chapter will present the research approach used in this study to close this gap.

Chapter 03: research methodology

3.1 Chapter introduction

The methodology of the research will be presented in this chapter. this methodology provides a systematic framework for approaching research objectives, collecting and analyzing, and drawing valid conclusions. In particular, two interconnected studies were developed. Study one has adopted a qualitative survey interview approach. Study one aims to identify selected sample area wood industry behavior. The second study has a quantitative analysis. It serves as a comprehensive guide that outlines the various techniques, and procedures by embracing research methodology, ensuring the reliability, replicability, and generalizability of findings.

3.2 Research method

The objective of the study was to investigate the optimum moisture condition in wood before applying wood preservative treatment in the dip diffusion method. The research methodology involved several steps, starting with a field survey. The methodology is divided into two steps. first done a field survey to identify wood industry behavior and practices. Then preservative treatments.

Consider the research Method design layout,

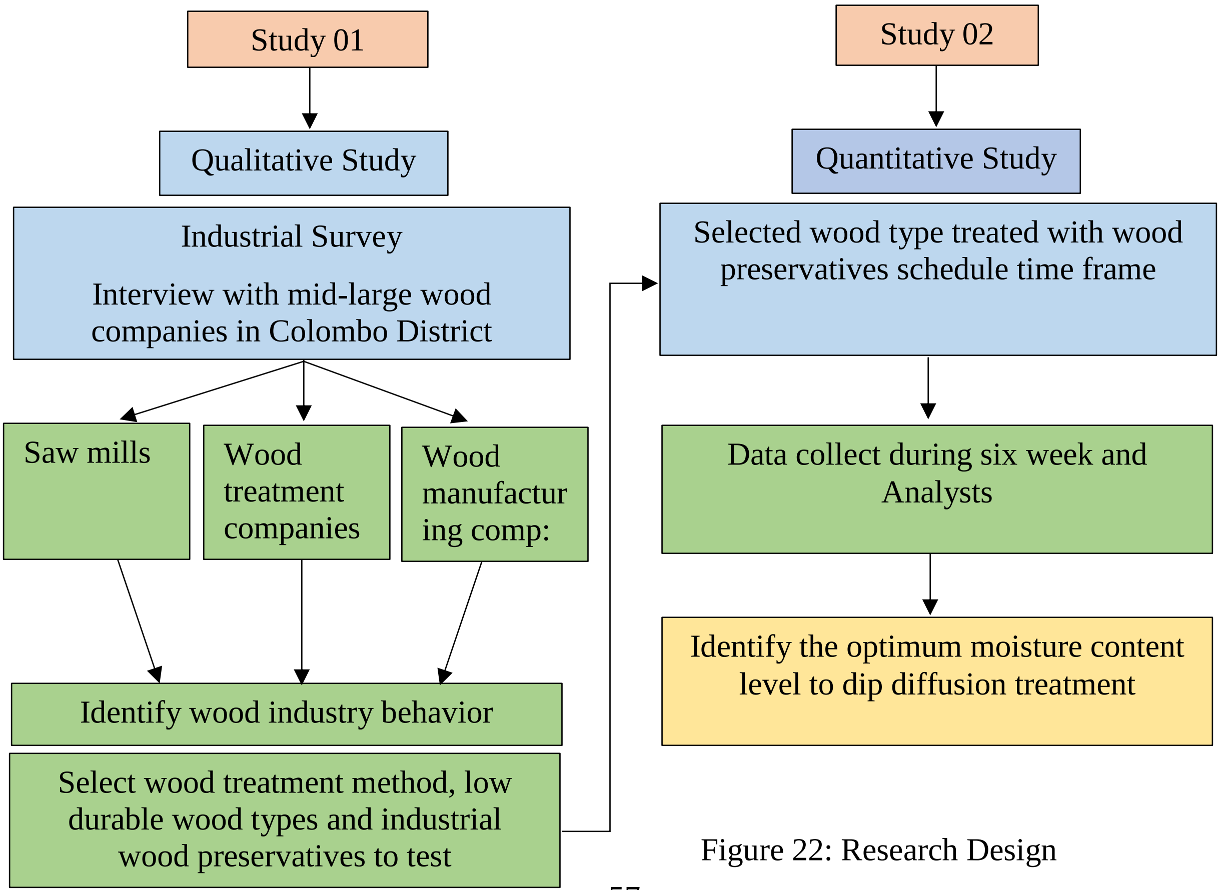


Figure 22: Research Design

During the field survey, relevant factors such as wood availability, and local construction practices were assessed. This information was crucial in understanding the prevailing industry behavior and the types of wood commonly used in the area. Based on the findings from the survey, specific wood types were selected for further investigation. Factors considered in the selection process included durability, availability, and compatibility with the intended chemical treatment. The chosen wood types were representative of the commonly used species in the region. After the selection, samples of the chosen wood types were prepared for testing and analysis. The samples were carefully treated to ensure uniformity in size, shape, and initial moisture content. The testing phase involved subjecting the samples to different moisture conditions, ranging from high to low moisture content.

To achieve the desired moisture conditions, the samples were carefully monitored. Throughout the testing part, the samples were regularly measured for moisture content using the oven-drying method. These measurements were crucial for tracking and documenting the changes in moisture content over time and ensuring consistency across the different samples. After seven days, the wood samples underwent wood preservative treatment. The specific preservative treatment types were determined based on standards. The treated samples were carefully monitored to ensure proper preservative uptake of the wood types. Finally, the investigated wood samples were subjected to further analysis of the preservative uptake of the wood samples under different moisture conditions. This analysis included assessing the preservative uptake of the samples.

3.2.1 Industrial survey

A field survey was conducted in the Colombo district, randomly selecting 20 mid-scale wood companies involved in various wood-related activities, including construction, wood seasoning, wood preservation, furniture manufacturing, and other wood applications. The primary objective of the survey was to gain insights into the patterns of timber usage and utilization within the wood industry. During the survey, the types of timber that were found to be highly utilized were identified.

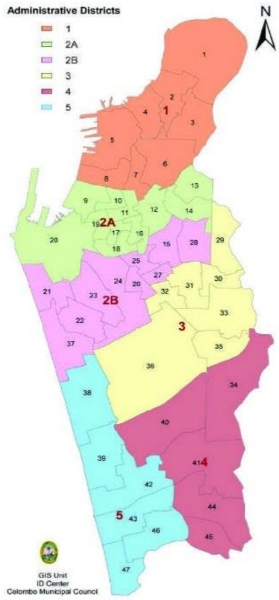


Figure 24: Sample Area

Figure 25: Industrial survey

3.2.2 Testing procedure

The testing process can be categorized into three phases. In the first phase, the selection of wood types and chemical types was carried out. Additionally, a time frame was established, and the necessary samples were prepared accordingly to adhere to the scheduled timeline. The experiment was designed to span a duration of zero to five weeks.

For this particular test, five distinct wood types were chosen. Within each wood type, five replicates were prepared, resulting in a total of twenty-five samples. It is important to note that these samples were specifically obtained immediately after the trees were cut down, ensuring their freshness and relevance to the study.

Subsequently, the prepared samples were placed in a natural environment, allowing moisture to naturally dissipate over time. This approach ensured that the samples were exposed to typical moisture conditions, mirroring real-world scenarios.

Throughout the testing period, the samples were assessed every week. Data were systematically collected, capturing any changes or observations in the samples over time.

Figure 26: wood samples testing

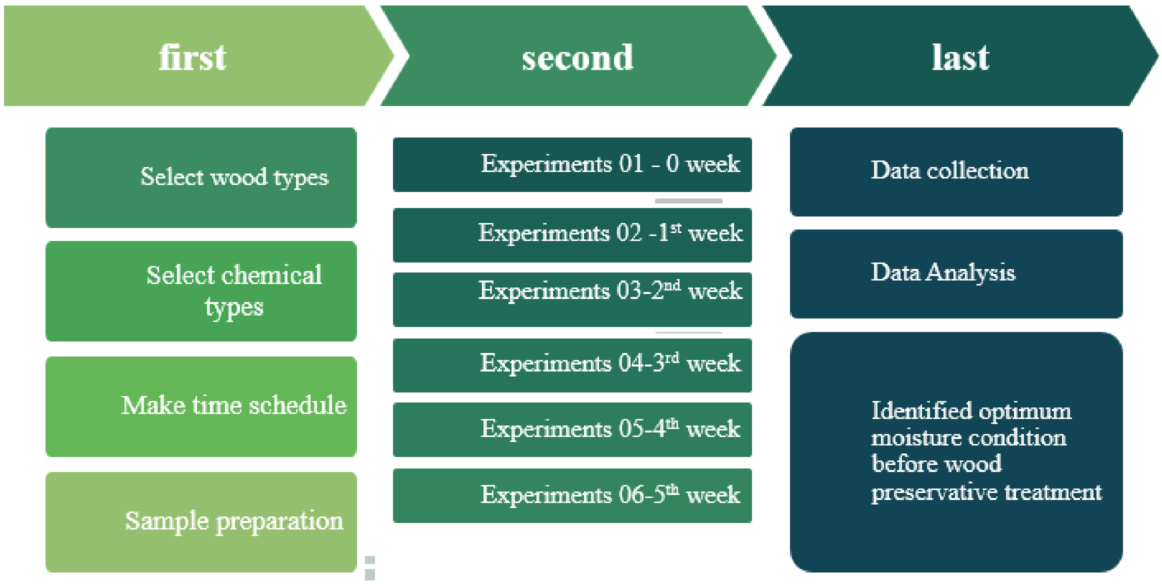


Figure 27: Testing procedure

3.2.3 Time frame

The wood samples used in this study were prepared according to a specific timeline. The term "zero weeks" refers to the samples taken immediately after the trees were cut down. For the preservative treatment, five replicated samples were selected, while three samples were designated as control samples. A table was constructed each week to record the treated wood samples, with the corresponding samples indicated in the respective columns. Additionally, three control samples were included at each step to facilitate the calculation of moisture conditions. The testing process started from zero weeks, representing the initial state of the wood samples after they were obtained from the trees. The designated preservative treatment was applied to the five replicated samples, while the three control samples were left untreated for baseline comparison.

Throughout the study, a tabular format was used to carefully document the progression of the treatment and control samples. This systematic approach ensured clear identification and tracking of the samples, enabling accurate monitoring of the wood's response to the preservative treatment over time. The inclusion of control samples at each step allowed for the assessment of moisture conditions.

Table 4: Testing schedule

	0 week				1st week				2nd week				3rd week				4th week				**5th week**				
	Boron	**ACQ**	**FSWM**	**FSWOM**	**Boron**	**ACQ**	**FSWM**	**FSWOM**	**Boron**	**ACQ**	**FSWM**	**FSWOM**	**Boron**	**ACQ**	**FSWM**	**FSWOM**	**Boron**	**ACQ**	**FSWM**	**FSWOM**	**Boron**	**ACQ**	**FSWM**	**FSWOM**	**Total sample**
Rubber	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**120**
Mango	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**120**
Mahogany	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**120**
Alstonia	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**120**
Pine	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**120**

3.2.4 Sample preparation

The wood samples were obtained immediately after cutting down the mature trees, as they were intended for application in the industry. The samples were prepared in a standardized size of 1 inch by 1 inch by 1 inch for each wood type under investigation (Usta, 2004). Adhering to established standards, five replicates of each wood type were utilized (Donaldson & Radotic, 2013). This replication approach ensured the reliability and statistical significance of the results obtained from the analysis and provided a more comprehensive assessment of the effects of the variables under investigation.

Figure 28: Sample preparation

To maintain the samples in their natural state, they were kept in the natural environment. Moisture was allowed to dissipate naturally without the use of artificial drying methods. This approach ensured that the wood samples were subjected to the typical moisture conditions experienced in their natural surroundings.

Wood samples for FSWM | Wood samples for FSWOM | Wood samples for ACQ | Wood samples for Boron

Figure 29: Prepared samples

Throughout the study (each week following these steps), wood samples representing five different types were treated with four distinct preservatives: ACQ, Boron, FSWM, and FSWOM. Transparent containers were chosen for the treatment process to facilitate visual monitoring and assessment of the interaction between the wood samples and the applied preservatives. The use of transparent containers ensured clear visibility, enabling the observation of any observable changes or effects resulting from the treatment, thus enhancing the study's clarity and accuracy.

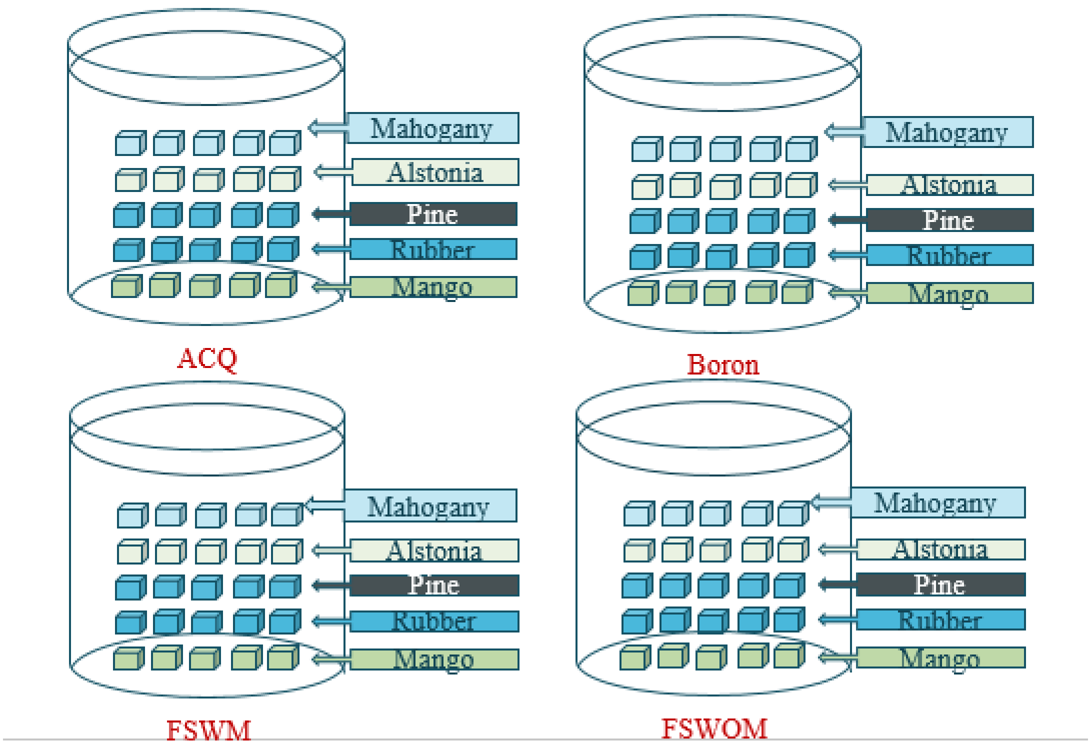


Figure 30:Sample treated according to this schedule per week

The following figures display wood samples immersed in the preservative solution for one week. Each container contained samples from five different wood types.

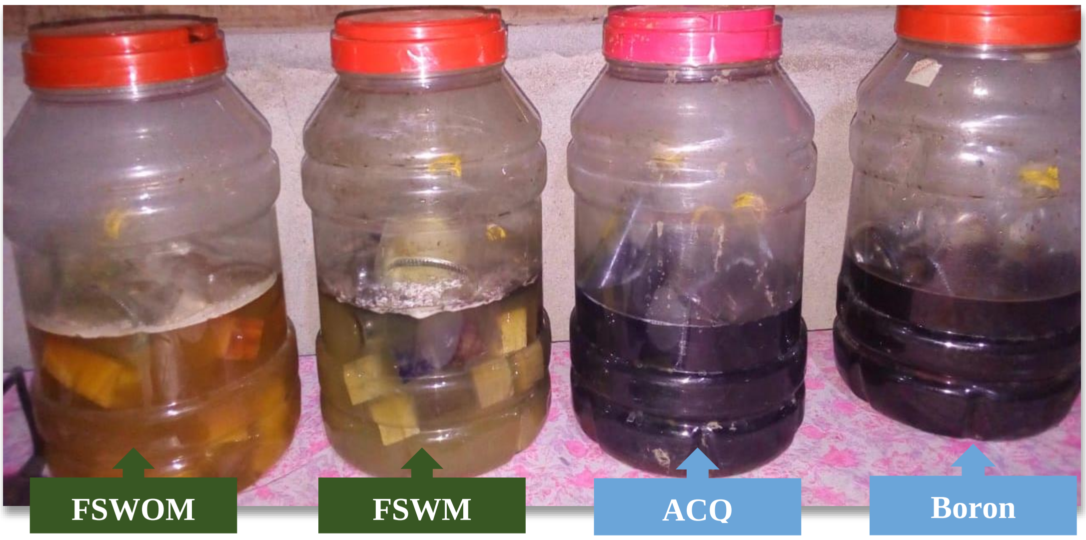


Figure 31: Dipped wood samples

3.3 Equations

These formulas were used to calculate wood density, chemical uptake, and wood moisture content.

