SEPTEMBER 2024

M.Sc. in Mechanical Engineering

AHMET KILIÇ

REPUBLIC OF TÜRKİYE

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

INVESTIGATING THE IMPACT OF EXPANDED PERLITE ON THE THERMAL AND MECHANICAL PROPERTIES OF LIGHTWEIGHT COMPOSITE WOOD

M.Sc. THESIS

IN

MECHANICAL ENGINEERING

BY

AHMET KILIÇ

SEPTEMBER 2024

INVESTIGATING THE IMPACT OF EXPANDED PERLITE ON THE THERMAL AND MECHANICAL PROPERTIES OF LIGHTWEIGHT COMPOSITE WOOD

M.Sc. Thesis

in

Mechanical Engineering

Gaziantep University

Supervisor

Prof. Dr. Recep YUMRUTAŞ

Co-Supervisor

Asst. Prof. Dr. Hakan TUTUMLU

by

Ahmet KILIÇ

September 2024

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Ahmet KILIÇ

ABSTRACT

INVESTIGATING THE IMPACT OF EXPANDED PERLITE ON THE THERMAL AND MECHANICAL PROPERTIES OF LIGHTWEIGHT COMPOSITE WOOD

KILIÇ, Ahmet
M.Sc. in Mechanical Engineer
Supervisor: Prof. Dr. Recep YUMRUTAŞ
Co-Supervisor: Asst. Prof. Dr. Hakan TUTUMLU

September 2024

81 pages

The global population is rapidly increasing, leading to a significant rise in energy consumption. The importance of using energy more efficiently is highlighted by the depletion of fossil fuel reserves and the high cost of energy production facilities. In Türkiye, a significant proportion of energy consumption is used in buildings, with heating, cooling and ventilation processes being the main factors. This situation creates the need to improve the thermal performance of existing building materials or to develop new materials with superior thermal properties. In this study, materials with high thermal insulation and suitable mechanical properties were developed using perlite, which is abundant in Türkiye. Samples were then thoroughly tested for their thermal and mechanical performance. In the first phase, production methods and mixing ratios were determined and samples of wood- plastic composites with expanded perlite were produced by increasing the expanded perlite content by 5% and reducing the other components by 5%. In the second phase, thermo-physical and mechanical properties of the samples were evaluated. The result of the study indicated that the lowest thermal conductivity was observed in sample HAR-5.9, with a value 0.082 W/mK. Numerous samples were obtained, with compressive strength ranging from 0.4937 MPa to 14.0878 MPa, flexural strength varying between 0.056 MPa and 15.5422 MPa and density values between 0.841 g/cm^3 and 0.471 g/cm^3.

Key Words: Lightweight building materials, Wood-plastic composite, Perlite,
Thermal insulation

ÖZET

GENLEŞTİRİLMİŞ PERLİTİN HAFİF KOMPOZİT AHŞABIN ISIL VE MEKANİK ÖZELLİKLERİ ÜZERİNDEKİ ETKİSİNİN İNCELENMESİ

KILIÇ, Ahmet
Yüksek Lisans Tezi, Makine Mühendisliği
Danışman: Prof. Dr. Recep YUMRUTAŞ
İkinci Danışman: Dr. Öğr. Üyesi Hakan TUTUMLU

Eylül 2024

81 sayfa

Küresel nüfus hızla artmakta ve bu durum enerji tüketiminde önemli bir artışa yol açmaktadır. Fosil yakıt rezervlerinin tükenmesi ve enerji tesislerinin yüksek maliyetleri, enerjinin daha verimli kullanılmasının önemini göstermektedir. Türkiye'de enerji tüketiminin önemli bir kısmını binalar oluşturmakta olup, ısıtma soğutma işlemleri bu tüketiminin başlıca etkenleridir. Bu durum, mevcut yapı malzemelerinin ısıl performansının arttırma ya da üstün ısıl özelliklere sahip yeni malzemeler geliştirilme gerekliliğini ortaya koymaktadır. Bu çalışmada, Türkiye'de bol miktarda bulunan perlit kullanılarak, yüksek ısı yalıtım ve uygun mekanik özelliklere sahip kompozit malzemeler geliştirilmiş ve bu malzemelerin ısıl ve mekanik özellikleri incelenmiştir. İlk aşamada, üretim yöntemleri ve karışım oranları belirlenmiş; genleştirilmiş perlit oranı %5 artırılırken, diğer bileşen oranları %5 azalttırılarak ahşap-plastik kompozit numuneler üretilmiştir. İkinci aşamada ise üretilen numunelerin termo-fiziksel ve mekanik özellikleri değerlendirilmiştir. Çalışma sonucunda, en düşük ısı iletkenlik HAR-5.9 numunesinde 0.082 W/mK olarak ölçülmüştür. Basma mukavemeti 0.4937 MPa ile 14.0878 MPa, eğme mukavemeti 0.056 MPa ile 15.8422 MPa ve 0.841 g/cm^{3}vile 0.471 g/cm^3 arasında değişen yoğunluk değerlerine sahip bir çok numune elde edilmiştir.

Anahtar Kelimeler: Hafif yapı malzemesi, Ahşap plastik kompozit, Perlite, Isı yalıtım.

''Dedicated to my family''

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Dr. Recep YUMRUTAŞ for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I would like to express my love and gratitude to my family for their support, always best wishes.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

ρ	Rho
Φ	Phi

LIST OFABBREVIATIONS

ASTM	American Society for Testing and Material
ABS	Acrylonitrile Butadiene Styrene
DIA	Dynamic Image Analysis
DMA	Dynamic Mechanical Analysis
DSC	Differential Scanning Calorimetry
HDPE	High-Density Polyethylene
HWC	Hollow Wood Composite
LDF	Low-Density Fiberboard
LDPE	Low-Density Polyethylene
MAPP	Maleic Anhydride Grafted Polypropylene
MF	Melamine Formaldehyde
MMC	Metal Matrix Composite
MMT	Montmorillonite
NBR	Nitrile Rubber
Pb	Lead
PCM	Phase Change Material
PE	Polyethylene
PEG	Polyethylene Glycol
PET	Polyethylene Terephthalate
PF	Phenol Formaldehyde
PHWC	Phase –Change Hollow Wood Composite
PLA	Polylactide
PMC	Polymer Matrix Composite
PP	Polypropylene
PU	Polyurethane
PVC	Polyvinyl Chloride
RCP	Recycled Thermoset Composite Particle
RWP	Reprocessed Wood-Plastic Composite Particle

SBR	Styrebe-butadiene rubber
SEM	Scanning Electron Microscopy
TGA	Thermogravimetric Analysis
TÜİK	Türkiye İstatistik Kurumu
UP	Unsaturated Polyester
UPV	Ultrasonic Pulse Velocity
VE	Vinyl Ester
VWP	Virgin Wood Particle
WPC	Wood-Plastic Composite
X-RD	X-Ray Diffraction
Zn	Zinc

CHAPTER 1
INTRODUCTION

One of the most crucial factors influencing the development of countries is the equilibrium between energy supply and demand. As a consequence of the rapid growth in global population, both the requirements for and the costs of energy are escalating day by day. Concurrently, the rapid growth of the global population is driving the acceleration of urbanization and industrialization. According to data from the Turkish Statistical Institute (Türkiye İstatistik Kurumu, TÜİK) reports that the country's population was approximately 67 million in 2000. This figure reached 85.372 million 2023 and is projected to reach 104.739 million by 2050 [1]. The rate of depletion of energy resources in country has increased as a consequence of population growth. In order that the maximum possible amount of potential energy resources may be available for future generations, measures must be taken to utilize energy in a more effective and efficient manner.

The global consumption of energy is undergoing a continuous increase due to economic growth, industrialization and population growth. The growth rate of energy consumption in 2021 was 4.9%, while in 2022 this rate increased to 2.1%. This increase is above the mean rate of 1.4% observed between 2010 and 2019. The values indicate that after 2020, there has been a notable rise in energy consumption, signifying a surge in the necessity for energy. A review of the sectoral distribution of global energy consumption reveals that the industrial sector, which accounts for 37% of total energy consumption. The next largest consumer of energy is the buildings, which accounts for 30% of global energy consumption [2, 3]. In Turkey, energy consumption rates exhibit a trajectory that is a parallel to global trends. The mean annual rate of increase in energy consumption in Turkey was 4% between 2010 and 2020. In 2021, the rate increased by 8% and then decreased by 3% in 2022. By 2023, a 2.1% increase had been observed. A sectoral analysis of energy consumption in Turkey indicates that the industrial sector is responsible for approximately 37% of total energy consumed as of 2021. A total of 28% of total energy consumption is attributed to building, while the transport sector account for 24%. The agricultural sector accounts for a relatively modest proportion of total energy consumption, representing only 4% of the total [4]. The rise in energy consumption has led to an increase in CO_2 emissions, which have in turn resulted in adverse environmental consequences due to the greenhouse gas effect [5]. As indicated by data from Turkish Statistical Institute (TÜİK), the sectoral distribution of total greenhouse gas emissions in 2021 is as follows: 71.3% were attributable to energy use, 13.3% to industrial processes, 12.8% to agricultural activities and 2.6% to waste management [6].

The effective and efficient utilization of energy has been identified as a priority area of research and development, with the objective of reducing the environmental impact, the consumption of energy resources and the economic problems experienced both in our country and in other countries around the world. A comprehensive examination of global energy consumption by sector has revealed that buildings account for approximately 30% of the total, ranking second the industrial sector. The ratio is generally employed in addressing heating, cooling and ventilation requirements of buildings. The aforementioned rate is augmented to 34% when the production processes of material such as iron, steel and cement used in the construction of buildings are taken into account [2]. The term “buildings” encompasses all structure that facilitate the fulfillment of basic human needs, including residential, educational, healthcare, and commercial facilities. Various thermal insulation materials are used to reduce energy consumption in buildings. Nevertheless, the fire resistance classes of the prevailing exterior thermal insulation materials constrain their deployment in specific locations. The utilization of high densities of fire resistant thermal insulation materials has the effect of increasing the dead load weight of the structure, which in turn has an adverse impact on the seismic performance [7]. Furthermore, while thermal insulation materials with a porous structure provide thermal protection in short term, they are susceptible to external environmental conditions over an extended period, resulting in a reduction in their thermal protection capacity.

In addition, it is accepted that population growth and technological advancement will persist, thus leading to escalation in consumption habits. This situation gives rise to the advent of more significant environmental issues that diminish the quality of life of individuals as a consequence of the escalation in the quantity of waste. The most effective method of averting this issue is to curtail the generation of waste through the conscientious purchasing habits of consumers, coupled with an expansion in the utilization of eco-friendly commodities. In recent years, WPC materials have become widespread usage in our country. These composite materials are particularly favored in the construction industry and their applications are becoming increasingly diverse. The use of WPCs is conducive to more efficient utilization of natural resources and contributes to the reduction of waste. These composite materials provide a sustainable solution, combining durability, cost-effectiveness and environmentally friendly attributes [8].

In light of the aforementioned factors, it is clear that there is a need to develop low-density, non-combustible exterior insulation materials that are capable of providing long-term thermal protection. The objective of this study is to develop a WPC thermal insulation material incorporating expanded perlite for use in building applications. The primary objective is to reduce energy consumption and conserve energy, thereby contributing to the existing literature on WPC thermal insulation materials. Furthermore, this research aims to develop a locally sourced product utilizing expanded perlite, a processed form of perlite with abundant reserves in our country. A principal objective of this study is to promote sustainability, which is achieved by incorporating recycled plastic in the production process to encourage the utilization of waste and recycled materials in composite material manufacturing. It is anticipated that the thermal conductivity value of the expanded perlite-wood-plastic composite thermal insulation material produced will be less than 0.1 W/m K, which is the minimum requirement for use in the construction sector.

The study comprises two principal phases: a review of the relevant literature and a series of experimental studies. A review of the literature was conducted to investigate the mixture ratios and production methods of the materials to be used. In this process, a comprehensive analysis of the existing literature was conducted, taking into account the findings and recommendations of similar studies. The results of the literature reviews enabled the properties and qualification of the materials to be used in the experimental studies and the production methods of the samples to be determined. In the experimental phase, a series of tests were conducted to ascertain the mechanical, physical and thermal properties of the samples produced at varying contents and ratios. These tests have been meticulously designed and executed with the objective of optimising the performance of the materials and determining the optimal mixing ratios. The data obtained and the contribution to existing literature are discussed.

CHAPTER 2

LITERATUR SURVEY

In recent years, numerous studies has been conducted with the objective of enhancing the properties of wood-plastic composite materials, which are extensively utilised in the construction industry. The majority of these studies have concentrated on examining the mechanical characteristics of the composites when materials such as expanded perlite are incorporated. Nevertheless, a significant number of these studies fail to provide a comprehensive analysis of the thermal, mechanical, water absorption, fire resistance, and microstructural characterisation properties of the materials in question. This section evaluates the current literature on the effects of expanded perlite on wood-plastic composites, particularly those used in building exterior face, and provides a comprehensive summary of the research conducted in this area.

Arslan and Aktaş [9] aimed to evaluate the insulation materials used in the construction sector according to their heat and sound properties. In this study, insulation materials are considered as traditional, alternative and advanced insulation materials. Information about the heat transmission coefficient, density, specific heat, current status of insulation materials and evaluation of insulation material properties using different standards and methods are given. In addition, the need for new materials and technologies to be produced in Türkiye has been emphasized by examining the issues of sustainability, energy efficiency and related environmental impact. The importance of developing insulation materials with advanced properties in future studies on this subject has been emphasized.

The thermal and mechanical performances of composite materials formed by the addition of wood fibres or particles, rice husk, fibres and lubricants into the plastic matrix at varying ratios were investigated by Yong Guo et al. [10]. It was observed that as the ratio of wood fibre in the composite materials increased, the melting temperature and crystallinity of the composites decreased, while the crystallization temperature and viscosity increased. Upon increasing the wood fibre ratio to 60%, it was observed that the dimensional stability of WPCs exhibited a tendency towards constant behaviour. However, when the wood fibre ratio was further increased, the processability was found to be adversely affected. The addition of lubricants increased the workability of WPCs by reducing their viscosity at low temperatures, but negatively affected their dimensional stability at high temperatures. Consequently, the increase in wood fibre content resulted in a reduction in the compressive strength of composite materials. In order to optimize the thermal and mechanical properties of WPCs, it was emphasised that the selection of the content, ratio and types of components used in the production of composite materials is of great importance.

Qi et al. [11] developed phase-change hollow wood composite materials (PHWC), comprising hollow thermoplastic tubes filled with phase change material (PCM), and investigated the thermal and mechanical properties of these materials. In this study, phase change materials, including polyethylene glycol (PEG), were incorporated into polyvinyl chloride (PVC) pipes at varying ratios with the objective of enhancing the insulation characteristics of low-density fibreboard (LDF) and hollow wood composites (HWC). The resulting composites have acquired properties that facilitate energy conservation and enhance thermal insulation performance. The thermal conductivity coefficient of low-density fibreboard, HWC and PHWC was found to vary between 0.06 and 0.07 W/mK, indicating that the composites exhibit commendable thermal insulation performance. The mechanical tests revealed a notable enhancement in mechanical strength upon the incorporation of phase change materials.

The study by Temiz et al. [12] examined the mechanical and insulating characteristics of hybrid polymer composite materials and identified potential insulation materials that could contribute to energy savings in the construction sector. In the course of the research, composite samples were prepared with varying contents and ratios using materials including fly ash, PVC waste, sawdust and oak bark. A series of tests were conducted to ascertain the mechanical and thermal properties of the prepared samples. The results of the heat and sound transmission tests indicate that the samples containing cement and pumice exhibit high heat permeability performance, while the samples containing PVC waste demonstrate effective sound insulation properties. Furthermore, it is indicated that specimens comprising fly ash, PVC and pumice exhibit a compressive strength of 4 MPa. The findings underscore the significance of polymer-added composites in advancing sustainability and energy efficiency. It is further highlighted that these materials can be extensively utilized in diverse sectors beyond construction, offering substantial environmental and economic benefits.

Zhang et al. [13] examined the structural characteristics and thermal insulation capabilities of two distinct wall configurations incorporating WPCs. The objective of the design of WPC integrated walls was to enhance the thermal performance of timber structures. The study compared the thermal performance of single-layer and double-layer frame walls. The single-layer walls exhibited a heat transfer coefficient of 0.414 $W/(m^2 \cdot K)$ when integrated with a 20 mm thick WPC wall, while the double-layer walls demonstrated a heat transfer coefficient of 0.207 $W/(m^2 \cdot K)$ when integrated with a 50 mm thick WPC wall. The findings demonstrate that WPC integrated walls exhibit robust stability and performance in cold climates, fulfilling thermal properties and contributing to enhanced energy efficiency through augmented thermal performance.

By combining perlite and montmorillonite (MMT) with polylactide (PLA) in an extrusion machine and solvent dissolution process, Tian and Tagaya [14] created PLA-perlite and PLA-MMT composite materials. Thermal stability was analysed using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), while morphology was investigated through the use of scanning electron microscopy (SEM) and X-ray diffraction (XRD). The study demonstrated that the incorporation of inorganic compounds resulted in enhanced mechanical and thermal properties of PLA. The results of the dynamic mechanical analysis (DMA) indicated that the modulus of elasticity of the PLA-perlite composite was greater than that of pure PLA. The findings indicate that the integration of inorganic materials into PLA results in an improvement in its mechanical and thermal characteristics.

El Makssoudi et al. [15] developed composite materials using expanded perlite and unsaturated polyester resin. The mechanical and chemical properties of the composites were analysed. The composite materials were produced using a variety of formulations incorporating expanded perlite and other fillers. The results demonstrated that the density of the composite materials decreased with an increase in the expanded perlite content. Furthermore, it was demonstrated that the composites containing plastic waste exhibited the highest strength.

Atagür et al. [16] a research study was conducted to investigate the mechanical, thermal and viscoelastic properties of composite materials produced by incorporating expanded perlite into high-density polyethylene (HDPE). The study involved the addition of varying proportions of expanded perlite (5%, 10%, 20%, 30%) to the HDPE matrix. Among the composites produced, the composite with 5% expanded perlite was determined to have the highest tensile strength. Nevertheless, while the increase in expanded perlite ratio increased the flexural strength, it was determined that there was a decrease in tensile strength after 10% expanded perlite. Thermogravimetric analysis (TGA) demonstrated that the incorporation of expanded perlite did not influence the degradation temperature of HDAPE. Additionally, it was observed that the thermal conductivity of HDPE decreased with the incorporation of expanded perlite, indicating a better thermal insulation performance.

In a study carried out by Uluer et al. [17], the authors examined the utilization of expanded perlite in thermal insulation technologies and the thermal conductivity standards of perlite-based materials. The objective of the study was to evaluate the potential of perlite as a thermal insulation material in the building sector, either as a direct or indirect application. It is emphasised that expanded perlite can be an ideal insulation material due to its low density, high porosity and non-flammability properties. Moreover, it presents a multitude of advantages in comparison to existing thermal insulation materials, particularly in terms of its high fire resistance.

