



Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Development of Waste Based Composite for Footwear Production Applications

Master's Final Degree Project

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Kaunas, 2023



Kaunas University of Technology
Faculty of Mechanical Engineering and Design

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Industrial Engineering and Management (6211EX018)

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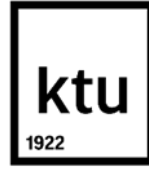
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Development of Waste Based Composite for Footwear Production Applications

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Task of the Master's final degree project

Given to the student – Mohamed Akbar Rabic Mohamed

1. Title of the Project

Development of Waste Based Composite for Footwear Production Applications

(In English)

Atliekų pagrindu pagaminto kompozito, skirto avalynės pramonei, kūrimas

(In Lithuanian)

2. Hypothesis

Rubber waste can be used as an alternative materials in the production of orthopaedic devices

3. Aim and Tasks of the Project

Aim: to obtain a new waste-based composite material sheets for footwear production applications that can replace traditional insole materials.

Tasks:

1. To evaluate the most suitable waste materials and its optimal ratio for the creation of the composite
2. To select binders of the composite preparation
3. To determine the influence of the composition on the structure, physical and mechanical properties of composite
4. To compare the properties of obtained composite with traditional insole materials
5. To determine the impact of the use of production waste on the cost of composite raw materials

4. Initial Data of the Project

N/A

5. Main Requirements and Conditions

To perform tensile tests of composite materials in accordance with LST EN 12568:2010 and hardness in accordance with ISO 7619-1 standard methodology.

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Summary

Nowadays environmental requirements keep on increasing, specifically more related to waste produced from production. Manufacturing companies should take measures in recycling or use their materials for secondary purpose. Furthermore, well known recycling here and later methods exists for standard materials like wood and thermoplastic polymers. This is not the case for thermoset polymers, which are used extensively, especially in the footwear industry. At present the most widely used method of disposal of the thermosets polymers are landfills and incineration, which results in high air, land, and water pollution. These pollutions greatly affect the environment. The aim of the project is to obtain a new waste based composite material sheets for the footwear production applications that can replace traditional insole materials. This obtained material should be cost effective in comparison to the existing material. Ethylene vinyl acetate copolymer. beech wood waste generated in the manufacturing of footwear were used for the fabrication of the composite. Lamination design of three-layered composite was also studied to investigate the effects of the layer thickness and waste content and binder on the structure, water absorption and mechanical properties of the composites. Composites were prepared using two kinds of binding materials polyamide and expanded polystyrene. It was found that the waste obtained from the manufacturing of shoe parts such as last and insole milling can be used to produce composite sheet with good physical and mechanical properties, i.e. similar or better to the existing insole materials, such as cardboard or cork. The mechanical properties of three-layered composite decreased with increasing beech wood content. Composites containing binder materials have significantly higher values of strength and resistance of the flexing in comparison to composites without binders. As a final part of this project, impact of the use of production waste on the cost of composite raw materials was determined.

Rabic Mohamed Mohamed Akbar. Atliekų pagrindu pagaminto kompozito, skirto avalynės pramonei, kūrimas. Magistro baigiamasis projektas, vadovė doc. Kristina Žukienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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Reikšminiai žodžiai: avalynė, pakartotinis naudojimas, reaktoplastikai, mediena, kompozitai.

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Santrauka

Šiais laikais aplinkosaugos reikalavimai nuolat auga, ypač susiję su gamybos atliekomis. Gamybos įmonės turėtų imtis priemonių perdirbdamos šias medžiagas arba naudoti šias medžiagas antrinei paskirčiai. Yra gerai žinomi standartinių medžiagų, tokių kaip mediena ir termoplastiniai polimerai, perdirbimo metodai. Tai netaikoma termoreaktingiems polimerams, kurie plačiai naudojami, ypač avalynės pramonėje. Šiuo metu plačiausiai naudojamas termoreaktingų polimerų šalinimo būdas yra sąvartynai ir deginimas, todėl labai teršama oras, žemė ir vanduo. Ši tarša labai veikia aplinką. Projekto tikslas – gauti naujus atliekų pagrindu pagamintus kompozitinių medžiagų lakštus, skirtus avalynės gamybai, galinčius pakeisti tradicines vidpadžių medžiagas. Gautas kompozitas turėtų būti ekonomiškai efektyvus, palyginti su šiuo metu naudojamomis medžiagomis. Darbe kompozito gamybai panaudotas etileno vinilacetato kopolimeras ir buko medienos atliekos, susidaranti gaminant avalynę. Taip pat buvo tiriamas trijų sluoksnių kompozito laminato gavimo galimybė, siekiant ištirti sluoksnio storio, atliekų kiekio ir rišiklio įtaką kompozitų lenkimo ir stiprumo savybėms. Kompozitai buvo ruošiami naudojant dviejų rūšių rišamąsias medžiagas – poliamidą ir putų polistireną. Nustatyta, kad atliekos, gautos gaminant avalynės detales, tokias kaip kurpalis ir vidpadis frezavimo būdu, gali būti panaudotos geromis fizinėmis ir mechaninėmis savybėmis pasižyminčio kompozitinio laminato gamybai. Nustatyta, kad trislauksnio kompozito laminato mechaninės savybės padidėjo didėjant buko medienos kiekiui. Kompozitai, kurių sudėtyje yra rišamųjų medžiagų, pasižymi žymiai didesnėmis stiprumo ir atsparumo lenkimui vertėmis, palyginti su kompozitais be rišamųjų medžiagų. Baigiamojoje šio projekto dalyje nustatytas gamybos atliekų panaudojimo poveikis žaliavų kompozitams savikainai.

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Introduction

Footwears become one of the important fundamental basic accessories of life, which we cannot ignore. Day by day production and usage of footwears are increasing what eventually brings us more footwear waste. The waste generation problem in the footwears has outstretched to the position where we are incapable to pass over it anymore. Manufacture of footwear process will result in the release of huge quantity of carbon dioxide. Footwears that are made of synthetic materials will require many years to become compost. From the second of manufacture as late as their termination of life, they affect and damage the health of our environment. Not only this will negatively affect our environment, but also affecting negatively by the poisonous chemicals released by the footwears. Footwear waste will fetch up in dumping ground. It pollutes the environmental surroundings by discharging the harmful chemicals towards the ground and porewater. Pigments emancipate heavy metals while soles degrade into chemicals such as polyurethane. Incineration of footwears is also not the forever solution because it emits a huge quantity of chemicals into the environment resulting in air pollution. Such issues as air and water pollution causing chemicals are one of the main components that are causing cancer. Majority of the impact caused by the footwears are mainly from the production and gaining unprocessed materials. Non-renewable resources are mainly used to energise the industries, which are producing footwears. Igniting these combustible fuels emits carbon dioxide and other harmful greenhouse gases, which mix with the environment. The carbon dioxide and greenhouse gases are one of the major reasons for global warming. After the production of footwears, these are distributed all over the world, which results in the usage of transport, and it usually increases the pollution as well. We are not capable to eliminate all the issues in usage of footwears. But we can eliminate the major issues by introducing sustainable production in footwears. Life standards can be increased by implementing sustainability, secure the habitat and conserve the natural resources for upcoming age groups. It can be reduced by using the recycled raw materials for the production of footwears. These recycled raw materials will reduce the impact of the damage caused by gaining of unprocessed raw materials and it will pave the path to use the footwears in afterlife. Following to the reduction of impact, it also paves the industry to reduce the cost used for the production of footwears, which results in beneficial of economic way.

The aim of this work is to obtain a new waste-based composite material sheets for footwear production applications that can replace traditional insole materials.

Tasks:

1. To evaluate the most suitable waste materials and its optimal ratio for the creation of the composite
2. To select binders of the composite preparation
3. To determine the influence of the composition on the structure, physical and mechanical properties of composite
4. To compare the properties of obtained composite with traditional insole materials
5. To determine the impact of the use of production waste on the cost of composite raw materials.

1. Formation of footwear production waste and possibilities of their reuse

Footwears are one of the common products, which are used by almost all the people of the world. Day by day production of footwears are increasing. New methods, new designs arise but recycling of the waste generated during their production is not yet grown. During the milling operation of last and insoles, a huge amount of footwear waste are produced. Generally, these wastes are thrown away or dumped in landfills.

1.1. Footwear production waste

In the year 2021, almost 22.2 billion pairs of shoes are being manufactured across the world. 20.5 billion pairs in 2020, 24.3 billion pairs in 2019, 24.2 billion pairs in 2018, 23.5 billion pairs in 2017 [1]. As we can see year by year, the production of footwears keep on increasing which eventually generates huge amount of waste.

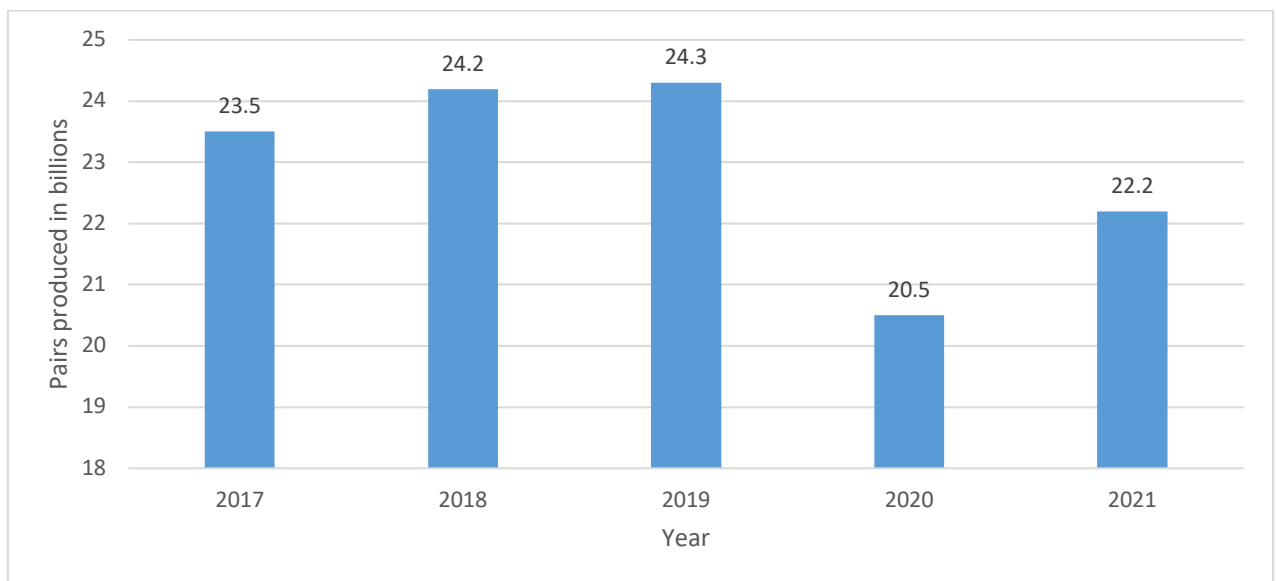


Fig. 1. Footwear production by year

There was a reduction of footwear production in the year 2020 because of COVID-19 Pandemic which affects the production of footwear. In the year 2021 the production of footwear starts to climb due to relaxation in pandemic and it keeps increasing, in the upcoming years the production of footwears will keep on increase.

Footwear manufacturing is kind of exhaustive business involving lot of effort which cannot be automated fully. It needs artisanship in every stage of manufacture. Excess of hundred actions is needed for producing a set of footwear. With the help of modern machines, the time required for the manufacturing has been decreased greatly and the procedures are accomplished independently. Based on the category and the substances used, the production procedure may differ [2]. Many different varieties are footwears are being made in order to fulfil the customers satisfaction due to developing fashion trends and needs.

The footwear production factories are one of the most assorted production sector in which it implements a different quality, quantity and parameter of materials to produce the outcomes varying from various categories and trends of footwears to specific particular footwears. Leather, rubber, wood, clothing materials are the fundamental primary raw materials that are normally used in the

manufacture of footwear. These varieties are different in many perspectives such as visualization, mechanical qualities, assistance life, various medical purpose and reusing, recycling and healing choices during their end life. Primary raw material election on the manufacture of footwear actions greatly impacts the both usage life of shoes as well its purpose after its end life.

In the recent time periods, the footwear manufacturing companies had put down remarkable actions in developing efficiency of materials and usage of energy. In balancing with the actions taken, the reuse and recycle of footwears after their end life actions are really low. In actual life most of the footwears that are damaged, used and which their end life has begun are thrown away and dumped in the landfills. Management model for the waste control is more necessary in deciding the various methods for the usage of footwears after their end life. The waste management option encourages to use the materials after end life by several methods such as recycling and reusing. This approach helps to decide the materials how to use depending upon the quality and parameters involved in reusing and recycling [3].

There are different types of waste that are generated from different parts of the footwear such as upper, sole, lower soles, clothing, garments, middle sole, sticking agents, etc. in a data an average of one hundred and thirty four tons of waste per million pairs are generated from the above part of the footwear, one hundred and twenty tons of waste per million pairs are generated from the soles part of the footwear, 4800 kilos of waste per million pairs are generated from the sticking agents and chemicals of footwear and eleven tons of waste per million pairs are generated from the homemade type waste [4].

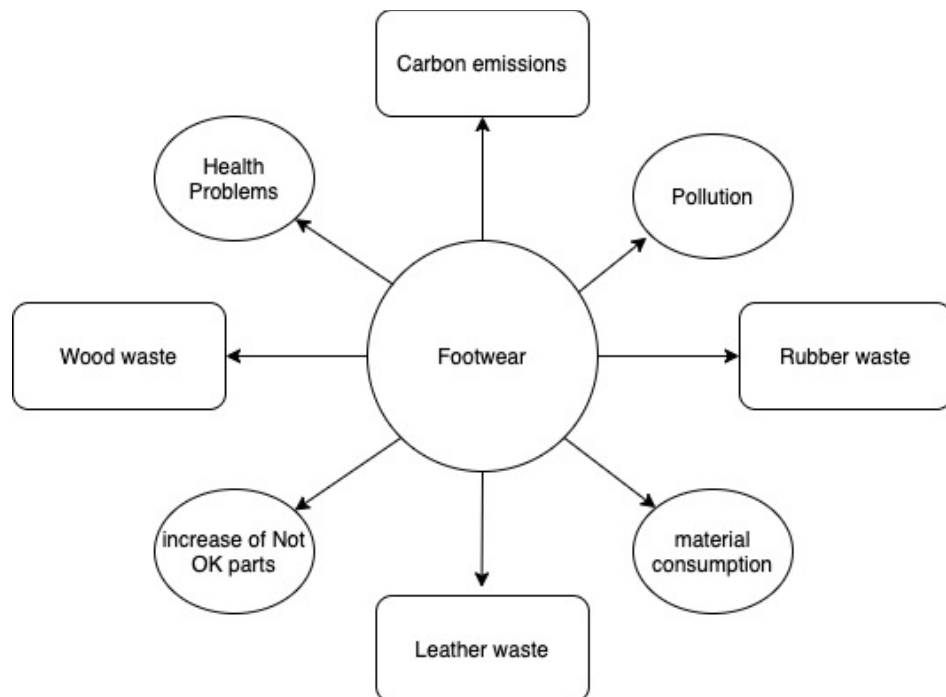


Fig. 2. Issues generated by footwear

According to the data gained, as we can see soles in the footwear are one of the greatest influencers of generating the waste materials. Materials used in the production of soles cannot be degraded easily in which it can last in the dump for a minimum period of thousand years. Physically sole is a part of footwear, which is most, subjected to many stress and impact where it results in easy wear and tear

of soles. After the soles have been damaged, mostly these footwears are considered as life end footwears. The footwear waste generation can be greatly reduced by reusing these footwear soles.