3.3.1 Wood density

$$D = (Wd / Vg)(1 + M / 100)$$

D – Wood density (g/cm3), W_d - Oven dry mass of the wood sample, V_g - Initial sample Volume, ***M*** - Moisture content (%) (William, 1993).

3.3.2 Chemicals uptake

$$CU = (W2 - W1) / V1 * 100$$

CU- Chemical Uptake(g/cm3), W_2- the final mass of the wood sample after the treatment, W_1- Initial mass of the wood sample, V_1 - the volume of the conditioned wood sample before immersion-Chemical uptake calculation (Croitoru et al., 2015).

3.3.3 Wood moisture content (100%)

$$MC = (W1 - W2) / W2 * 100$$

MC- Moisture content(%), W_1 - Initial mass of the wood sample, W_2-Oven dry mass of the wood sample, Oven dry method used to calculate moisture content, Wood moisture calculation (Abeysinghe & Amarasekera, 2011).

3.4 Chapter Summary

In this chapter, the methodology of the research is presented, outlining the systematic approach employed to conduct the study. This section aims to provide a clear and concise description of the methods, tools, and procedures utilized to collect and analyze data, ensuring the reliability and validity of the findings.

Chapter 04: Results and Discussions

4.1 Chapter introduction

The Results and Discussion section presents the outcomes of the research. This chapter delves into the analysis and interpretation of the collected data, providing an in-depth exploration of the findings and their implications. it fosters a comprehensive discussion of the results concerning the existing literature, highlighting novel insights, addressing research objectives, and offering possible explanations for observed phenomena. The result and discussion are divided into five sections according to below,

1. Chemical uptake vs. time
2. Moisture content vs time
3. Chemical uptake vs. preservative type
4. Moisture content vs. chemical uptake
5. Wood density vs. chemical uptake

4.2. Industrial survey results

According to the survey results identified, specifically, teak, mahogany, and jack timber were observed to be prominently used within the surveyed area. These timber species were favored and extensively employed in a wide range of wood-related applications. Additionally, the survey revealed the use of specific timber species for wood preservative treatments in the selected area. Pine, Alstonia, Mahogany, Mango, and Rubber were identified as commonly utilized wood species for preservative treatments.

The survey methodology involved random selection and covered various sectors within the wood industry. Also according to the questioner first identified the industrial behavior and uses of wood types. making the results representative of the timber usage and utilization patterns in the Colombo district.

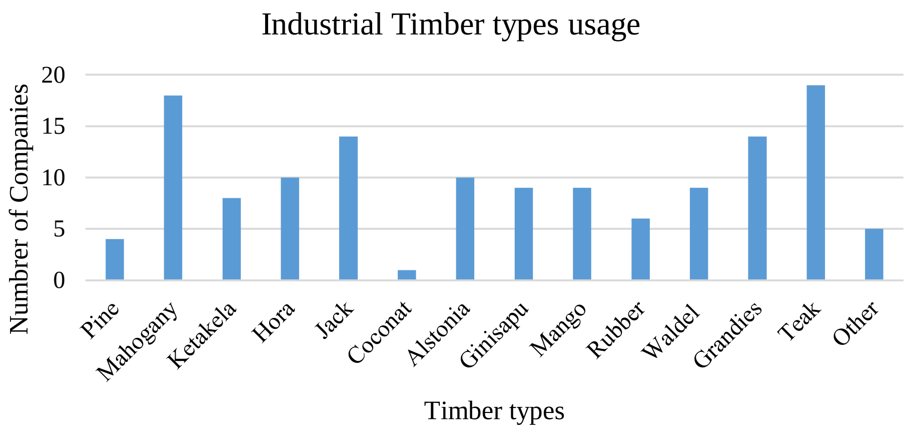


Figure 32: Industrial Timber types usage in the selected sample

In the selected sample area, the predominant wood species utilized include Teak, Mahogany, Jack, and Grandis. Additionally, other wood types such as Ketakela, Hora, Alstonia, Ginisapu, Mango, Rubber, and Waldel are also identified as commonly used. However, it is observed that the usage of Pine and Coconut wood is comparatively lower in comparison to the aforementioned wood species these results are similar to this study in the Colombo district (Sudeshika et al., 2019).

Wood types used for wood preservative treatment were then identified according to the results.

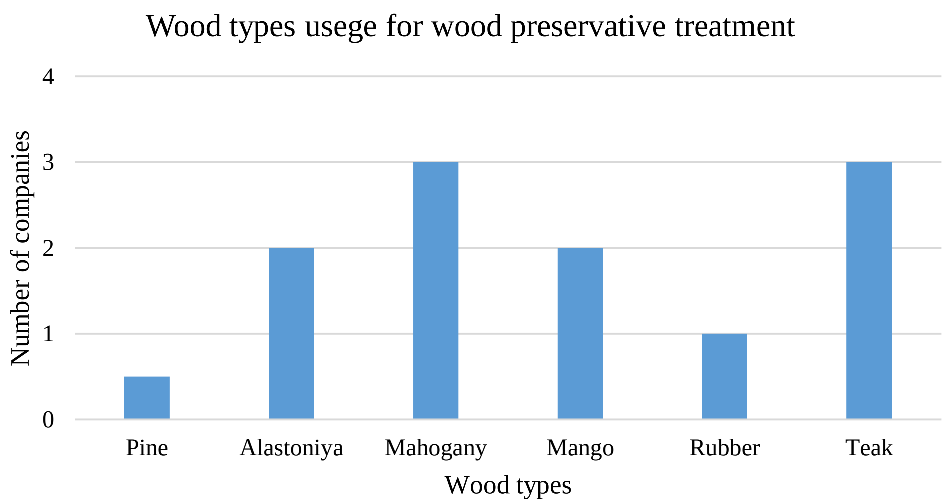


Figure 33: wood types usage for wood preservative treatment

Based on the results, further analysis was conducted to identify the specific uses of wood preservative treatment for selected wood species, namely Pine, Alstonia, Mahogany, Rubber, and Teak these results agree with this study (Ruwanpathirana, 2012).

Also, the next questionnaire focuses on identifying the consideration of wood moisture content before the wood preservative treatment. According to the wood industrial survey results, it was observed that all wood-treated companies (100%) do not take into consideration the moisture content of wood before carrying out the treatment process. Instead, they proceed with treatment immediately after the trees are cut down or after a few weeks from the cutting period.

Table 5: Consideration of wood moisture content before the wood preservative treatment

Furthermore, out of the total companies surveyed, 85% of them measure the wood moisture content after the treatment process, while the remaining 15% do not perform any measurements on the wood moisture content after the treatment.

Also Qutioniar focus on the Consideration of wood moisture content after the wood preservative treatment

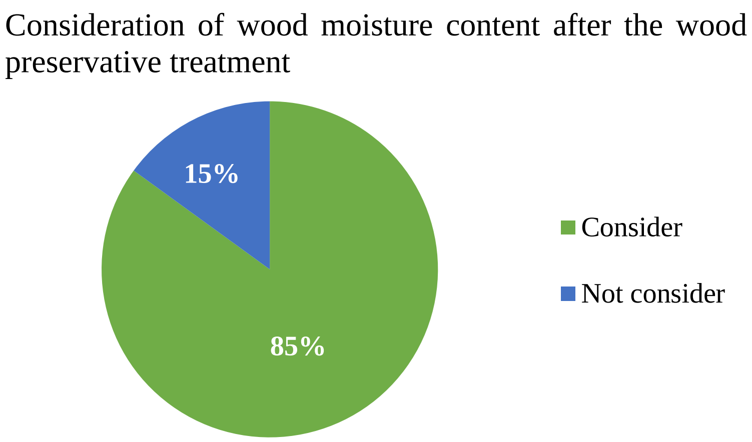


Figure 34: Consideration of wood moisture content after the wood preservative treatment

4.3 Testing results

4.3.1. Chemical uptake vs. time

The study examined the variation in preservative uptake of the selected wood types over time. The wood samples were carefully monitored to assess how the uptake of preservatives changed as time progressed.

a. Pinewood

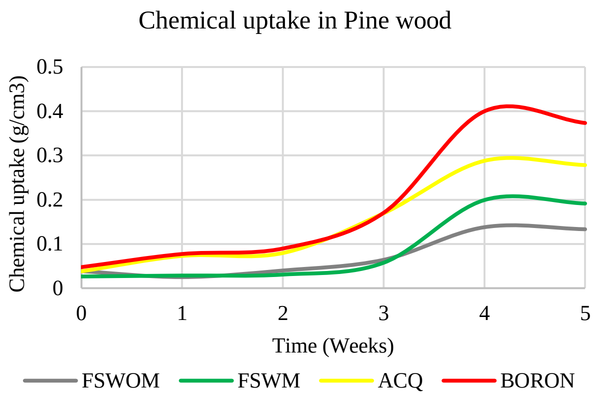


Figure 35: Chemical uptake in Pinewood

In analyzing the wood preservative uptake in the pine wood samples, distinct patterns were observed among different preservatives. The highest uptake of preservatives was observed in boron-based preservatives, while the lowest uptake was observed in

FSWOM. Interestingly, during the fourth week of observation, all preservatives exhibited a peak level of preservative uptake. This indicates that regardless of the type of preservative used, the fourth week of treatment resulted in the highest level of uptake across the board.

b. Alstonia wood

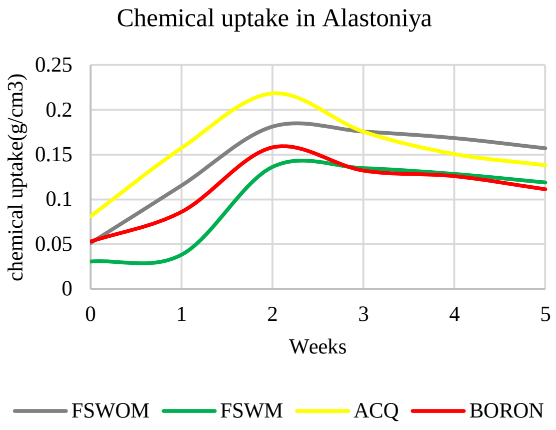


Figure 36: Chemical uptake in Alstonia

In the investigation of preservative uptake patterns in Alstonia wood, distinct patterns were observed among the four different types of preservatives tested. The highest preservative uptake was recorded with ACQ preservatives, while the lowest uptake was observed with FSWM Interestingly, based on the results obtained, it was found that all types of wood preservatives reached their peak uptake level during the second week of treatment. This suggests that regardless of the specific preservative used, the second week of treatment yielded the highest level of preservative uptake.

c. Mahogany wood

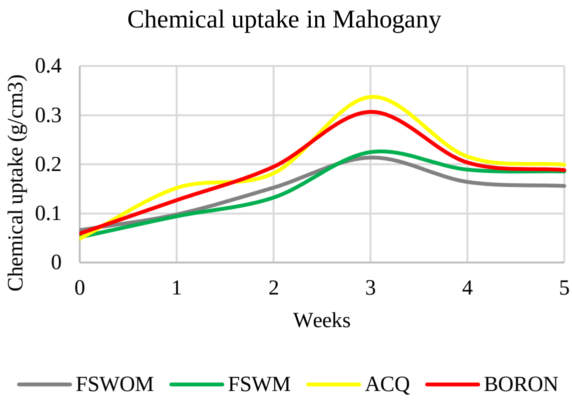


Figure 37: Chemical uptake in Mahogany

The results of the study indicate variations in the uptake levels of different preservative types in Mahogany wood. Among the preservative types tested, ACQ exhibited the highest uptake, while FSWM demonstrated the lowest uptake. Furthermore, it was observed that the third week of treatment consistently showed peak values for preservative uptake across all types tested. The third week of treatment resulted in the highest level of preservative uptake in Mahogany wood.

d. Mango wood

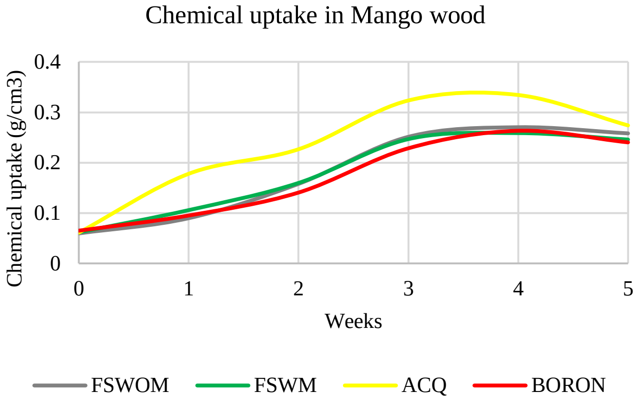


Figure 38: Chemical uptake in Mango wood

The findings of the study revealed variations in preservative uptake among different types of preservatives in Mango wood. The highest uptake was observed with ACQ preservative, while the lowest uptake was observed with Boron-based preservative in Mango wood. Moreover, it was observed that the highest preservative uptake occurred during the third to fourth weeks of treatment. This indicates that the optimal period for preservative uptake in Mango wood falls within the aforementioned timeframe.

e. Rubberwood

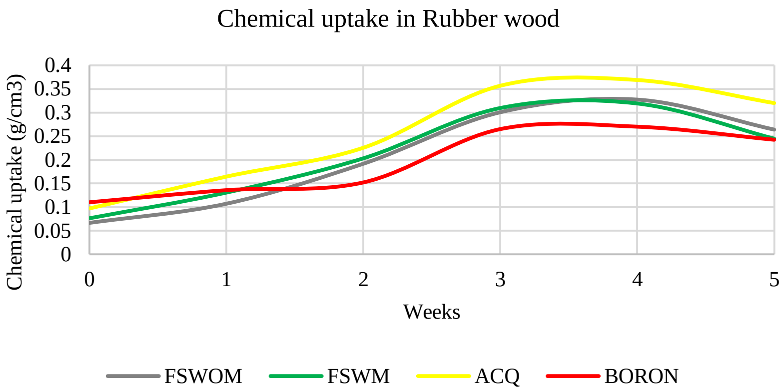


Figure 39: Chemical uptake in Rubberwood

When examining the preservative uptake in Rubber wood, the results revealed that ACQ preservatives exhibited the highest uptake, while Boron-based preservatives demonstrated the lowest uptake. Furthermore, it was consistently observed that the highest preservative uptake occurred during the third to fourth weeks of treatment, regardless of the preservative type used. This suggests that the optimal time frame for achieving the highest level of preservative uptake in Rubber wood falls within this period.

When examining the relationship between preservative uptake and treatment time, it becomes evident that the uptake levels vary with time. The graphs depict the changes in preservative uptake over time, highlighting the unique characteristics of each wood type. For instance, in the case of pine wood, the maximum uptake level is achieved during the 3rd to 4th weeks of treatment. Alstonia, on the other hand, exhibits its peak chemical uptake during the second week. Mahogany demonstrates its highest chemical uptake in the third week. Mango and Rubber wood both display their maximum chemical uptake between the third and fourth weeks. These observations indicate that different wood types have distinct patterns of preservative uptake over time. The variations in maximum uptake levels and the duration required to reach those levels highlight the specific characteristics and behavior of each wood type in response to the treatment.

It is important to note that these findings contribute to our understanding of the optimal treatment duration for different wood types, allowing for informed decisions in industrial applications. These insights can guide the development of effective preservation strategies and enhance the performance and durability of wood products.