Altuntaş and Arıkan [18] investigated the mechanical, thermal and morphological properties of expanded perlite in WPC materials. A variety of composite materials were produced using polypropylene (PP), expanded perlite, wood flour, corncob flour and MAPP couplig agent. The findings of the study indicated that an increase in the proportion of expanded perlite resulted in a notable enhancement in flexural strength, shock resistance and surface hardness. Thermal analyses demonstrated that the degradation temperature of the composites increased, as did the crystallization temperatures. Scanning electron microscopy (SEM) analyses demonstrated that expanded perlite infiltrates the voids within the composite material, thereby forming a more robust structure. The data demonstrated that expanded perlite is a suitable filler material.

In a study conducted by Sombatsompop et al. [19], the effects of zinc (Zn) and lead (Pb) stearates and zeolite on the structural and thermal stability of PVC and wood PVC composites (WPVC) were investigated. The characteristics of the stabilisers in PVC and WPVC, including thermal ageing, polyene formation, weight loss and degradation temperature, were evaluated. It was observed that the addition of stabilisers to PVC and WPVC resulted in increased thermal stability, a slowing down of the degradation reaction at high temperatures and a reduction in polyene formation. The addition of zeolite was observed to result in an increase in the degradation temperature and thermal stability of PVC.

The structural and thermal properties of PVC and wood-PVC composites (WPVC) were evaluated by Chaochanchaikul et al. [20] through the application of stabilisers, with the results demonstrating the enhanced thermal stability of PVC and WPVC composites. The addition of wood particles led to an increase in the thermal degradation of the PVC, whereas an increase in the ratio of different stabilisers was observed to result in a decrease in the degradation of PVC and WPVC.

The objective of the investigation led by Jeamtrakull et al. [21] was to examine the wear behaviour of wood PVC composites (WPVC) through the addition of various woods and glass fibre reinforcement. In the study, three distinct types of wood flour were employed, with 10 phr of glass fibre and PVC added at a constant rate. The results demonstrated that the bending strength increased and the mechanical wear properties improved. In addition to the wood type and content, the reinforcing element to be added in wood PVC composites has a significant effect on a number of properties, including wear resistance and mechanical properties.

The objective of Cruz-Salgado et al. [22] was to optimise the tensile and flexural strengths of a wood-plastic composite manufactured using polyethylene terephthalate (PET) and wood flour. Additionally, the objective was to develop environmentally friendly composite materials utilising PET and wood flour. In the study, the mechanical properties of composite materials produced at varying mixing ratios were evaluated. The results of the tests indicated that the optimal parameters were PE, PET type 0.85, and 10% wood flour as additives, with a tensile strength of 225 MPa and a flexural strength of 32 MPa. It was observed that the composition ratios of the composites exert an influence on the mechanical performance. Furthermore, it was demonstrated that optimising the particle size of the fibre filler can enhance the tensile and flexural strength of composite materials while simultaneously reducing their moisture absorption.

In their study examining the performance and environmental impact of wood-plastic composites (WPC), Schwarzkopf et al. [8] demonstrated the potential of these composites in industrial applications. It was posited that WPCs have demonstrated an increasing potential and market share in recent years, particularly in exterior decking and board applications. The research in question undertook a comprehensive analysis of the impact of various factors, including wood mixing components, wood species, particle size and aspect ratio, on the performance of WPCs. The necessity for the appropriate distribution of wood particles, the utilisation of coupling agents and the selection of components to optimise the mechanical properties of wood-plastic composite materials is emphasised. Furthermore, the environmental impact of WPCs is compared with that of solid wood, and the advantages of these composites for sustainability are presented. In particular, the contribution of WPCs obtained from renewable resources to environmental sustainability is indicated, specifically in terms of their capacity to reduce carbon dioxide emissions.

Krause et al. [23] evaluated the influence of incorporating recycled materials in the production of WPC on the internal structure and physicomechanical properties of the composite. In the study, three distinct materials were utilized as virgin wood particles (VWPs), reprocessed wood-plastic-composite particles (RWPs), and recycled thermoset composite particles (RCPs). All wood-polypropylene composite materials produced contained 60% wood material and were manufactured using a co-rotating extruder. The internal structure of the composites was examined using X-ray micro-computed tomography and dynamic image analysis (DIA) techniques. It was established that the length and aspect ratio of the particles underwent alteration as a consequence of the processing stage. A reduction in particle length was observed, with a decrease ranging from 17 to 70%. Similarly, a reduction in particle length was observed, with a decrease of between 10 and 40% in the length and aspect ratio of the particles. The mechanical tests revealed notable improvements in the mechanical properties of the composites comprising RWP and RCP materials as fillers. The impact flexural strength exhibited an increase of up to 300%, while the tensile strength demonstrated an increase of up to 75%.

Beygi et al. [24] performed a series of analyses utilising nanoclay, which is hypothesised to enhance the mechanical and thermal properties of wood, PVC and low-density polyethylene (LDPE) composites. Composites with varying ratios of LDPE and Cloisite 30B nanoclay content were produced by pressure moulding after melting. Scanning electron microscopy (SEM) analyses revealed the absence of bonding issues between the lignocellulosic reinforcement element and the PVC and LDPE matrix materials. The composite containing 30 phr LDPE was found to exhibit the highest impact strength, with a value of 2887.33 kJ/m². Moreover, it was established that the impact strength increased with the incorporation of 3 phr of nanoclay into the composite. The data obtained indicated that wood-PVC composites containing 30 phr LDPE and 3 phr Cloisite 30B exhibited optimal properties.

In conclusion, the existing literature presents a substantial body of research investigating the effects of expanded perlite on WPC materials. However, the majority of these studies do not fully address the impact of expanded perlite on the mechanical and thermal properties of WPCs, nor do they provide a comprehensive examination of water absorption, fire resistance, and microstructural characterisation properties. In this context, the present study investigates the effects of expanded perlite on the thermal and mechanical properties of WPCs, as well as on water absorption, porosity, fire resistance, and microstructural characterisation properties.

CHAPTER 3

COMPOSITES, PLASTICS AND PERLITE MATERIALS

3.1 Composites

Composite materials are advanced engineering materials comprising two or more component materials with significantly different physical or chemical properties [25]. The objective of these materials is to exhibit advanced properties that cannot be achieved by a single component. The term "composite material" is typically used to describe a substance comprising two distinct phases: a matrix and a reinforcement. The matrix represents the continuous phase, providing structural integrity and support, while the reinforcement represents the discontinuous phase, imparting strength and stiffness to the composite. The constituent component of the composite material do not undergo dissolution when in contact with one another [26]. The matrices employed in composite materials are constituted of a plethora of materials, polymers (thermosets and thermoplastics), metals, and ceramics. The matrices serves to provide the product with its shape, ensure the load transfer by maintaining the cohesion of the reinforcement component, and offers protection from environmental factors. The reinforcement components of a composite material are generally fibres or particles that enhance the mechanical properties of the composite [27]. The objective in the production of composite materials is to enhance one or more of the properties, including mechanical properties, corrosion resistance, high-temperature resistance, thermal conductivity and weight. Despite their lightweight nature, composite materials exhibit high strength-to-weight and stiffness-to-weight ratios. Furthermore, composite materials demonstrate high resistance to corrosion, thereby ensuring their longevity. The composite materials can be manufactured in a variety of shapes and sizes, so allowing for design flexibility and exhibiting well thermal and electrical insulation properties [27-28].

Composite materials play an important role in modern engineering and technological progress. These materials offer a multitude of advantages in comparison to traditional materials and are employed in a diverse range of applications across various industrial sectors. Firstly, composite materials offer high durability and strength despite their lightweight, which makes them an important material in the automotive, aerospace and defence industries [28]. Also, the high corrosion and chemical resistance properties of composite materials provide the potential for extensive utilisation in the marine and petrochemical industries. A further advantage is the flexibility and formability of composite materials. These properties are of great consequence in structural applications within the field of architecture and construction. Another advantage of composite materials is their ability to insulate against thermal and electrical energy transfer. This advantage provides for its use in a variety of settings, including electronic devices, infrastructure, bridge decks, and building exteriors. Finally, the production of composite materials from recyclable materials gives an important advantage in terms of sustainability [29]. Given all these advantages, composite materials are increasingly favoured in various industries.

Nevertheless, the use of composite materials is not without some disadvantages. The production of composite materials necessitates a series of processes, including the addition of resin, the incorporation of reinforcing materials, moulding, and the curing of the material. This production process is characterised by higher costs and the need for greater expertise compared to conventional metal and ceramic processing. Furthermore, the rectification of production process errors is a challenging and expensive undertaking [30]. Composite materials are anisotropic. The mechanical, thermal and electrical properties of composite materials are dependent on the production method and the orientation of the reinforcing components. Moreover, the mechanical properties of composite materials are subject to alteration in accordance with the direction of the applied load. The prediction and modelling of the mechanical behaviour of composite materials under different loading conditions challenges, primarily due to the complexity of their microstructure [31]. A further disadvantage is the heterogeneous structure of composite materials, which renders the separation and reuse of these materials' components a challenging process [29].

Composite materials can be classified into three principal categories according to the type of matrix employed: metal matrix composites, ceramic matrix composites and polymer matrix composites.

3.1.1 Metal Matrix Composite

Metal matrix composite materials (MMCs) are a specific type of high-performance composite material, comprising reinforcing materials embedded in a metal matrix. The matrix material is usually one of metals such as aluminum, magnesium, titanium or copper. The reinforcement elements are usually composed of harder and stronger materials such as ceramics, whiskers or fibres [32].

Metal matrix composites exhibit a range of beneficial properties, including high strength, stiffness, wear resistance, tensile strength, fatigue resistance and thermal conductivity. The enhanced mechanical characteristics of these materials make them suitable for use in applications where they can replace parts manufactured from steel, aluminium or cast iron. Nevertheless, the elevated cost of production precludes its broader utilisation, given the challenges associated with the formation of a homogeneous microstructure [32-33].

The production of MMC materials is usually achieved through a range of techniques, including powder metallurgy, liquid metal infiltration, mixing casting and extrusion. Thanks to these production methods, the material is being used in a number of high-tech industries, including aviation, automotive, and defense [33].

3.1.2 Ceramic Matrix Composite

Ceramic matrix composites are an advanced type of composite, combining the superior mechanical, physical, chemical and thermal properties of ceramics. These composites incorporate the properties of ceramics, including low density, high hardness, and excellent wear resistance, high temperature resistance, chemical resistance, and low coefficient of thermal expansion. The most commonly utilised ceramic materials in the production of ceramic matrix composites are alumina (Al_2O_3), silicon carbide, silicon nitride, zirconium dioxide (ZrO_2) and boride [34].

Ceramic matrix composites are used in automotive, aerospace, space, energy, metallurgy and chemical industries due to their advantages such as high hardness, wear resistance, mechanical strength, high temperature and corrosion resistance, low density and thermal expansion coefficient. Contrary to this, the elevated production costs, brittleness, insufficient impact strength, processing difficulties and intricate design of ceramic matrix composites restrict their utilization [35].

3.1.3 Polymer Matrix Composite

Polymer matrix composites (PMCs) are composite materials comprising polymer-based matrices reinforced with diverse materials to enhance their mechanical, thermal, and electrical properties. The principal objective of reinforcing elements in PMCs is to impart additional desirable properties, such as strength and stiffness that the matrix material is unable to provide on its own. The selection of the materials used in the composition of polymer matrix composites is dependent upon the desired properties of the resulting material. A variety of fibres, including carbon, glass, and aramid, are employed as reinforcing elements in polymer matrix composites [36].

Polymer matrix composite materials offer significant advantages in a range of industrial areas, due to their diverse properties. The elevated strength-to-weight ratio enhances the reduction of weight and the improvement of fuel efficiency in the aerospace and automotive industries. The resistance of polymer matrix composite materials to corrosion is a crucial factor in ensuring the long-term usability and durability of products in the marine and chemical industries. The design flexibility capacity plays an important role in the development of structural elements in the engineering and construction sectors. The low density results in enhanced fuel efficiency and a concomitant reduction in transportation costs, due to the diminished weight of the material in question across a range of industrial sectors, including aerospace, automotive and transport [29]. Polymer matrix composite materials have a number of disadvantages, which must be taken into account when selecting the material and determining the intended application area.

Despite the numerous advantages of polymer matrix composites, including high strength, low density and corrosion resistance, these materials also possess certain disadvantages. The initial disadvantage is that the production process of PMC materials is complex. Generally, a multi-stage production process involving heat and pressure is employed, which increases production costs [37]. Additionally, the difficulty of recycling PMC materials represents a substantial disadvantage. A further disadvantage is that these materials possess an anisotropic structure. Additional, the identification and rectification of damage to PMC materials prove challenging.

3.2 Wood-Plastic Composite (WPC)

The term "wood polymer composite" or "wood-plastic composite" (WPC) is used to describe a material that is formed by combining wood fibres, particles or flour with thermoplastic or thermosetting polymers. The incorporation of wood into the polymer matrix facilitates the enhancement of the material's physical properties, including hardness and strength, thereby enabling its utilisation in specific applications. These composites, which were initially deployed in low-performance applications, have begun to be utilised in high-performance applications with the advent of plastics, synthetic materials and material science. The use of wood-plastic composites (WPCs) has recently increased in the construction and furniture industries, particularly in response to developments and innovations in polymer technology and the utilisation of recycled materials [38].

WPCs have been employed in a multitude of applications due to their superior properties in comparison to traditional wood and plastic materials. These features are lower cost compared to plastic material, better dimensional stability, can be produced in desired size, colour and shape, resistant to cracking, fungi and insects and can be produced from waste materials [38-39]. The mechanical, thermal, physical and biological properties of wood-plastic composite materials are contingent upon the properties and ratios of the matrix, reinforcement and filler elements that constitute this composite. The mechanical, thermal, physical, and biological properties of wood-plastic composite materials exhibit variations depending on the properties and ratios of the matrix, reinforcement, and filler elements that constitute this composite. The most commonly utilised plastics in these composite materials are polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC). Polyethylene (PE) is the preferred material for applications that require flexibility and durability, whereas PVC is the preferred material for applications that require high temperature resistance [40].

3.2.1 Advantages and Disadvantages of WPC

The advantages of WPCs include the following:

- The material can be produced from waste materials, thereby reducing production costs.
- Easy to process.

- The WPCs can be shaped, patterned and coloured in accordance with the desired aesthetic effect.
- The addition of mineral fillers enables the desired properties and low density to be achieved.
- The WPCs is resistant to damage that may be caused by external influences.
- The WPCs can be produced in the desired shape through the use of moulds.
- The utilisation of petroleum derivatives is diminished, thereby reducing the emission of carbon [25-26].

While WPCs offer numerous advantages, these composites also present certain drawbacks that limit their widespread use in specific applications. The primary disadvantages of WPCs include the following:

- Compatibilization problems arising in the production of composites made of wood and plastic.
- The occurrence of colour and other physical changes in wood as a result of elevated production temperatures.
- There is a requirement for personnel who are suitably qualified to identify and address the underlying causes of changes in the WPC production process.
- Fungal and insect-induced deterioration during the storage of wood [25-26].

3.2.2 Uses of WPCs

The characteristics of wood plastic composites derived from the combination of wood and plastic are more advanced in terms of the individual properties of the materials. Therefore, it is becoming increasingly used prevalent in a diverse range of industrial sectors. Furthermore, the advent of numerous enterprises manufacturing this specific material has facilitated the expansion of WPCs' applications. Wood plastic composites have been employed in landscaping applications, including the construction of fences, tables, benches, and play equipment. WPCs are also employed in the construction industry for the fabrication of exterior cladding and accessories, as well as for use in outdoor applications. Additionally, it is employed in the fabrication of window frames and doors [41, 42].

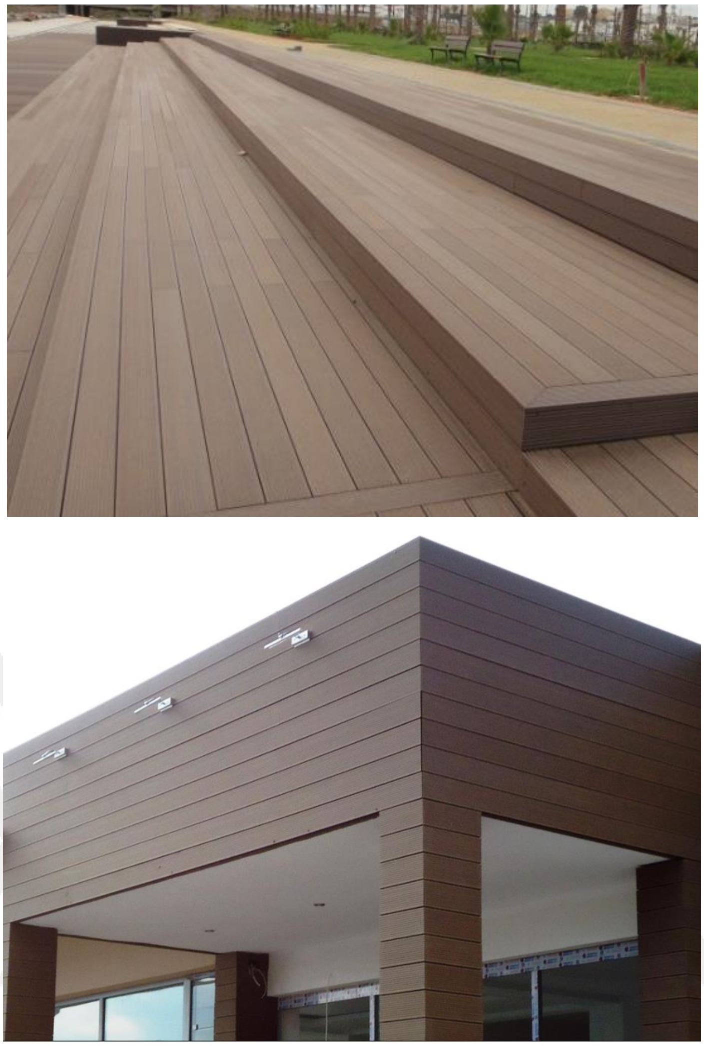

Figure 3.1 WPCs used in the construction industry [43]

3.2.3 WPC Production Methods

The techniques employed in the production of wood plastic composite materials are contingent upon the specific type of plastic utilized. The production of composite materials with a thermoplastic matrix is conducted in two stages. These stages are mixing and shaping process. The selection of reinforcement, filler and additive materials for use in the composite material is determined. Subsequently, the aforementioned materials are combined with the molten thermoplastic in order to create a homogeneous composite material. The mixture can be shaped without delay with the assistance of moulds or it can be granulated and employed at other times.

Thermosets are in a liquid form and are referred to as resins. The forming process occurs via a chemical reaction, and thermosets are not required to undergo softening or heating procedures prior to utilisation.

3.2.3.1 Extrusion Process in WPC Manufacturing

The extrusion method is one of the most prevalent manufacturing techniques employed in the production of plastic matrix composite materials. The extrusion process is the most distinctive feature that distinguishes this production method from others due to the continuous and high production capacity. Thermoplastics are generally used in the materials produced in this production method. The extrusion process is brought to a conclusion by melting and combining the mixture with additives, reinforcing components, fillers, and thermoplastic matrix until a homogeneous and fluid state is attained; subsequently, the mixture is passed through a mould under pressure, thereby assuming the desired shape-which may range from simple sheets to complex profiles [44].