Waste produced from the footwear due to the fabrication of upper part, lining, fabrication of insole, leather part, heels, soling of rubber are in the cutting or milling stage [5]. Majority of the footwear waste are generated during the process of cutting or milling which means, excess of raw materials are being used for the manufacture of footwear. Almost it is impossible to reuse these excess raw materials since they require certain shape and structure to use in footwear. Here an idea of using composites came into way. Since insole is one of the greatest factor for the generation of waste, using composites for insole preparation will pave the path to reuse those excess raw material.

Footwear uses different raw materials for different parts, raw materials including leather, polyurethane, thermoset polymers (rubber), poly vinyl chloride, rubber, adhesives, metals, textiles and fabrics. Considerable amount of thermoset polymers are being used in making footwears [6]. Irreversible hardening of soft solid or liquid is called as thermoset polymers. The process of making thermoset polymers is called as curing. This makes hard to recycle and becomes one of the main reason to dump or thrown away them after their use.

One of the well known method to reduce the extensive raw material wastage is 3D printing. In a data, it shows the cost of making 3D printed insole is more expensive than traditional method of making the insole. Because 3D printing involves scanning, separate raw material, 3D printer, pre processing, post processing, time consuming [7]. 3D printing technology is good at saving materials but the customer demands make them almost impossible to use due to economic factor and time needs.

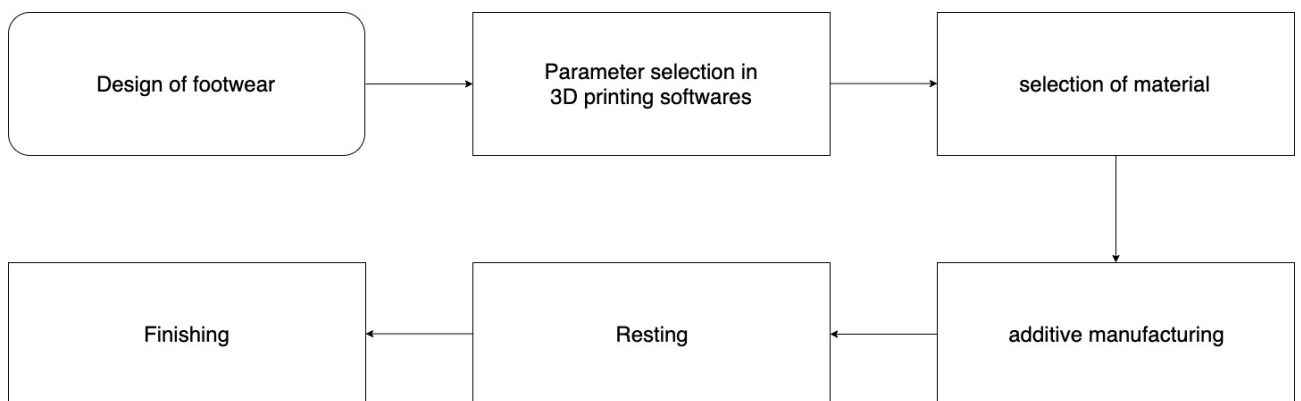


Fig. 3. 3D Printed footwear process

New design trends, huge manufacturing of footwears for various events and activities have initiated as per the customers requirements had made the customers to purchase numerous number of pairs in various times. These activities paves the path to lesser usage time. These activities lead to generation of huge amount of shoe rejection due to high number of production. Usually, these customer waste end life shoes are ignored. Proper measures such as reuse of shoes, recycling of materials, redesigns and sustainability should be considered by the manufacturer to protect the environmental surroundings.

1.2. Recycling methods for thermoset polymers

Due to the long-lasting life and extraordinary properties, thermoset resins are the selection for manufacturers. Because of their insoluble property and infusible elevated density networks, these

thermoset elements are observed to be impractical to recycle or use again. Now a days production and usage of thermoset polymers are increased, eventually increasing the generation of unwanted waste, increased land fills, creating problem at high environmental and economic crisis which lead us to forcefully to make solution to this issue.

Polymer materials that are being produced by the use of process thermosetting is called as thermosetting polymers. In the event of polymer response and cross link the polymer to produce a up to date polymer the polymer material develops molecular weight [8]. Process used in making thermoset polymers is called as curing. This curing technique creates covalent bond in the middle of individual chains that are existing in the polymers. There are few disadvantages in using thermoset polymers, they are non recyclable, non reusable, hard to surface finish, bad thermal conductivity, failure of products happen when used in extended vibrations.

Conventional thermoset polymer material having enduring networks is almost impossible to be restyle, reused or recovered. Dissimilar to the thermoset polymer, freshly evolved vitrimer-type polymers can be reused by restyling due to the covalent adaptable networks [9]. Vitrimer type polymers paves the path to restyle, reuse and recover. This property of cross linked polymer allows the traditional processing procedures such as various moulding techniques including injection, hot press etc.

Thermoset composites can be prepared with the help of polyester and calcium carbonate as the binder. These materials are finely grinded to become powder then it is mixed with the thermoset resins as binder to get tempered in required shape which are used in manufacture of truck body fragments. Different fragments of the truck body contains different ratio of recycled powder. Mechanical and chemical properties of the composite fragments are being analysed to verify for use in body construction. This method of reuse paves the way to reuse the composite produced by waste materials without changing the production activities and without making any effect on the properties of the composites [10].

Thermoset polymers of phenyl maleimide go through the degradation process called as ammonolysis to the grade of oligomeric components that are soluble at normal room temperature. Ammonolysis is the process of establishing amines avail once of aminating factors. While in case different thermoset polymers of bisphenol-A or Melamine will go through the degradation process in critical temperature as 160°C with lengthy time response [11]. Linear polymers are produced by the polyimides that underwent the process of ammonolysis in the temperature of 160°C by the free radical polymers. This reaction generates polymers in resulting of mass distribution in aspect of huge molar mass with oligomeric fraction. this reaction paves the path to reuse the thermoset polymers to recycle by the use of ammonia.

Epoxy thermoset polymers of biological based can be created from the hardwood lignin that are being depolymerized native. These hydrogenolysis oil lignin generates the epoxy thermoset polymers that are completely recyclable. Depolymerized lignin oils can be extracted by the reaction of eucalyptus nitens and eucalyptus saligna wood with specific condition of Pd-catalysed mild hydrogenolysis. Another reaction of this lignin oils in the mixture with epichlorohydrin generates the thermoset polymer which are biodegradable [12]. Thermoset polymers are created by chemical reaction. That makes the environmental damage and hard to recycle or reuse it. But now bio based epoxy thermoset polymers can be created with the use of this method.

Preparation of nanoporous thermosetting polymer proposes the recycling option. Fuel cells, sensors can be made with nanoporous thermosetting polymer. After use, they can be reused. Using solvents, nanoporous thermosetting polymer are usually made through the process of free radical mechanisms during the process of polymerization [13].

Thermosetting resins can be prepared through vegetable oils with the process of polymerization of monomers and they can be made through the crosslinking process with the linear systems [14]. Now a days many alternative components are being made which are bio degradable in order to maintain sustainability and to improve the environmental protection. In the past few years, biologically based materials are being created due to the ability to reuse and to maintain sustainability. These bio degradable thermosetting polymer have high thermal stability than usual thermoplastics.

Shape memory materials are one of the excellent property which is highly supportive to recycling. Shape memory property can be influenced in thermosetting polymer too. These shape memory thermosetting polymer have various properties such as fire resistance, good performance, photo rememberable capability [15]. These shape memory property is one of the most needed property in modern world. During electrical accidents, fire accidents these thermosetting polymers make a huge loss of human lives and it's applicable to economic loss too, but these multifunctional property with own healing capacity of thermosetting polymer will make a great change.

Matrix in the thermosetting polymers are being less researched in the reason of their reusing problem and complex matrix. Used thermoset polymers can be used with acrylonitrile butadiene styrene for the approach of rapid tooling. Reinforcement of thermoset can be used with the fusion of thermoplastic matrix for the reusing purpose since recycling of single thermoset polymer matrix is the hard activity. These recycled thermosetting material can be reused by the process of fused deposition modeling[16]. Fused deposition modeling is the type of 3D printing technology in which the material is melt and then deposits on through filaments.

Without the use of catalyst and a simple process, a bio thermoset polymer can be prepared. Cross linkage of glycerol and citric acid and renewable reagents with the process of polymerization reaction that takes place in the temperature surrounding of 90°C -150°C. this reaction takes place in the controlled condition such as temperature, time and ratios [17].

Recycling by the mechanical way is the current used technology that is used mostly in the recycling of thermosets. The process of thermoset recycling deals with the deduction in the amount of waste and it's use due to it's fillers property for the preparation of composites.

1.3. Composites based on waste rubber

One of the most common waste generated from footwears is leather, studies shows that the leather waste are generally produced by chromium tanned leather, and insoles of the shoes. To recycle this waste leather, the leather is recycled with styrene butadiene rubber and acrylonitrile butadiene rubber. The waste leather is made into small fibre of 1mm range. These leather fibres are charged with 10-25 parts phr (per hundred parts of rubber) which results in forming the non reactive composite [18]. These non reactive non hazardous waste composite can be used in making of soles, or other parts of footwear that is non reactive to the skin of the human body.

Cement cannot be used individually, to activate the cement to be strong, it needs to be mixed with components such as sand and gravels. Here instead of using such components as binders, grinded rubber is being used as a binder. Grinded waste rubber cement composite have matching physical strength and better elastic strength [19]. Generally woods are being used in the construction of houses. But using woods will lead to great deforestation which will affect the nature. Alternative material for building the houses is cement. So this concrete rubber waste composite will be an alternative materials to build homes, which is cheap and posses greater physical properties.

Rubber plastic composite can be made by the process of hot moulding technique. Preparation of rubber plastic composite starts with the grinding of plastic and rubber in to fine particles. They are then mixed and moulded at high temperature in order to melt and combine together to form a composite. This composite is being used in constructions, building homes, fillers, reinforcing agents [20]. This method of making composite will be more sustainable since the plastic which is non biodegradable in nature is being reused to make another useful application.

Turbostratic flash graphene can be produced from rubber waste. Normal traditional way to produce the graphene is long time process, addition to time consuming it is energy consuming and solvent intensive process. These circumstances make the graphene production to limit the mass production. The Turbostratic flash graphene can be produced in less time from rubber waste. The process takes place in controlled condition such as voltage and time [21]. This Turbostratic flash graphene can be easily illustrated and sprinkled. This material can be used as a cement aggregate resulting in the high compressive strength.

Considerable grade carbon can be produced from the composite of rubber waste thermolysis products. Fractionation of the thermolysis products resulting in extraction of gasoline and diesel fuels. Ash generated by the burning of this rubber waste thermolysis product composite contains components such as iron, zinc, and silicon. This ash can be used as the raw material for the manufacturing of zinc oxide [22].

Rubber waste can be used in the production of fuels and additives by the process of pyrolysis. Pyrolysis is the process of degrading the materials at high temperatures. In other words, the pyrolysis is defined as the burning of materials in the absence of oxygen at the high temperature of 500 °C [23]. Now a days transportation is growing due to the modern environment and manufacturing of more products. All these transportations use rubber tyres. After it's life they are thrown away as waste which leads to dump fills. Generation of fuel from the waste rubber will act as an alternative to reuse the waste rubbers.

Rubber can be treated with kerosene with various heat environment with various ratio which are subjected with concentrated carbonic acid and neutral water to produce isobutanol. In this reaction fractional distillation method is used to separate the alcohol and water obtained. This isobutanol is used to increase the octane number in the gasoline. The separated alcohol, water and acid with kerosene is heated with the container consists of sodium tetramer [24]. This high-octane gasoline is efficient in turbocharging and have high compression ratio.

High number of wastes are being produced from rubber tires. Rubbers are flammable, which eventually creates air pollution. This rubber tires can be used to produce rubber coke. The manufacture of rubber coke is obtained by the process of pyrolysis. This rubber coke is utilized for

the clearing of waste waters, it also can be used in the production of blast furnace coke by acting as charge to the coal materials [25].

Waste rubbers can be recycled by separating the 3D structure. This breakage of three-dimensional structure can be obtained by the process of devulcanization. Devulcanization is the process of breaking the chemical bond of sulfur-sulfur and carbon-sulfur present in the rubber. This process allows to break the backend network without decomposing or destroying the material. this devulcanized rubber can be used to produce new materials without decreasing the mechanical and physical properties by mixing with virgin rubber [26].

Rubber waste and plastic waste composites can be used in construction of road. This rubber plastic waste composite act as an alternative material for the road construction without any difference in their properties. The composite can be prepared by mixing plastic waste, fly ash and rubber waste. This rubber waste is changed to bitumen mix to improve their binding property, density, water resistance, stiffness, elasticity, and stability. This act of composite helps to reduce the rubber waste from the environment resulting in reduction of pollution to the surroundings [27].

Vulcanized rubber can be used as aggregate in cement composites after the ultraviolet treatment. Grinded rubber after physiochemical treatment mixed with cement to form composite have properties increased such as acoustic, thermal, and mechanical. Lesser the quantity of rubber in the composites, greater it's mechanical strength and dynamic modulus. Higher the quantity of rubber, higher the elastic strength. So, the ratio varies depends on the usage of composites [28]. Rubber is hydrophobic in nature which allows us to get water resistant mixture, due to the ductility of nature the rubber cement composite helps to decrease the load effect.