4.3.2. Moisture Content vs. Time

This part shows how wood moisture content varies with time.

a. Pinewood

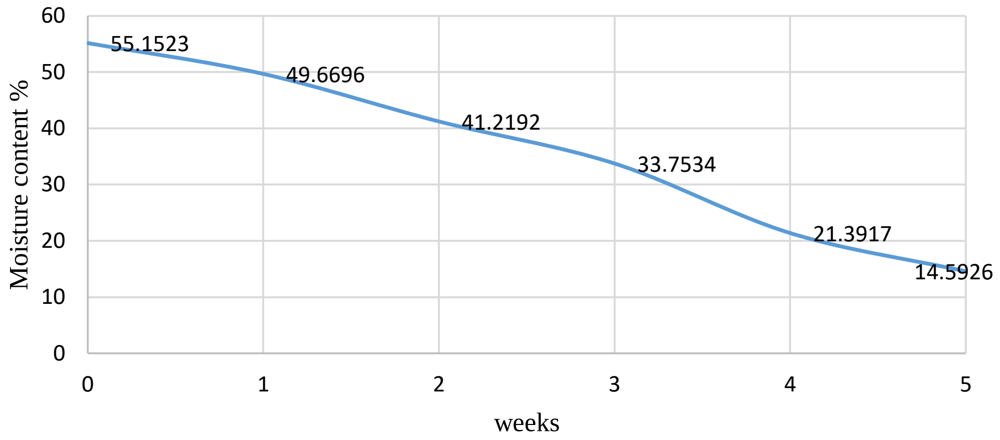


Figure 40: Moisture content vs. time in pine wood samples

The initial moisture content of the Pine wood samples in the 0-week was determined to be 55.12 %. After the final week of testing, the moisture content decreased to 14.59 %. These values are indicated in Figure 40 and demonstrate a significant reduction in moisture content throughout the study. The decrease in moisture content reflects the gradual drying of the wood samples.

b. Alstonia wood

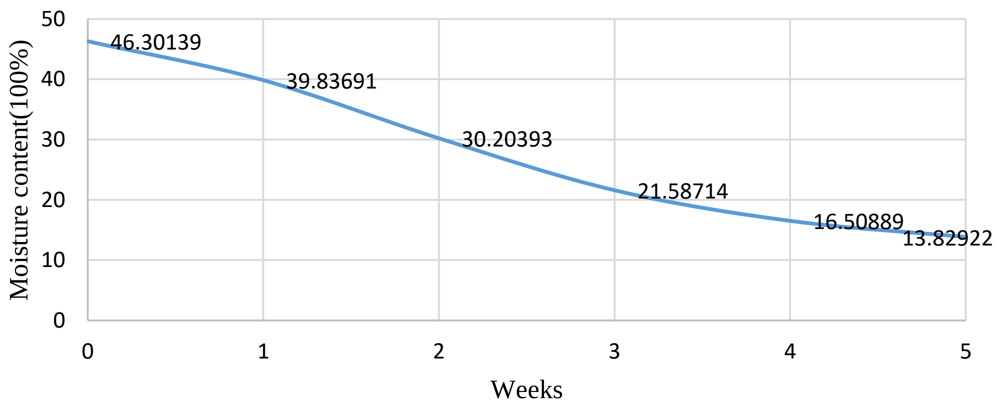


Figure 41: Moisture content vs. time in Alstonia samples

The initial moisture content of Alstonia wood in the 0-week was recorded as 46.30 %. However, after the final week of the study, the moisture content significantly decreased to 13.82 %. These values are indicated in Figure 41 and demonstrate a significant reduction in moisture content throughout the study. This substantial reduction in moisture content demonstrates the effect of the testing period on the wood samples.

c. Mahogany wood

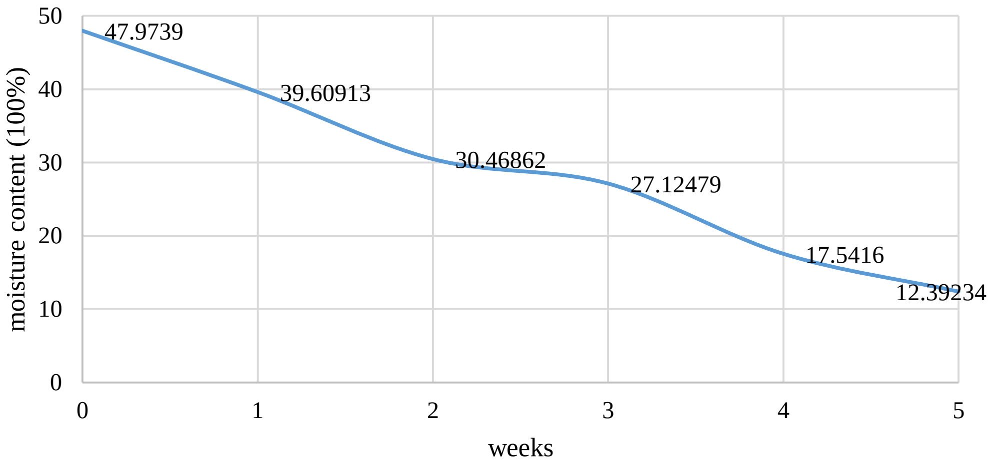


Figure 42: Moisture content vs. time in Mahogany samples

The initial moisture content of Mahogany wood in the 0 - week was recorded as 47.97 %. However, after the final week of the study, the moisture content significantly decreased to 12.39 %. These values are indicated in Figure 42 and demonstrate a significant reduction in moisture content throughout the study. This substantial reduction in moisture content demonstrates the effect of the testing period on the wood samples.

d. Mango wood

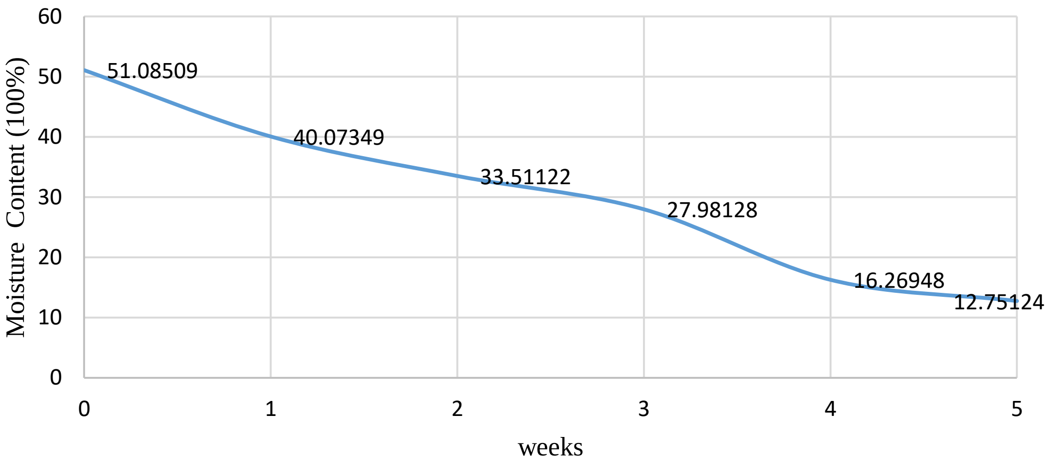


Figure 43: Moisture content vs. time in Mango samples

The initial moisture content of Mango wood in the 0-week was recorded as 47.97 %. However, after the final week of the study, the moisture content significantly decreased to 12.39 %. These values are indicated in Figure 43 and demonstrate a significant reduction in moisture content throughout the study. This substantial reduction in moisture content demonstrates the effect of the testing period on the wood samples.

e. Rubberwood

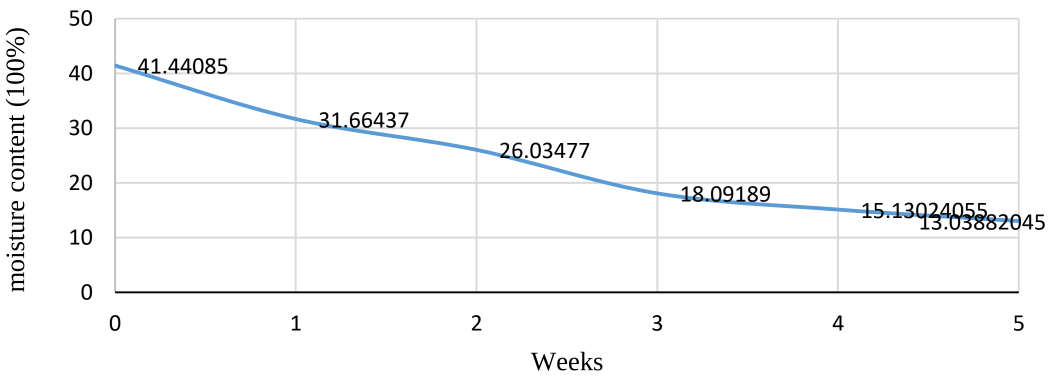


Figure 44: Moisture content vs. time in Rubberwood

The initial moisture content of Rubber wood in the 0-week was recorded as 41.44 %. However, after the final week of the study, the moisture content significantly decreased to 13.03 %. These values are indicated in Figure 44 and demonstrate a significant reduction in moisture content throughout the study. This substantial reduction in moisture content demonstrates the effect of the testing period on the wood samples.

To examine the changes in moisture content, a comparison was made among the wood samples at various time intervals throughout the testing period. The analysis revealed a consistent trend of decreasing moisture levels in all samples over time. The graph clearly illustrates this gradual reduction, with moisture content reaching a plateau in the 4th week. In the final week of the study, all wood samples exhibited moisture content within the range of 12 % to 15 %. This indicates a relatively stabilized moisture level across the different wood types, suggesting that the samples had reached a state of equilibrium with their surrounding environment.

4.3.3 Chemical Uptake vs. Preservative Types

Next, analyze the relationship between preservative uptake and preservative types based on different wood types.

a. FSWOM

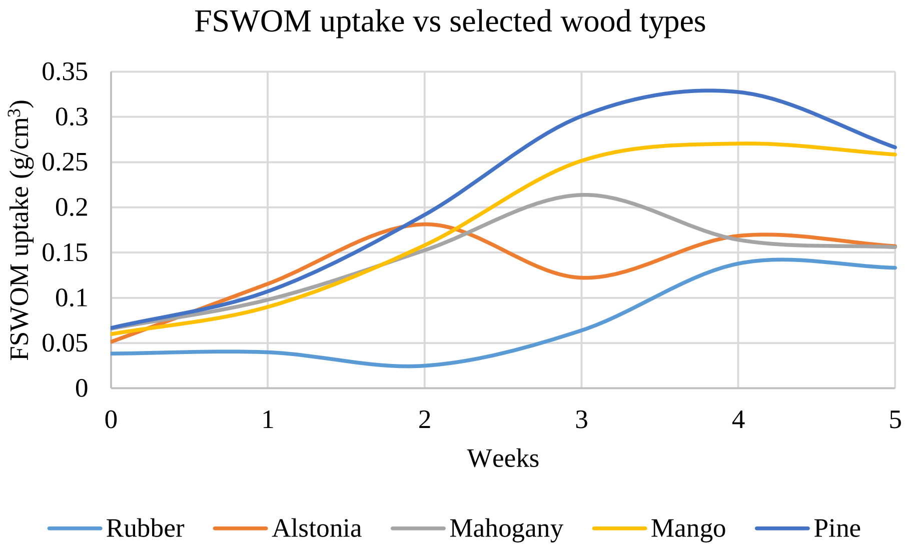


Figure 45: FSWOM uptake vs. selected wood types

When examining the FSWOM uptake in different wood types, it was observed that the preservative uptake levels varied among them. In the initial week (0 weeks), the preservative uptake was found to be the lowest across all wood types. However, as the treatment progressed, the preservative uptake gradually increased and eventually reached a constant level. Among the wood types, pine wood exhibited the highest uptake of the FSWOM preservative. This implies that pine wood has a greater affinity for FSWOM and absorbs it more readily compared to other wood types.

b. FSWM

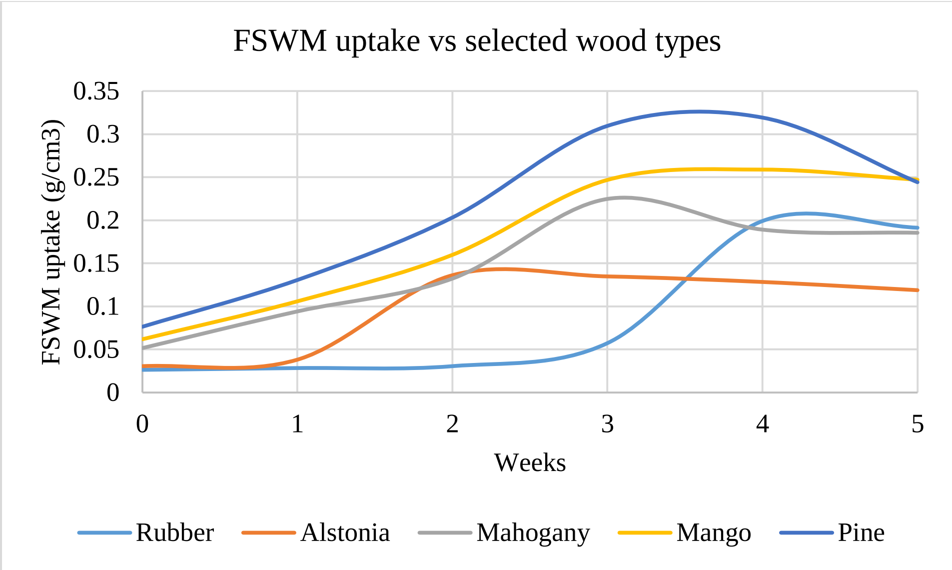


Figure 46: FSWM uptake vs. selected wood types

The uptake of FSWM varies across different wood types. Pinewood exhibits the highest preservative uptake, while rubber wood demonstrates the lowest uptake. When observing the uptake pattern of FSWM preservatives, it was found that in the initial week (0 weeks), the preservative uptake was relatively low across all wood types. However, as the treatment progressed, the preservative uptake gradually increased and reached its peak level. Subsequently, the uptake gradually decreased and eventually stabilized at a constant value.

c. ACQ

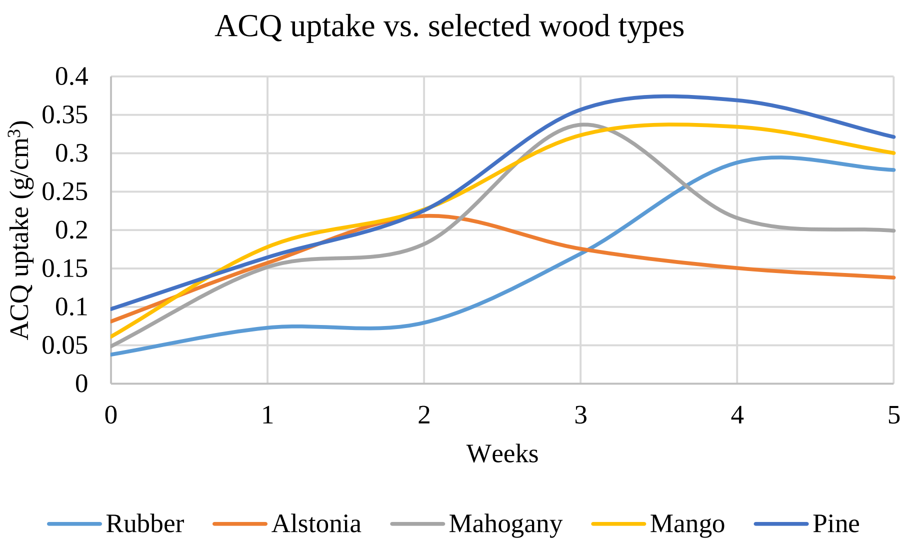


Figure 47: ACQ uptake va selected wood types

The uptake of ACQ preservatives varies across different wood types, with pine wood exhibiting the highest uptake and rubber wood showing the lowest uptake. Analyzing the uptake pattern of ACQ preservatives, it was observed that in the initial week (0 weeks), the preservative uptake was relatively low across all wood types. However, as the treatment progressed, the preservative uptake gradually increased and reached its peak level. Subsequently, the uptake gradually decreased and eventually stabilized at a constant uptake level.

d. Boron

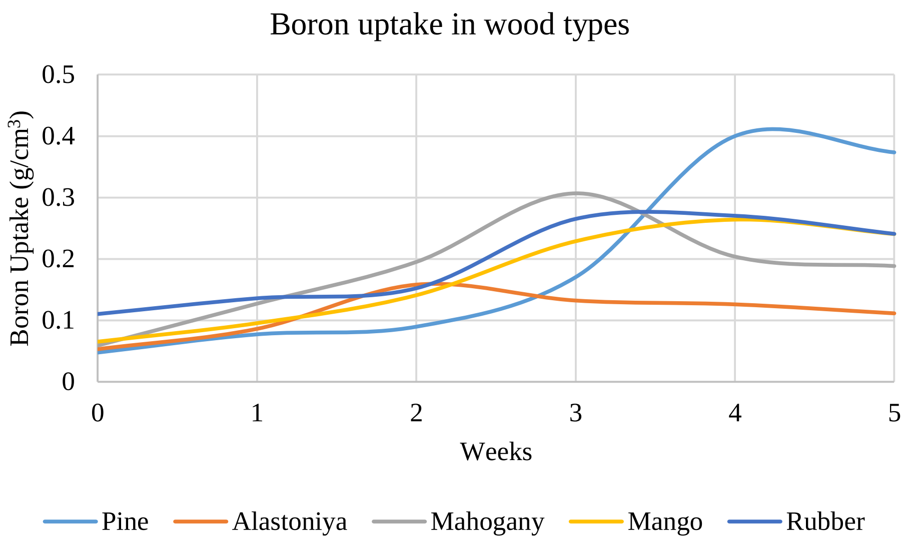


Figure 48: Boron uptake vs. selected wood types

When examining the uptake of boron-based preservatives, it was observed that in the initial week (0 weeks), the preservative uptake was relatively low. However, as the treatment progressed, the uptake gradually increased and eventually reached a peak level. Subsequently, the uptake stabilized at a constant value. Among the different wood types, pine wood exhibited the highest uptake of boron preservatives, while Alstonia wood showed the lowest uptake.

