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Initial Investigation of Using the Waste Rubber Tires as a New Sustainable Material for Electric Conductive Rigid Pavement

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INITIAL INVESTIGATION OF USING THE WASTE RUBBER TIRES AS A NEW SUSTAINABLE MATERIAL FOR ELECTRIC CONDUCTIVE RIGID PAVEMENT

A Thesis

by

ISLAM RADWAN

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ABSTRACT

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The accumulation of snow on roadways poses deadly risks and financial damage. Traditional de-icing methods are environmentally harmful, structurally damaging, and unsustainable. They are also labor-intensive and dangerous in crowded areas. Heated pavement systems (HPS) like hydronic and electrically conductive concrete (ECON) have gained popularity, but their high cost and reliance on carbon fiber and carbon black contribute to raw material depletion. This research presents a sustainable alternative for de-icing snow on pavements. It utilizes waste rubber tires (WRT) as a heating source by passing current through embedded steel wires. The method involves distributing WRT pieces along the pavement to melt snow. It offers a more sustainable, environmentally friendly, and cost-effective solution than other alternatives. By leveraging WRT's heating properties, this approach mitigates snow accumulation efficiently while addressing the concerns of resource depletion and environmental impact.

DEDICATION

I dedicate my work to my mother, my father, and my brothers. Thanks to the almighty for helping me and guiding me through the difficult times. Without my supervisor, family, and friends' constant support and help, my journey here at UTRGV would not have been possible.

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I would like to acknowledge my supervisor, Dr. Mohamed Abdel-Raheem, for his outstanding guidance and support. His knowledge and expertise in advanced construction methods and his ongoing mentorship have helped me overcome all the difficulties I faced during this master's program. I am delighted that I got the opportunity to work in the Construction Research Field under his supervision. Besides, I am very thankful to Dr. Jungseok Ho, Dr. Philip Park, and Dr. Thang Pham. I also want to thank Dr. Heinrich Foltz for his guidance.

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CHAPTER I

INTRODUCTION

Since ancient times, developments in transportation infrastructure have facilitated rapid urbanization; consequently, transportation safety has been a top priority. The climate conditions, such as rain, ice, or snow, have a considerable influence on the frequency of accidents. This chapter's aim is to introduce the study, identify the problem explain the objectives of the research, and outline the thesis's content.

1.1 General Overview

It is important to keep roads clear of snow and ice in colder regions because it can lead to infrastructure decomposition, concrete pavement degradation, as well as negative environmental impacts due to the use of traditional deicing methods such as spraying chemicals on the pavement surface and using large snow removal machines like plows and shovels. Traditional techniques have a few drawbacks, including ineffectiveness in removing snow at low temperatures, negative environmental impact due of probable pollution of surrounding water bodies, and higher labor expenses. Recently, Heated Pavement System (HPS) has been offered as an alternative to traditional snow melting methods. It includes two main methods, the first is the Hydronic Heating Pavement System (HHPS), The second type is the Electric Heated Pavement System (EHPS). Although paving materials have a wide range of non-structural features to consider, the usage of electrical and thermal properties of paving materials has the greatest potential for providing long-term solutions to pavement systems. Over the previous few decades, several research on this issue have been published.

1.2 Problem and Objectives

Although most earlier studies focused primarily on the efficiency of melting snow electrically or through heat, other considerations, such as the cost, environmental impact, or societal impact of the approach used, were not considered. in other word, most of the studies did not consider the sustainability of the method. This study is being conducted to fill the gaps that may exist and to suggest a new method of construction that is both environmentally friendly and economical for melting snow. As the number of vehicles increases, huge quantities of waste tires are generated every year, and the waste-tire-disposal has been a serious ecological concern in metropolitan regions worldwide. Thus, using waste rubber tires (WRT) in the construction industry, particularly in pavement systems, Consequently, the occupied landfills where a large quantity of waste rubber tires (WRT) is typically kept would be reduced. Additionally, lowering the storing time for these tires in landfills since waste tires commonly generate "black pollution" due to their inability to biodegrade and posing a harm to the environment. The goal of this research is to examine the feasibility of a new construction technique for melting snow off pavement. This research takes a different method by substituting waste rubber tires (WRT) for the raw materials such as carbon black and carbon fiber that are used in ECON systems to alter the concrete layer properties and adjust the electrical conductivity properties of the concrete to create heat to melt the snow in the previous studies. To be more precise, this study work is based on the idea of utilizing the mesh of steel wires embedded in rubber tires as an electrical and heat conducting element to create enough heat to melt the snow.

The goals of this study:

1- Solving the problem of the snow accumulation on rigid roads such as highways, bridges, and airport runways.
2- Minimize the consumption of the raw materials by using WRT as a renewable and sustainable material, since a large amount of WRT is generated every year.
3- Establish new uses of WRT by opening new paths of utilizing the WRT in Civil and construction industry.

1.3 Conceptualization

This research was inspired by the invisible thermally conductive paint used to defrost and defog laminated car windshield glass. This study used a similar concept, which resulted in the creation of an innovative methodology for deicing pavements utilizing electrically conductive stripes. This approach is considered as a more sustainable construction option for safely and securely removing ice and snow from the pavement due to its low cost, little pavement damage, and environmental friendliness.