Another method of preparing plastic wood composite is done by the process of injection moulding process. Thermoplastics polypropylene, low density polyethylene, wood powder, maleic anhydride polypropylene have been researched in recent research. As a result of research, the composite mixture with polypropylene and low density polyethylene have high mechanical properties than separate component of polypropylene and low density polyethylene [29].

1.4. Properties and production processes of waste wood and rubber composites

There are generally four different types of composites,

1. Polymer matrix composites
2. Metal matrix composites
3. Ceramic matrix composites

Each composites have different procedure to prepare and have different properties [30]. Here we are focusing mainly on polymer matrix composites.

Common method for production for the rubber wood composite is hot pressing technique. In this method, rubber and wood are pre heated in order to remove the excess moisture present in the materials. This can be either achieved by either heating in oven or treated by ultra violet rays. After the treatment, they are mixed with binders then made into specific form, then the mixture is hot compressed by compressing machine for several minutes with high temperature. During this process the materials get heated, binders get activated forming a solid composite. After hot compressing, they are cooled down in room temperature [31].

The materials can be with different ratios depending upon the requirement of composite. Higher the rubber quantity greater it's elasticity, resistant to water and greater strength. In some cases, instead of binders, rubbers can also be used as binders. In this case, rubber particles act as the adhesives for composites. This method of composite preparation is also done by hot pressing technique. In this case the composite preparation takes place under 160°C with the pressure of 15 MPa. During this hot compression process, the rubber got melted and bonded with the wood particles resulting in the formation of rubber wood composite [32].

The wood waste and rubber composite can be created through vacuum and pressure process. At first the moisture is removed from the material by preheating and air from the material is removed by vacuum. Then natural rubber latex is added to the wood particle. Which in then it is been subjected to 6 bars of pressure for about 2 hours. This situation are fair enough to embed the maximum quantities of latex in the materials. The excess pressure in vacuum surrounding makes the latex to infiltrate into the wood materials which gives the bonding to make the composite [33].

Higher the rubber and higher the binder is greater it is hardness. Higher the wood quantity higher the modulus strength and higher the tensile strength. Higher the rubber content, greater it is deformation. So, the ratio of rubber and wood can be modified depending on the purpose of composite.

A two-roll mill was used to create sheets of devulcanized waste rubber from waste rubber (WR) powder that had been vulcanized and introduced in a variety of curative ratios (DWR). Thermoplastic elastomers (TPE) were created by mixing either WR or the created DWR in a set ratio of 70 rubber to 30 expanded polystyrenes (EPS) in the absence or presence of gamma irradiation at 100 kGy. A coupling agent of 1 wt% of maleic anhydride in relation to rubber was utilized [34].

1.4.1. Composites formation parameters and processes

Summary of composition formation parameters is presented in the Table 1.

Table 1. Summary of composition formation parameters

Material	Rubber (plastic)/ wood flour ratio	Temperature, °C	Time, min	Pressure, MPa	Binder %	Binder	Literature
Rubber, wood	6:4	190	5	4	2	EPS	35
Rubber, wood	7:3	190	5	4	2	EPS	35
Rubber, wood	5:5	190	5	4	2	EPS	35
Rubber, wood	6:4	185	7	4	7.5	polypropylene	36
Rubber, wood	7:3	185	7	4	7.5	polypropylene	36
Rubber, wood	5:5	185	7	4	7.5	polypropylene	36

Composite made by multilayer parameters have increased mechanical properties. These increased mechanical properties of composites are used in various products that have different applications. These types of composites are made by hot pressing method. The purpose of making composites by this method is to use the applications of each layer. This method of preparing composites have many advantages including flextual loading parameters [37].

2. Experimental analysis to develop Waste Based Composite for Footwear Production Applications

Finding the process that can be used in the manufacture of footwear part at a reasonable price and in accordance with circular economy principles is one of the parts of this project. The following steps and techniques are used to create a composite of rubber and wood to initiate this research.

2.1. Materials utilized to prepare composites

In the research, expanded ethylene vinyl acetate (EVA) crumbs and beech flour waste from the footwear industry were combined in a variety of densities and hardnesses. PA 2000 polyamide powder waste (PA) generated during the process of selective layer sintering (SLS) and expanded polystyrene (EPS) were used as binders during the formation of composites.

Commercial insole materials like cork, Texon, and Bartoli and non-woven sheet Biagoli were used for comparisonal analysis. Cardboard for insoles is usually produced by multi-layer molding. When forming the sheet, the fibers are oriented in the direction of the sheet. As a result, the insoles made from them have a high flexibility in the transverse direction, which ensures a good conformity of the insole and the flexibility.



Fig. 4. Commercial insole materials

The properties of these materials were given in the Table 2 below.

Table 2. Characteristics of commercial insole materials

Samples	Flexural modulus, MPa	Flexural strength, MPa	Deformation at max, mm	Hardness, Shore A
Texon	534.8	11,32	7.13	86.5
Cork	8.42	0.54	8.96	59
Non – Woven sheet	306.5	5.2	8.7	89
Bartoli	2932.12	31.4	3.5	96

To obtain the similar properties of these materials, EPS and PA were mixed with the wood to enhance anhesion of composite, since the rubber crumbs softens and have good adhesion at high temperatures. Properties of EVA, beech wood and expanded PS and PA are reviewed in the Table 3 below.

Table 3. Characteristics of materials

Material	Features	Uses
EVA L	Hardness = 35-55 Shore A Density = 0.179 -0.255 g/cm ³	In the production of footwear and sports equipment
Beech Wood	Density – 0.710 g/cm ³ Modulus of Elasticity – 14.31 GPa Radial – 5.7% Tangential – 11.6%	In the manufacture of footwear
EPS	Density – 0.011 g/cm ³ Melting point – 200 ⁰ C	Used for packing and insulation
PA	Density – 1.35 g/ cm ³ Melting point – 223 ⁰ C	Used in textiles and carpets

2.1.1. Preparation of composite

In this study, the three-layered rubber/wood/rubber composite is prepared. This type of composite have several advantages including higher flexural strength and high stiffness. The layers are heat compressed and made like sandwich composites. The rubber is used as a skin material and wood is used as a core.

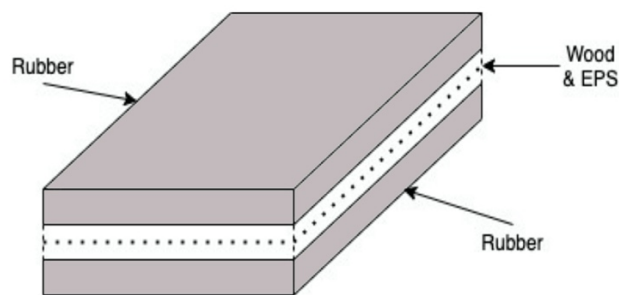


Fig. 5. Layered composite

The method which is used in preparation of composite in this research is laminated composite. The composite is yet to be made in dimension of 280 mm × 140 mm with the use of hot pressing technique. Upper layer of the lamination consists of rubber and middle layer of lamination consists of wood mixed with EPS or PA. Thickness of average insole is 0.4 mm to 0.7 mm, width will be 75 mm and length will be 280 mm [38].

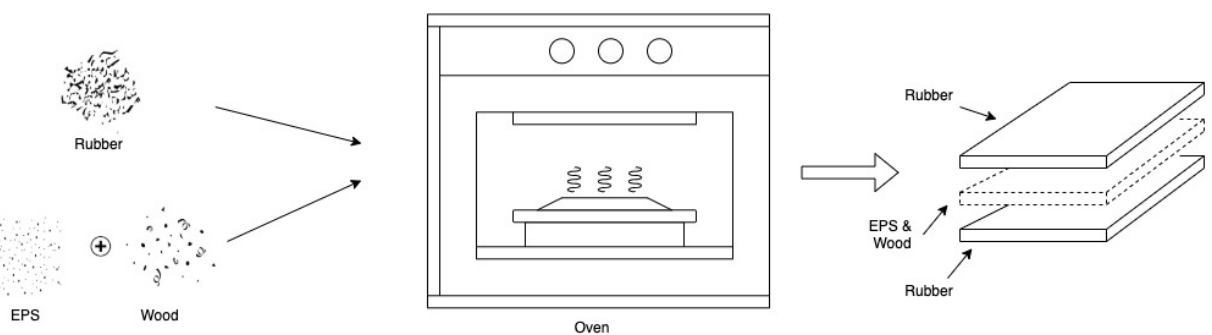


Fig. 6. Preheating and drying process

The required amount of EVA, beech wood powder and EPS or PA waste were weighted. Wood and binder is mixed manually for the time period of 60 seconds. Before the layering, components of

composite were preheated and dried in an oven at the temperature of 130 °C to eliminate the excess water available in the materials. This preheating process takes about the time of 7 min.

After preheating process is done, the materials were fixed in all the layer for formation, it is then patted with wooden block which has smooth surface to make the air to let go of the materials (Fig. 7-12). The layers were made in to required dimensions with the help of mould. The mould was then removed, the layered composite was then kept in laboratory presses Joos-Laboratory-Press LAP 40 (Gottfried Joos Maschinenfabrik GmbH & Co., Germany) which have the compression capacity that can go upto 400 kN.



Fig. 7. Lamination 1 – Rubber



Fig. 8. Lamination 2 – Wood with expanded polystyrene



Fig. 9. Lamination 3 – Rubber



Fig. 10. Patting process



Fig. 11. Composite in the mould



Fig. 12. Manufactured composite

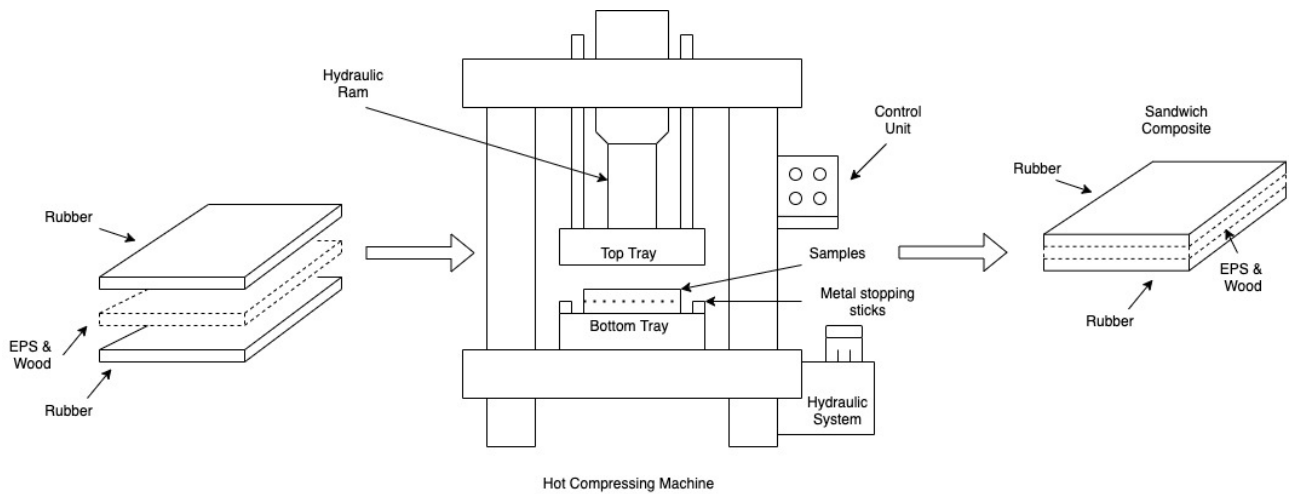


Fig. 13. Composite manufacturing process

The sample was compressed at the force of 134 kN with the pressure of 4 MPa. The compression took place in the temperature of 165°C. The total compression process takes about 7 min. The sample was taken from the machine and then was allowed to reduce the temperature in the room temperature for few minutes.

Two types of binders with different ratios were being used to make the composites. The composition of the samples are shown in the Table 4.

Table 4. Combination used in making the composites

Type of binders	Content of binders %	Composition of the samples Rubber:Wood:Rubber
no	0	4: 2: 4
EPS	10.0	4: 2: 4
EPS	10.0	2: 6: 2
EPS	10.0	0:10:0
EPS	10.0	5:0:5
no	0	2: 6: 2
PA	2.5	4: 2: 4
PA	5.0	4: 2: 4
PA	7.5	2: 6: 2
PA	15.0	2: 6: 2

To perform testing, the prepared samples were cut into pieces with required dimensions.

2.2. Properties estimation

Property estimation was carried with the help of different estimation methods such as hardness estimation, density estimation, tensile strength estimation, three point bending test, water absorption test and statistical analysis. These estimation methods were conducted in the temperature of $25 \pm 3^\circ\text{C}$.

2.2.1. Particle size analysis

The particles size was estimated using the pictures obtained by a transmitted-light microscope Nikon Eclipse E200 (Japan). The average of particles size was calculated with over 20 readings to provide the approximate size result.

2.2.2. Scanning Electron Microscopy

A scanning electron microscope (FEI Quanta 200 FEG, Hillsboro, Oregon, USA) in a low-vacuum mode was used to observe the microstructure of samples.

2.2.3. Hardness estimation

Hardness is found with the help of Shore A durometer HPSA-M instrument which have the standard ISO 7619-1. The HPSA-M have a pointer at the bottom which exactly shows the hardness result needed for the testing. For the hardness ascertainment, the pointer is placed in the place where hardness needs to be measured. The top ring which has spring loaded mechanism is pressured to bottom until the ring reaches the marking showed in the case. Hardness value obtained by this standard method gives exact value with lower errors. Average of ten measurements is used to obtain the final result of hardness in the composites. These ten readings were obtained by testing various places of the sample composites.

2.2.4. Density estimation

The obtained specimens were subjected to determine the weight with a digital instrument KERN EW 4200-2NM in which this instrument have the accuracy of 0.001g. The following formula is used to determine the density of the material.

$$\rho = m / V \quad (1)$$

Where ρ is the density of the material, m is the mass of the material and V is the volume of the material.

2.2.5. Water absorption test

According to the ISO standard 22649:2016 the estimation for the water absorption test was done. To begin this test the sample specimens were slit into shapes with dimension of 50 mm \times 50 mm. The cut-out specimens were primarily weighted and then soaked in pure water for almost six hours. The samples were weighted after the soaking. The water absorption of the sample was calculated by using the formula

$$W_a = \frac{m_f - m_i}{\text{sample area}} \quad (2)$$

Where W_a is the water absorption, m_f is the weight of sample after soaking, m_i is the weight of sample before absorption.