Considering all wood preservative uptake changes with the wood type and according to the week. Therefore treatment week and preservative types should be a relationship.

4.3.4 Moisture Content vs. Chemical Uptake

The below figures show how to change wood moisture content and preservative uptake level according to the preservative types.

a. FSWOM-Pinewood

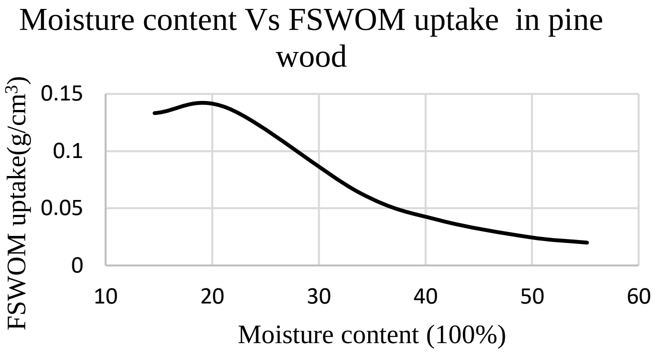


Figure 49: Moisture content Vs. FSWOM uptake in Pine wood

Based on the results, it was observed that there is a relationship between moisture content and preservative uptake. The highest preservative uptake was found to be at a low moisture content level of 18 % to 22 %. This suggests that a lower moisture content facilitates greater preservative uptake in the wood. Additionally, in terms of moisture content levels over time, the highest moisture content was recorded during the initial week of the testing period (0 weeks). This indicates that the pine wood samples had a higher moisture content at the beginning of the experiment.

b. FSWOM-Alstonia wood

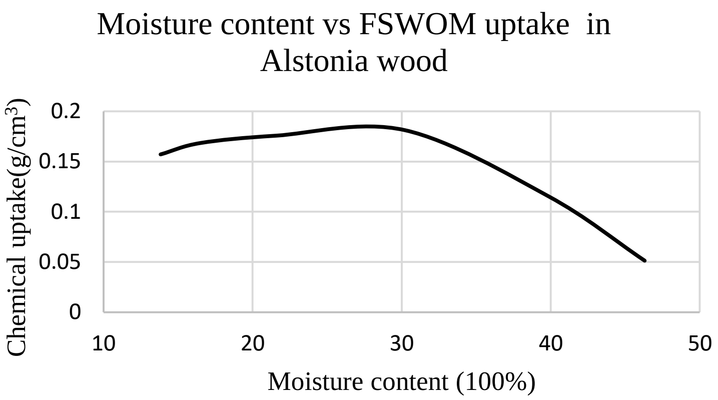


Figure 50: Moisture content vs. FSWOM uptake in Alstonia wood

In the case of Alstonia wood, the highest uptake of FSWOM was observed at moisture conditions ranging from 28 % to 30 %. This indicates that the wood samples with a moisture content within this range exhibited the greatest absorption of the FSWOM preservative.

c. FSWOM-Mahogany

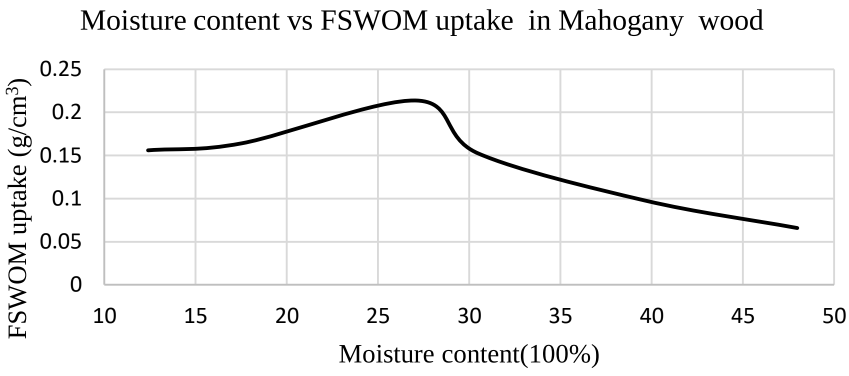


Figure 51: Moisture content vs. FSWOM uptake in Mahogany wood

In the case of Mahogany wood, the highest uptake of FSWOM (preservative name) was observed at moisture conditions ranging from 26 % to 28 %. This indicates that the wood samples with a moisture content within this range exhibited the greatest absorption of the FSWOM preservative.

d. FSWOM-Mango wood

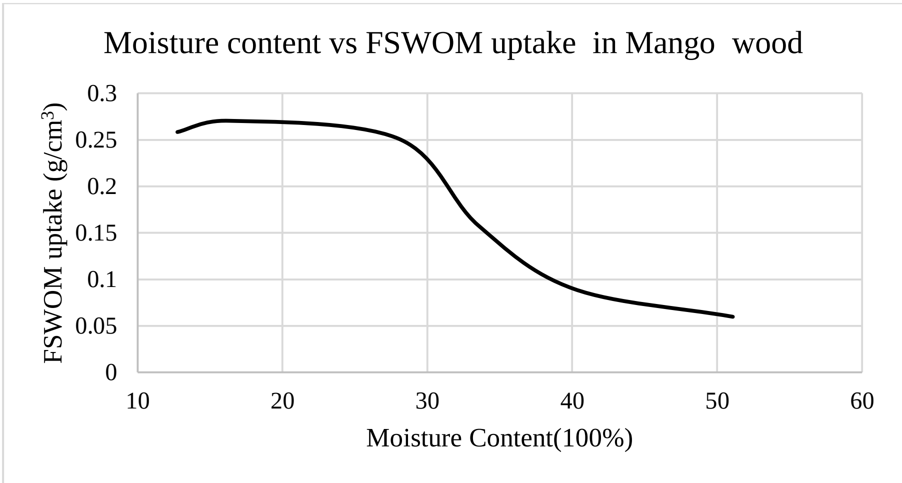


Figure 52: Moisture content vs. FSWOM uptake in Mango wood

In the case of Mango wood, the highest uptake of FSWOM was observed at moisture content levels ranging from 16 % to 26 %. This indicates that the wood samples with a moisture content within this range demonstrated the most effective absorption of the FSWOM preservative. Based on these findings, it can be concluded that the optimal moisture content range for achieving the best chemical uptake in Mango wood is between 16 % and 26 %.

e. FSWOM-Rubberwood

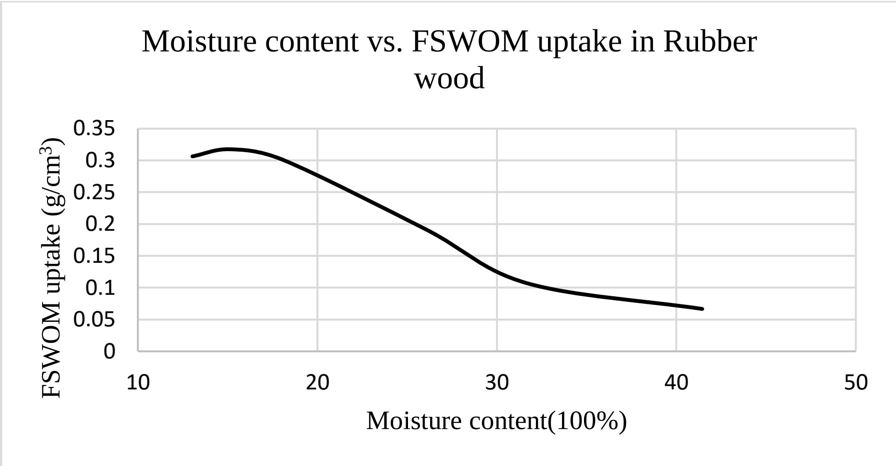


Figure 53: Moisture content vs. FSWOM uptake in Rubberwood

In the case of rubber wood, the highest uptake of FSWOM (preservative name) was observed at a moisture content level of 14 % to 17 %. This indicates that the rubber wood samples with a moisture content of 14 % to 17 % exhibited the highest absorption of the FSWOM preservative. Consequently, it can be inferred that the optimal moisture content level for achieving the highest FSWOM uptake in rubber wood is 14 % to 17 %.

4.2 FSWM

a. FSWM- Pinewood

This part discusses how the FSWM preservative vary with the different moisture content level in tested wood types

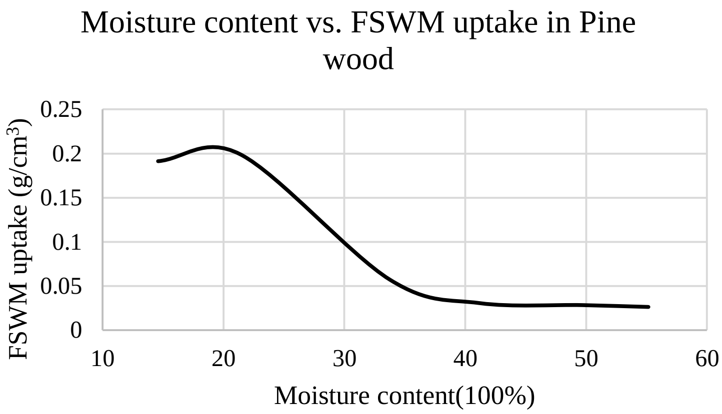


Figure 54: Moisture content vs. FSWM uptake in Pine wood

In the case of Pine wood, the optimal moisture content level for achieving the highest uptake of FSWM preservative was found to be between 18 % and 22 %. This range demonstrated the most effective absorption of the FSWM preservative, resulting in the best preservative uptake in pine wood.

b. FSWM- Alstonia wood

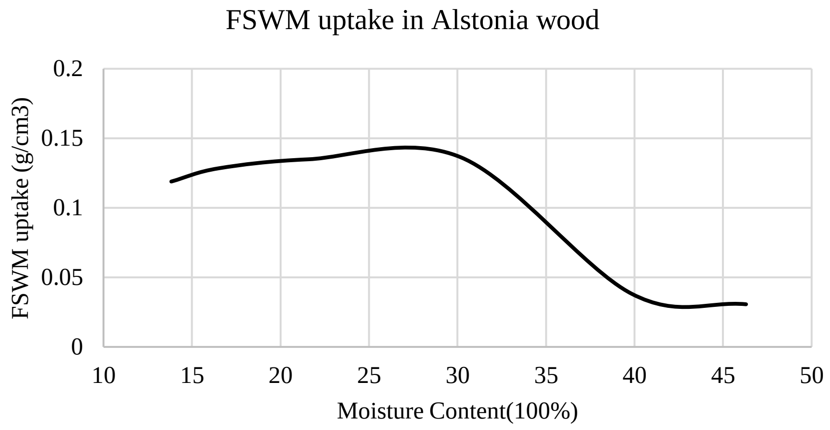


Figure 55: Moisture contents FSWM uptake in Alstonia wood

In the case of Alstonia wood, the highest uptake of FSWM preservative was observed at a moisture content level between 26 % and 30 %. Therefore, it can be concluded that the best preservative uptake in Alstonia wood occurs within this specific moisture content range.

c. FSWM- Mango wood

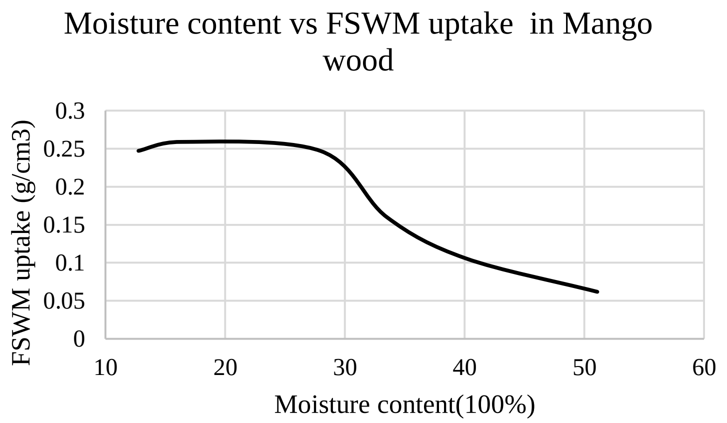


Figure 56: Moisture content vs. FSWM uptake in Mango wood

Consider the Mango wood's highest FSWOM uptake shown in the 16 % to 28 % moisture content level. Therefore this moisture content is the best value for mango wood treatments.

d. FSWM- Rubberwood

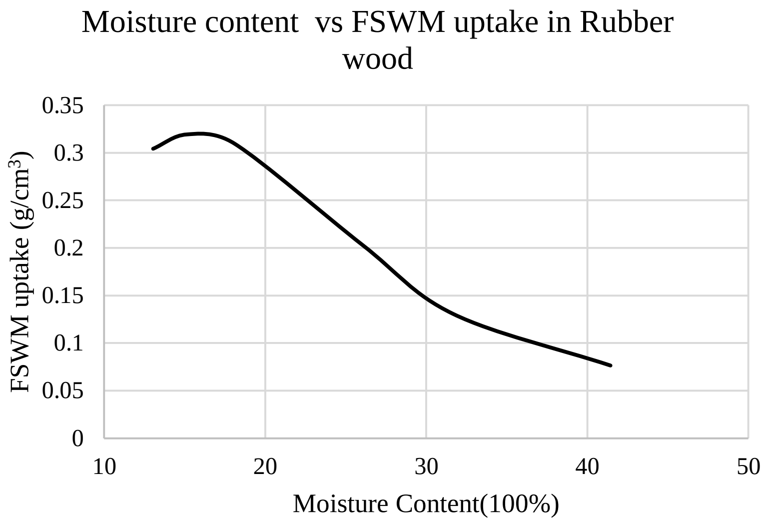


Figure 57: Moisture content vs. FSWM uptake in Rubberwood

In the investigation, it was observed that the peak FSWM uptake occurs within the moisture content range of 14 % to 18 %.

e. FSWM- Mahogany wood

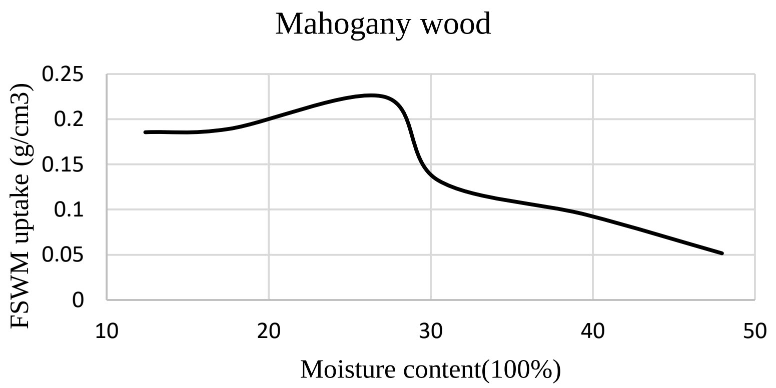


Figure 58: Moisture content vs. FSWM uptake in Mahogany wood

Based on the research findings, it has been determined that for mahogany wood, the optimal FSWM uptake is observed within the moisture content range of 24 % to 28 %. Therefore, to achieve the highest preservative uptake, it is recommended to treat the wood under these specific moisture conditions.

a. ACQ- Pinewood

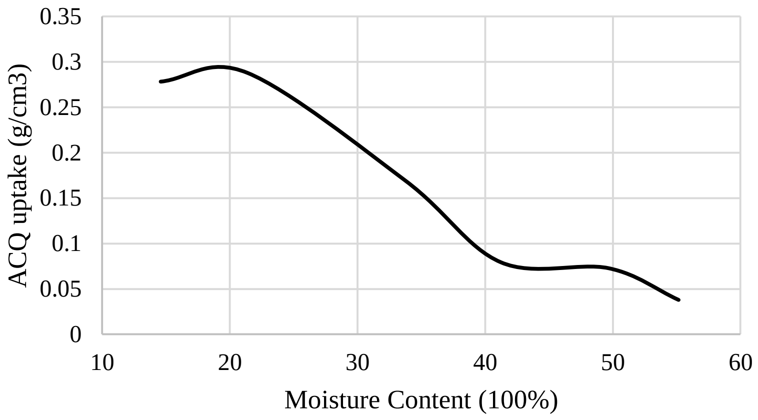


Figure 59: Moisture content vs. ACQ uptake

Based on the research outcomes, it has been identified that the most significant ACQ uptake is observed within the moisture content range of 18 % to 22 %. If the wood in question is pine, it is advisable to treat it within these moisture conditions to achieve optimal ACQ uptake.