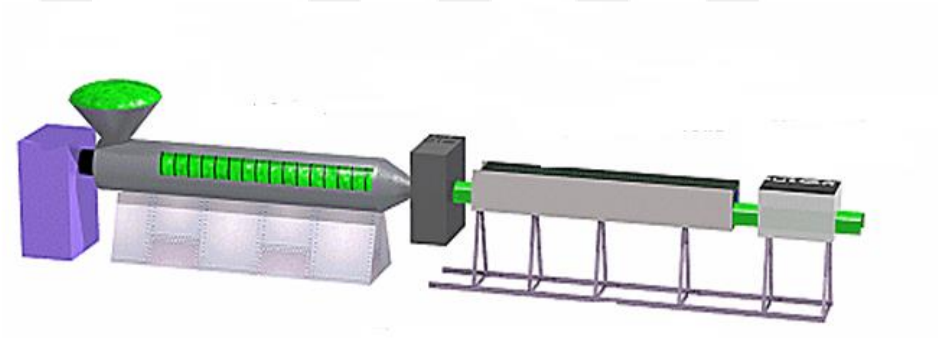

Figure 3.2 Extrusion Machine [45]

The production of WPC by the extrusion method is a process that occurs in a series of fundamental stages. The preliminary phase of the process entails the blending of wood fibres or pieces, thermoplastics, additives and fillers with the objective of obtaining a homogeneous mixture. Subsequently, the mixture is fed continuously into the feed hopper. Utilising heaters of a barrel surrounding, the mixture present within the barrel is melted. The substance is transported forward in the barrel via the action of an extrusion screw. This process ensures the uniform distribution of the materials within the mixture throughout the matrix material. Once the melted and homogenised mixture has reached the barrel outlet, it passes through the mould, which has been produced in accordance with the desired shape. The final stage of the process is to pass the material through a cooling unit filled with water, whereupon it is cut into suitable lengths. This step is taken in order to facilitate the solidification process [44-45]. The direct feeding method involves the addition of the matrix and reinforcing elements, which are to be used in the extrusion process, from a different of feed hoppers. The transfer of the matrix and reinforcement elements to be used in granular form from the same feeding unit constitutes indirect feeding [45].

3.2.3.2 Injection Molding Process in WPC Manufacturing

The injection moulding method is the most suitable method for a series production. Differently from the extrusion method, the molten material is injected into a mould under pressure. This method, which is predominantly employed in the processing of thermoplastic materials, can also be utilised in the production of thermoset materials, with the requisite modifications being made to the manufacturing process. Since the injection molding method has a high degree of automation systems, labour costs are reduced. Also this method enables the creation of designs that are difficult to achieve with other methods [45-46].

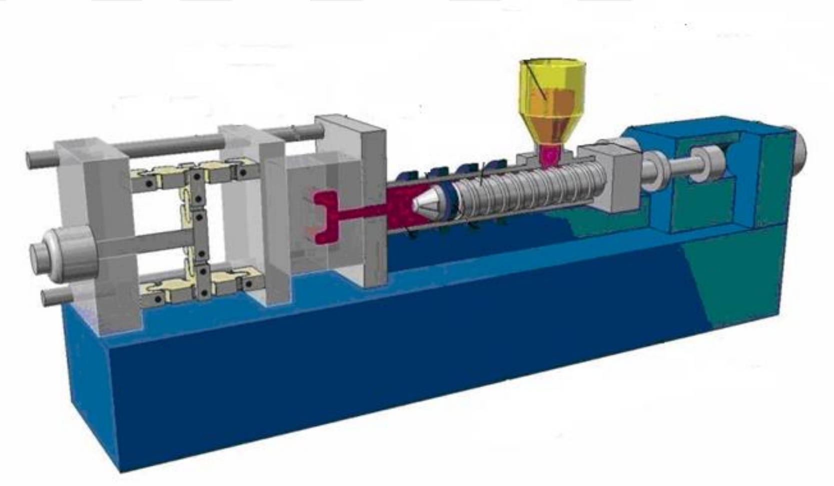

Figure 3.3 Injection Molding Machine [46]

The homogenous WPC mixture is transferred from the feed hopper into the injection moulding machine. The molten WPC mixture is injected into the mould, situated at the outlet of the cylinder, via a sudden movement of the screw.

The material is maintained within the mould under elevated pressure for a designated period of time. Once the cooling process is complete, the mould is opened to remove the WPC in its solid form [46].

3.2.3.3 Continuous Pressing for Sheet Production

A significant manufacturing technique employed in the production of wood-plastic composites is continuous press technology. This method is particularly utilized to create flat and broad surface WPC boards, which are utilized in furniture and numerous other applications. Despite the similarities between this production method and that of particle fibre board, there are notable differences, particularly in the cooling process at the end of the manufacturing cycle [47].

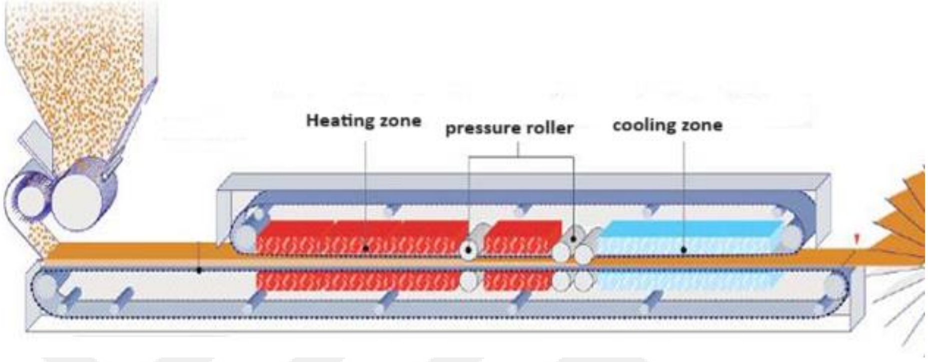

Figure 3.4 Continuous Pressing Machine for Sheet Production [42]

In the continuous press method, wood dust or fibres and molten thermoplastic are mixed until a homogeneous mixture is achieved. The resulting WPC mixture is then compressed and shaped on heated moulds with the assistance of rollers. During this process, the WPC mixture is spread homogeneously and brought to a specific thickness. As the material is heated, it reaches a workable softness and consistency [47]. Consequently, the material is distributed uniformly within the mould. During the manufacturing process, a variety of lubricants are employed to prevent the WPC boards from adhering to the moulds and pressure belts. Subsequently, the WPC sheet is conveyed to the cooling unit. The sheet undergoes a process of hardening during the cooling phase. As the thickness of the WPC sheet produced increases, the length of the cooling unit required also increases. Subsequently, the plate emerging from the cooling unit is trimmed to the desired length and width [48].

3.2.3.4 Compression Molding in WPC Manufacturing

This method entails the introduction of the composite material into a heated mould, whereupon the material is shaped into the desired configuration under the application of high pressure. In the production of thermoset matrix composites, the utilisation of diverse pressing techniques is a common practice. The production of this type of composite material has been developed in two distinct ways.

The initial stage of the production process, namely the pressure moulding method employed in the manufacture of wood-plastic composite materials, commences with the preparation of the raw materials. The raw materials that constitute the composite material are combined to form a homogeneous mixture. This homogeneous mixture is then placed in a heated mould, which is subsequently closed and subjected to high pressure. The high pressure and heat cause the thermoplastic to soften and become fluid, thereby covering the wood fibres or pieces. The mould is then cooled, and the resulting product assumes the desired shape [47].

In the second production method, the homogeneous mixture is subjected to heating via the use of an extrusion machine. The molten mixture is then introduced into a cold mould, where pressure is applied. The mixture undergoes a rapid combination process, resulting in the formation of the product upon cooling [49].

3.3 Plastics

Plastics are a wide variety of polymeric compounds available in synthetic, semi-synthetic or organic form, which can be formed into the desired shape when hot and retain this shape when cold or hardened [50]. The primary raw material utilized in the production of plastic is petrol or crude oil. In 2012, approximately 8% of global oil production was utilized for the manufacture of plastics and the operation of related production facilities. It is projected that this proportion will reach 20% by 2050 [51]. Plastics are used in many areas of life and their use is expanding rapidly. The rapid growth in the use of plastics can be attributed to a number of factors:

- The ability of plastics to be formed into different shapes, sizes and forms;
- Resistance of plastics to water, moisture and electricity;
- Plastic' long-term durability in the environment without deformation.

Plastics are widely used in many industries and applications due to these properties [52].

The majority of plastic produced globally is utilised in the packaging, construction and automotive industries. The remaining portion is utilized in other sectors such as agriculture and medicine.

Plastics are primarily derived from crude oil and petroleum through various chemical processes. Polymers are produced by a process called polymerisation, in which monomer molecules chemically combine to form long chains, resulting in the formation of the plastic polymer. Polymers are divided into four groups according to the areas in which they are used:

- Plastics
- Fibres
- Adhesives
- Coating

and into three groups according to their physical properties:

- Amorphous
- Crystalline
- Semi-crystalline

The formation of crystals in the amorphous parent structure is randomly orientated. The rate of crystallisation increases as the cooling rate decreases. The mechanical properties increase as the rate of crystallisation increases [53].

The plastics industry operates at production temperatures above the degradation temperatures of biological materials. This industry often uses organic and inorganic fillers such as glass fibre and calcium carbonate to increase production efficiency, which can lead to higher production temperatures. However, when wood is used as a reinforcement, the production temperature should be kept below 180°C as higher temperatures can cause the wood to degrade. Typically, when using organic materials such as wood, plastics with a high melt flow index and low softening temperature are used [54].

Plastics production in Türkiye has increased in recent years. In 2023, the total production in the plastics industry amounted to 10.8 million tonnes. This number places Türkiye second in Europe and sixth in the world. In 2023, Turkey's imports of processed plastics increased by 5.6% compared to 2022 [55].

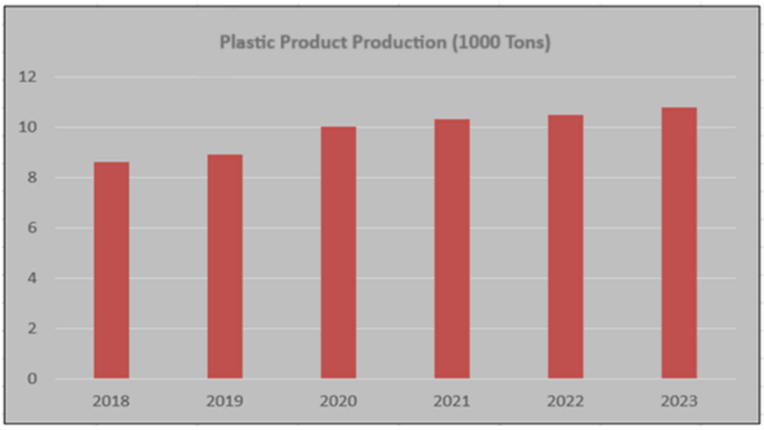

Figure 3.5 Plastic Product Production [55]

Approximately 50% of plastic manufactured globally are produced in Asia. China represents the largest proportion of this figure. Türkiye generates approximately 2.8% of the global total of plastic production, with an annual output of 10.8 million tonnes. One of the most significant obstacles Turkey encounters in its plastics production sector is the elevated cost of imported raw materials. Turkey is dependent on foreign suppliers for the vast majority (85%) of the raw materials it utilises in plastic production [56].

There are three types of plastics depending on the chemical bond in their structure and their reaction when exposed to heat: thermoplastics, thermosets and elastomers.

3.3.1 Thermoplastics

Thermoplastics are polymers that melt with temperature and flow under pressure, can be shaped and return to solid state when cooled. Upon reheating, the material can be melted and molded, and it hardens when cooled. The thermoplastics does not undergo any chemical changes during these processes. Furthermore, it can be broken down into smaller forms and reused. The reason for this is the absence of chemical bonds between macromolecules in thermoplastics. This feature enables thermoplastic materials to be recycled [57]. In addition, thermoplastics can be dissolved with chemical solvents.

Thermoplastics can be classified into two categories based on the arrangement of macromolecules. If the arrangement of macromolecules is random, it is designated as 'amorphous'. The thermoplastics in question exhibit a transparent appearance. Thermoplastics whose macromolecules are arranged in a regular pattern are designated as 'semi-crystalline' polymers [58].

The processing temperature of thermoplastics is relatively low, which allows for more efficient production processes. These low processing temperatures contribute to reduced energy costs and increased production rates. Thermoplastics can be moulded and reshaped on numerous occasions without substantial deterioration or loss of properties. The ability to be recycled renders the material in question more sustainable, thus contributing to a reduction in environmental impact. In addition, the recyclability of these materials assists in the reduction of waste, thereby facilitating the implementation of an environmentally conscious production process. Furthermore, they exhibit low thermal conductivity. The properties render thermoplastics suitable for use as matrix elements in the production of composite materials.

The most significant plastic of the thermoplastic group are polyethylene, polypropylene, nylon, polystyrene, carbon fluoride, polyvinyl chloride, vinyls and cellulosics.

Table 3.1 Properties of some thermoplastics

Materials	**Density (g/cm^3)**	**Tensile Strength (MPa)**	**Elastic Modulus (GPa)**	**Melting Temperature (°C)**
LDPE	0.91-0.93	8-24	0.2-0.4	105-115
HDPE	0.94-0.97	20-37	0.8-1.5	130-140
PVC	1.35-1.45	45-70	2.5-4.0	160-212
PP	0.90-0.91	30-40	1.0-1.5	160-170
ABS	1.04-1.07	35-45	1.5-1.25	105-115
Nylon 6.6	1.14	70-80	2.0-2.5	255-265
PET	1.38-1.41	50-90	2.8-3.4	245-260

3.3.2 Thermosets

Thermosets are polymers that undergo a chemical change when heated, resulting in a fixed, irreversible shape. This chemical transformation results in a substantial modification of the polymer's molecular structure, thereby producing a material that is rigid and durable. Additionally, these substances are frequently referred to as synthetic glues. Thermosets are manufactured through a process known as fatigue polymerisation, whereby the polymers form cross-links and become solidified upon heating. Thermosets usually exhibits a cross-linked molecular structure. This nomenclature is derived from the bonds that are formed as a consequence of chemical reactions between the macromolecules that constitute thermosets. Prior to undergoing any moulding or heat treatment, thermosets form thread-like chains that are similar in structure to those of thermoplastics. However, the application of heat during the moulding process causes the molecules to form high-density bonds with cross-links. This chemical transformation results in a substantial modification of the polymer’s molecular structure, thereby producing a material that is rigid and durable. Therefore, thermosetting plastics are not suitable for recycling in the same manner as thermoplastic materials [58].

The durability and thermal stability of thermosetting plastics is attributable to their polymeric structure. Furthermore, the material exhibits a hardening structure as a consequence of the covalent closure of cross-links under the influence of temperature. The cross-linked structure enables thermosetting materials to retain their shape and withstand deformation even when subjected to high temperatures. Therefore, thermosets possess resistance to elevated temperatures and demonstrate minimal loss of mechanical properties with increasing temperature. Additionally, the low coefficient of thermal expansion of these materials guarantees their stability against temperature fluctuations. Thermosets possess chemical resistance and are largely unaffected by most solvents. These all properties render thermoset plastics a prevalent material in a multitude of industries, including automotive, aerospace, electronics, and construction [59].

The most commonly utilised thermosetting plastic materials can be categorised into the following groups: epoxy resins, phenol formaldehyde, polyester, urea formaldehyde, melamine formaldehyde and polyurethane.

Table 3.2 Properties of some thermosets

Materials	Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)
Epoxy	1.15-1.0	60-90	2.5-4.0
PF (Phenol Formaldehyde)	1.3-1.4	70-100	5.0-7.0
PU (Polyurethane)	1.2-1.25	50-80	1.5-2.5
MF (Melamine Formaldehyde)	1.5-1.6	60-90	4.0-5.5
UP (Unsaturated polyester)	1.1-1.2	30-50	2.0-3.5
VE (Vinyl ester)	1.1-1.2	40-70	2.5-4.0

3.3.3 Elastomers

Elastomers are cross-linked rubber-like polymers that exhibit the capacity to undergo significant deformations under the application of specific forces, and subsequently return to their original shape and length when the force is removed. The term "elastomers" is derived from their notable elasticity. This behaviour is attributable to the low cross-link density inherent to the structural composition of elastomers, which enables them to undergo stretching and deformation without incurring irreversible alterations to their internal configuration. The incorporation of an elevated number of cross-links within the structure of elastomers enables the formation of a more resilient and rigid configuration. At elevated temperatures and under the influence of deformation forces, the dark liquid exhibits flow characteristics [60].

Elastomers can be classified into two principal categories: general-purpose and special-purpose elastomers. Synthetic rubbers, including polyisopyrene (natural rubber), styrene-butadiene rubber (SBR) and nitrile rubber (NBR), are elastomers with a broad range of applications. Due to its low cost and ready availability, it is employed in a multitude of applications across a range of fields. Speciality elastomers are a category of elastomer that has been developed for particular applications. They often display enhanced characteristics, including elevated temperature resistance, chemical resistance and robust mechanical strength [61].

The use of elastomers in the production of wood-plastic composite materials is not a common practice. However, it has the potential to offer advantageous outcomes in the integration of matrix and reinforcement components in composite materials. Moreover, the incorporation of elastomers into WPCs can enhance impact resistance, flexibility and the overall mechanical properties of the resulting material [62].

Elastomers are employed in a multitude of sectors across numerous industries. Elastomers are utilised in the manufacture of vehicle components that are commonly employed in the automotive industry, including transmission belts, windscreen wipers, brake hoses, gaskets and air hoses. In the oil and gas industry, the utilisation of elastomers is evident in the production of pipes and conveyor belts. Rubbers and elastomers, such as polyurethane and silicone, are commonly used in medical devices and implants due to the favourable characteristics of biocompatibility, durability, and the capacity to emulate the mechanical properties of human tissues [63].

3.4 Perlite

Perlite is a glassy amorphous volcanic rock, formed by the rapid cooling of viscous lava. As a function of the rapid cooling process, the lava, which contains between 2 and 5 per cent of water that is bound within the rock, undergoes a transformation into a glass-like structure. The fracturing of certain types of perlite produces small spheres, which has led to the derivation of the word 'perlite' from the French word 'perle,' meaning pearl. The term 'perlite' is used to refer to the raw form of the material, whereas the term 'expanded perlite' is used to describe the product obtained by expanding the raw perlite. Perlite rocks may exhibit variation in terms of their structural properties and colour. Although the colour range of the material in question spans from transparent grey to shiny black, it is observed to undergo a change in colour to white following the expansion process [64-65]. When perlite is subjected to sudden heating between 700 and 1100 °C, it undergoes an expansion process accompanied by the release of water vapour, resulting in the formation of a porous and lightweight structure. This material is referred to as expanded perlite. It is possible for the volume of perlite to increase up to 20 times during this process.

The expansion rate of perlite is subject to a number of factors, including:

- The quantity of water present within the perlite.

- The rate at which a temperature is applied.
- The structure of perlite.
- The amount of water remaining in the perlite at the expansion point [66].