2.2.6. Three Point flexural test

Three-point flexural test is used to determine flexural stress and flexural strain. Three-point flexural testing method consists of 2 supports and force is applied in the middle.

The following formula is used to calculate the flexural stress. The flexural stress is defined as the stress in the point of bending where failure occurs.

$$\sigma_f = \frac{3FL}{2bh^2} \quad (3)$$

Where σ_f is the flexural stress, F is the force applied, L is the span length, b is the width of specimen, and h is the thickness.

Followed by flexural stress, flexural strain is calculated. The following formula is used to determine the flexural strain. Flexural strain is defined as the maximum strain in which the mid point faces.

$$\varepsilon_f = \frac{6sh}{L^2} \quad (4)$$

Where ε_f is the flexural strain, s is the deflection, L is the span length, h is the thickness of specimen.

2.2.7. Tensile strength estimation

Room temperature is made as a standard to do the tensile strength ascertainment by Tinius Olsen universal testing machine. Load capacity used in testing is 50kN, length of the gauge is set to be 50mm and speed of cross head is set to be 10 mm/min. 5 specimens are subjected to testing in each sample.

The following formula is used to determine the tensile strength of the material.

$$\sigma = F/A \quad (5)$$

where σ is the tensile strength, F is the force applied, and A is the area of the specimen.

The following formula is used to determine the elongation at break for the specimen, which is followed by tensile strength ascertainment.

$$\varepsilon = (\varrho_1 - \varrho_0) / \varrho_0 = \Delta\varrho / \varrho_0 \quad (6)$$

$$\varepsilon = \frac{\Delta\varrho}{\varrho_0} * 100, \% \quad (7)$$

Where ε is the elongation at break, $\Delta\varrho$ is the increase of specimen length inbetween the gauge marks, and ϱ_1 is the length between two end gauge.

The following formula is used to determine the modulus of the specimen, which is followed by elongation at the break calculation.

$$E = \frac{(\sigma_{0.025} - \sigma_{0.005})}{(\varepsilon_{0.025} - \varepsilon_{0.005})} \quad (8)$$

Where σ is the stress, E is the modulus and ε is the elongation.

2.2.8. Statistical analysis

Mean value is determined in order to start the statistical analysis. Mean is defined as the median of the acquired values. The following formula is used to determine the mean value,

$$X = \frac{\sum_{i=1}^n x_i}{n}, \quad (9)$$

Where X is the mean value.

The following formula is used to determine the standard deviation, which is followed by the mean value figuring.

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - X)^2}{(n-1)}}, \quad (10)$$

Where i is the serial number of the sample, x_i is the dimension of the i -th sample and n is the number of samples.

$$\sigma^2 = \frac{\sum_{i=1}^n (x_i - X)^2}{n-1}, \quad (11)$$

Where σ is the standard deviation.

The following formula is used to determine the coefficient of variation, which is followed by the standard deviation figuring.

$$V = (\sigma/X) * 100 \quad (12)$$

Where σ is the standard deviation, X is the mean value.

The following formula is used to determine absolute error, which is followed by coefficient of variation.

$$\Delta = \sigma/tb * SQRT(tb) \quad (13)$$

Where σ is the standard deviation and Δ is the absolute error and tb is the trail balance.

The following formula is used to determine relative error, which is followed by absolute error figuring.

$$\delta = (\Delta/X) * 100 \quad (14)$$

Where δ is the relative error, Δ is the absolute error, X is the mean.

The following formula is used to determine the confidence interval, which is followed by relative error figuring.

$$I_{\beta} = X \pm \delta \quad (15)$$

Where I_{β} is the confidence interval, X is the mean and δ is the absolute error.

3. Results

The variation in properties of layered composite with expanded polystyrene (EPS) binder for wood core layer has been studied, and comparisons have also been made with results from some previous investigations using polyamide (PA) binder. Particle size of each materials have been observed along with binding structure of wood with binders have been studied. Water absorption capacity of each composites have been observed.

3.1. Microscopic Observations

The morphology of EVA crumbs, beach wood flour, EPS and PA is shown in figures below. As can be seen that EVA and wood particles have an irregular shape. The used rubber particle have various size ranging from 75 μm to 1650 μm . The mean dimension of rubber particles is approximately equal to 248 μm (Fig.16). Wood particles that is used in making the layered composites have of size approximately equal to 165 μm (Fig.17), but size of particles ranging from 41 μm to 1450 μm . EPS beads have an approximate size of 772 μm (fig. 14). PA powder particles have the size approximately equal to 30.53 μm (fig. 15).

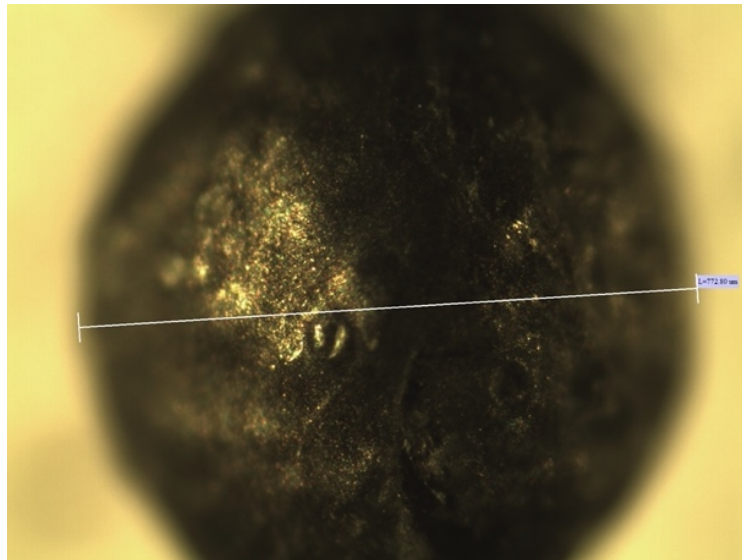


Fig. 14. EPS bead used in making the composite at magnification of 10 \times

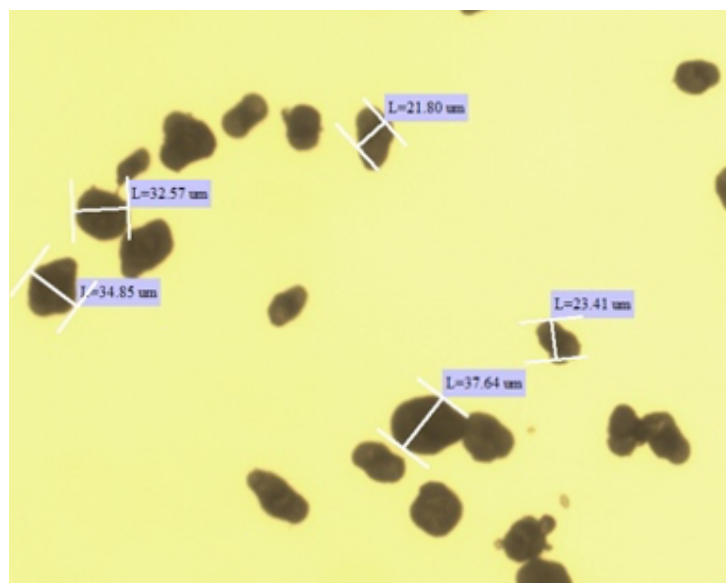


Fig. 15. PA binder used in making the composite at magnification of 40×

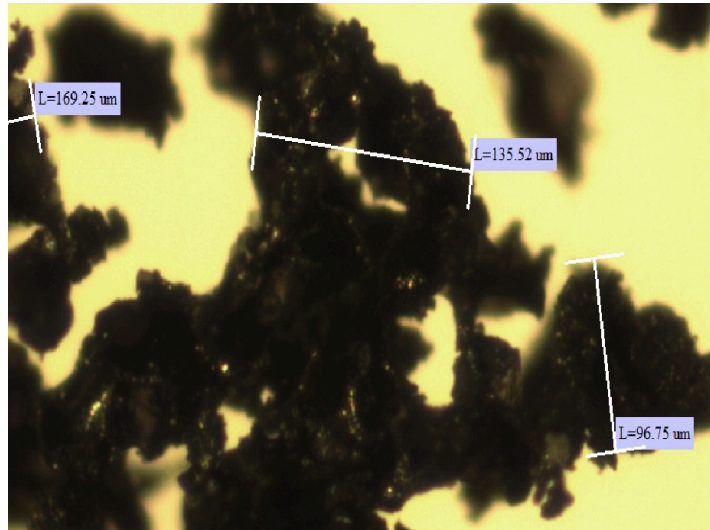


Fig. 16. Rubber crumbs used in making the composite at magnification of 10×

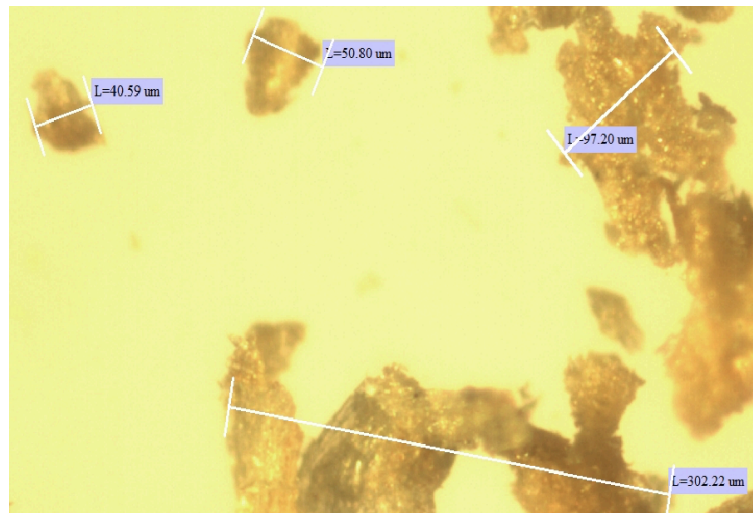
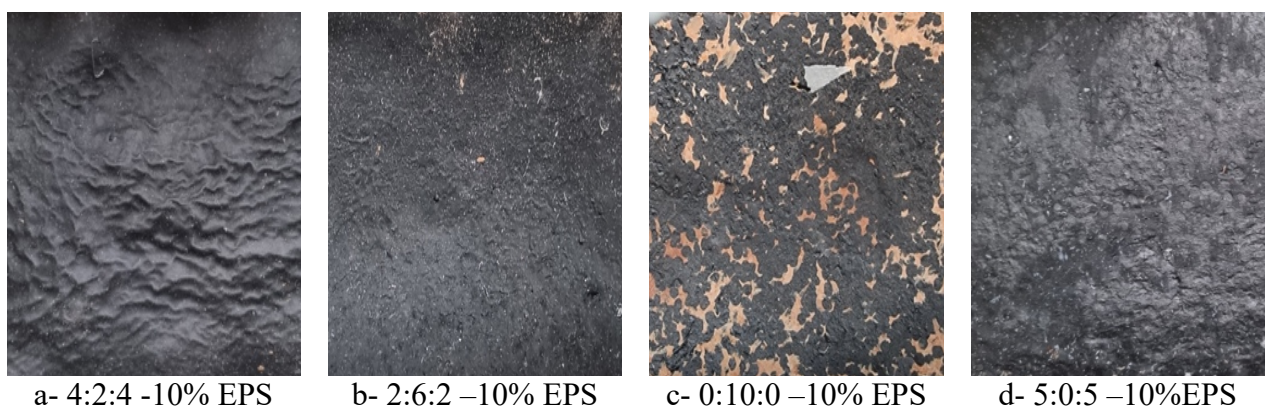


Fig. 17. Wood flour used in making the composite at magnification of 10×

The composite images presented in the Fig 18 show enough uniform dispersion of PA and EPS particles in the wood flour. The wrinkling of bottom and upper rubber layer (skin layer) of layered composite is observed due to shrinkage of middle wood layer. Shrinkage in wood with binder composite can be a source of residual stresses in wood with PA and EPS binders due to the mismatch in thermal expansion coefficients between wood and thermoplastic binders [39]. To reduce the shrinkage of middle wood layer fillers or other non-shrinking additives can be added.



a- 4:2:4 -10% EPS

b- 2:6:2 -10% EPS

c- 0:10:0 -10% EPS

d- 5:0:5 -10%EPS

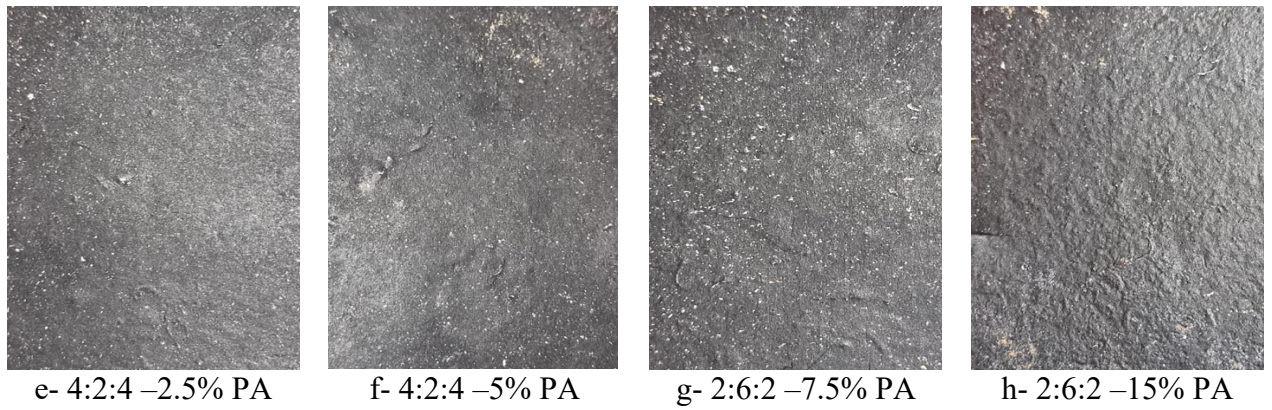


Fig. 18. Photographs of rubber/wood/rubber composites with EPS (a-d) and PA (e-h) at different binder ratio

The SEM image of the cross-sectional surface of the EVA and wood interface is shown in Fig. 19. EVA and wood particles is clearly visible, indicating no wood flour degradation during processing. The EVA/wood interface without interfacial gaps is observed indicating good interlaminar adhesion between EVA and wood.