b. ACQ- Alstonia wood

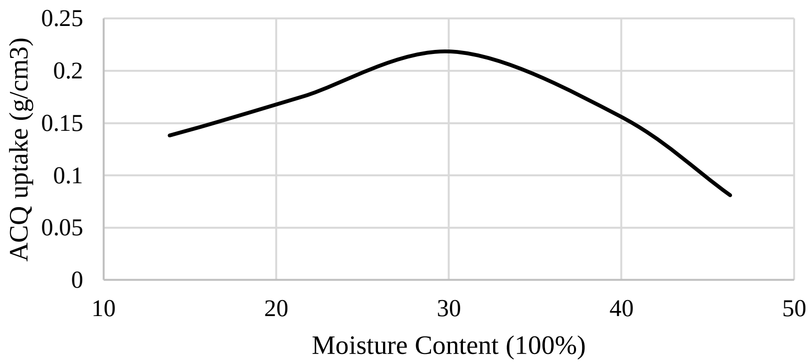


Figure 60: Moisture content vs. ACQ uptake

Based on the research findings, it has been determined that the highest ACQ preservative uptake in Alstonia wood is observed within the moisture content range of 28 % to 32 %. Therefore, to achieve the maximum preservative uptake, it is recommended to treat Alstonia wood within this specific moisture range.

c. ACQ- Mahogany wood

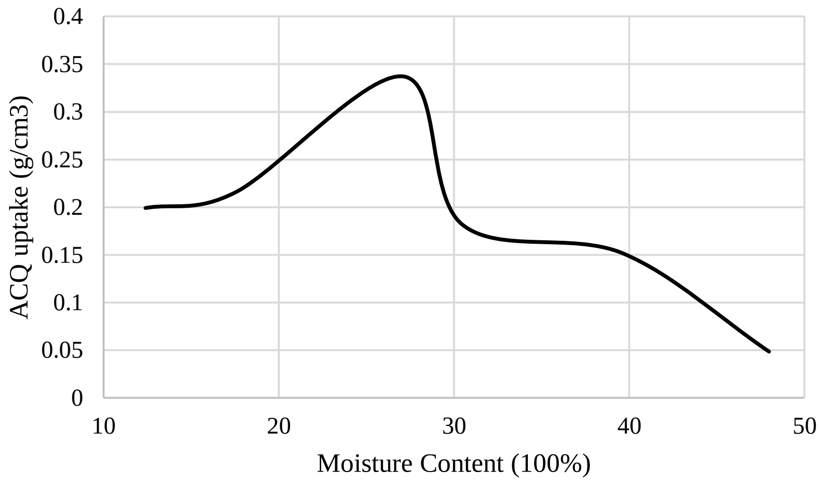


Figure 61: Moisture content vs. ACQ uptake

Based on the research outcomes, it has been established that the optimal ACQ uptake is observed within the moisture content range of 26 % to 28 %. Therefore, to achieve the highest ACQ uptake, it is advised to treat the wood within this specific moisture range.

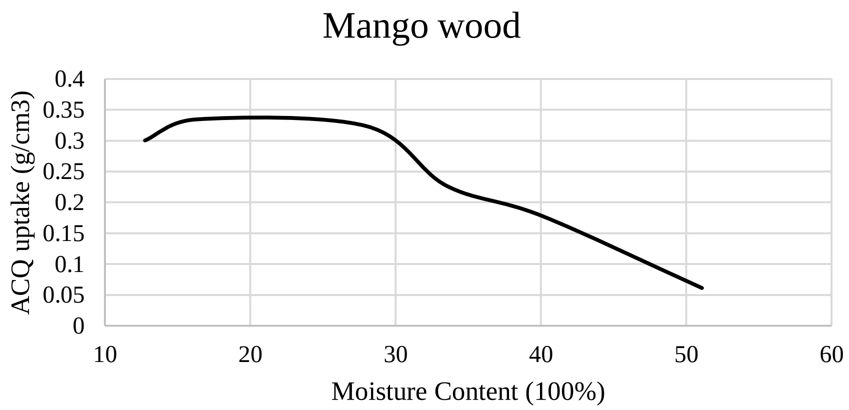


Figure 62: Moisture content vs. ACQ uptake in Mango wood

In the case of Mango wood, the highest uptake of ACQ was observed at moisture conditions ranging from 18 % to 28 %. This indicates that the wood samples with a moisture content within this range exhibited the greatest absorption of the ACQ preservative.

f. ACQ- Rubberwood

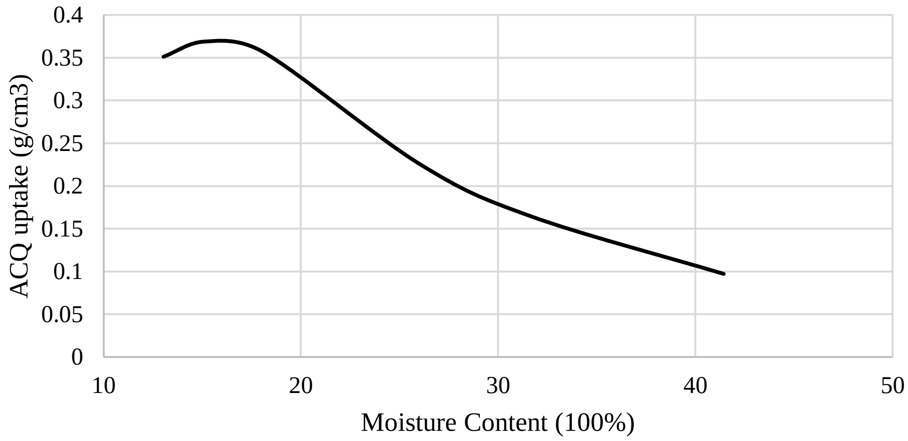


Figure 63: Moisture content vs. ACQ uptake in Rubber wood

In the case of Rubber wood, the highest preservative uptake of ACQ was observed at moisture conditions ranging from 15 % to 18 %. This indicates that the wood samples with a moisture content within this range exhibited the greatest absorption of the ACQ preservative.

Boron preservatives

a. Boron-Pinewood

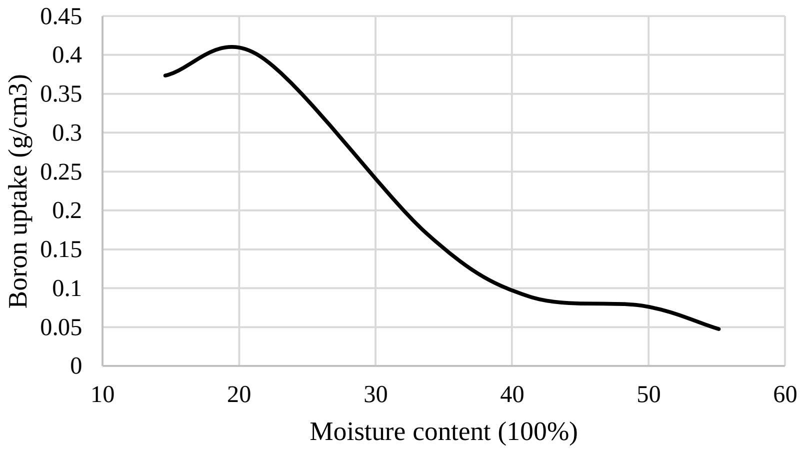


Figure 64: Moisture content vs. boron uptake in pine wood

Based on the research findings, it has been determined that the greatest boron uptake is observed within the moisture content range of 18 % to 22 %. Therefore, to achieve the highest boron uptake, it is recommended to maintain the wood within this specific moisture range during treatment.

b. Boron-Alstonia wood

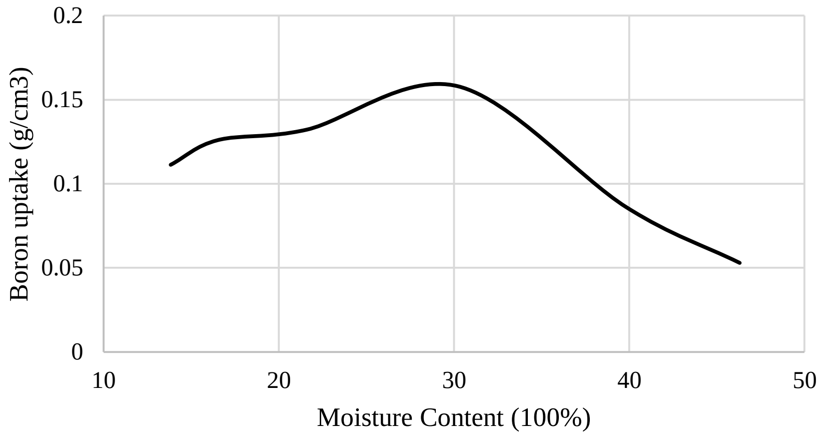


Figure 65: Moisture content vs. Boron uptake in Alstonia wood

Based on the research findings specific to Alstonia wood, it has been observed that the highest uptake of boron preservative occurs within the moisture content range of 28 % to 32 %. Therefore, to obtain the most effective boron preservative uptake, it is advisable to treat Alstonia wood while maintaining a moisture content level within this specific range.

c. Boron-Mahogany wood

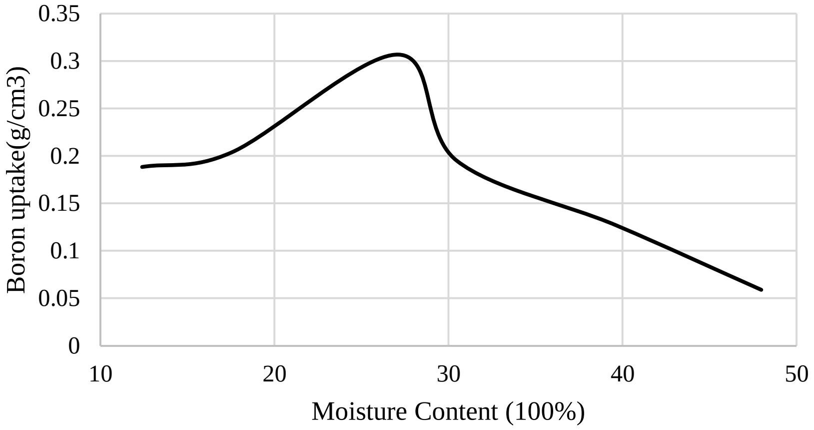


Figure 66: Moisture content vs. Boron uptake in Mahogany wood

Based on the research findings specific to Mahogany wood, it has been observed that the highest uptake of boron preservative occurs within the moisture content range of 26% to 28%. Therefore, to obtain the most effective boron preservative uptake, it is advisable to treat Mahogany wood while maintaining a moisture content level within this specific range.

d. Boron-Mango wood

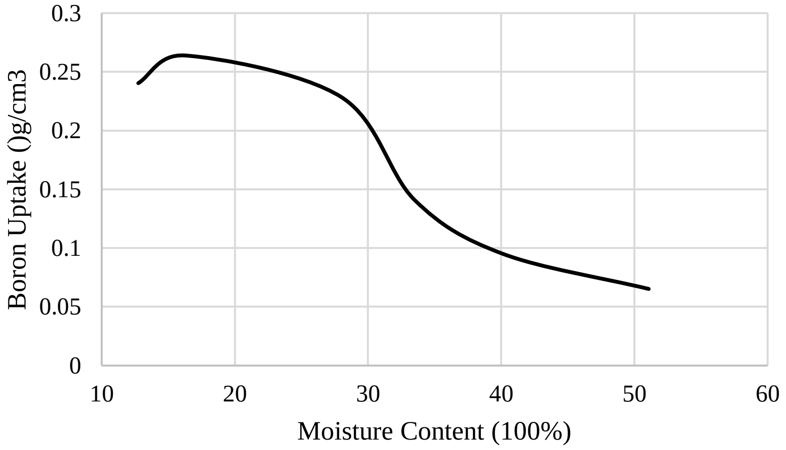


Figure 67: Moisture content vs. Boron uptake in Mango wood

Based on the results, it has been determined that the highest Boron preservative uptake in Mango wood is observed within the moisture content range of 16 % to 22 %.

Therefore, to achieve the maximum preservative uptake, it is recommended to treat Mango wood within this specific moisture range.

e. Boron-Rubberwood

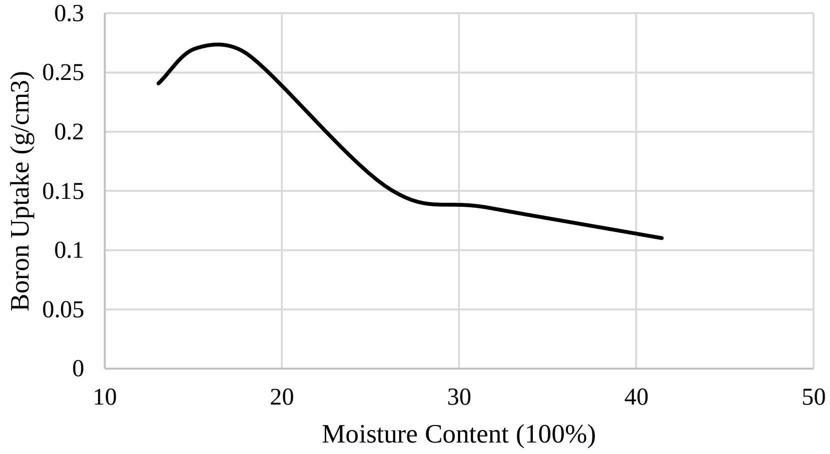


Figure 68: Moisture content vs. Boron uptake in Rubber wood

Based on the research findings specific to Rubber wood, it has been observed that the highest uptake of boron preservatives occurs within the moisture content range of 15 % to 18 %. Therefore, to obtain the most effective boron preservative uptake, it is advisable to treat Rubber wood while maintaining a moisture content level within this specific range.

4.3.5. Wood density vs. chemical uptake

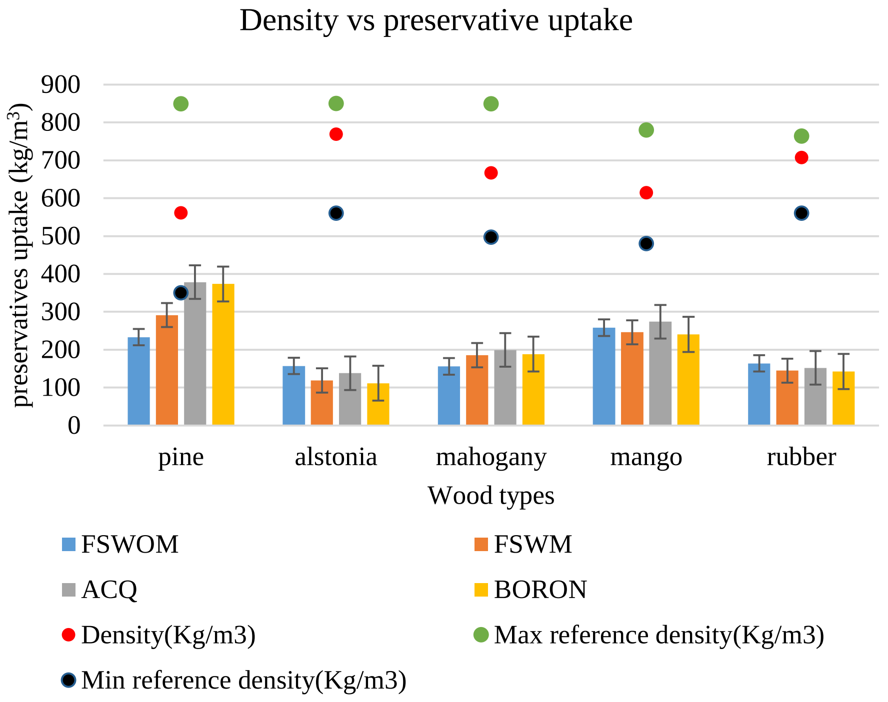


Figure 69: Wood density vs. preservative uptake

This part identified wood density on preservative uptake and identified novel organic preservatives that exhibit similar reactions to industrially used preservatives. The two industrially used preservatives, ACQ and Boron were compared with two novel organic preservatives, FSWOM and FSWM. The final constant wood densities for Pine, Rubber, Mango, Alstonia, and Mahogany were respectively 562 kg/m^3, 687 kg/m^3, 654 kg/m^3, 701 kg/m^3, and 667 kg/m^3. Calculated wood density values were through the reference maximum and minimum wood density values. Green color dotes show maximum density values the black color dot represents minimum values of the density of each wood type and red color dotes show calculated density values.