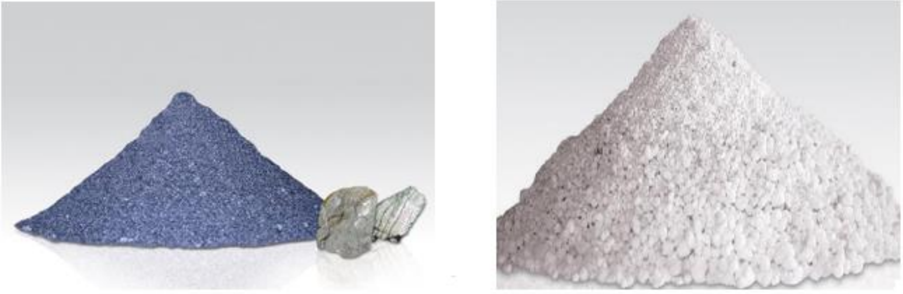

Figure 3.6 Perlite and expanded perlite [67]

The classification of perlite is dependent on the content and structure observed. The most common classifications include lithoidal, granular, spongy and onion membrane. These classifications are pivotal in determining the suitability of perlite for various industrial applications. In addition to the above-mentioned differences in content and structure, perlite types are also classified according to the water content. The high water content of perlite enables expansion to occur. The expansion process results in the formation of a lightweight and porous structure of perlite, rendering it an optimal material for use as an insulating and filler substance. These perlites are called active perlites. In other words, perlite that undergoes expansion between 700 and 900 °C is designated as active perlite, whereas that which undergoes expansion between 900 and 1100 °C is designated as passive perlite [66].

The ore of perlite is obtained through the open excavation of mines that have been established on the surface of the earth. The mining method in question is referred to as open-pit mining. The method in question provides an efficient means of extracting substantial quantities of perlite ore from deposits situated in close proximity to the surface. The perlite ore is then subjected to a crushing process in a jaw crusher. The crushing process is employed to ensure that the perlite acquires a more homogeneous structure and the desired particle sizes. In the event that the perlite ore is observed to be in a moist condition, it would be prudent to proceed with drying the ore prior to its passage through the crusher mechanism. Once the pre-processing of the perlite ore has been completed, it is passed through a series of crushers and sieved according to the desired dimensions. The screening process facilitates the attainment of the requisite homogeneous particle size for the expansion process. Then, the expansion process is initiated. The expansion process consists of 2 parts. The initial step is to preheating process. The preheating process, conducted at temperatures between 350 and 600 °C, is employed to facilitate the evaporation of water present within the perlite, which exhibits a degree of porosity. The milled and preheated perlite ore is subjected to expansion at temperatures ranging between 700 and 1100°C, with the precise temperature dependent on the specific type of ore in question [65, 68].

Table 3.3 Perlite Chemical Compositions [69]

Components	**Amount (%)**
SiO_2	71-74
Al_2O_3	12-14
K_2O	5-6
Na_2O	3-4
MgO	0.3
CaO	0.5
Fe_2O_3	0.5-1
TiO_2	0.09-0.012
Other	4.9

Expanded perlite is a material with a range of beneficial properties that make it suitable for use in a variety of applications across several sectors. These properties, including its low density, lightweight nature, chemical stability, high sound insulation and thermal insulation, make it an attractive material for use in the industrial, agricultural and construction industries. These properties serve to enhance the versatility of perlite, rendering it an indispensable component in a multitude of industrial processes. The perlite material exhibits an 85% porosity structure. The high porosity of perlite allows it to exhibit superior performance, particularly in applications requiring high levels of water absorption and insulation. The high porosity structure of this material allows for excellent water absorption capacity [70]. The use of perlite in horticulture and agricultural applications is due to its ability to retain water. The low density and favourable thermal insulation properties of perlite make it an optimal material for utilisation in construction-related applications. Additionally, it is employed as an insulating material in the manufacture of bricks and boards intended for use in high-temperature applications, such as furnaces. The high-temperature resistance of perlite renders it a favoured insulation material in contexts where such resilience is required. In addition, it is implemented as a thermal insulator in industrial contexts, a filler in the pharmaceutical and chemical industries, an additive in the ceramic and glass industries, and an insulator in steel structures against fire [71].

Table 3.4 Physical properties of perlite [67]

Properties	**Raw Perlite**	**Expanded Perlite**
Colour	Grey, Shades of grey and black	White, shades of grey
Softening Point	800-1100 °C	871-1093 °C
Melting Point	1315-1390 °C	1260-1343 °C
Specific Heat	0,2 kcal/kgC	0,2 kcal/kgC
Specific Weight	2200-2400 kg/m3	-
Thermal Conductivity	-	0.04 W/mK

Given that the raw material of perlite ore is mineral obsidian, there are perlite deposits in a multitude of countries across the globe. The majority of the world's perlite reserves are located in Turkey, China, Japan, the USA, Greece and Italy. The production of perlite in Turkey commenced in 1960. The majority of perlite reserves in Turkey are situated in the following locations: Izmir, Ankara, Nevsehir, Erzurum and Van [72].

Table 3.5 World production by country [73]

Country	Total Reserve Quantity (Million Tons)	Perlite Production in 2000 (Thousand Tons)	Perlite Production in 2010 (Thousand Tons)	Perlite Production in 2020 (Thousand Tons)
USA	50	684	414	520
Türkiye	750	130	230	640
Greece	120	500	500	700
Japan	100	250	210	230
Italy	60	60	60	70

CHAPTER 4
EXPERIMENTAL STUDY

In this study, experimental and theoretical studies were conducted to develop building out facade materials with low density, high strength, good thermal and fireproofing properties that can be used on the exterior of buildings by adding expanded perlite into wood-plastic composite materials. PVC, wood flour, expanded perlite were used to produce composite samples. A series of composite samples containing different ratios of compounds were produced. The produced composite samples were tested to determine the non-flammability, mechanical and thermal properties and the optimum mixing ratio.

4.1 Materials

4.1.1 Polyvinyl Chloride (PVC)

PVC was selected as the preferred plastic due to its extensive use in the industry, ready availability, and extensive literature on the subject. The extensive range of applications for PVC evinces its versatility and durability. The inherent rigidity and dimensional stability of PVC provide structural integrity to wood-plastic composite materials. Therefore, the combination of wood flour and PVC makes it robust and resistant to deformation. This combination of materials is designed to ensure the longevity and durability of WPCs, thereby making them a preferred choice for a variety of demanding applications. Furthermore, the low moisture absorption and water resistance properties of PVC enable the use of WPC in outdoor applications and high humidity environments. The aforementioned properties facilitate the reliable utilisation of WPCs in diverse climatic conditions and outdoor projects. [74-75].

The presence of chlorine atoms in the polymer structure of PVC provides a natural flame retardancy effect, as chlorine inhibits the combustion process. It is difficult to ignite and its properties remain unchanged between 10°C and 40°C. In general, PVC is a material with a long service life, resistance to the sun's UV rays, good mechanical properties, a low thermal conductivity coefficient and high chemical resistance. [76].

Table 4.1 Mechanical and thermos-physical properties of PVC [77]

Properties	Value
Density	1.35-1.45 g/cm^3
Tensile Strength	45-60 MPa
Flexural Strength	80-100 MPa
Impact Strength	2-5 kJ/m^2
Elastic Modulus	2,500-4,000 MPa
Melting Point	160-210 °C
Thermal Conductivity	0.14-0.22 W/mK
Specific Heat	0.9 J/gK

The study employed recycled PVC, given that PVC is a recyclable material. The recycling process provides a means of reducing the environmental impact of PVC and enhancing sustainability. The recycled PVC was procured from the Global Company in the Organised Industrial Zone of Gaziantep (OSB). The results of the density tests indicated that the density of recycled PVC was 1.34 g/cm^3.

4.1.2 Expanded Perlite

Expanded perlite is a lightweight and porous material that is produced by subjecting perlite ore to high temperatures. During this process, the particles of perlite expand and gain volume as a result of the evaporation of the water that is present within them. The expansion results in a considerable increase in the volume of perlite, thereby rendering it a lightweight material. Expanded perlite is characterised by a low density and thermal conductivity. These properties provide the basis for the effective utilisation of perlite as an insulation material, thereby contributing to energy conservation. These properties make it a suitable material for insulation. Additionally, expanded perlite is fire-resistant, which has made its extensive use in building materials. Perlite's fire resistance makes it a preferred material for projects that require fire safety. In this study, expanded perlite was purchased from Inper Perlite Insaat ve Ticaret Ltd. Şti. located in Gaziantep Organised Industrial Zone. Some properties of expanded perlite given by the company are given in the table.

Table 4.2 Properties of expanded perlite

Properties	**Value**
Structure	Amorphous, porous
Colour	White, light gray
Density	0.03-0.15 g/cm^3
Moisture Content	Max 1%
pH	6.5-7.5
Thermal Conductivity	0.04-0.06W/mK

4.1.3 Wood

Wood has been of great importance in the formation of civilisation since ancient times. Wood is an organic material that has been employed in a variety of industrial applications since the advent of human civilisation. Wood has been a fundamental building material throughout history, playing a pivotal role in the development of diverse cultures. Wood is an organic building material with a fibrous, heterogeneous and anisotropic texture, derived from a living organism, the tree. The composition of wood is defined by the presence of four main components: cellulose 40-50%, hemicellulose 20-35%, lignin 20-30% and other substances 5%. These components are crucial determinants of the durability and versatility of wood. Cellulose is the primary structural component of wood and possesses a fibrous structure. It enhances the physical properties of wood, including its resistance to bending and tensile. Hemicellulose is composed of shorter carbohydrates surrounding cellulose. By means of this, it endows wood with flexibility and water retention capacity. Furthermore, it fortifies the cell walls and serves as a storage material. Lignin is present within the cellulose fibres. It connects the cells of the wood and provides resistance to compression. This property increases the wood's resistance to compressive forces, thereby maintaining the structural integrity of the material. Concurrently, it imparts to wood a low water permeability and biological resistance. The physical, mechanical and thermal properties of wood are contingent upon its type, fibre direction and the environment in which it grows [78-79].

The wood utilized in the production of wood-plastic composite (WPC) materials is predominantly employed as particles or fibres. The role of these particles or fibres in determining the final properties of the material is of great consequence. The size of wood flour is typically expressed in mesh size units. The particle size of wood-plastic composite materials has a significant impact on their physical and mechanical properties. The utilisation of smaller particles results in enhanced moisture resistance and a superior outcome in terms of mechanical properties. The distribution of particles within the material is more uniform when they are smaller, which results in enhanced aesthetic qualities and performance. [80].

The addition of wood into polymer matrix composite materials confers a number of advantages.

- Wood is known to possess high tensile and flexural strength. The incorporation of wood particles or fibres into composite materials serves to enhance their mechanical properties, thereby increasing their overall strength.
- The low density of wood makes composite materials lightweight.
- Wood is a naturally renewable resource. It is a material of significant importance in terms of sustainability.
- The incorporation of wood into composite materials serves to enhance their aesthetic value, imparting a natural appearance and texture.

The wood flour utilized in this study was procured from the Carpentry Workshop at Gaziantep University and is derived from the larch tree.

Table 4.3 Properties of larch wood [80]

Physical Properties	**Value**
Oven-dry Density	0.49 g/cm^3
Air-dry Density	0.52 g/cm^3
Bulk Density in Green State	750-850 kg/m^3
Mechanical Properties	
Compressive Strength	45 N/mm^2
Flexural Strength	80 N/mm^2
Elastic Modulus	11000 N/mm^2
Tensile Strength (Parallel)	100 N/mm^2
Shear Strength	10 N/mm^2
Impact Resistance	0.4-0.7 kN/cm^2
Hardness (Parallel)	40 N/mm^2
Hardness (Perpendicular)	19 N/mm^2
Chemical Properties	
Cellulose	40-57 %
Lignin	25-29 %
Pentosan	8-11 %
pH	5.1

4.2 WPC mixture composition, mixing proportioning and sample preparation

WPC mix is defined as the appropriate selection and dosage of the compounds to be used for the production of composite materials with predetermined properties. In this study, sample were produced using wood flour, PVC and expanded perlite as test materials. Expanded perlite has a low coefficient of thermal conductivity (0.04-0.065 W/mK) and density (75 kg/m^3). The utilisation of expanded perlite has been employed with the objective of enhancing the thermal properties and reducing the weight of the composite materials to be produced. PVC is used in the composite material to be produced for its high mechanical properties, dimensional stability, water resistance and flame retardant properties. Wood flour was selected due to its favourable physical properties, including a low density (0.55 g/cm^3), renewability and a high strength-to-weight ratio.

Once the compounds to be included in the composite sample had been selected, the density of each compound present were determined with the accurately in order to apportion the mixture using the absolute volume method.

Table 4.4 Density of components

Component	**Density (g/cm3)**
PVC	1.34
Expanded Perlite	0.075
Wood Flour	0.55

This method is employed in the determination of the mixture ratio of composite materials. The homogeneity of the mixture and the performance of the final product are contingent upon the accurate determination of these ratios. It is predicated on the supposition that the sum of the volumes of the constituents that comprise the composite material is equal to the total volume of the mixture. This method, ensures that the components are mixed in accordance with the correct proportions. This ensures that the composite material attains the desired properties. The volume of the mould to be produced (the total volume of the mixture) is multiplied by the density of each of the components, thus yielding the mass of each component. Subsequently, the mass of the WPC mixture and the mass of the components to be employed are calculated by multiplying the percentage ratios of the components to be used in the WPC sample. The calculation is of great consequence in attaining a balanced composition of the material and in the acquisition of the desired mechanical and physical properties.In order to ascertain the percentages of the components, similar studies from the existing literature were used as a basis.

Table 4.5 WPC mixture composition and ratios

Group	Sample Number	Sample Name	PVC (%)	Expanded Perlite (%)	Wood (%)
Group 1	0	HAR-0	100	-	-
	1	HAR-1	90	5	5
	2	HAR-2	80	10	10
	3	HAR-3	70	15	15
	4	HAR-4	60	20	20
	5	HAR-5	50	25	25
	6	HAR-6	40	30	30
Group 2	7	HAR-5.1	50	5	45
	8	HAR-5.2	50	10	40
	9	HAR-5.3	50	15	35
	10	HAR-5.4	50	20	30
	11	HAR-5.5	50	25	25
	12	HAR-5.6	50	30	20
	13	HAR-5.7	50	35	15
	14	HAR-5.8	50	40	10
	15	HAR-5.9	50	45	5
Group 3	16	HAR-6.1	40	5	55
	17	HAR-6.2	40	10	50
	18	HAR-6.3	40	15	45
	19	HAR-6.4	40	20	40
	20	HAR-6.5	40	25	35
	21	HAR-6.6	40	30	30
	22	HAR-6.7	40	35	25
	23	HAR-6.8	40	40	20
	24	HAR-6.9	40	45	15

The ratios of PVC, expanded perlite and wood flour in different proportions of WPC specimens arranged under three different groups are shown in Table 4.5. The aforementioned mixing ratios were prepared for the purpose of investigating the thermal and mechanical properties of WPC materials with expanded perlite.

After the mixture ratios were determined, the components were prepared for the production process. The moisture content of the wood flour is deemed to be optimal when it falls within the range of 2% to 8%, as per the standards set forth by ASTM D447 and ASTM D7031. The moisture content of the wood flour play a pivotal role in the production of WPC, as excessive evaporation lead to the formation of excessive voids within the material, as well as elevated gas pressures, which are undesirable outcomes. For this reason, the wood flour was maintained in an Asel furnace at a temperature of 50°C for a period of 24 hours. The optimal particle size of wood flour is 60/80 mesh [81]. Consequently, the wood flour was subjected to a 60 mesh sieving process.

Figure 4.1 The process of wood flour drying

Once the mixture ratios had been established and the components prepared for production, each sample was weighed in the established ratios on a precision balance. This step is critical for ensuring the homogeneity and quality of the final product. This process has been carried out with great rigour to ensure that the weight of each component is correct. This step was carefully executed, as inaccurate weighing could have a detrimental effect on the performance of the composite material. Mixtures prepared in specific ratios were subjected to a 5-minute stirring process in a mixing machine to ensure uniform distribution of the components within the mixtures. The mixing time was optimised in order to guarantee the homogeneous distribution of components and to ensure that the final composite exhibited the desired properties.

Figure 4.2 Electromechanical Sieve Shaker

Figure 4.3 Production Mold

Following homogenization of the mixture, it was poured into a 300 x 80 x 25mm resistance-heating mould. The hand layup method was conducted in accordance with the illustration in Figure 4.3. This stage of the moulding process is where WPC materials with expanded perlite are given their final shape. Then, the mould was closed and positioned within the press machine. This process contributes to an enhancement of the mechanical performance of the final product, achieved by an increase in its density, which is the result of a reduction in the number of voids or pores within the composite material. At this juncture, the temperature of the mould was incrementally elevated to 210°C with the assistance of a thermostat.

Figure 4.4 Hand Lay-Up Method for Transferring Mixtures into the Mold

A gradual increase in the mould temperature was implemented in order to minimise the occurrence of thermal stresses. Additionally, gradual temperature increase ensures the material heats uniformly and reduces the risk of deformation. Once the mixture within the mould had begun to melt, the male and female components of the mould were compressed until a complete closure was achieved. The application of pressure by the press machine ensured that the molten mixture filled the mould cavities and assumed its final shape.

Figure 4.5 Press Machine

Following the completion of the heating process, the mould was maintained under pressure for a period of 15 minutes during the subsequent cooling process. The objective of this practice is to ensure the dimensional stability of the hot demoulded specimen during its transition to a cold environment. The study produced a total of 100 samples, comprising four samples from each mixture ratio.

Figure 4.6 Produced Composite Material (30x8x2.5cm)

4.3 Test Method on WPC

This section divides the tests to be applied to WPC materials produced with expanded perlite into three categories: mechanical, thermal and material micro-characterisation. The mechanical tests comprise compressive strength, three-point bending strength, bulk density, water absorption, flammability and ultrasonic sound velocity tests. The thermal tests comprise thermal conductivity, specific heat and thermal diffusivity tests. The micro-characterisation of the produced samples is determined by porosity test.

4.3.1 Compressive Strength Test

The compressive strength test is the most widely used property in the construction industry for quality control and the identification and classification of the material to be used. This is due to the practicality of the compressive strength test and its correlation with many other properties. Compressive strength test was conducted utilising a Shimadzu AG-X brand universal testing machine, which has a maximum capacity of 300 kN. Compressive strength test was conducted on four specimens for each mixture ratio.

s

Figure 4.7 Compressive Strength Test

In the test performed in accordance with the standards set forth by the American Society for Testing and Materials ASTM C165, the loading speed was selected to be 1.27 mm/min. after the dimensions of the sample had been entered into the device screen and the loading speed had been adjusted, the test was initiated. In addition, the compressive strengths of the composite materials were evaluated by ensuring that the deformation did not exceed 10% during the testing procedure. The test was concluded by calculating the mean value of the four samples of each mixture ratio obtained as a result of the test.

4.3.2 Flexural Strength Test

Three-point bending test was conducted on four specimens of each blend ratio, with dimensions of 30 x 8 x 2.5 cm. The tests were conducted in accordance with the standards set forth by the ASTM C203. The loading rate was calculated in accordance with the equation set forth in this standard.

$$R = ZL^2/6d \qquad (4.1)$$

R= rate of crosshead motion, mm/min

L= support span, mm

d= depth of beam, mm

Z= rate of straining of the outer fiber, mm/mm Z shall equal 0.01.