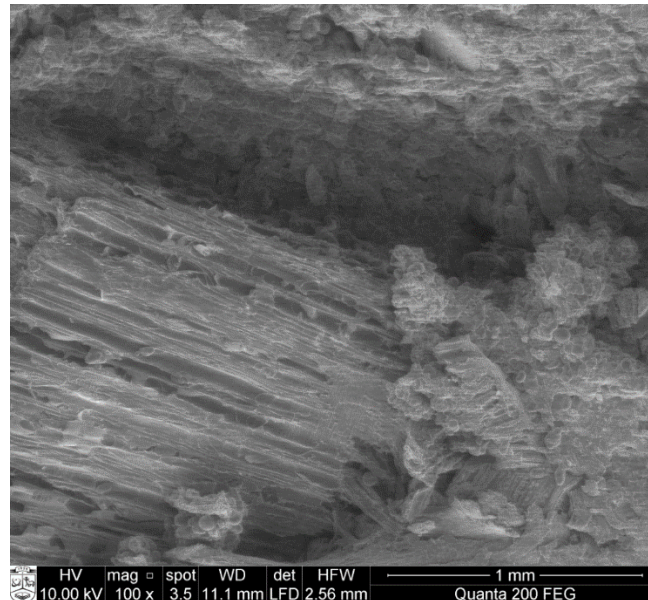


Fig. 19. Scanning electron micrographs for EVAC and wood interface at magnification of 100×

Good adhesion between EPS and wood interface was also observed through an optical microscope (Fig. 20). However, there are some bubbles on the surface of the wood and EPS sample. This is the result of EPS binder used since the EPS beads have lot of air stuffed in it. While heating and compressing, the air particles try to come out and as they do not have enough pressure to break the surface and cooling temperature, they are trapped inside the surface of the composite. Adhesion between PA and wood interface was observed which have good adhesion but it is not clearly visible under microscope since the PA particles are minute in size (Fig 21).

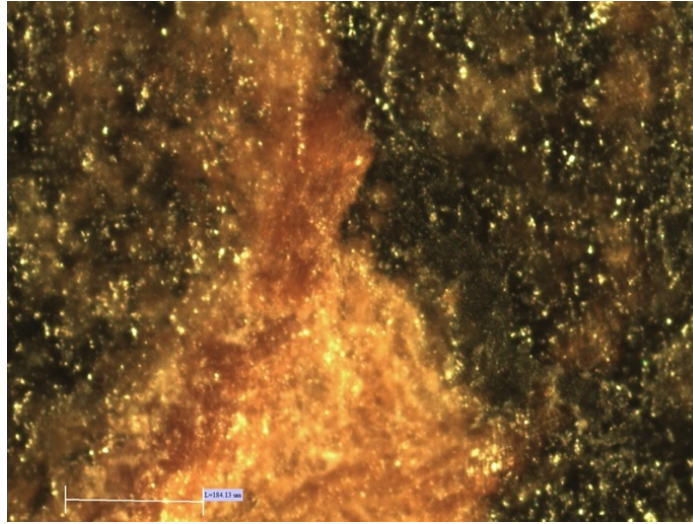


Fig. 20. Wood with EPS binder interface obtained by optical microscopy at magnifications of 60×

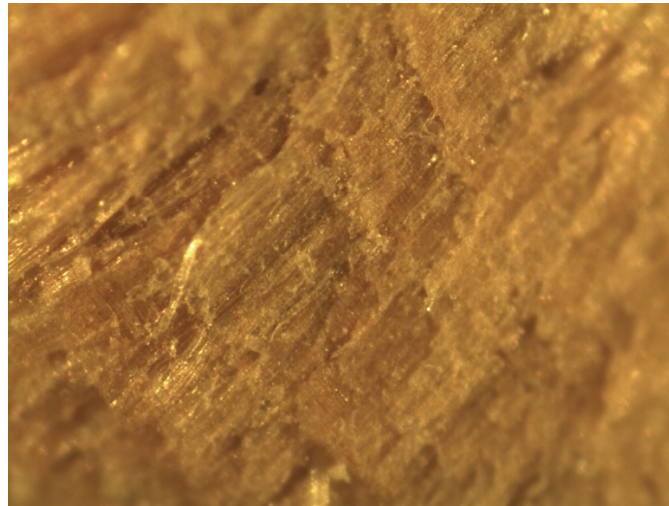


Fig. 21. Wood with PA binder interface obtained by optical microscopy at magnifications of 60×

3.2. Physical properties

Non compromisable factors such as hardness and density are one of the main properties for the insole of shoes since these two properties have the ability to increase the chance of incidents to happen [40]. Increasing in the hardness and density of insole decreases the chance of incident. Therefore, hardness of the samples are being determined. To obtain these results, ten readings at different points of the samples are being taken and the average is used to obtain the hardness of the sample. As we can see in this Fig. 22, the average of rubber wood ratio of 4:2:4 with 2.5 % of PA binder have the higher hardness value of 94.4 Shore A. composites without binders posses less hardness value of 87.5 Shore A. In comparison with EPS binder with PA binder composite, the composite with PA binders has higher hardness value.

It is found that the produced composite has similar hardness to commercial insole materials.

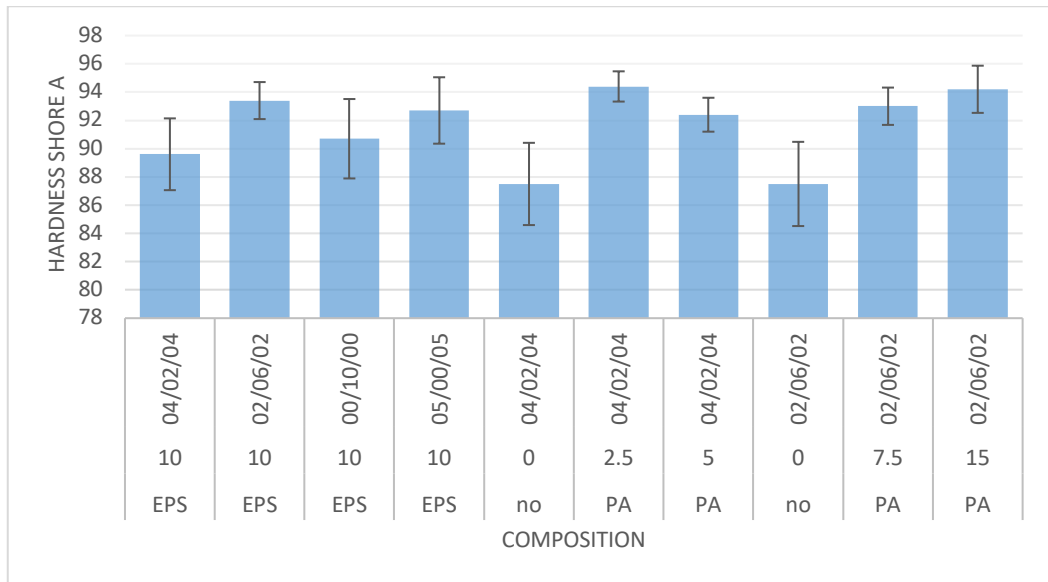


Fig. 22. Comparison of average hardness of each composite sample

The density investigation shows that average density of rubber wood composite ratio of 4:2:4 with EPS binder of 10 % have the highest value of 939 kg/m³. In this case, the results are almost same as hardness as the composites with no binders possess less density value but opposite to hardness the composites using PA binder have slight lower average value than the composites using EPS binder.

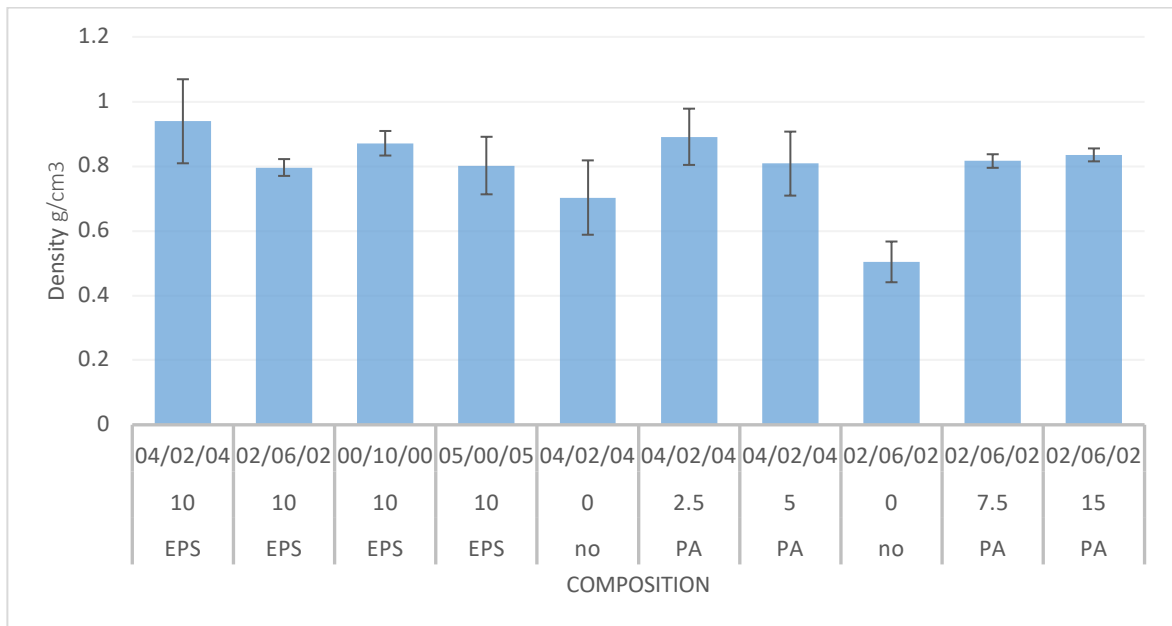


Fig. 23. Comparison of average density of each sample

The hydrophilicity of the traditional insole materials plays a crucial role on the performance and comfort of footwear. Therefore, the water absorption properties of prepared composite samples were investigated. The water absorption capacity is estimated through the soaking of samples in water with equal area. By this estimation, this shows that the composite that have more wood content absorb more water due to the hydrophilic character of wood, which is responsible for the water absorption in composite (Fig. 24). Composite made only of wood, without rubber have absorbed water content of 4.844 kg/m². Another interesting finding is that as the quantity of PA binder increases, the

absorption capacity decreases due to the presence of hydrophobicity of PA. As can be expected the lowest water absorption is characteristic for rubber samples.

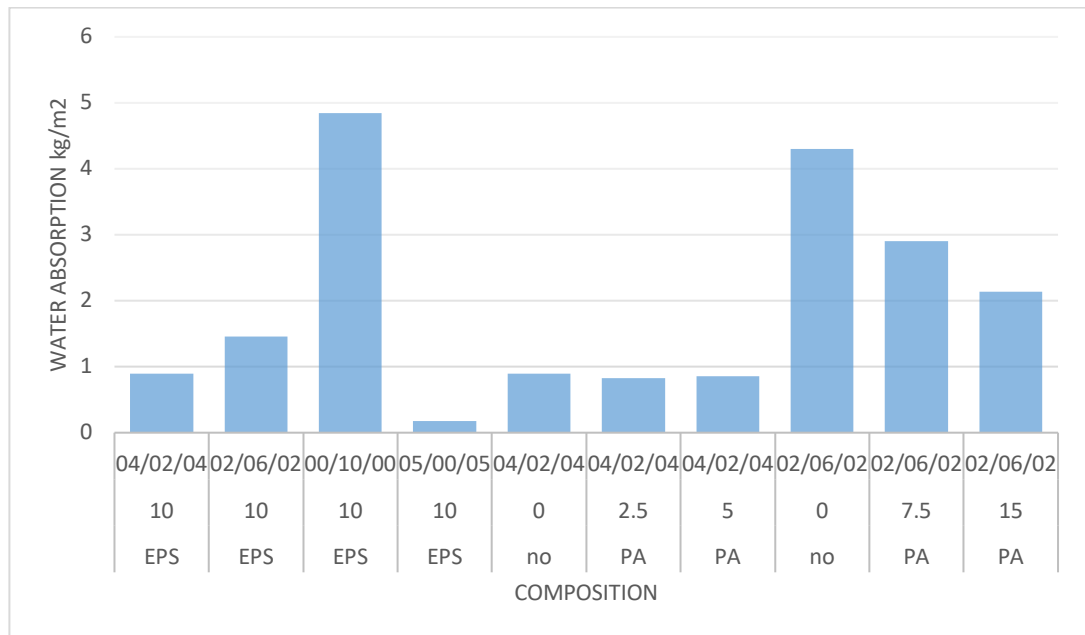


Fig. 24. Comparison of average water absorption of each sample

The water absorption of Bartoli cardboard samples is equal to 1.98 kg/m², Texon cardboard 0.72 kg/m².

3.3. Mechanical Properties

It is known that insole materials undergo exclusive forms of stresses and strains in footwear during walking. Bending strength is important in order to handle the stress caused by the huge amount of the pressure is impacted on the material [41]. The similar flexural stress values are obtained for all composites. One reason for this could be that the core layer (wood) has a lower influence on the flexural properties of three-layered composite in comparison with the skins (rubber) [37]. The main changes in the composition of the studied composite were made in the core (wood) by changing the amount and type of binder. The layered composite with rubber wood ratio of 4:2:4 with 10 % EPS binder have the highest flexural stress of 19.65 MPa and the composite with rubber wood ratio of 2:6:2 and without binder have the lowest flexural stress of 13.75 MPa.

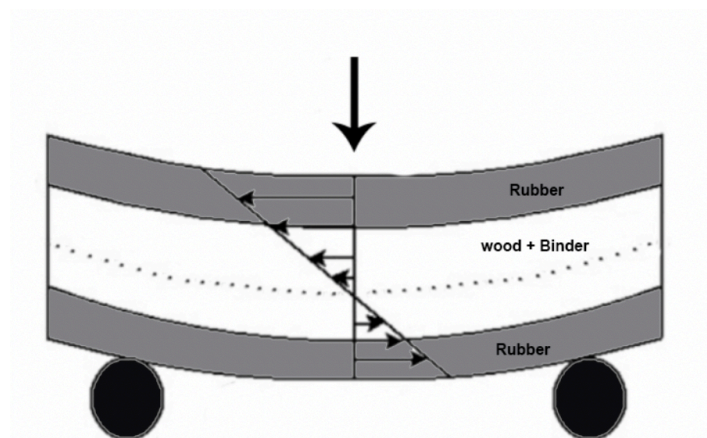


Fig. 25. Load distribution in a three-layered composite under three point bending test.