Respectively minimum and maximum wood density values were as Pine – 274 kg/m^3 to 697 kg/m^3 (Repola, 2006), Alstonia- 560 kg/ m^3 to 850 kg/m^3, Mahogany- 497 kg/m^3 to 849 kg/m^3 (Wood - Densities of Various Species, n.d.), Mango – 480 kg/m^3 to 780 kg m^3 (Saranpää, 2003) and Rubber - 640 to 720 kg/ m^3 (Ruwanpathirana, 2012).

The results revealed a relation between wood density and preservative uptake. It was observed that as the wood density increased, the chemical uptake of both the industrially used preservatives and the novel organic preservatives decreased significantly. This finding indicates that high wood density restricts the absorption of preservatives into the wood structure, impeding their efficacy as protective agents.

4.3 Statistical analysis

This research mainly focuses on wood moisture content and wood preservative uptake in the selected wood species. Therefore this part discussed about correlation between the wood moisture content and wood preservative uptake.

4.3.1 Moisture content vs. preservatives uptake in Pinewood

The correlation analysis aimed to examine the relationship between moisture content and the uptake of four distinct wood preservatives in five wood types.

H_0 = There is no significant correlation between chemical uptake and moisture content in Pinewood

H1 = There is a significant correlation between chemical uptake and moisture content in Pinewood

Table 6: Pairwise Pearson Correlations of Pinewood

Sample 1	Sample 2	Correlation	P-Value	Conclusion (P considering 0.05 level)
FSWOM	moisture content(x)	-0.965	0.002	H0 = Rejected
FSWM	moisture content(x)	-0.919	0.010	H0 = Rejected
ACQ	moisture content(x)	-0.970	0.001	H0 = Rejected
Boron	moisture content(x)	-0.951	0.003	H0 = Rejected

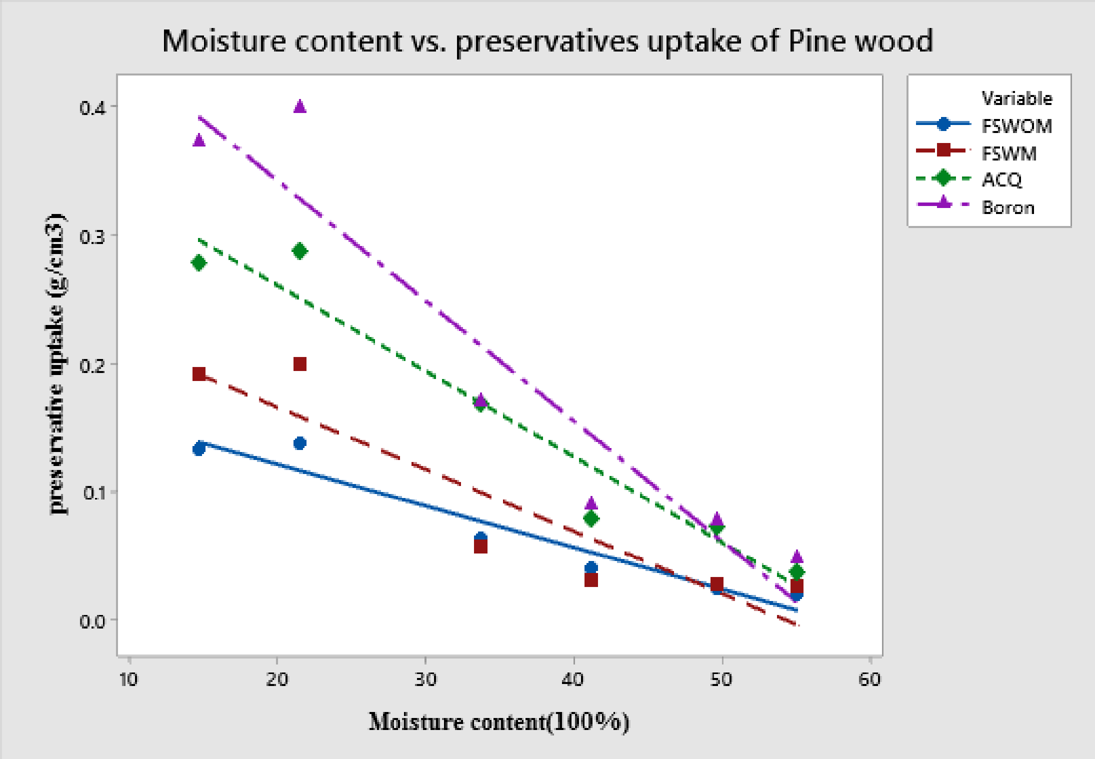


Figure 70: Scatter plot of Moisture content vs. preservative uptake in Pinewood

There was a negative correlation between each chemical uptake and the moisture content in the pine wood. FSWOM, FSWM, ACQ and Boron showed strong negative correlations with the moisture content of pine wood as $r= -0.965$, $P= 0.002$ ($P<0.05$); $r=-0.919$, $P=0.010$ ($P<0.05$); $r=-0.970$, $P=0.001$($P<0.05$), $r = -0.951$, $P=0.003$($P<0.05$); respectively.

When considering all four types of chemical substances uptake was statistically significantly correlated with the moisture content of the Pinewood. Therefore the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted. Therefore FSWOM preservatives can be recommended for Pine wood in 18 % to 22 %, FSWM is 18 % to 22 %, ACQ is 18% to 22 % and boron is 18% to 22 %.

4.3.2 Moisture content vs. preservative uptake in Alstonia wood

H0 = There is no significant correlation between chemical uptake and moisture content in Alstonia wood

H1 = There is a significant correlation between chemical uptake and moisture content in Alstonia wood

Table 7: Pairwise Pearson Correlations of Alstonia wood

Sample 1	**Sample 2**	**Correlation**	**P-Value**	**Conclusion (P considering 0.05 level)**
FSWOM	moisture content	-0.801	0.055	H0 = Accepted
FSWM	moisture content	-0.845	0.034	H0 = Rejected
ACQ	moisture content	-0.349	0.498	H0= Accepted
Boron	moisture content	-0.646	0.166	H0= Accepted

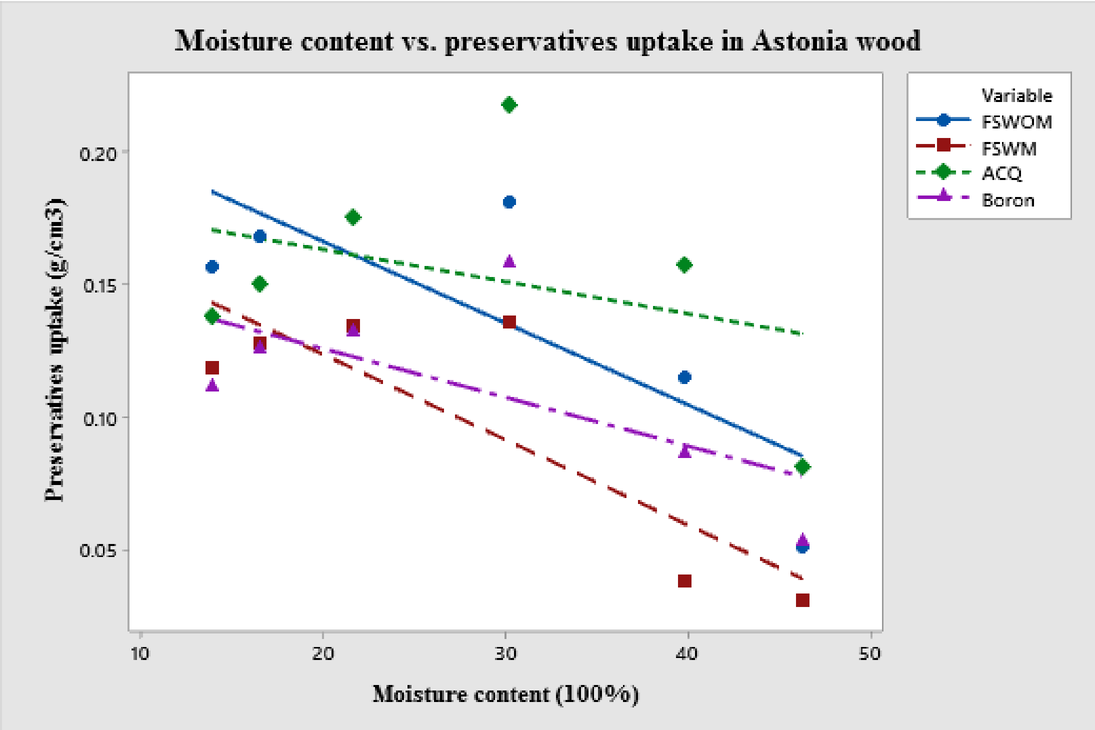


Figure 71: Scatter plot of Moisture content vs. preservative uptake in Alstonia wood

There was a significant negative correlation between each chemical uptake and the moisture content in the Alstonia wood. FSWOM, FSWM, ACQ, and Boron showed negative correlations with the moisture content of Alstonia wood as r= -0.801, P= 0.055 (P>0.05); r= -0.845, P= 0.034 (P<0.05); r= -0.349, P= 0.498 (P>0.05); r= -0.646, P= 0.166 (P>0.05); respectively.

According to static analysis, there is a negative correlation between **Moisture content vs. chemical uptake In alsto**nia **wood, but co**nsidering the **P values for FSWOM,** ACQ, **a**nd Boron it shows a significant level **greater tha**n 0.05 so H0 accepted. And no significant correlation between preservative uptake and moisture content level. It would be another factor affecting the preservative uptake or there isn't a leaner relationship. but H0 was rejected for FSWM and There is a significant correlation between preservative uptake and moisture content level in Alstonia wood.

Finally, according to the static analysis can only recommended FSWM moisture content range of 26 % to 30 % for the Alastonia wood

Because the FSWOM, ACQ, and Boron preservatives null hypothesis accepted. can't recommend moisture rang because P values were higher than 0.005. Therefore It would affect other factors to the Alstonia wood preservatives uptake.

4.3.3 Moisture content vs. preservative uptake in Mahogany wood

H0 = There is no significant correlation between chemical uptake and moisture content in Mahogany wood

H1 = There is a significant correlation between chemical uptake and moisture content in Mahogany wood

Table 8: Pairwise Pearson Correlations of Mahogany wood

Sample 1	**Sample 2**	**Correlation**	**95% CI for ρ**	**P-Value**	**Conclusion (P considering 0.05 level)**
FSWOM	moisture content	-0.723	(-0.967, -0.214)	0.014	H0 = Accepted
FSWM	moisture content	-0.841	(-0.982, -0.091)	0.036	H0 = Rejected
ACQ	moisture content	-0.613	(-0.951, -0.395)	0.196	H0 = Accepted
Boron	moisture content	-0.632	(-0.954, -0.369)	0.179	H0= Accepted

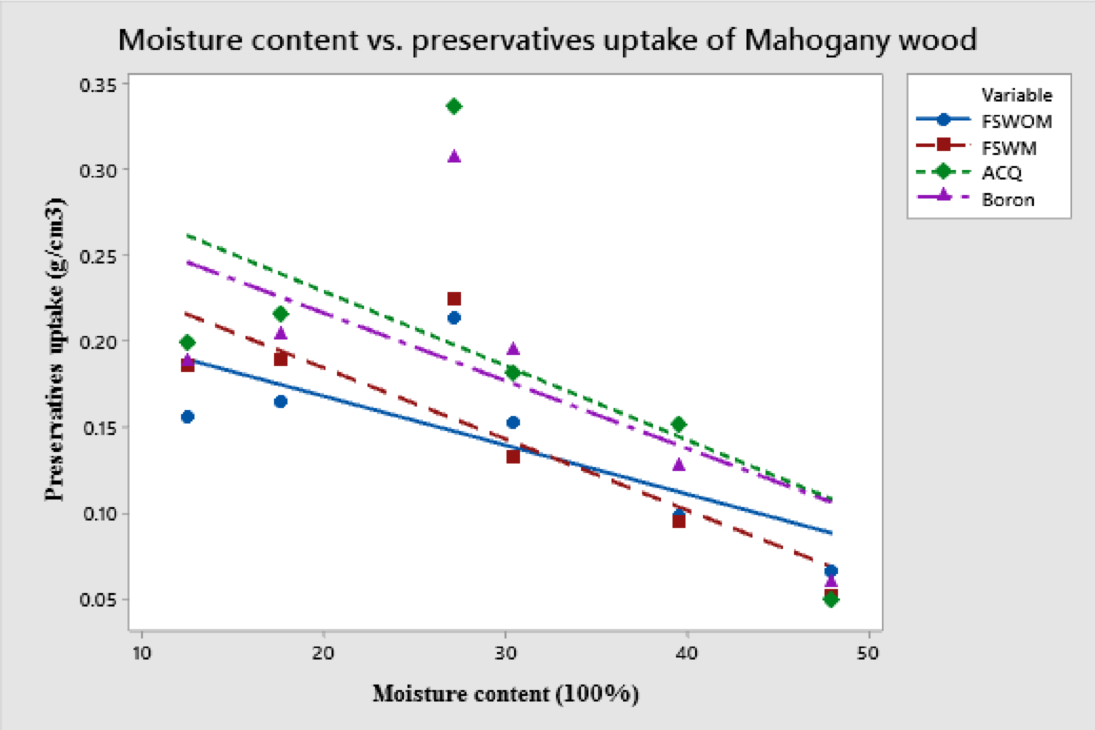


Figure 72: Scatter plot of Moisture content vs. preservative uptake in Mahogany wood

There was a significant negative correlation between each chemical uptake and the moisture content in the Mahogany wood. FSWOM, FSWM, ACQ, and Boron preservatives showed strong significant correlations with the moisture content of Mahogany wood as r=-0.723, P= 0.014 ($P<0.05$); r= -0.841, P= 0.036 ($P<0.05$), r= -0.613, P= 0.196 ($P>0.05$), r= -0.632, P= 0.048 ($P>0.179$); respectively.

When considering all four types of chemical substances uptake was statistically significantly correlated with the moisture content of the Mahogany wood. It shows a negative correlation between Moisture content vs. chemical uptake, but consider the P values for FSWOM, ACQ, and Boron significant levels more than 0.05 therefore H0 is accepted. And no significant correlation between preservative uptake and moisture content level. It would be another factor affecting the preservatives uptake or there is no leaner relationship but H0 was rejected for FSWM, There is a significant correlation between preservatives uptake and moisture content level in mahogany wood

Finally, according to the static analysis, only the recommended FSWM moisture content range is 24 % to 28 % for the Mahogany wood

Because the FSWOM, ACQ, and Boron preservatives null hypothesis was accepted. Can not recommend a moisture range because P values were higher than 0.005. Therefore It would affect other factors in the Mahogany wood preservatives uptake.