Figure 4.8 Three-Point Bending

In accordance with the sample dimensions, the loading rate was calculated to be 4.71 mm/min. Once the dimensions of the sample and the loading rate had been entered into the device, the test was initiated and the bending strength values were subsequently recorded.

4.3.3 Archimedes' Principle Test

Archimedes' principle was used to determine the density of wood-plastic composites reinforced with expanded perlite. This method is a widely employed technique for the accurately evaluation of the volumetric characteristics of composite materials. The wet mass reflects the maximum water absorption capacity of the sample and helps determine the porosity level of the material. The wet mass of the composite samples was obtained from the preceding test, which was conducted with the objective of determining the water absorption rate. The samples were subjected to drying in an oven and then submerged at a depth of at least 5 cm below the surface of the water in order to ascertain their apparent mass in water. The volume of the samples was calculated on the basis of the difference between the saturated mass and the submerged mass, with the density of water serving as a reference point. The density of the material was ultimately determined by dividing the dry mass of the sample by the computed volume. Density value represents a fundamental parameter for the evaluation of the mechanical and thermal properties of the material.

Figure 4.9 Archimedes' Principle

The density of the sample was determined using the following formulas:

$$V = \frac{M_{liquid} - M_{air}}{\rho_{water}} \quad (4.2)$$

$$\rho = \frac{M_d}{V} \quad (4.3)$$

V = the volume of the sample, (m^3)

M_{liquid} = the mass of the sample when fully submerged in water, (kg)

M_{air} = the mass of the sample in air, (kg)

ρ_{water} = the density of water, (typically 1000 kg/m^3)

ρ = the density of the sample, (kg/m^3)

M_d= the mass of the dry sample, (kg)

4.3.4 Water Absorption Test

Given that the water entering the pores of the produced samples affects the mechanical and thermal properties of the composite material, it is of great importance to conduct a water absorption test on each sample. The samples, for which the dry bulk density has been determined, are maintained in a pool of water for a minimum of 48 hours at a depth of at least 5 cm below the water surface.

Figure 4.10 Water absorption test

Following a two-day period, the samples removed from the water are wiped with a cloth and weighed on a precision balance without delay. At this stage, the saturated mass (M_{liquid}) of the samples is noted. The percentage of water absorption capacity is calculated using the following formula:

$$\Delta W = \left(\frac{M_{liquid} - M_d}{M_d}\right) \times 100 \qquad (4.4)$$

ΔW= water absorption (%)

M_{liquid}= the mass of the sample when fully submerged in water, (kg)

M_d= mass of the dry sample, (kg)

4.3.5 Porosity Test

Porosity testing is a method used to determine the proportion of voids present within a given material. The Archimedes-based method is employed for the measurement of porosity in wood-plastic composite samples reinforced with expanded perlite. Initially, the saturated weight (M_{sat}) and submerged weight (M_{sub}) of the samples are ascertained through the utilisation of the Archimedes principle. The dry weight (M_d) of the samples has been previously measured. Using these values, the total volume, solid volume, and void volume of the material have been calculated. Finally, the porosity (Φ) has been determined as the ratio of the void volume to the total volume.

$$V_p = \frac{M_{liquid} - M_{air}}{\rho_{water}} - \frac{M_d}{\rho} \tag{4.5}$$

$$\Phi = \frac{V_p}{V} \tag{4.6}$$

V_p= the void volume of the sample, (m^3)

V = the volume of the sample, (m^3)

M_{liquid} = the mass of the sample when fully submerged in water, (kg)

M_{air} = the mass of the sample in air, (kg)

M_d= mass of the dry sample, (kg)

ρ_{water} = the density of water, (typically 1000 kg/m^3)

ρ = the density of the sample, (kg/m^3)

4.3.6 Ultrasonic Pulse Velocity Test

Four samples of each mixture ratio are weighed and their weights are determined. This step is carried out with great precision in order to the homogeneity of the samples and the consistency of the experimental results. The sample that is closest to the average of the samples is then selected for sound velocity measurements. The calculation of ultrasonic pulse velocities is conducted in accordance with the specifications outlined in the ASTM E494 standard. This standard is employed as an industry-wide accepted reference point to guarantee the precision and reproducibility of the measurements. Prior to undertaking sound measurement experiments, the device is calibrated with a sample with known sound velocity. It is of paramount importance to ensure that the measuring device provides accurate results by undertaking this calibration step.

Figure 4.11 Ultrasonic Pulse Velocity Device

The ultrasonic sound transmission rates are measured on four occasions from two different points, and the resulting data are averaged.

4.3.7 Thermal Conductivity, Specific Heat, and Thermal Diffusivity Test

The procedures employed for the samples selected for sound velocity measurements were repeated in these experiments in an identical manner. The thermal conductivity, specific heat, and thermal diffusivity values of the samples were determined using a TPS 2500 S Hot Disc device.

Figure 4.12 TPS 2500 S Hot Disc Thermal Constant Analyzer

In order to obtain a measurement, the thermal properties of each sample were determined from three different points, and the test was terminated by taking the average.

4.3.8 Surface Burning Characteristic Test

The objective of this test is to ascertain the flame resistance of building materials and to determine their thermal decomposition and combustion characteristics. The tests were conducted in accordance with the standards set forth by the ASTM in the E84 standard.

Figure 4.13 Flame Resistance Test

The dimensions and weights of the specimens were measured prior to the commencement of the test. Subsequently, the blowtorch was situated at a distance of 5 cm from the specimens. During the flame resistance test, the temperature at the sample surface reached 780°C. Following the conclusion of the testies, evidence of wear was discerned on the surface of the samples, and the resulting weight changes were calculated as a percentage.

4.3.9 Microscopic Analysis of Composite Microcharacterization

In this experiment, microscopic observations were conducted to examine the internal structure of wood-plastic composites reinforced with expanded perlite. As the internal structure of the material comprises pores and voids that directly impact its mechanical and thermal performance, it is essential to investigate these characteristics in detail. These observations were conducted with the objective of gaining insight into the material's microstructure and to provide critical data for potential production improvements.

Figure 4.14 Nikon Eclipse MA100

To this end, the selected samples were analysed using a Nikon Eclipse MA100 microscope, with the microstructure observed at 20x magnification. The microscope was selected for the purpose of identifying critical parameters, such as porosity and void distribution. Such microscopic observations are a common practice in the literature and provide valuable insights for understanding and enhancing the material's performance.

CHAPTER 5

RESULT AND DISCUSSIONS

In this section, the thermal, mechanical and internal structure properties of the samples produced by the addition of expanded perlite at varying ratios to the WPC material were determined through a series of tests. To ascertain the mechanical properties of the manufactured samples, tests were conducted, including those for compressive strength, three-point bending strength, dry density, water absorption rate and ultrasonic sound transmission. In order to determine the thermal properties, tests were performed for thermal conductivity, specific heat and thermal diffusivity. In addition, tests were conducted to assess the porosity and internal structural properties of the samples. The influence of the internal structural configuration of the composite materials on their comprehensive performance has also been evaluated, and the manner in which this configuration contributes to the mechanical and thermal properties of the material has been investigated. The tests were conducted using samples at room temperature for the strength tests and samples that had been dried for the thermal and acoustic tests. This drying process was done to circumvent the potential influence of water humidity on the test outcomes. Moreover, the effect of incorporating highly expanded perlite into wood-plastic composite materials has been extensively studied. It is of the utmost importance to make precise adjustments to the expanded perlite ratio in order to guarantee the optimal performance of wood-plastic composites materials. The findings offer significant insights into the utilisation of composite materials in diverse applications. The results of the tests conducted on the manufactured samples are presented in Figure 7.1. These results provide a clear indication of the influence of expanded perlite on the properties of wood-plastic composite materials, thereby highlighting the potential benefits and limitations of its incorporation.

Table 5.1 Thermal and mechanical properties of composite samples produced

Group	Sample Number	Sample Name	Density (g/cm3)	Compressive Strength (Mpa)	Flexrual Strength (Mpa)	Water Absorption (%)	Thermal Conductivity (W/mK)	UPV (km/s)
Group 1	0	HAR-0	0.8412	14.0878	15.8422	11.37	0.1246	1.2887
	1	HAR-1	0.7728	8.4364	8.2595	14.13	0.1166	0.9503
	2	HAR-2	0.7381	4.0726	1.8954	21.55	0.1113	0.8163
	3	HAR-3	0.6946	2.8873	0.6203	28.02	0.1050	0.7162
	4	HAR-4	0.6392	1.7500	0.3945	35.18	0.0987	0.6238
	5	HAR-5	0.5994	1.2107	0.3816	39.1	0.0952	0.5643
	6	HAR-6	0.5293	0.7006	0.0989	68.57	0.0936	0.5185
Group 2	7	HAR-5.1	0.6457	2.3956	0.6270	20.43	0.1184	0.7014
	8	HAR-5.2	0.6331	1.8939	0.5460	27.57	0.1067	0.6478
	9	HAR-5.3	0.6184	1.6258	0.4854	34.14	0.0998	0.6181
	10	HAR-5.4	0.6042	1.3986	0.4147	35.74	0.0969	0.5834
	11	HAR-5.5	0.5994	1.2107	0.3816	39.1	0.0952	0.5643
	12	HAR-5.6	0.5739	1.0387	0.3087	48.04	0.0925	0.5512
	13	HAR-5.7	0.5514	0.9517	0.2514	51.69	0.0911	0.5408
	14	HAR-5.8	0.5426	0.8640	0.2210	54.67	0.0871	0.5319
	15	HAR-5.9	0.5125	0.7488	0.1945	71.54	0.0824	0.5298
Group 3	16	HAR-6.1	0.5982	0.9776	0.3640	27.11	0.1035	0.6634
	17	HAR-6.2	0.5791	0.8974	0.3248	43.84	0.1017	0.5996
	18	HAR-6.3	0.5682	0.8304	0.2737	57.28	0.1002	0.5716
	19	HAR-6.4	0.5562	0.7862	0.2305	43.95	0.0979	0.5493
	20	HAR-6.5	0.5373	0.7462	0.1681	63.94	0.0965	0.5330
	21	HAR-6.6	0.5293	0.7001	0.0989	66.1	0.0936	0.5185
	22	HAR-6.7	0.5008	0.6588	0.0710	68.62	0.0902	0.5098
	23	HAR-6.8	0.4852	0.5844	0.0664	77.13	0.0887	0.4961
	24	HAR-6.9	0.4712	0.4937	0.0560	76.31	0.0851	0.4860

5.1 Test Results of Mechanical Properties

The calculated density of the produced samples are presented in Table 5.1. The sample with the highest density was identified as HAR-0 (0), exhibiting a value of 0.8412 g/cm³, while the sample with the lowest density was HAR-6.9 (24), with a density of 0.4712 g/cm³. The reduction in the density of the HAR-6.9 (24) sample is occurred to the incorporation of expanded perlite and an increase in porosity due to compressing during the manufacturing process. The enhanced porosity has resulted in the material containing a greater volume of air, which has caused a reduction in density. A reduction in density of 44% was observed in all samples produced. The reduction can be explained by the lightweight structure imparted by the expanded perlite, the increased porosity or voids, and the specific production parameters.

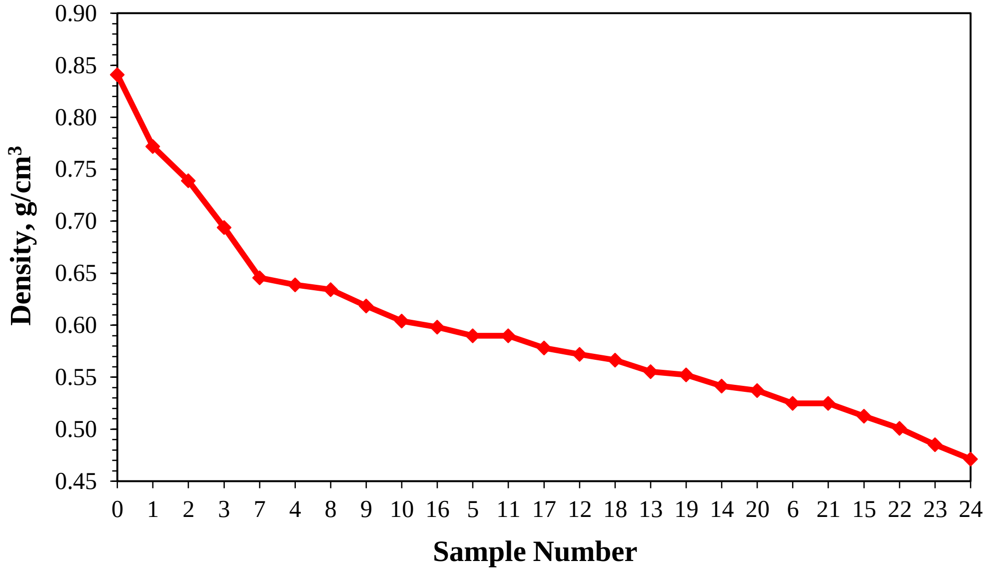

Figure 5.1 Change in density of manufactured composite samples

As the proportion of expanded perlite in the composite samples increased, a corresponding decrease in density was observed. The sample with the lowest density exhibits the least density as a consequence of its lower PVC content and higher proportions of expanded perlite and wood flour.

The results of the compressive strength and three-point bending strength tests on the produced samples are of great importance for the evaluation of the mechanical performance of composite materials. These tests provide fundamental data for predicting the performance of materials in critical applications such as construction and structural engineering. The results of the compressive strength and 3-point flexural test indicated that the compressive strength exhibited a range of 0.4937 MPa to 14.0878 MPa, while the 3-point flexural strength demonstrated a range of 0.0560 MPa to 15.8422 MPa. This extensive range of strength demonstrates the potential for optimising composites for a variety of application areas. The parameters that were identified as affecting the compressive strength of the composite materials produced were found to be surface incompatibility between the components, matrix-expanded perlite ratio, particle size and distribution, density and production conditions. As illustrated in Figure 5.2, sample HAR-0 (0) exhibited the highest compressive strength 14.08 MPa, while sample HAR-6.9 (24) demonstrated the lowest compressive strength 0.49 MPa.

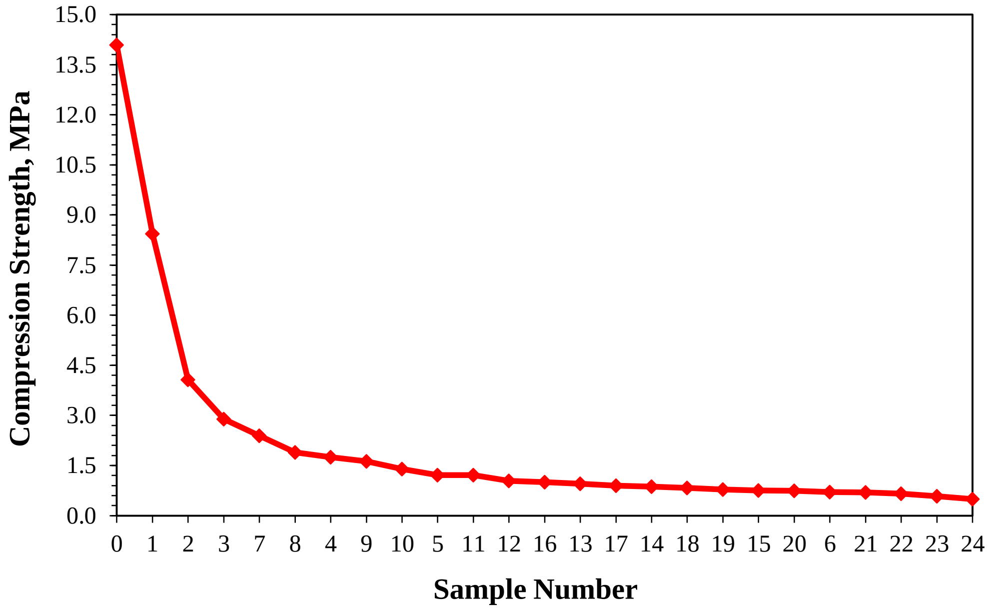

Figure 5.2 Compressive strength values of the composite samples produced

The data indicated a 96.52% reduction in compressive strength. It was observed that increase in the ratio of expanded perlite resulted in reduction in compressive strength across all sample groups. The presence of voids in the composite hinders its ability to evenly distribute the applied loads, which in turn weakens the material’s mechanical strength. The observed outcome is a consequence of the inferior surface performance that exists between the expanded perlite and the matrix material.

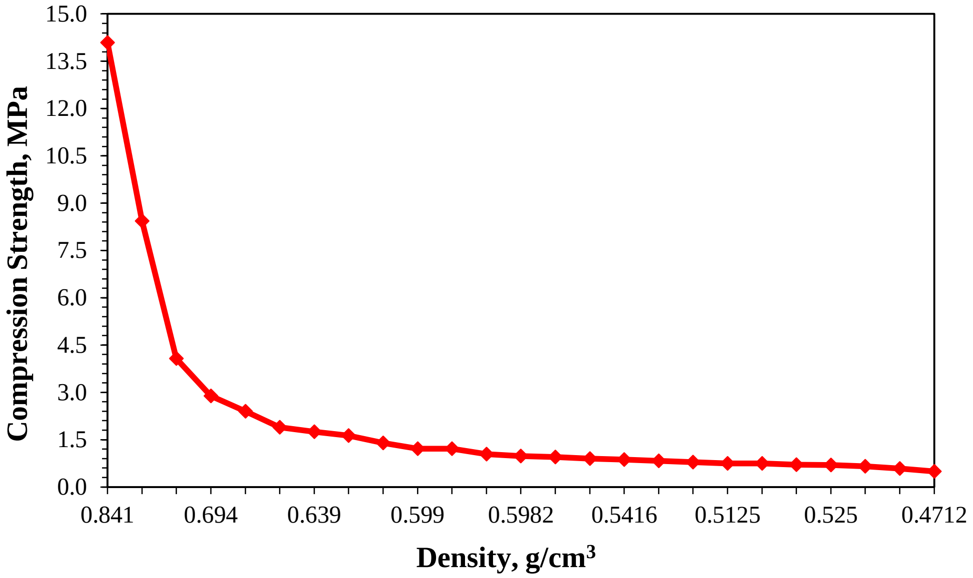

Figure 5.3 Relationship between compressive strength and density

The relationship between density and compressive strength is shown in Figure 5.3. As the ratio of expanded perlite increased, the porosity or air voids within the composite material also increased, resulting in a reduction in density. The increased porosity or air voids result in the composite material possessing lower compressive. Furthermore, the heterogeneous distribution of the composite material's components also diminishes its compressive strength.