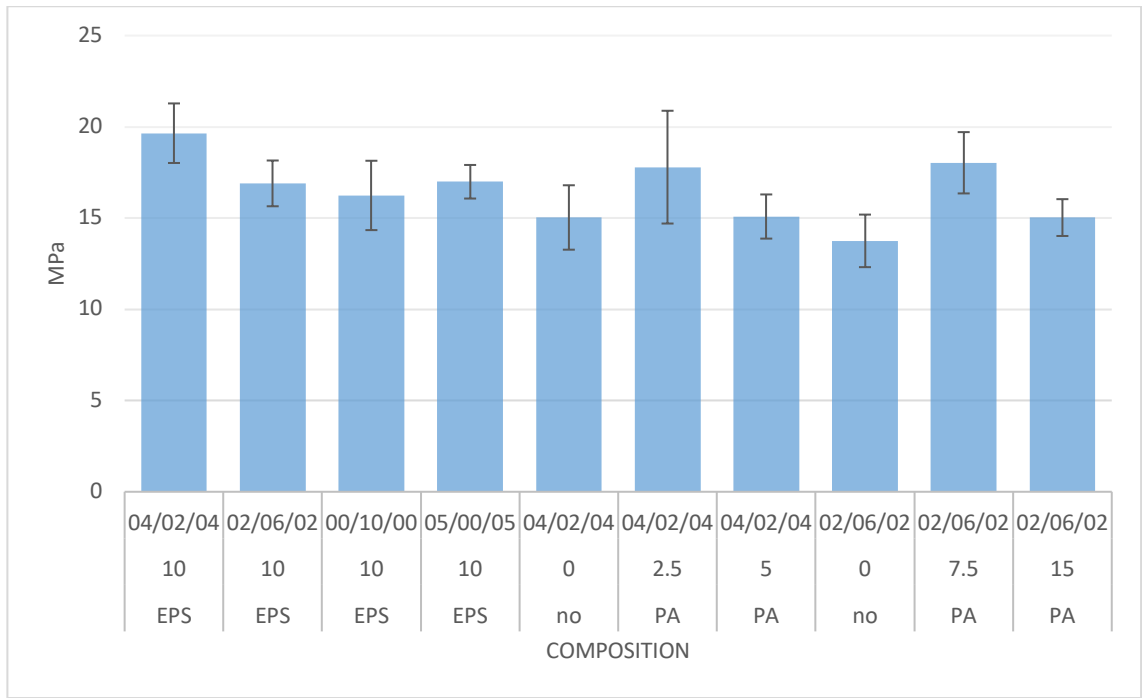


Fig. 26. Comparison of average flexural stress of each sample

In the flexural stress estimation, the composite with rubber wood ratio of 4:2:4 with 10% EPS binder have the highest flexural stress of 19.65 MPa and the composite with rubber wood ratio of 2:6:2 with 0 percent binder have the lowest flexural stress of 13.75 MPa.

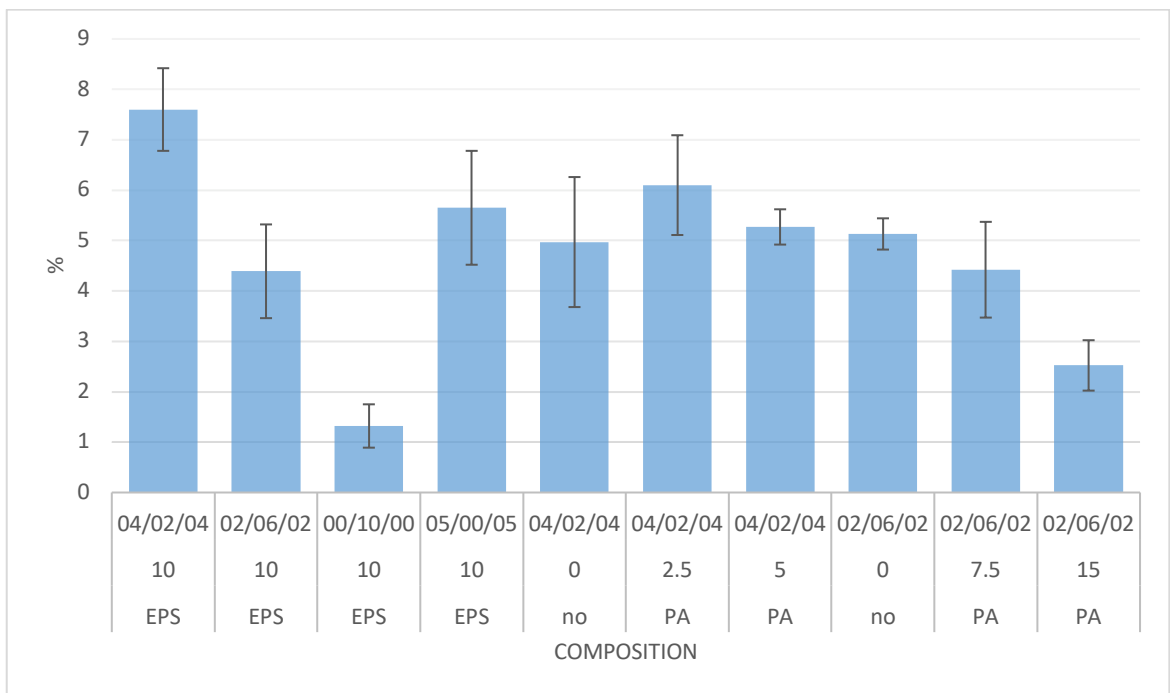


Fig. 27. Comparison of average flexural strain of each sample

In the flexural strain estimation, the composite with rubber wood ratio of 4:2:4 with 10% EPS binder have the highest flexural strain of 7.6% and the composite with rubber wood ratio of 0:10:0 with 10% EPS binder have the lowest flexural strain of 1.32%.

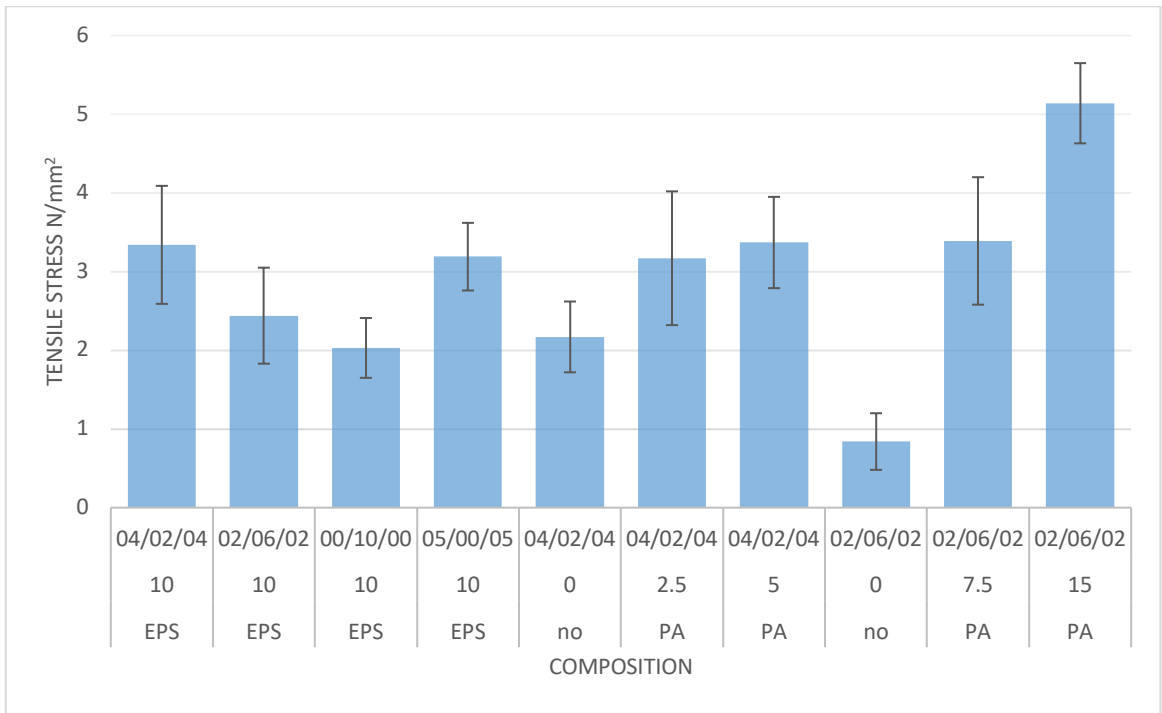


Fig. 28. Comparison of average tensile stress of each sample

Composite with rubber wood ratio of 2:6:2 and PA binder of 15 % have highest tensile strength value of 5.14 N/mm². Composite with no binder with the rubber wood ratio of 2:6:2 have lowest tensile strength value of 0.84 N/mm². In this case, the composites with PA binders are estimated to have high tensile strength.

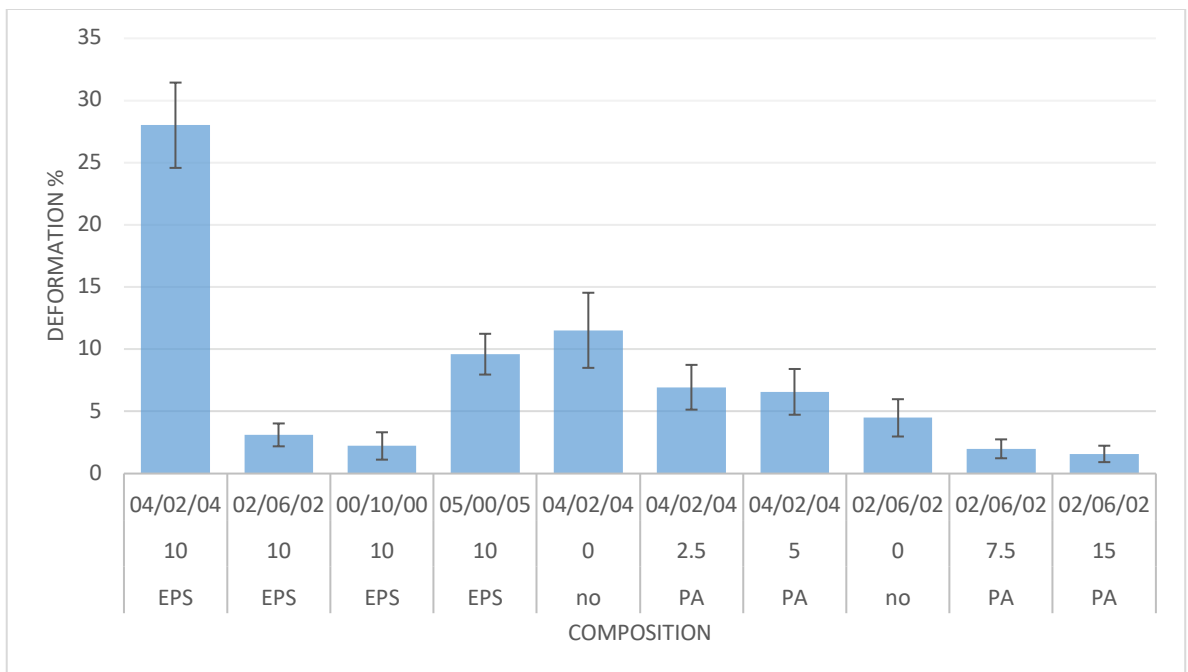


Fig. 29. Comparison of tensile strain of each sample

According to the values obtained, it is found that the composite that have more rubber content than wood with high binder capacity have the highest deformation (i.e) the composite with rubber wood ratio of 4:2:4 with 10% of EPS binder have deformation value of 28.01%. The composite with rubber

wood ratio of 2:6:2 with 15% of PA binder have the lowest deformation value of 1.58%. Here in this case, the wood ratio plays an important role as we can see the composites with lower wood content have lower deformation values.

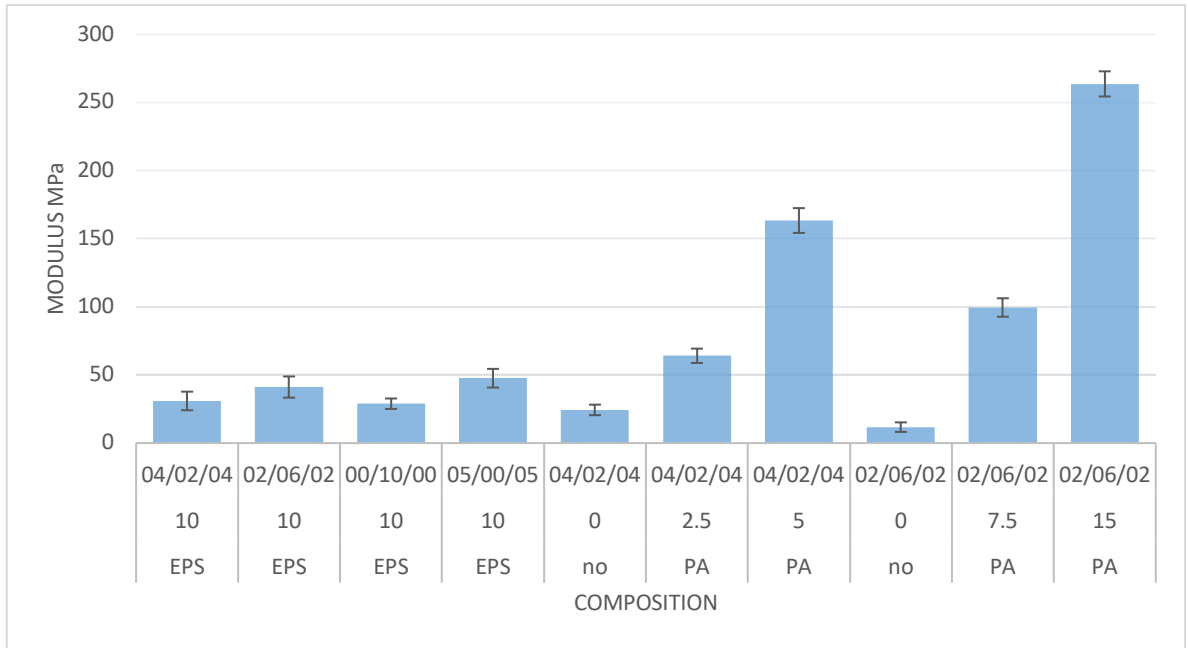


Fig. 30. Comparison of average modulus of each sample

Composite with rubber wood ratio of 2:6:2 with the PA binder of 15 % have highest modulus value of 263.56 MPa and the composite with rubber wood ratio of 2:6:2 with no binder have the lowest modulus value of 11.71 MPa. This modulus estimation shows that wood content and PA binder content plays an important role in modulus value.