4.3.4 Moisture content vs. preservatives uptake in Mango

H0 = There is no significant correlation between chemical uptake and moisture content in Mango wood

H1 = There is a significant correlation between chemical uptake and moisture content in Mango wood

Table 9: Pairwise Pearson Correlations Mango wood

Sample 1	Sample 2	Correlation	95% CI for ρ	P-Value	Conclusion (P considering 0.05 level)
FSWOM	moisture content	-0.938	(-0.993, -0.532)	0.006	H0 =Rejected
FSWM	moisture content	-0.938	(-0.993, -0.528)	0.006	H0 =Rejected
ACQ	moisture content	-0.910	(-0.990, -0.378)	0.012	H0 =Rejected
Boron	moisture content	-0.945	(-0.994, -0.573)	0.004	H0 =Rejected

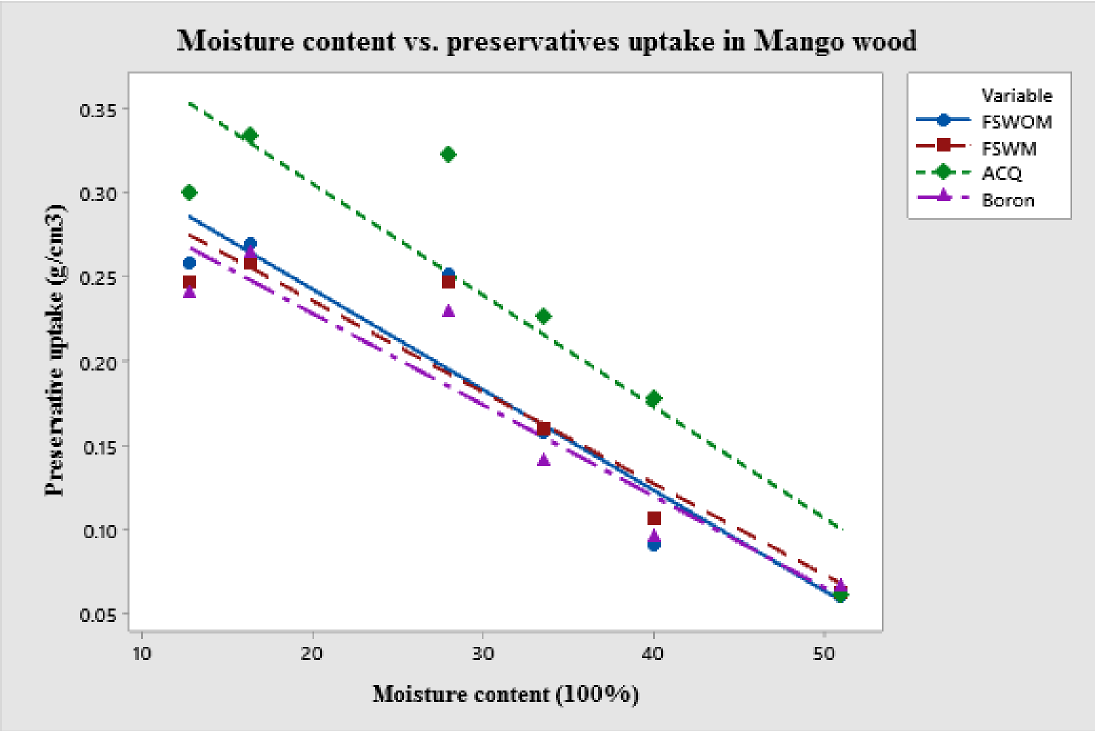


Figure 73: Scatter plot of Moisture content vs. preservative uptake in Mango wood

There was a significant negative correlation between each chemical uptake and the moisture content in the Mango wood. FSWOM, FSWM, ACQ, and Boron preservatives showed strong negative significant correlations with the moisture content of Mango wood as r= -0.938, P= 0.006 (P<0.05); r= -0.938, P= 0.006 (P<0.05), r= -0.910, P= 0.012 (P<0.05), r= -0.945, P= 0.004 (P<0.05); respectively.

When considering all four types of chemical substances uptake was statistically significantly correlated with the moisture content of the Mango wood. Therefore the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted.

Finally, according to the static analysis moisture content can be recommended to FSWOM, FSWM, ACQ, and Boron preservatives. Because the null hypothesis was rejected. as the FSWOM moisture content range is 16 % to 26 %, FSWM is 16 % to 28 %, ACQ is 18 % to 28 % and Boron is 16 % to 22 % for the Mango wood

4.3.5 Moisture content vs. preservatives uptake in Rubber wood

H0 = There is no significant correlation between chemical uptake and moisture content in Rubber wood

H1 = There is a significant correlation between chemical uptake and moisture content in Rubber wood

Table 10: Pairwise Pearson Correlations of Rubber Wood

Sample 1	Sample 2	Correlation	95% CI for ρ	P-Value	Conclusion (P considering 0.05 level
FSWOM	moisture content	-0.976	(-0.998, -0.793)	0.001	H0 = Rejected
FSWM	moisture content	-0.979	(-0.998, -0.814)	0.001	H0 = Rejected
ACQ	moisture content	-0.960	(-0.996, -0.675)	0.002	H0 = Rejected
Boron	moisture content	-0.927	(-0.992, -0.464)	0.008	H0 = Rejected

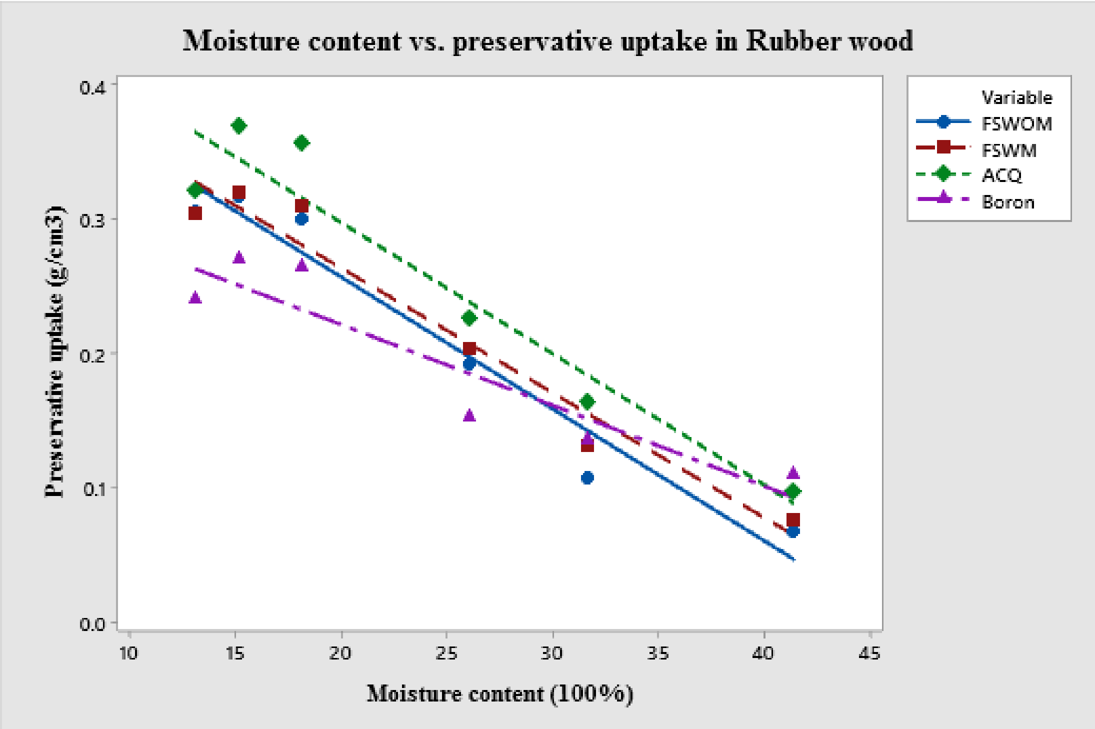


Figure 74: Scatter plot of Moisture content vs. preservative uptake in Rubber wood

There was a significant negative correlation between each chemical uptake and the moisture content in the Rubber wood. FSWOM, FSWM, ACQ and Boron preservatives showed strong negative significant correlations with the moisture content of Rubber wood as r=-0.976, P= 0.001 (P<0.05); r=-0.979, P= 0.001 (P<0.05), r=-0.960, P= 0.002 (P<0.05), r= -0.927, P= 0.008 (P<0.05); respectively.

According to the person correlation, there is a negative correlation between Moisture content vs. chemical uptake for all preservative types. because according to the regression analysis, the p-value of these preservatives uptakes less than the significant level and H0 rejected and H1 Accepted, therefore Rubber wood has a negative significant correlation between Moisture content and preservative uptake for all preservative types.

When considering all four types of chemical substances uptake was statistically significantly correlated with the moisture content of the Rubber wood. Therefore the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted.

Finally, according to the static analysis moisture content can be recommended to FSWOM, FSWM, ACQ, and Boron preservatives. Because the null hypothesis was rejected. as the FSWOM moisture content range is 14 % to 17 %, FSWM is 14 % to 18 %, ACQ is 15 % to 18 % and Boron is 15 % to 18 % for the Rubberwood

4.4 Chapter Summary

Wood type	Preservative type	(r-value) Correlation coefficients	(P value)	Conclusion (P considering 0.05 level)
Pine	FSWOM	-0.965	0.002	H_0 = Reject / H_1 Accepted
	FSWM	-0.919	0.010	H_0 = Reject/ H_1 Accepted
	ACQ	-0.970	0.001	H_0 = Reject/ H_1 Accepted
	Boron	-0.951	0.003	H_0 = Reject/ H_1 Accepted
Alstonia	FSWOM	-0.801	0.055	H_0 = Accepted / H_1 Rejected

	FSWM	-0.845	0.034	H_0 = Rejected/ H_1 Accepted
	ACQ	-0.349	0.498	H_0 = Rejected/ H_1 Accepted
	Boron	-0.646	0.166	H_0= Accepted / H_1 Rejected
Mahogany	FSWOM	-0.723	0.104	H_0 = Accepted / H_1 Rejected
	FSWM	-0.841	0.036	H_0 = Reject / H_1 Accepted
	ACQ	-0.613	0.196	H_0 = Accepted / H_1 Rejected
	Boron	-0.632	0.179	H_0= Accepted / H_1 Rejected
Mango	FSWOM	-0.938	0.006	H_0 = Rejected / H_1 Accepted
	FSWM	-0.938	0.006	H_0 = Rejected / H_1 Accepted
	ACQ	-0.910	0.012	H_0 =Rejected / H_1 Accepted
	Boron	-0.945	0.004	H_0= Rejected / H_1 Accepted
Rubber	FSWOM	-0.976	0.001	H_0 = Rejected / H_1 Accepted
	FSWM	-0.979	0.001	H_0 = Rejected / H_1 Accepted
	ACQ	-0.960	0.002	H_0 =Rejected / H_1 Accepted
	Boron	-0.927	0.008	H_0= Rejected / H_1 Accepted

This part provides information on the optimum moisture content for wood preservative treatments based on the selected wood types and preservative types. Additionally, it discusses how preservative uptake varies concerning wood density.

The study determined the recommended moisture content ranges for the selected wood preservative types and wood types according to the data analysis results. These ranges ensure optimal preservative uptake during treatment. For FSWOM preservatives can recommended to Pine wood in 18 % to 22 %, FSWM is 18 % to 22 %, ACQ is 18% to 22 % and boron is 18% to 22 %.

And considering Alastonia wood can only recommend FSWM moisture content range of 26 % to 30 %. Because the FSWOM, ACQ, and Boron preservatives null hypothesis accepted. cant to recommended moisture ranges.

Similarly, consider the Mahogany wood can only recommended FSWM moisture content range of 24 % to 28 %. Because the FSWOM, ACQ, and Boron preservatives null hypothesis accepted. Can not recommend moisture ranges for the Mahogany wood.

According to the static analysis data, moisture content can be recommended for the Mango wood. All preservative types (FSWOM, FSWM, ACQ,and Boron) null hypotheses were rejected. Therefore FSWOM moisture content range is 16 % to 26 %, FSWM is 16 % to 28 %, ACQ is 18 % to 28 % and Boron is 16 % to 22 % for the Mango wood.

Finally, consider the Rubberwood moisture content can be recommended to FSWOM, FSWM, ACQ, and Boron preservatives. Because the null hypothesis was rejected. as the results FSWOM moisture content range is 14 % to 17 %, FSWM is 14 % to 18 %, ACQ is 15 % to 18 % and Boron is 15 % to 18 % for the Rubberwood

According to the statistical correlation analysis, H_0 is rejected for some wood types and preservative types and H1 was accepted for some wood types and preservative types.

When Alstonia and Mahogany null hypothesis accepted. Can not to recommended moisture ranges for FSWOM, ACQ and Boron because P values were higher than 0.005. Therefore It would affect other factors to the Alstonia wood preservatives uptake. Therefore the study identified a relationship between wood moisture content and preservative uptake. It was observed that as wood moisture content increased, there was a significant decrease in preservative uptake. This finding suggests that higher-moisture content of woods exhibits lower rates of preservative absorption. Understanding this relationship enables practitioners to make informed decisions regarding wood selection based on desired preservative uptake levels. By considering the recommended moisture content ranges and wood characteristics, practitioners can optimize the effectiveness of preservative treatments.

Chapter 5: Conclusions and Future Works

5.1 Conclusion

In conclusion, the objective of this study was to determine the optimal moisture content before applying different wood preservatives to Pine, Alstonia, Mahogany, Mango, and Rubberwood. The experimental results indicate that moisture content directly affects preservative uptake during wood treatment.

Based on the findings, the recommended optimum moisture content for the preservative treatments. FSWOM preservatives can be recommended for Pine wood is 18 % to 22 % for all four preservative types. And considering Alastonia wood can only recommend FSWM moisture content range of 26 % to 30 %. consider the Mahogany wood can only recommended FSWM moisture content range of 24 % to 28 %. Mango wood can recommended FSWOM moisture content range is 16 % to 26 %, FSWM is 16 % to 28 %, ACQ is 18 % to 28 % and Boron is 16 % to 22 % for Mango wood. Finally, Rubber wood moisture content is recommended as the FSWOM moisture content range is 14 % to 17 %, FSWM is 14 % to 18 %, ACQ is 15 % to 18 % and Boron is 15 % to 18 % for the Rubber wood. Alstonia and Mahogany null hypothesis accepted. Can not to recommended moisture ranges for FSWOM, ACQ and Boron because P values were higher than 0.005. Therefore It would affect other factors in the Alstonia wood preservative uptake

The study confirms that moisture content significantly affects the uptake of preservatives during wood treatment. The experimental findings indicate that preservative uptake is limited by the moisture content present in the wood. Therefore, reducing the moisture content through drying can lead to a noticeable improvement in the maximum amount of preservatives that can be absorbed by the wood. Therefore, considering the specific wood type and the type of preservative being used, maintaining the recommended moisture content ranges before the treatment can optimize the effectiveness of the wood preservative application. This finding aligns with the research conducted by Usta (Usta, 2004). These findings provide valuable insights for industries and practitioners involved in wood preservation, contributing to the overall quality and durability of wood-based products.

The findings of the study established a relationship between wood density and preservative uptake. It was observed that as the density of the wood increased, there was a significant decrease in the preservative uptake (Nath et al., 2020). Both industrially utilized preservatives and the novel organic preservatives type react as same.

5.2 Recommendations

Based on the findings of the study the following recommendations were grasped.

i. Incorporate the recommended moisture content ranges identified in this study into industry guidelines and standards for wood preservation. This will provide practitioners with clear instructions on the moisture content requirements for effective preservative uptake in different wood types.
ii. Further, explore and refine drying techniques and equipment to achieve the recommended moisture content levels before preservative treatment. Investigate innovative methods such as vacuum drying or radiofrequency drying, which may offer advantages in terms of efficiency and preservation of wood quality.
iii. When selecting wood species for specific preservative treatments, take into account the density characteristics and their impact on preservative uptake. Opt for wood species with lower density, if feasible, to enhance the absorption of preservatives and improve treatment effectiveness.
iv. Conduct comprehensive field studies to evaluate the long-term performance and durability of wood products treated at the recommended moisture content levels. Monitor the effectiveness of the treatments over extended periods, assess decay and insect resistance, and evaluate the overall quality and lifespan of the preserved wood.

By implementing these recommendations, practitioners, and industries can enhance the efficiency and effectiveness of wood preservative treatments, leading to improved preservation outcomes and the production of durable wood-based products.

5.3 Future Development and Possibilities

i. Based on the study, several potential areas for future development and possibilities can be identified as the following.

ii. Conduct further research to optimize the formulation of wood preservatives, taking into account the specific wood types and their moisture content requirements. Fine-tuning the composition and concentrations of preservatives can potentially enhance their efficacy and increase preservative uptake, leading to improved wood preservation outcomes.

iii. Explore the development and utilization of environmentally friendly and sustainable wood preservative alternatives. Investigate bio-based preservatives derived from natural sources, such as plant extracts or microbial agents, that can effectively protect wood against decay and insects while minimizing environmental impact. This avenue of research aligns with the growing demand for eco-friendly and sustainable preservation practices.

iv. Conduct long-term monitoring and evaluation of preserved wood products in real-world applications. Assess the durability, resistance to decay, and performance of treated wood over extended periods of exposure to different environmental conditions. This data can provide valuable insights into the long-term effectiveness of the recommended moisture content ranges and preservative treatments, further validating their practical application.

v. Collaborate with industry associations, regulatory bodies, and stakeholders to develop standardized guidelines and best practices for wood preservation. Encourage the adoption of the recommended moisture content ranges and treatment protocols based on the specific wood types and preservatives used. This will contribute to the establishment of consistent and effective wood preservation practices across the industry.