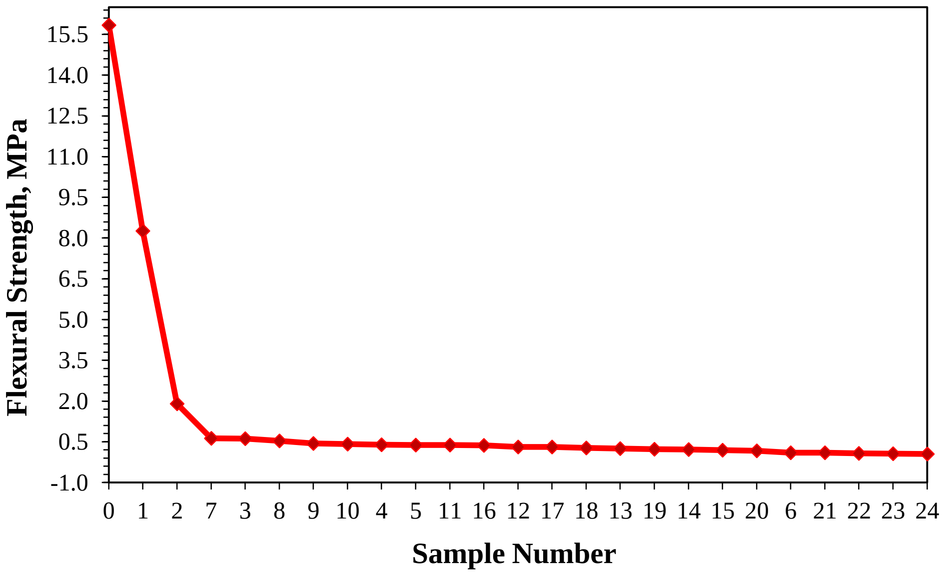

Figure 5.4 Flexural strength values of the composite samples produced

The highest flexural strength was observed in composite sample HAR-0, which exhibited a value of 15.84 MPa. In contrast, the lowest flexural strength was recorded in composite sample HAR-6.9, which demonstrated a value of 0.056 MPa. When all the samples were taken into account, it was revealed that there was a 98% decrease in bending strength. The same reasons that result in a decrease in compressive strength also caused a decrease in flexural strength. An increase in the proportion of expanded perlite results in an increasing pore ratio within the composite material, accompanied by a reduction in density. Therefore, a decrease in flexural strength occurs.

Figure 5.5 shows the water absorption capacities of composite materials that were dried in a drying oven and then soaked in water for 48 hours. The data indicated that the water absorption capacity of the samples ranged from 11.37% to 86.31%. The water absorption capacity of WPC materials with expanded perlite addition was found to vary depending on the compression ratio, expanded perlite-matrix ratio and type.

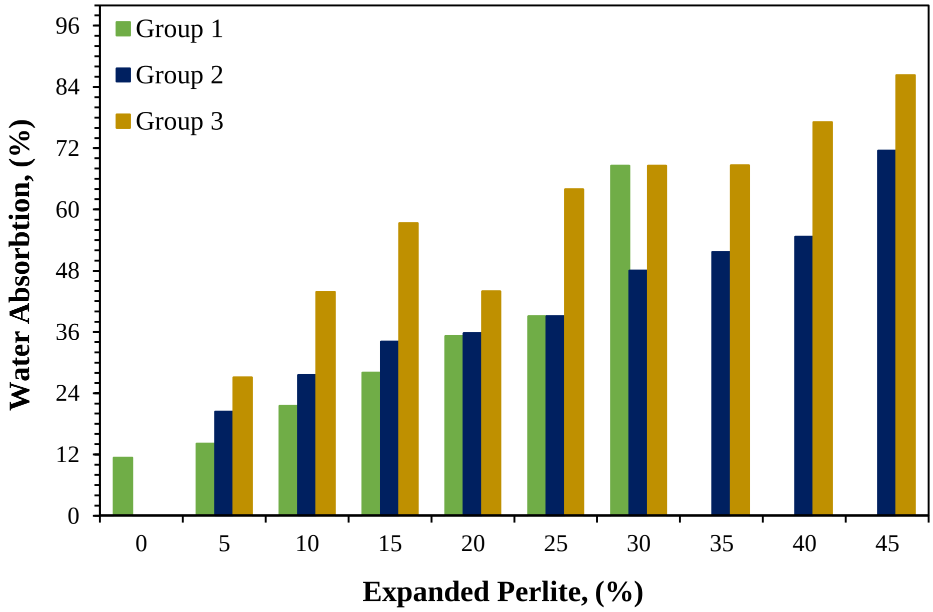

Figure 5.5 Effect of expanded perlite ratio on water absorption

The type and quantity of matrix, filler materials, and reinforcement elements present in the mixture has been demonstrated to exert a notable influence on the water absorption capacity. Additionally, the interaction between these materials and expanded perlite can further enhance or reduce the overall absorption characteristics, depending on the compatibility between components. However, it has been established that the type and quantity of expanded perlite exert a more pronounced influence in this context. Due to its hydrophilic property and porous, lightweight structure, expanded perlite exhibits a high water absorption capacity. In fact, the combination of perlite's intrinsic properties and the material's interaction with the matrix has drastically affected both the short-term and long-term water retention characteristics.

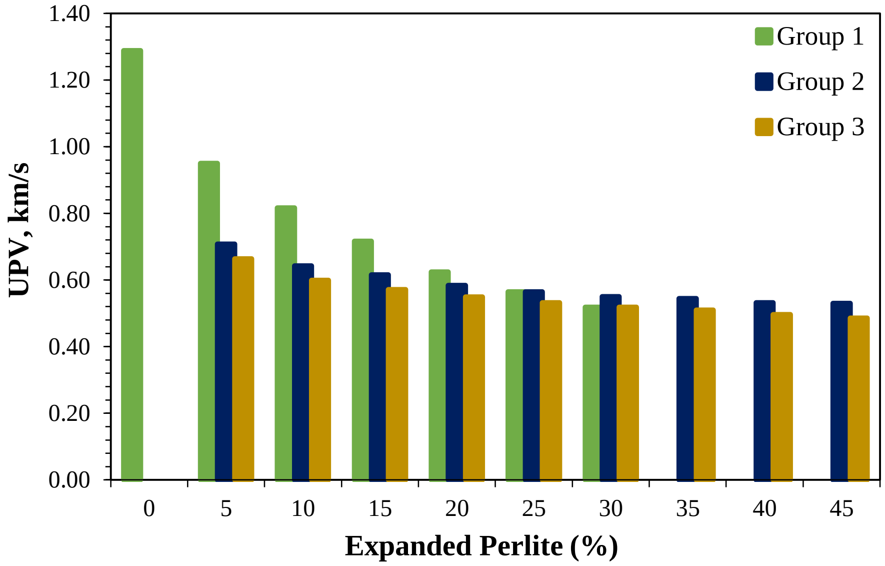

Figure 5.6 Effect of expanded perlite ratio on UPV values

Figure 5.6 shows the ultrasonic pulse velocity (UPV) values of composites produced through the addition of expanded perlite. The data obtained indicated that the ultrasonic pulse velocity of the tested samples ranged between 1.2287 km/s and 0.486 km/s. As the amount of voids and porosity within the composite material increased, a corresponding reduction in ultrasonic pulse velocity rates was observed. This is because air acts as an insulator against both heat and sound. It is anticipated that the sample with the lowest density will exhibit the highest porosity, which will in turn have a direct impact on the ultrasonic pulse velocity. It is therefore anticipated that this material will exhibit the lowest ultrasonic pulse velocity. Figure 5.7 shows that the composite sample HAR-6.9 (24), which has the lowest density of 0.45 g/cm^3, also exhibits the lowest ultrasonic pulse velocity. This correlation demonstrates the influence of density on the sound transmission properties of the composite material.

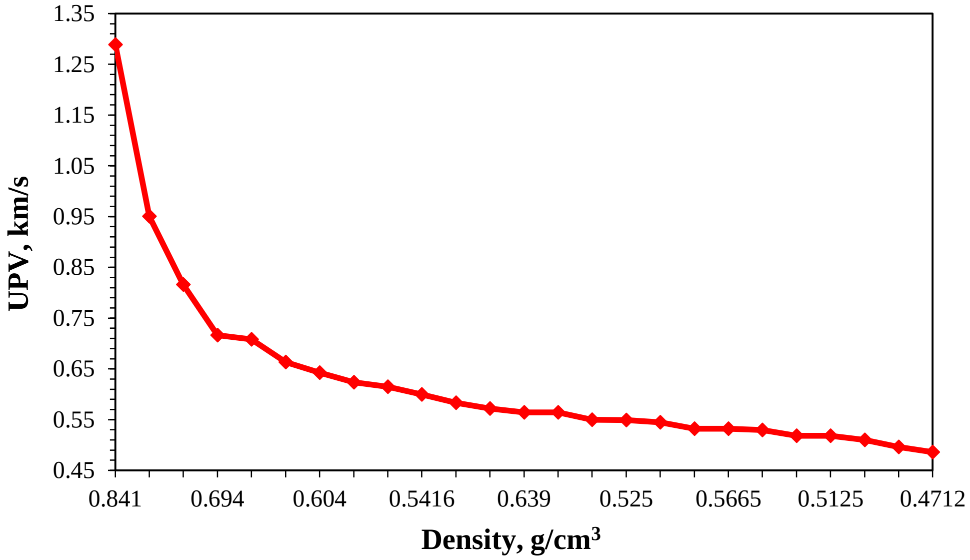

Figure 5.7 Relationship between UPV and density

5.2 The Result of Thermal Properties

Figure 5.8 illustrates the thermal conductivity values, Figure 5.10 depicts the specific heat values, and Figure 5.12 presents the thermal diffusivity values of the composites produced. The thermal conductivity values were found to range between 0.082 W/m K and 0.124 W/m K, the specific heat capacity values ranged from 2347.8 J/kg K to 1604,8 J/kg K, and the thermal diffusivity values were found to be between 1.434×10^{-7} m²/s and 0.644×10^{-7} m²/s, as determined by analysis of the test results. The findings suggest that as the proportion of expanded perlite increases, there is a corresponding reduction in the thermal conductivity of the material.

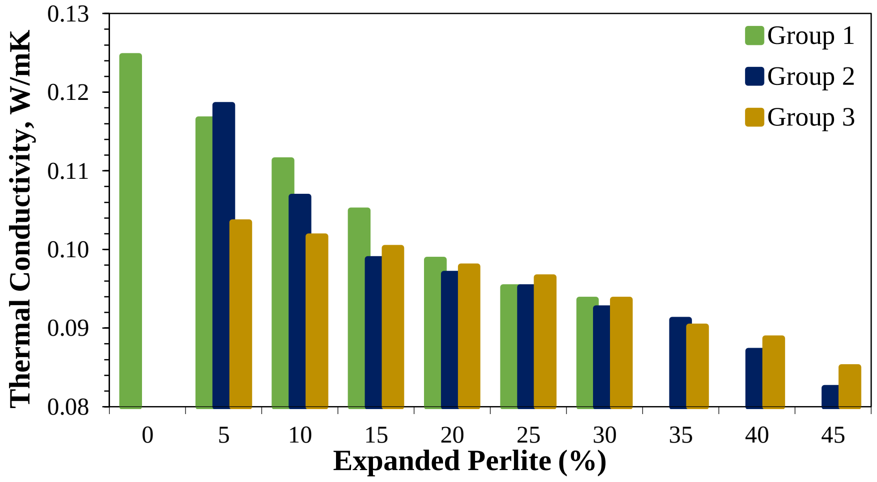

Figure 5.8 Effect of expanded perlite ratio on thermal conductivity values

The factors influencing the thermal conductivity of composite materials produced with expanded perlite have been determined to be density, compression ratio based on density, the proportion of expanded perlite incorporated into the mixture, the type of matrix material, and the matrix/expanded perlite ratio in Figure 5.8.

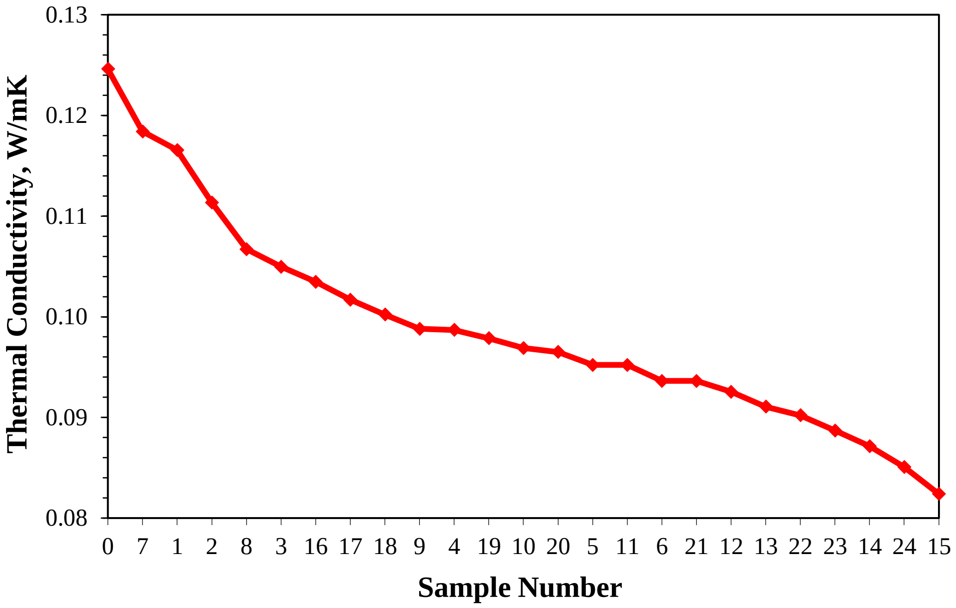

Figure 5.9 Relationship between thermal conductivity and composite samples

The rise in the ratio of voids or porosity in composite materials has resulted in an increase in the air content within the material, which has subsequently led to a reduction in thermal conductivity. The entrapped air acts as an effective thermal insulator by restricting heat transfer within the material, thereby significantly enhancing the composite's insulation properties. This reduction is typically parallel to the decline in density, which is linked to the incorporation of expanded perlite. The reduction in thermal conductivity is significantly influenced by a decrease in the density of the composite material and an increase in the amount of voids or porosity. Additionally, the inherently low thermal conductivity of expanded perlite also plays a crucial role in this reduction. The combination of increased porosity and the natural properties of expanded perlite makes these composites highly effective for thermal insulation in various applications.

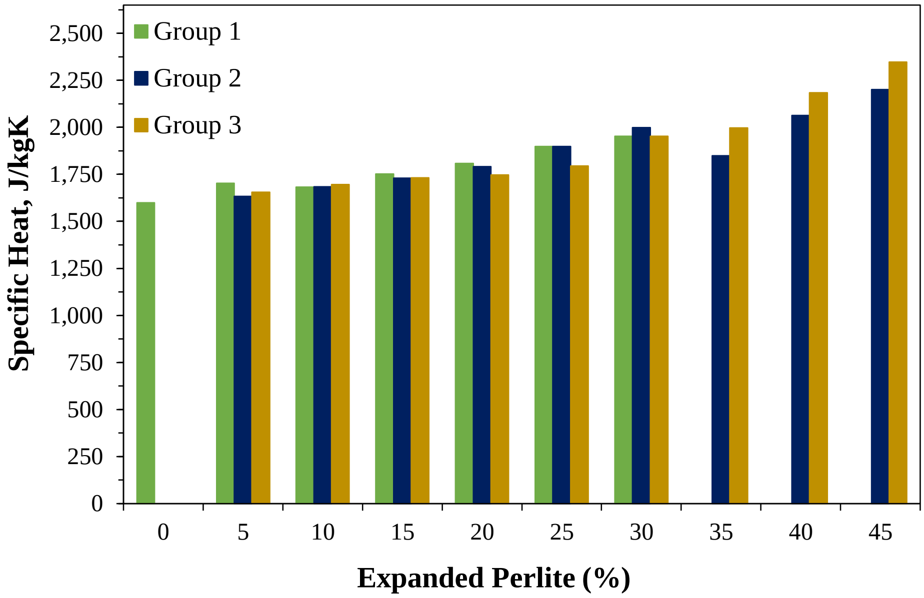

Figure 5.10 Effect of expanded perlite ratio on specific heat values

The specific heat values of the composite samples produced with an increasing ratio of expanded perlite are presented in Figure 5.10. Specific heat is a crucial factor in determining the heat storage capacity of materials. The greater a material's capacity to retain heat, the higher its insulation properties.

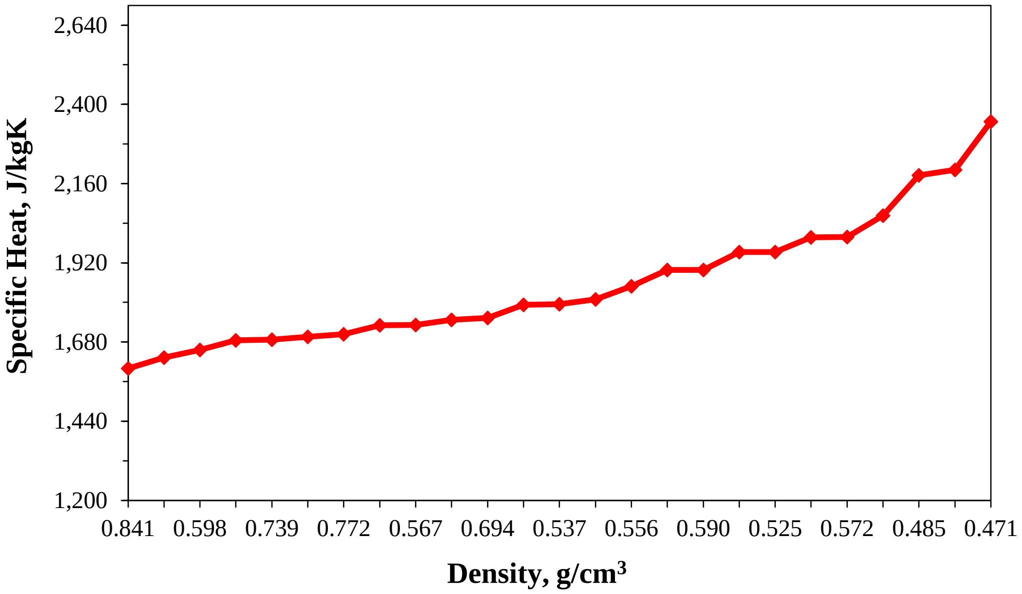

Figure 5.11 Relationship between specific heat and density

According to studies in the literature, as density decreases and the amount of voids within the material increases, specific heat tends to increase, indicating an inverse relationship between specific heat and density in Figure 5.11. Upon examination of the specific heat and density values of the materials produced, it was determined that while density is an effective factor, it does not determine the specific heat alone. The alterations in specific heat capacity and thermal diffusivity values illustrate that the porosity and void ratio within the internal structure of the composite material exert a considerable influence on its thermal properties.