4. Economical representation

4.1. Cost Estimation for composite Preparation.

The cost required to produce the composites are estimated in this calculation. This helps us to understand the economic effectiveness of the composite production.

There are two types of costs including direct cost and indirect cost. Indirect cost is defined as the cost that is required to maintain the machine, place rent, inflation which doesn't accredit the preparation of composite. Thus the indirect cost have been eliminated in this cost estimation. Direct production cost is defined as the cost that is required to prepare the composite including machine energy, labour cost, material cost. The composite preparation cost can be calculated by using the formula.

Production cost is the sum of material cost, manufacturing cost and labour cost

$$C_p = C_m + C_e + C_s \quad (16)$$

where C_p is the production cost, C_m is the manufacturing cost, C_e is the cost of energy consumption and C_s is the labour cost.

First, the material cost is calculated which is shown in the table below with the formula used

$$C_m = C_{pk} \times m \quad (17)$$

where C_m is the material cost, C_{pk} is the price per kg of the material, m is the quantity used in kg.

Table 5. Material cost for the quantity used in preparation of composite

Si no	Samples	materials	price per kg, EUR	Quantity used, g	Used quantity price, EUR
1	4:2:4	Rubber	3.02	80	0.242
		Wood	1.75	20	0.035
		EPS Binder	2.3	10	0.023
2	2:6:2	Rubber	3.02	40	0.121
		Wood	1.75	60	0.105
		EPS Binder	2.3	10	0.023
3	0:10:0	Rubber	3.02	0	0.000
		Wood	1.75	100	0.175
		EPS Binder	2.3	10	0.023
4	5:0:5	Rubber	3.02	100	0.302
		Wood	1.75	0	0.000
		EPS Binder	2.3	10	0.023
5	4:2:4	Rubber	3.02	80	0.242
		Wood	1.75	20	0.035
		Binder	0	0	0.000
6	4:2:4	Rubber	3.02	80	0.242
		Wood	1.75	20	0.035
		PA Binder	2.99	2.5	0.007
7	4:2:4	Rubber	3.02	80	0.242
		Wood	1.75	20	0.035

Si no	Samples	materials	price per kg, EUR	Quantity used, g	Used quantity price, EUR
		PA Binder	2.99	5	0.015
8	2:6:2	Rubber	3.02	40	0.121
		Wood	1.75	60	0.105
		Binder	0	0	0.000
9	2:6:2	Rubber	3.02	40	0.121
		Wood	1.75	60	0.105
		PA Binder	2.99	7.5	0.022
10	2:6:2	Rubber	3.02	40	0.121
		Wood	1.75	60	0.105
		PA Binder	2.99	15	0.045

Followed by material cost calculation, energy cost is calculated.

To prepare the composite, the composites are pressed with the help of hot compression machine, each composite is subjected to 7 minutes. Which is before the materials are preheated in oven for 7 minutes.

Time of preheating – 7 minutes – 0.112 hrs

Preheating power – 26.9 kW

Cost rate of energy – 0.312 Euro/ kWh [42]

Cost of energy consumed for hot compression machine can be calculated by using the formula

$$C_{ce} = E \times P \times T \quad (18)$$

where C_{ce} is the cost of energy of hot compression machine, E is the cost rate of energy, P is the power, T is the time utilized.

$$C_{ce} = 0.312 \times 26.9 \times 0.112 = 0.943 \text{ Eur}$$

Time of using hot compression machine – 7 minutes – 0.112 hrs

Hot compression power – 3.2 kW

$$C_{oe} = E \times P \times T \quad (19)$$

Where C_{oe} is the cost of energy of preheating oven, E is the cost rate of energy, P is the power, T is the time utilized.

$$C_{oe} = 0.312 \times 3.2 \times 0.112 = 0.112 \text{ Eur}$$

Total energy cost consumed for preparation of composite can be calculated by using the formula

$$C_e = C_{oe} + C_{ce} \quad (19)$$

$$C_e = 0.943 + 0.112 = 1.055 \text{ Eur}$$

Followed by energy cost calculation, labour cost estimation is done by using the formula

$$C_s = T_p \times S_h \quad (19)$$

Where C_s is the labour cost, T_p is the time utilised for preparation of composite and S_h is the salary cost of labour.

Total production time for making one sample composite including 5 min. of pre preparation of sample, 5 min. of machine preparation, 7 min. of preheating time, 7 min. of hot compression time and 5 min. of post preparation which results in the total time of 29 minutes (0.48 hr) per sample.

Average manufacturing technician salary per month in lithuania is 1209 Eur [43] which is 7.55 Eur per hour.

$$C_s = 0.48 \times 7.55 = 3.63 \text{ Euro.}$$

With the following findings, the total cost for the preparation of composite is presented in the table below.

Table 6. Total cost for the preparation of composite

Si no	Samples	materials	Material cost, Eur	Energy cost, Eur	Labour cost, eur	Total cost, Eur
1	4:2:4	Rubber	0.241	1.055	3.630	4.984
		Wood	0.035			
		EPS Binder	0.023			
2	2:6:2	Rubber	0.120	1.055	3.630	4.933
		Wood	0.105			
		EPS Binder	0.023			
3	0:10:0	Rubber	0	1.055	3.630	4.880
		Wood	0.175			
		EPS Binder	0.023			
4	5:0:5	Rubber	0.302	1.055	3.630	5.010
		Wood	0			
		EPS Binder	0.023			
5	4:2:4	Rubber	0.241	1.055	3.630	4.961
		Wood	0.035			
		Binder	0			
6	4:2:4	Rubber	0.241	1.055	3.630	4.969
		Wood	0.035			
		PA Binder	0.007			
7	4:2:4	Rubber	0.241	1.055	3.630	4.976
		Wood	0.035			
		PA Binder	0.014			
8	2:6:2	Rubber	0.120	1.055	3.630	4.910
		Wood	0.105			
		Binder	0			
9	2:6:2	Rubber	0.120	1.055	3.630	4.933
		Wood	0.105			
		PA Binder	0.022			
10	2:6:2	Rubber	0.120	1.055	3.630	4.955
		Wood	0.105			
		PA Binder	0.044			

As we can see from the above obtained value, in economic basis the composite made with the rubber and wood ratio of 5:0:5 with the binder quantity of 10% EPS is the expensive one of 4.984 euros per sample, and the composite with rubber wood ratio of 0:10:0 with binder quantity of 10% EPS is the cheapest with 4.883 euros. The price of the composite increases in accordance with the increase in rubber quantity.

4.2. Future focus of composites

4.2.1. Uses

The obtained rubber wood composite can be used as a replacement material for the insole cardboard materials of the footwears. For the production of all shoe materials, the environmental orientation of new developments is common such as an increase in the use of secondary raw materials, the use of components of biological origin, and ensuring zero waste (collection of waste from customer enterprises).

Each year tones of wood and rubber are being used in the manufacture of insole, the composite made of rubber and wood will pave a path to use rubber and wood waste. Usually thick EVA rubber is used in top layer of insole to provide soft structure since it directly contacts with the skin. In this research, layered composites are being used, so top layer can be made with reused rubber without changing the traditional insole properties and uses.

An illustration view of rubber wood layered composite is shown in the Fig 31.

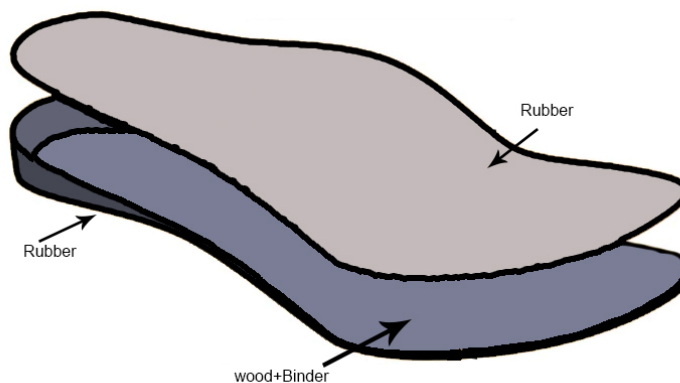


Fig. 31. Rubber wood layered composite insole

Obtained rubber wood composites have good tensile strength and hardness. The rubber wood composite can be used in the construction of beam if the composite is layered horizontally. This method of usage of rubber and wood waste will initiate the reusing process which will lead to sustainability [44]. The important requirement of beam structure should be light weight, strong, high tensile strength, with energy distribution property. According to this research, the layered wood and rubber composite beam full fills the necessary requirements.

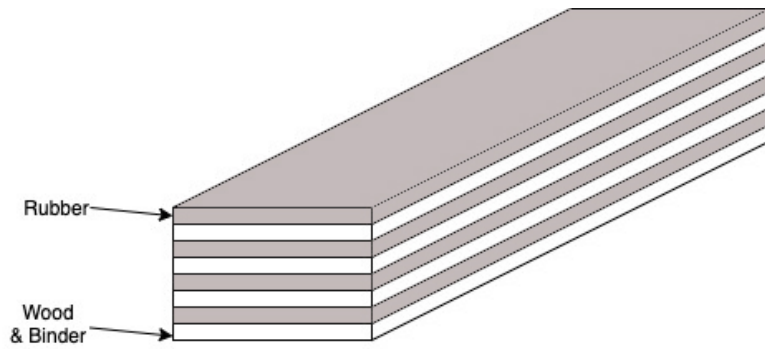


Fig. 32. Rubber wood composite beam

An rough illustration of rubber wood layered composite beam is shown in the Fig 32.

4.2.2. Endlife of rubber wood composite

All natural products can be recycled, wood is a natural products which can be decayed or recycled with proper methods. Endlife methods of rubber wood composite include landfills, incineration, or recycling methods such as thermal recycling, mechanical recycling and chemical recycling [45].

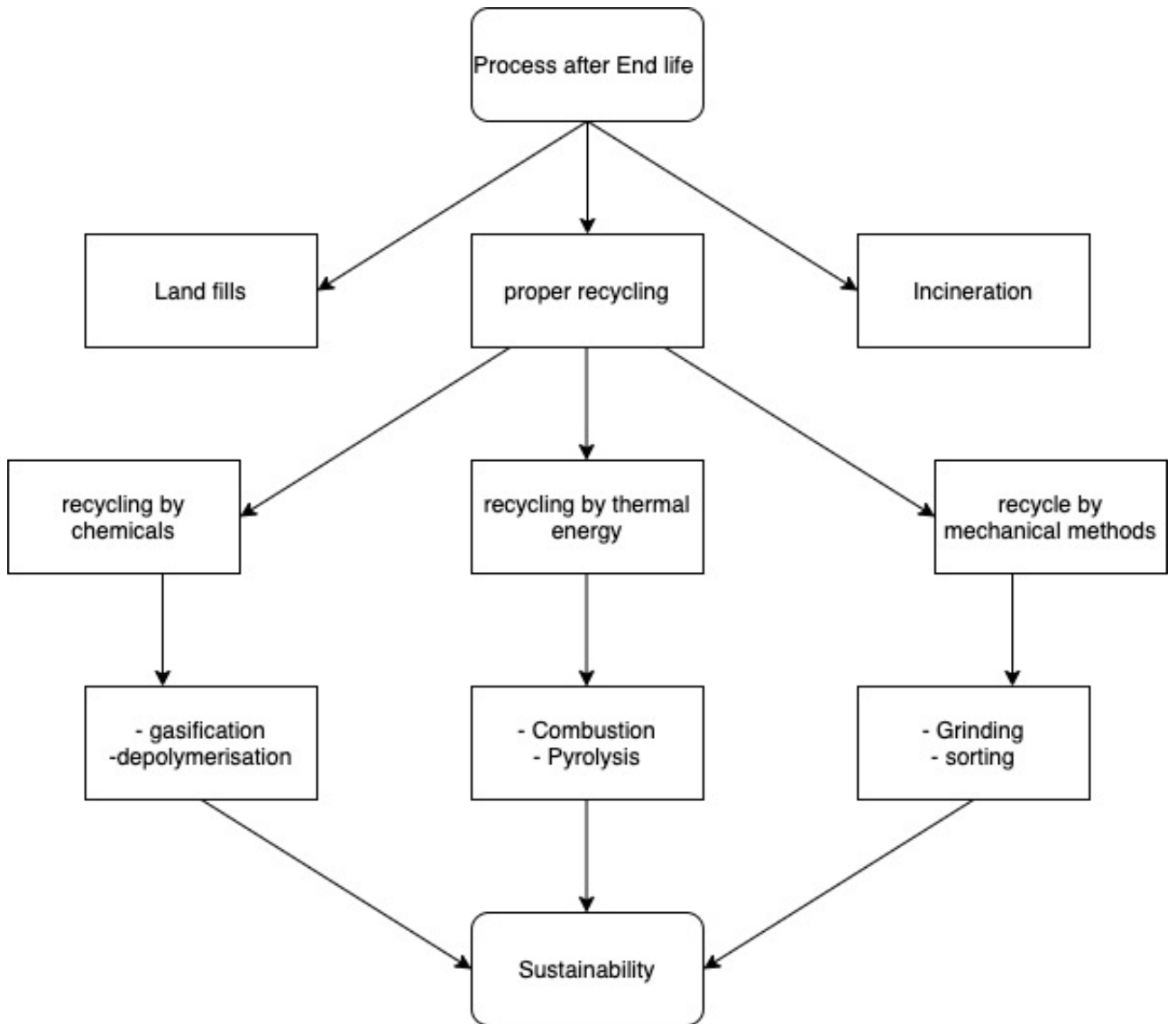


Fig. 33. Process after end life

Sustainability can be achieved through proper end life process. The end life process is generally divided into three types such as land fills, proper recycling, and incineration. Land fills is the easiest and non sustainable method. Land fills means dumping the waste material in the land. This land fills will cause harm to the environment since the waste materials will release harmful chemicals, contaminate the underground water. Incineration is defined as the burning of waste materials at high temperature. The end result is ash in this method. This method is used to reduce the size of waste and the rest of ash is used in making cosmetics, compost, fire control products etc.