By exploring these future development opportunities, researchers and practitioners can contribute to advancing the field of wood preservation, fostering sustainable practices, and improving the overall quality and durability of wood-based products

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Appendix

Appendix A: Industrial survey form

Investigating the wood chemical preservative treatment methods practice in Sri Lanka

This survey is based on post-graduate research and the survey conducted under the Department of Civil Engineering, University of Moratuwa, on the identification of timber preservation methods practiced in Sri Lanka, and this information is used purely for academic purposes only.
The information will not be passed on to any other organization or used for any legal purposes.

There are 32 questions in this survey

Introduction

Identification of wood industry type and nature.

[]company name

Please write your answer here:

[]What is the nature of your company? *

Please choose **all** that apply:

- ☐ wood sawing
- ☐ wood treatment
- ☐ wood production(construction and furniture product)

[]Which types of wood are mainly sawing? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **all** that apply:

- ☐ Pine
- ☐ Mahogay
- ☐ Mahogay
- ☐ Alastoniya
- ☐ Mango
- ☐ Rubber
- ☐ Other

[]What are the other wood types?

Only answer this question if the following conditions are met:
Answer was at question '3 [Q002a]' (Which types of wood are mainly sawing?)

Please write your answer here:

[]Do you use treated wood for wood production? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

- ◯ Yes
- ◯ no
- ◯ some time

[]why don't you use treated wood?

Only answer this question if the following conditions are met:
Answer was 'no' at question '5 [Q003a]' (Do you use treated wood for wood production?)

Please choose **all** that apply:

- ☐ customers are not consider about wood treatment (treat or nontreated)
- ☐ treated wood product are expensive than non treated wood product
- ☐ no wood treatment facilities

[]what is the largest selling category? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

- ◯ treated wood product
- ◯ non treated wood product

wood preservative treatment method

[]Do people aware of wood treatments? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

- ◯ Yes

No

May be

[]What are the wood preservative methods practice in your company? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please write your answer(s) here:

[]What are the wood types used for the wood preservative?

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Pine

Mahogany

Rubber

Alastoniya

Mango

other

[]which type of preservatives are used for the treatment?

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

Organic preservatives

Inorganic preservatives

[]What are the chemicals used for the treatments?

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please write your answer(s) here:

[]what are the uses of treated wood? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

[]what are the uses of treated wood? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose the appropriate response for each item:

	Increase	Same	Decrease
furniture product	○	○	○
construction work	○	○	○

[]Did you participate in any wood treatment workshops? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

Yes

No

[]what are the treatment conditions?

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

	pressure	temperature	time duration (date)	treatment type
teak				
mahogany				
pine				
mango				
alastoniya				
rubber				

[]Do you aware of the negative impact of wood chemical treatment? *

moisture

[]Do you consider the moisture content in the wood before chemical treatment? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

[]Why don't you consider moisture content in the wood before wood treatment? *

Only answer this question if the following conditions are met:
Answer was 'No' at question '17 [Q005a]' (Do you consider the moisture content in the wood before chemical treatment?)

Please choose **only one** of the following:

- ○ No idea
- ○ moisture content not affected to the wood treatment
- ○ don't have a moisture meter

[]After the wood treatment, Do you check the final wood moisture content before use? *

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

[]what are the wood wastes produced during the sewing process?

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Please choose **all** that apply:

- ☐ large size wood pieces
- ☐ small wood pieces
- ☐ wood dust
- ☐ other part

[]what are the wood wastes produced during the wood production process?

Only answer this question if the following conditions are met:
Answer was at question '2 [Q002]' (What is the nature of your company?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

- ☐ large size wood pieces
- ☐ small wood pieces
- ☐ wood dust
- ☐ other part

Appendix B: Preservatives Uptake data

FSWOM uptake

FSWOM uptake of selected wood types

week	moisture content	FSWOM uptake in pine wood g/cm3	
0	55.1523	0.020016	20.01577
1	49.6696	0.024898	24.89767
2	41.2192	0.039787	39.78745
3	33.7534	0.063953	63.95284
4	21.3917	0.137792	137.7915
5	14.5926	0.133154	133.1537

week	moisture content	FSWOM uptake(g/cm3)	
0	46.30139	0.05126	51.25991
1	39.83691	0.115457	115.4568
2	30.20393	0.18124	181.2404

3	21.58714	0.175748	175.7483
4	16.50889	0.168425	168.4254
5	13.82922	0.157075	157.075

week	moisture content	FSWOM uptake vs Mahogany wood	
0	47.9739	0.065906	65.9056
1	39.60913	0.097882	97.88201
2	30.46862	0.152559	152.5593
3	27.12479	0.213705	213.705
4	17.5416	0.164154	164.1538
5	12.39234	0.155977	155.9766

week	moisture content	FSWOM uptake vs Mahogany wood	
0	51.08509	0.059803	59.80323
1	40.07349	0.089949	89.94893
2	33.51122	0.158051	158.0514
3	27.98128	0.251418	251.4176
4	16.26948	0.270457	270.457
5	12.75124	0.258374	258.3743

week	moisture content	FSWOM uptake vs. moisture content in Rubber wood	
0	41.44085	0.066638	66.63788
1	31.66437	0.107158	107.1576
2	26.03477	0.191736	191.7365
3	18.09189	0.300725	300.7248
4	15.13024	0.317453	317.4532
5	13.03882	0.306307	306.3074

FSWM uptake

week	moisture content	FSWM uptake in pine wood	
0	55.1523	0.026362	26.36224
1	49.6696	0.028437	28.43704
2	41.2192	0.030634	30.6339

3	33.7534	0.057362	57.36228
4	21.3917	0.199181	199.1814
5	14.5926	0.19137	191.3703

week	moisture content	FSWM uptake in Alastoniya wood	
0	46.30139	0.030634	30.6339
1	39.83691	0.038201	38.20084
2	30.20393	0.136205	136.2049
3	21.58714	0.134862	134.8624
4	16.50889	0.128394	128.3939
5	13.82922	0.118874	118.8742

week	moisture content	FSWM uptake in Mahogany wood	
0	47.9739	0.051626	51.62605
1	39.60913	0.094221	94.22059
2	30.46862	0.132299	132.2994
3	27.12479	0.224811	224.8113
4	17.5416	0.189173	189.1735
5	12.39234	0.185512	185.512

week	moisture content	FSWM uptake in Mango wood	
0	51.08509	0.061878	61.87803
1	40.07349	0.105937	105.9371
2	33.51122	0.159882	159.8821
3	27.98128	0.246902	246.9019
4	16.26948	0.258863	258.8625
5	12.75124	0.247146	247.146

week	moisture content	FSWM uptake in Rubber wood	
0	41.44085	0.076402	76.40167
1	31.66437	0.130713	130.7128
2	26.03477	0.203209	203.2089
3	18.09189	0.309634	309.6343
4	15.13024	0.319276	319.276
5	13.03882	0.304217	304.2168

ACQ uptake

week	moisture content	ACQ uptake in pine wood	
0	55.1523	0.037957	37.95674
1	49.6696	0.072862	72.8623
2	41.2192	0.079453	79.45286
3	33.7534	0.16928	169.2797
4	21.3917	0.28791	287.9098
5	14.5926	0.278268	278.2681

week	moisture content	ACQ uptake in pine wood	
0	46.30139	0.081039	81.03947
1	39.83691	0.157319	157.3191
2	30.20393	0.218343	218.3428
3	21.58714	0.175626	175.6262
4	16.50889	0.150606	150.6065
5	13.82922	0.138158	138.1577

week	moisture content	ACQ uptake in pine wood	
0	47.9739	0.048697	48.69691
1	39.60913	0.151827	151.827
2	30.46862	0.181851	181.8506
3	27.12479	0.337095	337.0949
4	17.5416	0.21578	215.7798
5	12.39234	0.199181	199.1814

week	moisture content	ACQ uptake in pine wood	
0	51.08509	0.061268	61.26779
1	40.07349	0.178067	178.0672
2	33.51122	0.226764	226.7641
3	27.98128	0.323548	323.5477
4	16.26948	0.33441	334.4099
5	12.75124	0.300298	300.2976

week	moisture content	ACQ uptake in pine wood	
0	41.44085	0.09715	97.14973

1	31.66437	0.16452	164.5199
2	26.03477	0.225544	225.5436
3	18.09189	0.356745	356.7446
4	15.13024	0.368949	368.9493
5	13.03882	0.351229	351.2288

Boron uptake

week	moisture content		
0	55.1523	0.047476	47.47644
1	49.6696	0.077134	77.13396
2	41.2192	0.089583	89.58279
3	33.7534	0.170256	170.2561
4	21.3917	0.399949	399.9493
5	14.5926	0.373465	373.465

week	moisture content	Boron uptake in Alstonia wood	
0	46.30139	0.052969	52.96857
1	39.83691	0.086043	86.04342
2	30.20393	0.158051	158.0514
3	21.58714	0.132177	132.1773
4	16.50889	0.125953	125.9529
5	13.82922	0.111307	111.3072

week	moisture content	Boron uptake in Mahogany wood	
0	47.9739	0.058949	58.94889
1	39.60913	0.127051	127.0513
2	30.46862	0.195032	195.0317
3	27.12479	0.306705	306.7051
4	17.5416	0.203697	203.6971
5	12.39234	0.188319	188.3191

week	moisture content	Boron uptake in Mango wood	
0	51.08509	0.065173	65.17331
1	40.07349	0.095319	95.31902
2	33.51122	0.140843	140.8427
3	27.98128	0.228717	228.7168
4	16.26948	0.263989	263.9885
5	12.75124	0.240433	240.4334

week	moisture content	Boron uptake in Rubber wood	
0	41.44085	0.110209	110.2088
1	31.66437	0.135839	135.8388
2	26.03477	0.152193	152.1931
3	18.09189	0.265087	265.087
4	15.13024	0.270213	270.2129
5	13.03882	0.240738	240.7385

Appendix C: Moisture content variation with different period

moisture content

Wood Type	0	1	2	3	4	5
pine wood	55.1523	49.6696	41.2192	33.7534	21.3917	14.5926
Alstonia	46.30139	39.83691	30.20393	21.58714	16.50889	13.82922
mahogany	47.9739	39.60913	30.46862	27.12479	17.5416	12.39234
mango	51.08509	40.07349	33.51122	27.98128	16.26948	12.75124
rubber	41.44085	31.66437	26.03477	18.09189	15.13024	13.03882

chemical uptake

pine wood

chemical type	0 week	1 week	2week	3week	4 week	5 week
FSWOM	0.628	0.408	0.652	1.048	2.258	2.182
FSWM	0.432	0.466	0.502	0.94	3.264	3.136
ACQ	0.622	1.194	1.302	2.774	4.718	4.56
Boron	0.778	1.264	1.468	2.79	6.554	6.12

Alstonia

chemical type	0 week	1 week	2week	3week	4 week	5 week
FSWOM	0.84	1.892	2.97	2.88	2.76	2.574
FSWM	0.502	0.626	2.232	2.21	2.104	1.948
ACQ	1.328	2.578	3.578	2.878	2.468	2.264
Boron	0.868	1.41	2.59	2.166	2.064	1.824

mahogany

chemical type	0 week	1 week	2week	3week	4 week	5 week
FSWOM	1.08	1.604	2.5	3.502	2.69	2.556
FSWM	0.846	1.544	2.168	3.684	3.1	3.04
ACQ	0.798	2.488	2.98	5.524	3.536	3.264

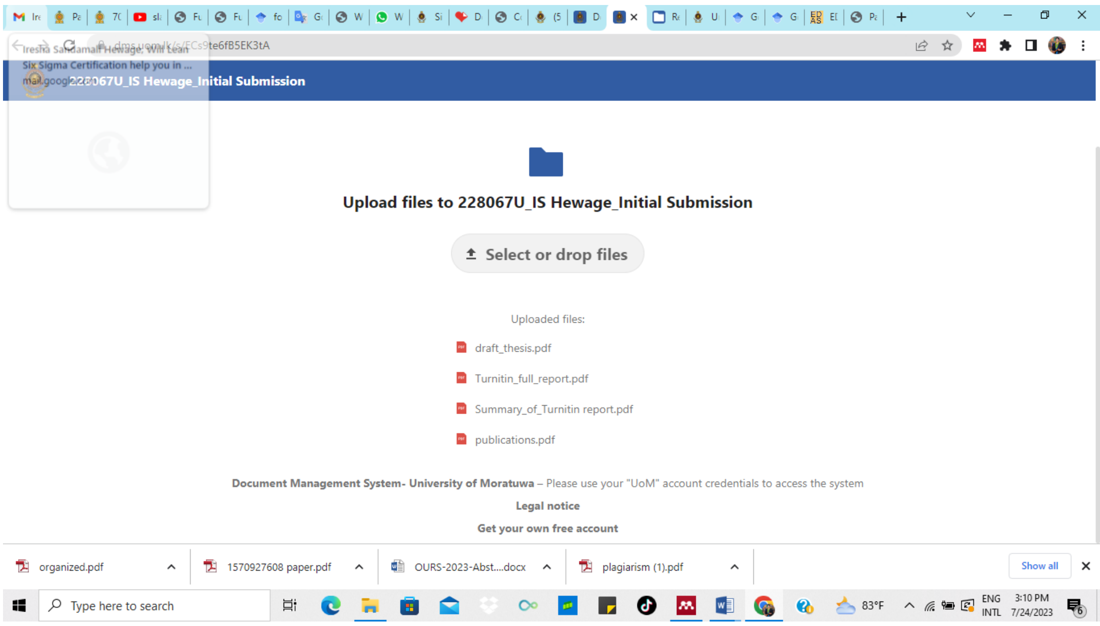
Boron	0.966	2.082	3.196	5.026	3.338	3.086

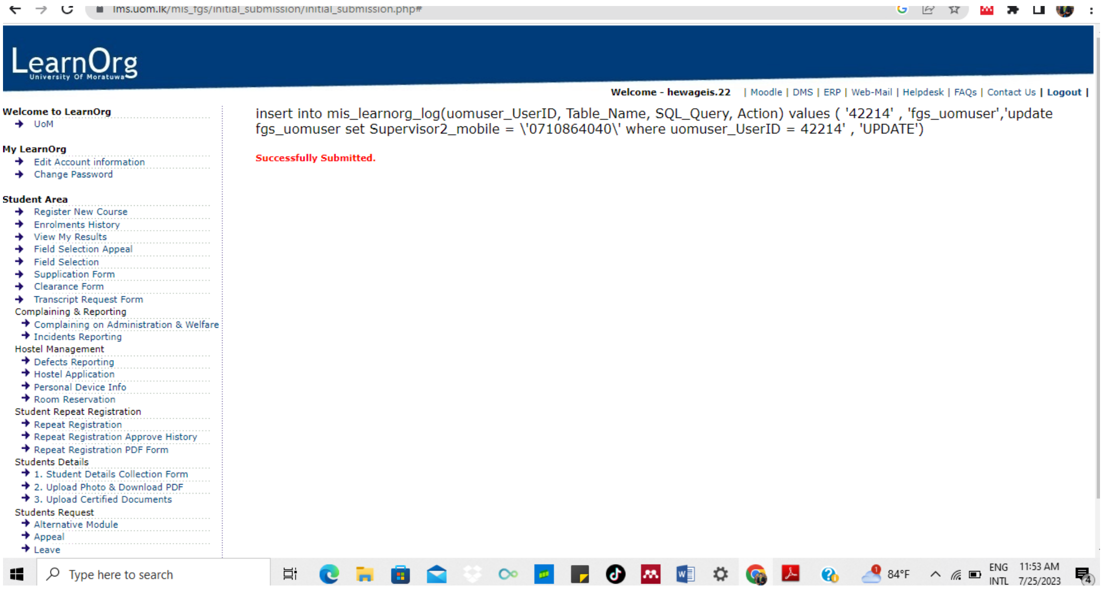
mango

chemical type	0 week	1 week	2week	3week	4 week	5 week
FSWOM	0.98	1.474	2.59	4.12	4.432	4.232
FSWM	1.014	1.736	2.62	4.046	4.242	4.032
ACQ	1.004	2.918	3.716	5.302	5.48	4.492
Boron	1.068	1.562	2.308	3.748	4.316	3.94

rubber

chemical type	0 week	1 week	2week	3week	4 week	5 week
FSWOM	1.092	1.756	3.142	4.928	5.366	4.326
FSWM	1.252	2.142	3.33	5.074	5.232	4.012
ACQ	1.592	2.696	3.696	5.846	6.046	5.246
Boron	1.806	2.226	2.494	4.344	4.428	3.974

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insert into mis_learnorg_log(uomuser_UserID, Table_Name, SQL_Query, Action) values ('42214' , 'fgs_uomuser','update fgs_uomuser set Supervisor2_mobile = \'0710864040\' where uomuser_UserID = 42214' , 'UPDATE')
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