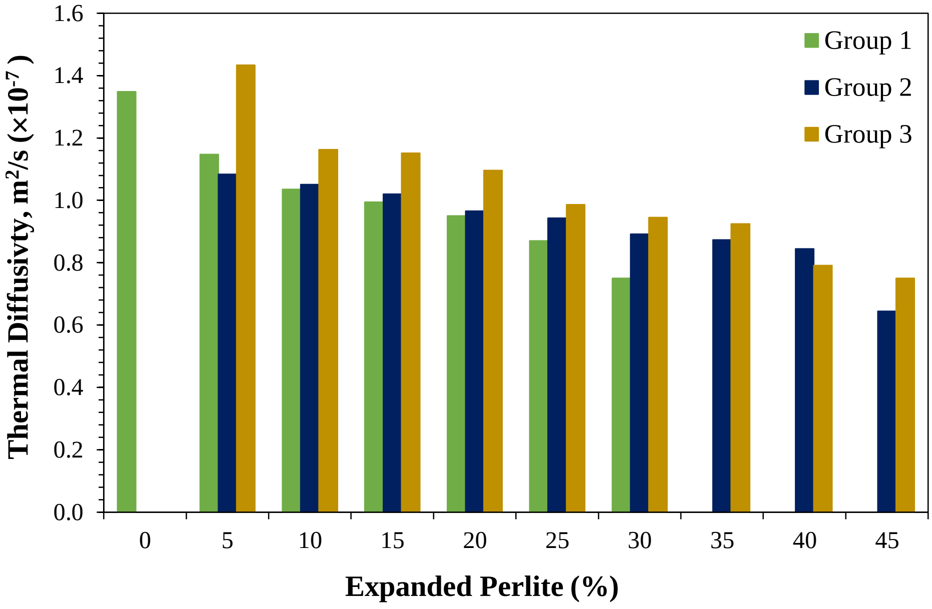

Figure 5.12 Effect of expanded perlite ratio on specific thermal diffusivity values

Thermal diffusivity is calculated by dividing a material's thermal conductivity by the product of its density and specific heat. Materials with low thermal conductivity and high specific heat capacity demonstrate low thermal diffusivity values. This is because a material with high specific heat can absorb more thermal energy before experiencing a significant temperature rise. Figure 5.12 shows the thermal diffusivity values of the composite samples, which are dependent on the content ratios. As the proportion of expanded perlite increases, the thermal diffusivity tends to decrease, highlighting the insulating properties of the material.

5.3 The Result of Surface Burning Characteristic Test

The outcomes of the fire resistance investigations on composite materials comprising varying proportions of expanded perlite are presented in Table 1 and illustrated in Figure 5.13. In Table 1, the initial and final weights of the samples were determined before and after the test, and the resulting mass losses were calculated and presented. Figure 5.13 illustrates the change in the percentage of mass loss of the samples with an increase in the ratio of expanded perlite. Upon examination of Table 5.2, it became evident that the observed weight changes ranged from 1.1% to 3.67%. The most significant weight change was observed in the HAR-6.9 (24) within Group 3, which is attributed to the higher wood flour content in this sample compared to the others, leading to observed weight change.

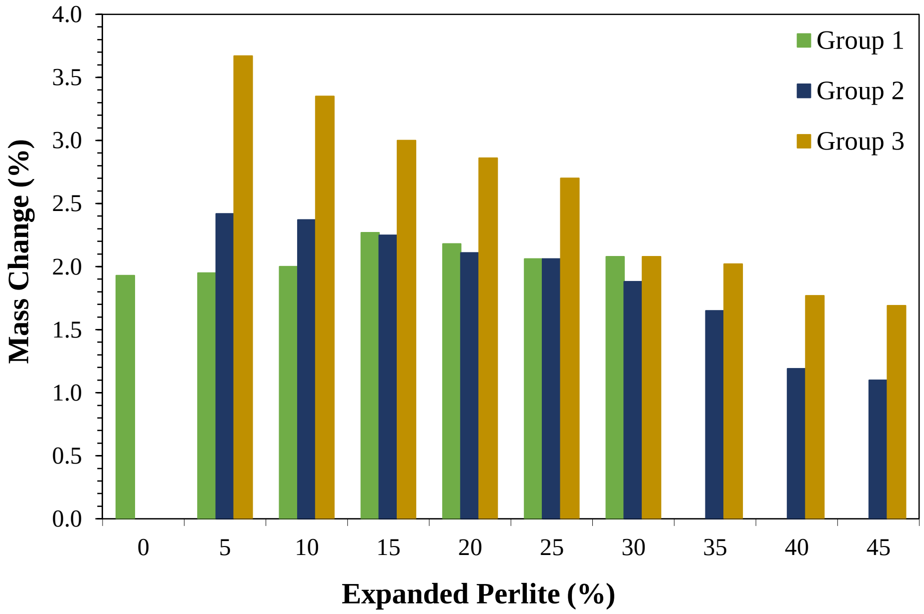

Figure 5.13 Effect of expanded perlite on ratio mass change values

This suggests that the higher the wood flour content in the composite, the more susceptible it is to mass loss during fire resistance tests. Additionally, the expanded perlite ratio appears to play a role in mitigating the mass loss, as seen in the other samples with lower wood flour content. This indicates that the fire-resistant properties of expanded perlite help reduce mass loss in composite materials during fire resistance tests. These properties support and enhance the overall flame-retardant characteristics of the composite material.

Table 5.2 Weight Changes in Flame Resistance Testing

	Samples	**Initial Weight (g)**	**Final Weight (g)**	**Change (%)**
Group 1	HAR-0	248.6	243.8	1.93
	HAR-1	230.3	225.8	1.95
	HAR-2	214.6	210.3	2.00
	HAR-3	184.7	180.5	2.27
	HAR-4	178.8	174.9	2.18
	HAR-5	164.9	161.5	2.06
	HAR-6	144.4	141.4	2.08
Group 2	HAR-5.1	185.7	181.2	2.42
	HAR-5.2	169	165	2.37
	HAR-5.3	191	187.3	1.94
	HAR-5.4	160.6	157.1	2.25
	HAR-5.5	164.9	161.5	2.06
	HAR-5.6	164.5	161.4	1.88
	HAR-5.7	157.5	154.9	1.65
	HAR-5.8	167.8	165.8	1.19
	HAR-5.9	135.8	134.3	1.10
Group 3	HAR-6.1	138.8	133.7	3.67
	HAR-6.2	137.3	132.7	3.35
	HAR-6.3	150.4	146.1	2.86
	HAR-6.4	133.4	129.4	3.00
	HAR-6.5	129.6	126.1	2.70
	HAR-6.6	144.4	141.4	2.08
	HAR-6.7	133.8	131.1	2.02
	HAR-6.8	130.2	127.9	1.77
	HAR-6.9	75.2	73.9	1.73

The thermal images of the front and rear surface temperatures of the HAR-5.9 sample at the five-minute mark, captured using a thermal camera, are presented in Figure 5.14. It was observed that while the temperature of the front surface of the sample reached 768°C, the temperature of the rear surface was only 41.1°C. Furthermore, in some samples, despite the front surface temperature reaching up to 950°C, the temperature at the rear surface did not exceed 53°C. The findings indicate that demonstrate that even at high temperatures, the thermal conductivity of the produced samples did not significantly increase.

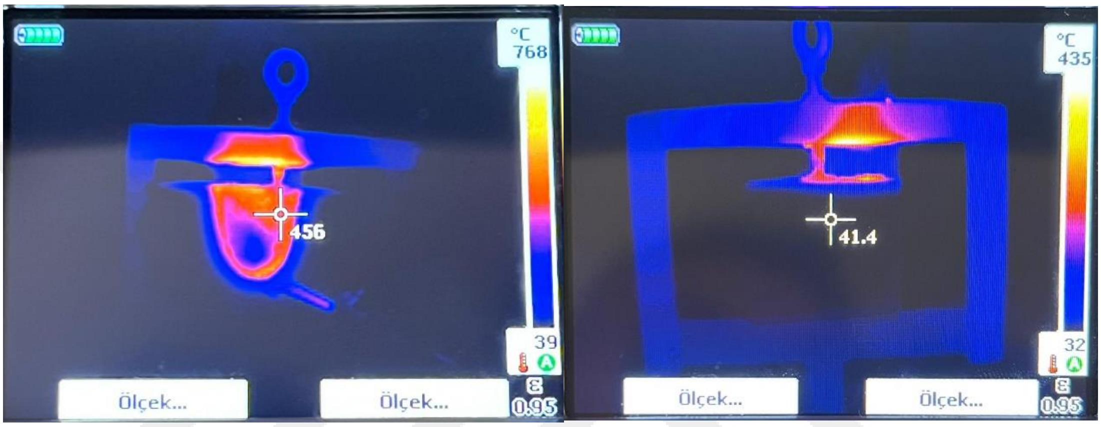

Figure 5.14 Front and rear surface temperatures of the HAR-5.9 sample

The post-test images of the tested samples are presented in Figure 5.15.

Figure 5.15 Appearance of the samples after 5 minutes of combustion test

5.4 Results of the Micro-characterisation Analysis

The results of the porosity test indicated a rise in the percentage of porosity as the material density declined. This was due to the increased content of expanded perlite. As expanded perlite is a low-density and highly porous material, its incorporation into the composite reduces the overall density while increasing the porosity. As a consequence, the reduction in density results in an increase in the void volume within the material, which in turn gives rise to an elevated porosity percentage.

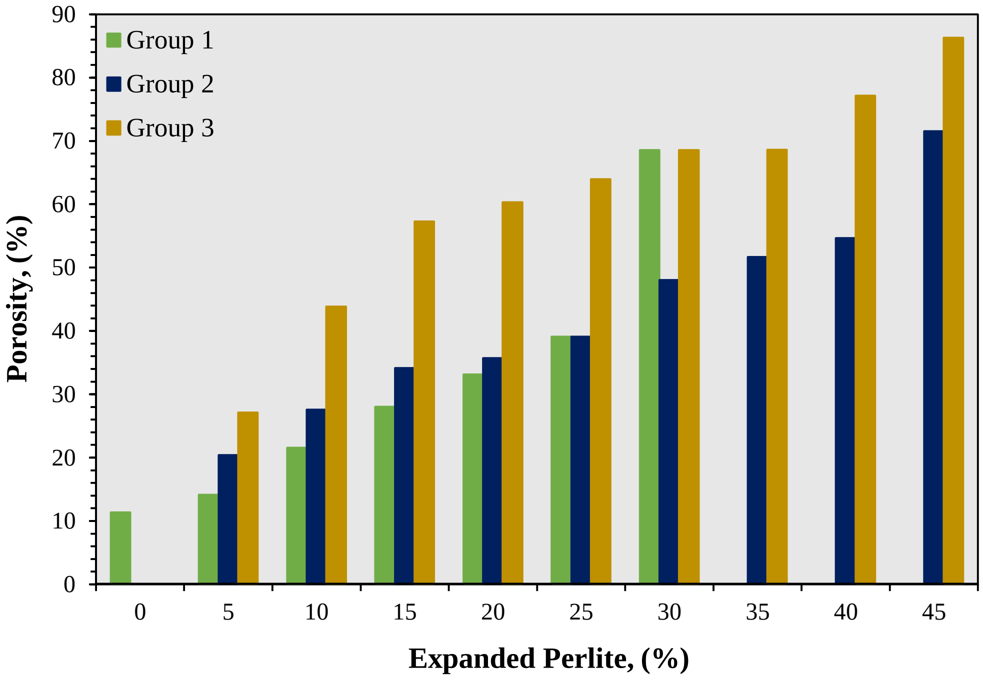

Figure 5.16 Effect of expanded perlite ratio porosity

As illustrated in Figure 5.17, the inverse relationship between density and porosity can have a significant impact on the material's structural integrity and potential applications.

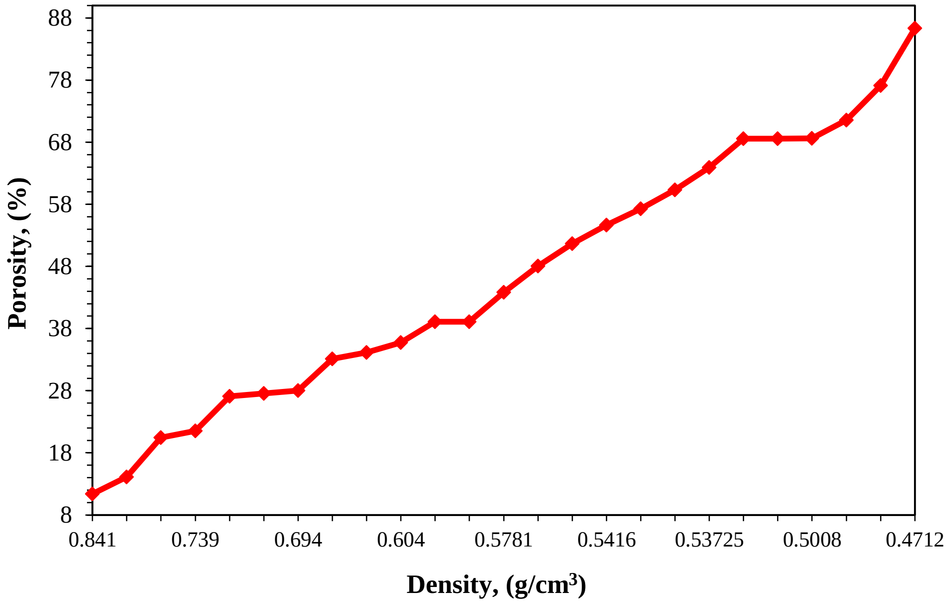

Figure 5.17 The relationship between apparent porosity and water absorption

An increase in porosity may result in a reduction in the mechanical strength of the material, while simultaneously enhancing its thermal and acoustic insulation properties. Furthermore, an inverse relationship between porosity and density is evident upon examination of Figure 5.17. As the density declines, the proportion of porosity rises.

Among the produced composite materials, three samples with distinct thermal conductivity properties were selected for analysis. These samples were designated HAR-5.9, HAR-6, and HAR-6.3. The samples were examined and images were captured using the Nikon Eclipse MA100 microscope. As observed in Figure 5.18, Figure 5.19, and Figure 5.20, the HAR-5.9 sample exhibits a more irregular pore size distribution compared to the other two samples. This irregular pore structure has led to the formation of air pockets within the material, which in turn has reduced thermal conductivity. The presence of trapped air in the pores explains the lower thermal conductivity of sample HAR-5.9 compared to the other two samples.

Figure 5.18 Microscopic Images of HAR-5.9

Figure 5.19 Microscopic Images of HAR-6

In addition, the increase in porosity has not only affected thermal conductivity, but has also led to a reduction in the mechanical properties of the composite materials, such as compressive and flexural strength. This increased porosity has weakened the structural integrity of the composite materials, causing a significant reduction in these properties, which in turn negatively affects the mechanical performance of the composite materials.

Figure 5.20 Microscopic Images of HAR-6.3

In conclusion, increase in porosity has a positive effect on the thermal conductivity of composites, but a negative effect on their mechanical properties. The results of this study indicate that the ratio of the components in the composite materials in should be adjusted with precision in accordance with the specific applications for which the material is intended.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATINS

The following conclusions can be drawn from the experimental a results:

- According to the Archimedes principle test, the increase in the proportion of expanded perlite in the composite samples results in a reduction in their density. The highest density was observed in the HAR-0 sample at 0.841 g/cm^3, while the lowest was recorded in the HAR-6.9 sample at 0.471 g/cm^3. As a result of varying composition ratios, the Group 3 samples, containing the highest amount of expanded perlite and the lowest matrix content, exhibited the lowest density values.
- The results of the thermal test indicate that the thermal conductivity of the samples under examination ranges between 0.0824 W/mK and 0.1246 W/mK, the specific heat capacity between 1600 J/kgK and 2347.8 J/kgK, and the thermal diffusivity between 0.644 m^2/s and 1.348 m^2/s. It is known that the thermal properties of WPC samples containing expanded perlite are contingent upon density. The density of composite materials is a pivotal parameter that is directly correlated with thermal conductivity, specific heat, and thermal diffusivity. By reducing the density of composite materials, lower thermal conductivity and thermal diffusivity can be achieved, while higher specific heat can be obtained. . Moreover, the variation in thermal diffusivity may be change upon factors such as the compression ratio and the type of wood employed. The reduction in thermal conductivity can be attributed to the low thermal conductivity of expanded perlite and the air trapped within the pores and voids of the material.
- The compressive strength of the produced composite materials was found to range between 0.4937 MPa and 14.087 MPa, while the three-point flexural strength varied from 0.0560 MPa to 15.8422 MPa. The key parameters influencing the strength of the composites were identified as density,

compression ratio, matrix/expanded perlite ratio, expanded perlite and wood flour content, and the poor surface compatibility of the components employed.

- The water absorption capacity of the composite samples ranged from 11.37% to 86.31%. As the proportion of expanded perlite increased, the water absorption capacity rose while the density fell. The sample with the highest capacity had the lowest matrix proportion and highest perlite and wood flour. The addition of perlite and wood flour to the composite material resulted in greater porosity, reducing density and boosting water absorption.
- The porosity of the composite materials ranged from 9.35% to 34.42%, while the UPV values varied from 0.486 km/s to 1.288 km/s. As porosity increased, UPV values decreased. The low density and thermal conductivity of entrapped air improves thermal and acoustic insulation. The proportion of expanded perlite and wood flour, as well as the compression ratio, contribute to increased porosity.
- In accordance with the ASTM E84 standard, the surface burning test was conducted. The front surface reached 768°C, while the rear surface reached 41.1°C. Composite samples exhibited low thermal diffusivity at elevated temperatures. Subsequent observations showed that the samples lost between 1.1% and 3.67% of their weight. This illustrates the composite material's stability in the face of fire, which can be attributed to the presence of expanded perlite. As the proportion of expanded perlite increased, weight loss was reduced.
- Based on the Micro-characterization Analysis, it was observed that the increase in the proportion of expanded perlite led to an increase in the porosity or voids within the produced composite materials. The reduction in thermal conductivity and UPV values observed in the composite materials can be explained by the presence of air trapped within the pores or voids. This phenomenon has the effect of enhancing both the thermal and acoustic insulation performance of the material, thereby contributing to its low density and high insulation properties.
- The use of perlite, which is abundant in Turkey, has the potential to reduce the country's dependency on imports, thereby contributing positively to the national economy. Additionally, the utilisation of primary components derived

from waste materials will serve to enhance sustainability, thereby conserving natural resources and significantly reducing negative environmental impacts. This approach will also promote the adoption of environmentally friendly production processes.

Based on the experimental findings, the following recommendations are proposed to further enhance the material's performance:

- In order to optimise the mechanical properties, it is necessary to adjust the mixture ratios in accordance with the intended application. Furthermore, the incorporation of compatibilizers and fillers can serve to enhance the mechanical performance of the composite samples.
- To diminish the water absorption capacity of composite materials, the incorporation of hydrophobic substances or the coating of the composite's outer surface with waterproof materials represents an efficacious methodology. These methodologies serve to diminish the water retention capacity of the porous structure, thereby enhancing the long-term durability and performance of the composite.

REFERENCES

[1] Türkiye İstatistik Kurumu. (2023). *Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları*. https://www.tuik.gov.tr

[2] International Energy Agency (IEA). (2023). *World Energy Outlook 2023*. https://www.iea.org/reports/world-energy-outlook-2023

[3] Enerdata. (2023). *Global Energy Trends 2023: Consolidated Energy Statistics & World Trends*. Research on energy efficiency, CO2 emissions, energy consumption, forecast (enerdata.net)

[4] Türkiye İstatistik Kurumu. (2019). *Enerji ve Tabii Kaynaklar İstatistikleri.* https://data.tuik.gov.tr/Kategori/GetKategori?p=Cevre-ve-Enerji-103

[5] Einarsdóttir, A. K., Dillman, K. J., & Heinonen, J. (2023). Energy consumption and human well-being: A systematic review. *Energies*, *16*(18), 6494.