The most sustainable and efficient method of recycling can be classified into chemical recycling, thermal recycling, and mechanical recycling. Mechanical recycling involves in grinding and sorting of materials. Chemical recycling involves in the gasification and depolymerisation. Gasification is the process in which converts the waste materials into fuels. Depolymerisation is the process in which the polymer is converted into monomer. Thermal recycling is the process in which the energy recovery by thermal treatment.

5. Optimum selection of composite

5.1. Properties comparison of composites with traditional insole materials

Three composites are selected on each tests conducted which are presented in the table below. The selection is based on the higher values obtained by each property examinations. In water absorption test, lower values are set to priority.

Table 7. Selection of materials based on each property

Properties	Composite 1	Composite 2	Composite 3
Hardness	2:6:2 - 10% EPS	4:2:4 - 2.5% PA	2:6:2 - 15% PA
Density	4:2:4 - 10% EPS	2:6:2 - 15% PA	4:2:4 - 2.5% PA
Water absorption	4:2:4 - 10% EPS	4:2:4 - 5% PA	4:2:4 - 2.5% PA
Flexural stress	4:2:4 - 10% EPS	4:2:4 - 7.5% PA	4:2:4 - 2.5% PA
Flexural strain	4:2:4 - 10% EPS	4:2:4 - 5% PA	4:2:4 - 2.5% PA
Tensile stress	4:2:4 - 10% EPS	2:6:2 - 7.5% PA	2:6:2 - 15% PA
Tensile strain	4:2:4 - 10% EPS	4:2:4 - 2.5% PA	4:2:4 - 5% PA
Modulus	2:6:2 - 15% PA	2:6:2 - 7.5% PA	4:2:4 - 5% PA

Three composites have been selected most in each test which are compared with the properties of the traditional insole materials.

Table 8. Properties comparison of selected composite with traditional insoles.

Samples	Hardness, Shore A	Flexural modulus, MPa	Flexural strength, MPa	Deformation at max, mm
Texon	86.5	534.8	11,32	7.13
Cork	59	8.42	0.54	8.96
Non – Woven sheet	89	306.5	5.2	8.7
Bartoli	96	2932.12	31.4	3.5
4:2:4 –10%EPS	89.6	30.92	19.65	7.6
4:2:4 – 2.5%PA	94.4	64.05	17.79	6.1
4:2:4 – 5%PA	92.4	163.31	15.08	5.27

During properties comparison the following three composites such as 4:2:4 – 10% EPS, 4:2:4 – 2.5% PA and 4:2:4 - 5% PA have been selected. To find the optimum composite cost of manufacturing should also be compared which will be shown in the following table below.

Table 9. Comparison of properties to obtain optimum composite

Samples	Density, kg/m³	water absorption, kg/m²	Tensile stress, n/mm²	Elongation, %	Cost, EUR
4:2:4 – 10%EPS	939	0.892	3.34	28.01	4.98
4:2:4 – 2.5%PA	891	0.828	3.17	6.94	4.96
4:2:4 – 5%PA	808	0.856	3.37	6.57	4.97

The price of traditional footwear insole is 5.49 euros [46]. In comparison with the results obtained with the traditional footwear properties and cost, the optimum composite to replace the traditional material for manufacturing of footwear is found to be 4:2:4 – 10% EPS composite.

Conclusions

1. In this research project layered composite from expanded ethylene vinyl acetate (EVA) crumbs and beech flour industrial waste was created and analysed to obtain a cost effective alternative material for the manufacturing of insoles. Polyamide (PA) powder waste generated during the process of selective layer sintering and expanded polystyrene (EPS) were used as a binders during the formation of composites. Various ratios of components wood and rubber leads to optimal properties of composites.
2. The analysis of effect of different type and content binders on the morphology, strength, water absorption of core of layred EVA/wood/EVA composite shows that the composites with 10% of EPS presented higher absorpction rate of 52.06 % than the composite with PA binder. The wood with 10% EPS binder presented better physical and mechanical properties than those with PA binders.
3. Morphological observations through SEM and optical microscopy as shown that good interlaminar adhesion between the EVA and wood layers and good interfacial adhesion between wood and PA or EPS binders. The increase in wood content in 2:6:2 with 10 % EPS led to lower tensile and flexular strength of layered composite, while their hardness, desnsity is in average with other composites and water absorption properties increases. Comparing all the results obtained, the optimized composite is found to be the composite with EVA/wood/EVA ratio of 4:2:4 with the EPS binder of 10 %.
4. The comparison of the properties of obtained layred composite with traditional insole materials, shows that proposed can be used to produce insole of the footwear. All the composites are produced from reused materials this leads to minimise resources and longer retention of raw materials in the life cycle.
5. The cost estimation reveals the manufacturing of composite with rubber with 10 % of EPS binder of is the expensive with 5.01 euro and the composite with 100% wood with EPS binder of 10% is the cheapest with 4.883 euros. The total cost for the production of all composites is 49.51euro. The average is found to be 4.95 euro which is the production cost of composite with the rubber wood ratio of 2:6:2 with PA binder of 15 %.

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Appendices

Appendix 1. Necessary calculations

3 Point Flexural Test for Sample 1

Nominal thickness	$1 \leq h \leq 3$	$1 \leq h \leq 3$	$1 \leq h \leq 3$	$1 \leq h \leq 3$
h	2.3	2.3	2.41	2.16
Width b	25	25	25	25
span length	$L=(16\pm 1)h$	$L=(16\pm 1)h$	$L=(16\pm 1)h$	$L=(16\pm 1)h$
L	34.5	34.5	36.15	32.4
applied force F N	50	50	50	50
Flexural stress	19.56522	19.5652174	18.67219917	20.83333
Deflection s mm	7.05	7.08	5.45	6.47
Flexural strain	0.081739	0.08208696	0.060304288	0.079877
Flexural strain %	8.173913	8.20869565	6.030428769	7.987654

3 Point Flexural Test for Sample 2

Nominal thickness	$1 \leq h \leq 3$	$1 \leq h \leq 3$	$1 \leq h \leq 3$	$1 \leq h \leq 3$
h	2.7	2.52	2.67	2.77
Width b	25	25	25	25
span length	$L=(16\pm 1)h$	$L=(16\pm 1)h$	$L=(16\pm 1)h$	$L=(16\pm 1)h$
L	40.5	37.8	40.05	41.55
applied force F N	50	50	50	50
Flexural stress	16.66667	17.8571429	16.85393258	16.24549
Deflection s mm	2.092	5.662	2.7	7.08
Flexural strain	0.020662	0.05991534	0.026966292	0.068159
Flexural strain %	2.066173	5.99153439	2.696629213	6.815884

3 Point Flexural Test for Sample 3

Nominal thickness	$1 \leq h \leq 3$	$1 \leq h \leq 3$
h	2.65	2.9
Width b	25	25
span length	$L=(16\pm 1)h$	$L=(16\pm 1)h$
L	39.75	43.5
applied force F N	50	50
Flexural stress	16.9811321	15.5172414
Deflection s mm	1.702	1.013
Flexural strain	0.01712704	0.00931494
Flexural strain %	1.7127044	0.93149425

3 Point Flexural Test for Sample 4

Nominal thickness	$1 \leq h \leq 3$	$1 \leq h \leq 3$	$1 \leq h \leq 3$	$1 \leq h \leq 3$
h	2.55	2.65	2.66	2.74
Width b	25	25	25	25
span length	$L=(16\pm 1)h$	$L=(16\pm 1)h$	$L=(16\pm 1)h$	$L=(16\pm 1)h$
L	38.25	39.75	39.9	41.1
applied force F N	50	50	50	50
Flexural stress	17.6470588	16.9811321	16.9172932	16.4233577
Deflection s mm	6.79	6.42	4.42	4.76
Flexural strain	0.07100654	0.06460377	0.04431078	0.04632603
Flexural strain %	7.10065359	6.46037736	4.43107769	4.63260341

Density Calculation for Sample 1

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
L mm	130	130	130	130
H1 mm	2.41	2.21	2.44	2.16
H2 mm	2.43	2.22	2.41	2.16
H3 mm	2.45	2.23	2.38	2.16
Avg H mm	2.43	2.22	2.41	2.16
W1 mm	20	20	20	20
W2 mm	20	20	20	20
W3 mm	20	20	20	20
Avg W mm	20	20	20	20
Volume mm³	6318	5772	6266	5616
Mass g	5.54	5.78	5.51	5.62
Density ρ (g/mm ³)	0.00087686	0.00100139	0.00087935	0.00100071
Density ρ (kg/m³)	876.859766	1001.386	879.348867	1000.71225

Density Calculation for Sample 2

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
L mm	130	130	130	130
H1 mm	2.6	2.52	2.87	2.75
H2 mm	2.7	2.52	2.67	2.77
H3 mm	2.8	2.52	2.47	2.79
Avg H mm	2.7	2.52	2.67	2.77
W1 mm	20	20	20	20
W2 mm	20	20	20	20
W3 mm	20	20	20	20
Avg W mm	20	20	20	20
Volume mm³	7020	6552	6942	7202
Mass g	5.74	5.21	5.47	5.66
Density ρ (g/mm ³)	0.00081766	0.00079518	0.00078796	0.00078589
Density ρ (kg/m³)	817.663818	795.177045	787.957361	785.892808

Density Calculation for Sample 3

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
L mm	130	130	130	130
H1 mm	2.6	2.7	2.6	2.65
H2 mm	2.65	2.9	2.7	2.85
H3 mm	2.7	2.8	2.5	3.05
Avg H mm	2.65	2.8	2.6	2.85
W1 mm	20	20	20	20
W2 mm	20	20	20	20
W3 mm	20	20	20	20
Avg W mm	20	20	20	20
Volume mm³	6890	7280	6760	7410
Mass g	6.19	6.306	5.73	6.46
Density ρ (g/mm ³)	0.0008984	0.00086621	0.00084763	0.00087179
Density ρ (kg/m³)	898.403483	866.208791	847.633136	871.794872

Density Calculation for Sample 4

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
L mm	130	130	130	130
H1 mm	2.45	2.85	2.46	2.54
H2 mm	2.55	2.65	2.66	2.74
H3 mm	2.65	2.45	2.86	2.94
Avg H mm	2.55	2.65	2.66	2.74
W1 mm	20	20	20	20
W2 mm	20	20	20	20
W3 mm	20	20	20	20
Avg W mm	20	20	20	20
Volume mm³	6630	6890	6916	7124
Mass g	5.72	5.24	5.67	5.45
Density ρ (g/mm ³)	0.00086275	0.00076052	0.00081984	0.00076502
Density ρ (kg/m³)	862.745098	760.522496	819.838057	765.019652

Modulus Calculation for Sample 1

Sample 1					
Stress					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Average
Force	157	193.6	158.4	108.2	
Height	2.43	2.22	2.41	2.16	
width	20	20	20	20	
Area	48.6	44.4	48.2	43.2	
stress σ n/mm²	3.23045267	4.36036036	3.28630705	2.50462963	3.34543743
n/cm²	323.045267	436.036036	328.630705	250.462963	334.543743

Elongation %					
Δq	7.56	14.35	10.84	23.275	
q_0	50	50	50	50	
ε	0.1512	0.287	0.2168	0.4655	
$\varepsilon\%$	15.12	28.7	21.68	46.55	28.0125
Modulus					
σ 0.0025	0.135	0.121	0.0954	0.0879	
σ 0.0005	0.049	0.058	0.0248	0.0601	
ε 0.0025	0.0025	0.0025	0.0025	0.0025	
ε 0.0005	0.0005	0.0005	0.0005	0.0005	
E	43	31.5	35.3	13.9	30.925

Modulus Calculation for Sample 2

Sample 2					
Stress					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Average
Force	84.3	132.9	175	127.2	
Height	2.7	2.52	2.67	2.77	
width	20	20	20	20	
Area	54	50.4	53.4	55.4	
stress σ n/mm²	1.56111111	2.63690476	3.27715356	2.29602888	2.44279958
n/cm²	156.111111	263.690476	327.715356	229.602888	244.279958
Elongation %					
Δq	1.325	1.6	1.51	1.785	
q_0	50	50	50	50	
ε	0.0265	0.032	0.0302	0.0357	
$\varepsilon\%$	2.65	3.2	3.02	3.57	3.11
Modulus					
σ 0.0025	0.129	0.122	0.217	0.167	
σ 0.0005	0.079	0.038	0.089	0.1	
ε 0.0025	0.0025	0.0025	0.0025	0.0025	
ε 0.0005	0.0005	0.0005	0.0005	0.0005	
E	25	42	64	33.5	41.125

Modulus Calculation for Sample 3

Sample 3					
Stress					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Average
Force	62.78	52.66	67.43	40.68	
Height	2.65	2.8	2.6	2.85	
width	20	20	20	20	
Area	53	56	52	57	
stress σ n/mm²	1.1845283	0.94035714	1.29673077	0.71368421	1.03382511
n/cm²	118.45283	94.0357143	129.673077	71.3684211	103.382511
Elongation %					
Δq	0.801	1.71	1.32	0.61	
q_0	50	50	50	50	
ϵ	0.01602	0.0342	0.0264	0.0122	
$\epsilon\%$	1.602	3.42	2.64	1.22	2.2205
Modulus					
σ 0.0025	0.092	0.089	0.086	0.0882	
σ 0.0005	0.049	0.018	0.024	0.033	
ϵ 0.0025	0.0025	0.0025	0.0025	0.0025	
ϵ 0.0005	0.0005	0.0005	0.0005	0.0005	
E	21.5	35.5	31	27.6	28.9

Modulus Calculation for Sample 4

Sample 4					
Stress					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Average
Force	165.4	171	165.4	175.4	
Height	2.55	2.65	2.66	2.74	
width	20	20	20	20	
Area	51	53	53.2	54.8	
stress σ n/mm²	3.24313725	3.22641509	3.10902256	3.20072993	3.19482621
n/cm²	324.313725	322.641509	310.902256	320.072993	319.482621

Elongation %					
$\Delta\rho$	4.3	4.71	4.98	5.22	
ρ_0	50	50	50	50	
ε	0.086	0.0942	0.0996	0.1044	
$\varepsilon\%$	8.6	9.42	9.96	10.44	9.605
Modulus					
σ 0.0025	0.121	0.109	0.086	0.138	
σ 0.0005	0.0039	0.0188	0.0075	0.043	
ε 0.0025	0.0025	0.0025	0.0025	0.0025	
ε 0.0005	0.0005	0.0005	0.0005	0.0005	
E	58.55	45.1	39.25	47.5	47.6