[6] Türkiye İstatistik Kurumu. (2023). *Sera Gazı Emisyon İstatistikleri 1990-2021*. https://data.tuik.gov.tr/Bulten/Index?p=Sera-Gazi-Emisyon-Istatistikleri-1990-2021-49672&dil=1]

[7] Üçler, M. (2021). İnşaat sektöründe yangına dayanıklı ısı yalıtım panelleri. *Journal of Construction Science*, 10(2), 55-67.

[8] Schwarzkopf, M. J., & Burnard, M. D. (2016). Wood-plastic composites—Performance and environmental impacts. In A. Kutnar & S. S. Muthu (Eds.), *Environmental impacts of traditional and innovative forest-based bioproducts* (pp. 19-43). Springer.

[9] Arslan, M., & Aktaş, M. (2018). İnşaat sektöründe kullanılan yalıtım malzemelerinin ısı ve ses yalıtımı açısından değerlendirilmesi. *Journal of Polytechnic-Politeknik Dergisi*, *21*(2), 299-320. https://doi.org/10.2339/politeknik.407257

[10] Guo, Y., Zhu, S., Chen, Y., & Li, D. (2019). Thermal properties of wood-plastic composites with different compositions. *Materials*, *12*(6), 881. https://www.mdpi.com/1996-1944/12/6/881

[11] Qi, C., Zhang, F., Mu, J., Zhang, Y., & Yu, Z. (2020). Enhanced mechanical and thermal properties of hollow wood composites filled with phase-change

material. *Journal of Cleaner Production, 256,* 120373. https://doi.org/10.1016/j.jclepro.2020.120373

[12] Temiz, H., Maras, M. M., & Kantarcı, F. (2020). Polimer katkılı kompozitlerin mekanik ve yalıtım özelliklerinin incelenmesi. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 8*(2), 1394-1406. https://doi.org/10.29130/dubited.568812

[13] Zhang, L., Chen, Z., Dong, H., Fu, S., Ma, L., & Yang, X. (2021). Wood plastic composites based wood wall's structure and thermal insulation performance. *Journal of Bioresources and Bioproducts, 6*(1), 65-74. https://doi.org/10.1016/j.jobab.2021.01.005

[14] Tian, H., & Tagaya, H. (2007). Preparation, characterization and mechanical properties of the polylactide/perlite and the polylactide/montmorillonite composites. *Journal of Materials Science, 42,* 3244-3250. https://doi.org/10.1007/s10853-006-0230-5

[15] El Makssoudi, A., Abdellaoui, H., El Ouatib, R., & Tahiri, M. (2014, February). Development of composite materials based on expanded perlite and plastic wastes: Mechanic-chemical properties. In *2nd Annual International Conference on Chemistry, Chemical Engineering and Chemical Process (CCECP 2014)* (pp. 38-46).

[16] Atagür, M., Sarikanat, M., Uysalman, T., Polat, O., Elbeyli, I. Y., Seki, Y., & Sever, K. (2018). Mechanical, thermal, and viscoelastic investigations on expanded perlite–filled high-density polyethylene composite. *Journal of Elastomers & Plastics, 50*(8), 747-761. https://doi.org/10.1177/0095244318765045

[17] Uluer, O., Karaağaç, İ., Aktaş, M., Durmuş, G., et al. (2018). Genleştirilmiş perlitin ısı yalıtım teknolojilerinde kullanılabilirliğinin incelenmesi. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 24(1), 36-42.

[18] Altuntaş, E., & Arıkan, A. K. (2022). Odun-plastik kompozit malzemelerde genleştirilmiş perlit kullanımının araştırılması. *Mobilya ve Ahşap Malzeme Araştırmaları Dergisi, 5*(2), 142-154. https://doi.org/10.33725/mamad.1208112

[19] Sombatsompop, N., Taptim, K., Chaochanchaikul, K., Thongpin, C., & Rosarpitak, V. (2008). Improvement of structural and thermal stabilities of PVC and wood/PVC composite by Zn and Pb stearates, and zeolite. *Journal of Macromolecular Science, Part A: Pure and Applied Chemistry, 45*(7), 534-541. https://doi.org/10.1080/10601320802100572

[20] Chaochanchaikul, K., Rosarpitak, V., & Sombatsompop, N. (2011). Structural and thermal stabilizations of PVC and wood/PVC composites by metal stearates and organotin. *BioResources, 6*(3), 3115-3131. https://doi.org/10.15376/biores.6.3.3115-3131

[21] Jeamtrakull, S., Kositchaiyong, A., Markpin, T., Rosarpitak, V., & Sombatsompop, N. (2012). Effects of wood constituents and content, and glass fiber reinforcement on wear behavior of wood/PVC composites. *Composites Part B: Engineering, 43*(7), 2721-2729. https://doi.org/10.1016/j.compositesb.2012.04.031

[22] Javier, C. S., Sergio, A. R., Roberto, Z. G., & Jorge, D. D. (2015). Optimization of the tensile and flexural strength of a wood-PET composite. *Ingeniería, Investigación y Tecnología, 16*(1), 105-112. https://doi.org/10.1016/S1405-7743(15)72111-6

[23] Krause, K. C., Sauerbier, P., Koddenberg, T., & Krause, A. (2018). Utilization of recycled material sources for wood-polypropylene composites: Effect on internal composite structure, particle characteristics and physico-mechanical properties. *Fibers, 6*(4), 86. https://doi.org/10.3390/fib6040086

[24] Beygi, M., Khorasani, S. N., Kamalian, P., Najafi, M., & Khalili, S. (2022). Mechanical and thermal expansion properties of wood-PVC/LDPE nanocomposite. *Fibers and Polymers, 23*(7), 1975-1982. https://doi.org/10.1007/s12221-022-4821-9

[25] Mohamed, S. B., Rashid, R. A., Muhamad, M., Ismail, J. (2019). Composite materials and types of machining. In *Down milling trimming process optimization for carbon fiber-reinforced plastic* (pp. 1-14). Springer. https://doi.org/10.1007/978-981-13-1804-7_1

[26] Qin, Q. H. (2015). Introduction to the composite and its toughening mechanisms. In *Toughening mechanisms in composite materials* (pp. 1-32). Woodhead Publishing. https://doi.org/10.1016/B978-1-78242-279-2.00001-9

[27] Sapuan, S. M. (2017). Materials selection for composites: concurrent engineering perspective. In *Composite Materials* (pp. 209-271). Springer.

[28] Varvani-Farahani, A. (2010). Composite materials: Characterization, fabrication, and application—research challenges and directions. *Applied Composite Materials, 17*, 63-67. https://doi.org/10.1007/s10443-009-9107-5

[29] Dawoud, M. M., & Saleh, H. M. (2018). Introductory chapter: Background on composite materials. In *Characterizations of Some Composite Materials*. IntechOpen. http://dx.doi.org/10.5772/intechopen.73357

[30] Kubásek, J., Dvorský, D., Čapek, J., Pinc, J., & Vojtěch, D. (2019). Zn-Mg biodegradable composite: Novel material with tailored mechanical and corrosion properties. *Materials, 12*(23), 3930. https://doi.org/10.3390/ma12233930

[31] Aydın, H. Y., & Altun, S. (2020). Odun kökenli malzemelerin takviyesi ile oluşturulan polilaktik asit matrisli kompozitler. *Bartın Orman Fakültesi Dergisi, 22*(3), 1061-1076. https://doi.org/10.24011/barofd.744585

[32] Malaki, M., Xu, W., Kasar, A. K., Menezes, P. L., Dieringa, H., Varma, R. S., & Gupta, M. (2019). Advanced metal matrix nanocomposites. *Metals, 9*(3), 330. https://doi.org/10.3390/met9030330

[33] Güler, Ö., & Bağcı, N. (2020). A short review on mechanical properties of graphene reinforced metal matrix composites. *Journal of Materials Research and Technology, 9*(3), 6808-6833. https://doi.org/10.1016/j.jmrt.2020.01.077

[34] Tosun, G., & Kurt, M. (2020). SiC takviyeli Al-Mg kompozitlerin yoğunluğunun ve mikroyapısının incelenmesi. *Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 9*(1), 589-597. https://doi.org/10.28948/ngumuh.595774

[35] Anamika, C. R. (2021). Current advances in the nanofiber (NF) based polymer composites. *Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12*(6), 07-22.

[36] Uslu, E., Gavgali, M., Erdal, M. O., Yazman, Ş., & Gemi, L. (2021). Determination of mechanical properties of polymer matrix composites reinforced with electrospinning N66, PAN, PVA and PVC nanofibers: A comparative study. *Materials Today Communications, 26*, 101939. https://doi.org/10.1016/j.mtcomm.2020.101939

[37] Callister Jr, W. D., Rethwisch, D. G., Blicblau, A., Bruggeman, K., Cortie, M., Long, J., & Mitchell, R. (2007). *Materials science and engineering: An introduction* (7th ed.). John Wiley & Sons.

[38] Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibres. *Progress in Polymer Science, 24*(2), 221-274. https://doi.org/10.1016/S0079-6700(98)00018-5

[39] Clemons, C. (2002). Wood-plastic composites in the United States: The interfacing of two industries. *Forest Products Journal, 52*(6), 10-17. ISSN: 0015-7473.

[40] Ünal, H., & Yetgin, S. H. (2022). Yüksek hız ve basınç şartlarında çalışan yüksek performanslı polietereterketon termoplastik polimerinin aşınma ve sürtünme davranışlarının belirlenmesi. *Mühendislik Bilimleri ve Tasarım Dergisi, 10*(2), 392-401. https://doi.org/10.21923/jesd.839905

[41] Özdemir, F. (2021). Perlit kullanımı ile odun plastik kompozitlerin fiziksel, mekanik ve yüzey özelliklerindeki değişimlerin belirlenmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi, 24*(1), 15-23.

[42] Avcı, E. (2012). Ahşap plastik kompozitlerin kullanım performansları üzerine araştırmalar (Doctoral dissertation, Doktora Tezi, İÜ Fen Bilimleri Enstitüsü, İstanbul).

[43] Orjin Kompozit. (n.d.). Kompozit cephe kaplama [Photograph]. https://www.orjinkompozit.com.tr/hizmet/kompozit-cephe-kaplama/

[44] Wilczyński, K., Buziak, K., Wilczyński, K. J., Lewandowski, A., & Nastaj, A. (2018). Computer modeling for single-screw extrusion of wood–plastic composites. *Polymers, 10*(3), 295. https://doi.org/10.3390/polym10030295

[45] Demirci, A. (2010). Plastik ekstrüderlerinde ısıtma-soğutma proseslerinin incelenmesi (Doctoral dissertation, Yüksek Lisans Tezi, Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul, 10-12).

[46] Behravesh, A. H., Zohdi Aghdam, A., & Soury, E. (2010). Experimental investigation of injection molding of wood/plastics composites. *Journal of Reinforced Plastics and Composites, 29*(3), 456-465. https://doi.org/10.1177/0731684408099406

[47] Matthews, S., Tanninen, P., Toghyani, A., Leminen, V., & Varis, J. (2022). Numerical evaluation of press forming parameters and mould geometry in wood plastic composite (WPC) products. *Key Engineering Materials, 926*, 1268-1275. https://doi.org/10.4028/p-0rrs28

[48] Lv, Y., Liu, Y., & Jing, W. (2022, April 26). Continuous flat pressing of MDF quality control model framework and collaborative programming approach based on wood fiber hot pressing mechanism. *Frontiers in Plant Science, 13*, 851219. https://doi.org/10.3389/fpls.2022.851219

[49] Rowell, R. M., & Rowell, J. (1996). *Paper and composites from agro-based resources*. CRC Press.

[50] Ugoeze, K. C., Amogu, E. O., Oluigbo, K. E., & Nwachukwu, N. (2021). Environmental and public health impacts of plastic wastes due to healthcare and food products packages: A review. *Journal of Environmental Science and Public Health, 5*(1), 1-31.

[51] Parker, L. (2018). Fast facts about plastic pollution. *National Geographic, 20*.

[52] Ciriminna, R., & Pagliaro, M. (2020). Biodegradable and compostable plastics: A critical perspective on the dawn of their global adoption. *ChemistryOpen, 9*(1), 8-13. https://doi.org/10.1002/open.201900272

[53] Şahin, Y. (2000). *Kompozit malzemelere giriş*. Gazi Kitabevi.

[54] Rowell, R. M. (2006). Advances and challenges of wood polymer composites. In *Proceedings of the 8th Pacific Rim Bio-Based Composites Symposium* (Vol. 15, pp. 2-11). Kyoto, Japan: BioComposites Group.

[55] PAGEV. (2023). *Türkiye Plastik Sektör İzleme Raporu 2023/3*. İstanbul: PAGEV. https://www.pagev.org/raporlar/turkiye-plastik-sektoru-2023-raporu

[56] Plastics Europe. (2023). Plastics – the Facts 2023: An analysis of European plastics production, demand and waste data. Brussels: Plastics Europe. https://www.plasticseurope.org/plastics-facts-2023

[57] Akyüz, Ö. F. (1999). Plastikler ve plastik enjeksiyon teknolojisine giriş. Pagyay.

[58] Fried, J. R. (1995). Polymer science and technology. Prentice Hall.

[59] Guo, Q. (Ed.). (2017). Thermosets: structure, properties, and applications. Woodhead Publishing.

[60] Ramezani, M., & Ripin, Z. M. (2012). Characteristics of elastomer materials. In M. Ramezani & Z. M. Ripin (Eds.), *Rubber-pad forming processes: Technology and applications* (pp. 43-64). Woodhead Publishing. https://doi.org/10.1533/9780857095497.43

[61] Peters, E. N. (2005). Plastics: information and properties of polymeric materials. *Mechanical Engineers' Handbook: Materials and Mechanical Design, 1*, 335-379.

[62] Borisova, O. V., Maksimkin, A. V., Dayyoub, T., Larionov, D. I., & Telyshev, D. V. (2023, June 20). Sustainable elastomers for actuators: "Green" synthetic approaches and material properties. *Polymers, 15*(12), 2755. https://doi.org/10.3390/polym15122755

[63] McMillin, C. R. (2006, July 1). Biomedical applications of rubbers and elastomers. *Rubber Chemistry and Technology*, *79*(3), 500-519. https://doi.org/10.5254/1.3547948

[64] Raji, M., Nekhlaoui, S., El Hassani, I. E. E. A., Essassi, E. M., Essabir, H., Rodrigue, D., & Bouhfid, R. (2019). Utilization of volcanic amorphous aluminosilicate rocks (perlite) as alternative materials in lightweight composites. *Composites Part B: Engineering*, *165*, 47-54. https://doi.org/10.1016/j.compositesb.2018.11.098

[65] KIRIMER, H. (1976). PERLİT. *Scientific Mining Journal*, *15*(6), 37-44.

[66] Orhun, O. (1969). Perlit. *Scientific Mining Journal*, *8*(4), 213-222.

[67] Turanlı, L., & Dernek, C. (2022). The use of perlite in cement and concrete systems in the world and Turkey. *Sürdürülebilir Mühendislik Uygulamaları ve Teknolojik Gelişmeler Dergisi*, *4*(2), 88-97. https://doi.org/10.51764/smutgd.987973

[68] Skubic, B., Lakner, M., & Plazl, I. (2013). Sintering behavior of expanded perlite thermal insulation board: modeling and experiments. *Industrial & Engineering Chemistry Research*, *52*(30), 10244-10249. https://doi.org/10.1021/ie400196z

[69] Atagür, M., Sarikanat, M., Uysalman, T., Polat, O., Elbeyli, I. Y., Seki, Y., & Sever, K. (2018). Mechanical, thermal, and viscoelastic investigations on expanded perlite–filled high-density polyethylene composite. *Journal of Elastomers & Plastics*, *50*(8), 747-761. https://doi.org/10.1177/0095244318765045

[70] Balo, F., Ucar, A., & Yucel, H. L. (2010). Development of the insulation materials from coal fly ash, perlite, clay and linseed oil. *Ceramics-Silikaty*, *54*(2), 182-191

[71] Akcay, H., Kilinc, S., & Karakaş, R. (1998). Preparation of a chromatographic solid support on the basis of perlite, and separation of uranium on a tributyl-phosphate-loaded perlite column. *Separation Science and Technology*, *33*(13), 2025-2037. https://doi.org/10.1080/01496399808545044

[72] Öncül, M. K. (1976). Türkiye Perlit Endüstrisi. *Scientific Mining Journal*, *15*(1), 35-43.

[73] United States Geological Survey (USGS). (2021). Perlite statistics and information. *U.S. Geological Survey*. Retrieved from

https://www.usgs.gov/centers/national-minerals-information-center/perlite-statistics-and-information

[74] Faruk, O., & Bledzki, A. K. (2011). Wood plastic composite: present and future. *Wiley Encyclopedia of Composites*, 1-20. https://doi.org/10.1002/9781118097298.weoc264

[75] Qiang, T., Yu, D., Zhang, A., Gao, H., Li, Z., Liu, Z., ... & Han, Z. (2014). Life cycle assessment on polylactide-based wood plastic composites toughened with polyhydroxyalkanoates. *Journal of Cleaner Production, 66*, 139-145. https://doi.org/10.1016/j.jclepro.2013.11.074

[76] Pillai, C. K. S., Prasad, V. S., Sudha, J. D., Bera, S. C., & Menon, A. R. R. (1990). Polymeric resins from renewable resources. II. Synthesis and characterization of flame-retardant prepolymers from cardanol. *Journal of Applied Polymer Science, 41*(9-10), 2487-2501. https://doi.org/10.1002/app.1990.070410947

[77] Khan, S. M., Gull, N., Khan, R. U., & Butt, M. T. Z. (2022). Polyvinylchloride (PVC): Structure and properties relationship. In Polyvinylchloride-based Blends: Preparation, Characterization and Applications (pp. 19-47). https://doi.org/10.1007/978-3-030-78455-3_2

[78] Shmulsky, R., & Jones, P. D. (2019). *Forest products and wood science: An introduction* (7th ed.). Wiley-Blackwell.

[79] Hunt, D. (2012). Properties of wood in the conservation of historical wooden artifacts. *Journal of Cultural Heritage, 13*(3), S10-S15. https://doi.org/10.1016/j.culher.2012.03.014

[80] Silva, A., Gartner, B. L., & Morrell, J. J. (2007). Towards the development of accelerated methods for assessing the durability of wood plastic composites. *Journal of Testing and Evaluation, 35*(2), 203-210. https://doi.org/10.1520/JTE100168

[81] Mitaľová, Z., Mitaľ, D., & Berladir, K. (2024). A concise review of the components and properties of wood–plastic composites. *Polymers*, *16*(11), 1556. https://doi.org/10.3390/polym16111556

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname **:** Ahmet KILIÇ

EDUCATION

		School Name, District, City	**Graduation Year**
High School	:	Gaziantep Türk Telekom Lisesi, GAZİANTEP	2012
University	:	Gaziantep Üniversitesi, Şehitkamil, GAZİANTEP	2021
M.S.c.	:	Gaziantep Üniversitesi, Şehitkamil, GAZİANTEP	2024

WORK EXPERIENCE

Year	**Organization**	**Position**
2020-2022	Mazıcıoğlu Yapı ve Mühendislik	Mechanical Engineer
2022-2024	Green Mühendsilik ve Danışmanlık	Mechanical Engineer