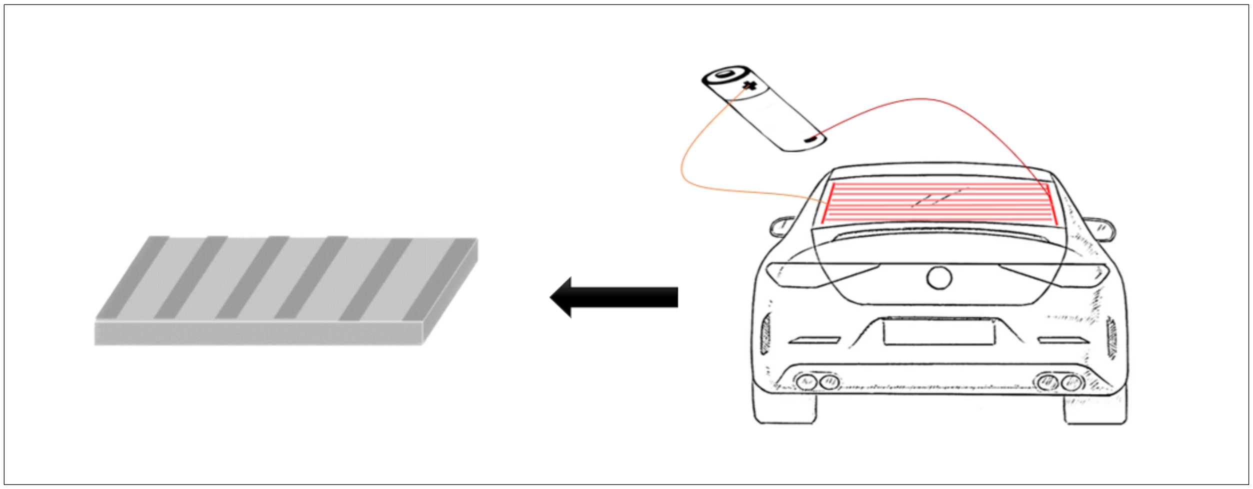


Figure 1: The conception of construction method of an electrically conductive pavement.

1.4 Methodology

Figure 2 shows the steps involved in this methodology until the desired model is achieved and then the results are observed.

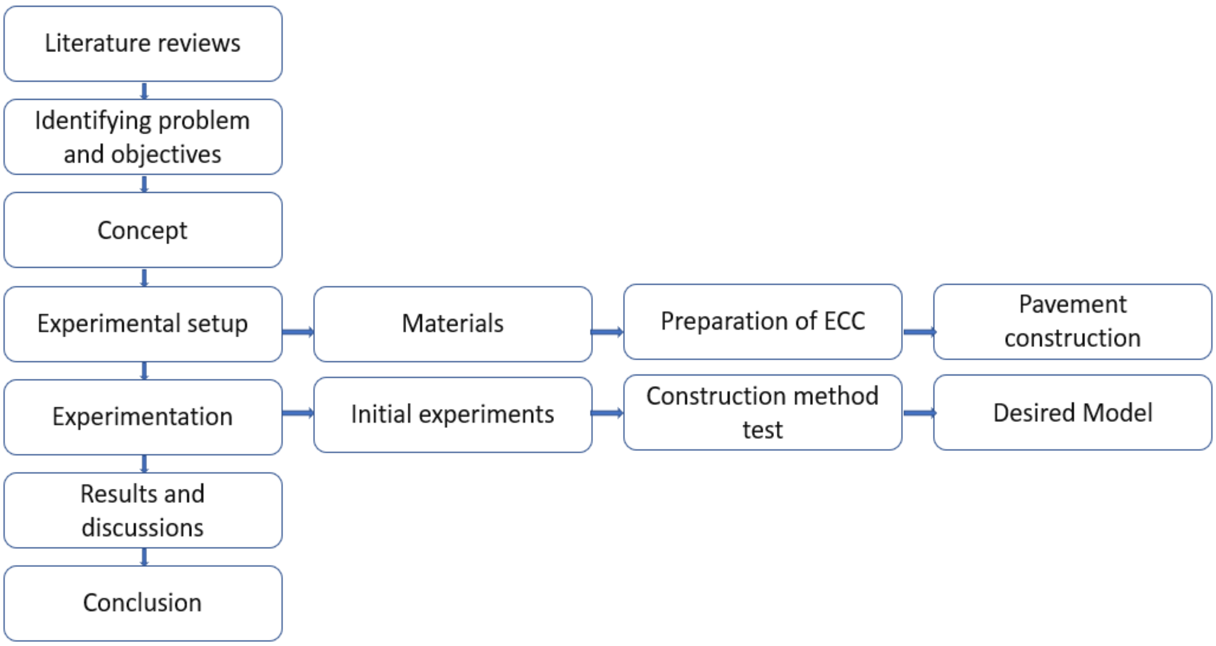


Figure 2: The methodology of this study

1.5 Thesis Organization

This thesis consists of five parts with the following contents:

Section 1 provides an overview of the subject of research. This section describes the research's problems and aims.

Section 2 provides a detailed review of the relevant literature of studies concentrating on various snow removal techniques.

Section 3 describes the model creation of the waste rubber tire and the processes used to apply the WRT into concrete specimens. This section also describes the material of the wire used as a bridge to help in passing the electricity into the rubber.

Section 4 is divided into three parts: the first describes the initial experiments conducted on the waste rubber tires until a good heat distribution was achieved; the second describes the experiments conducted on the concrete after the rubber was embedded in the concrete; and the third describes the snow melting experiment.

Section 5 summarizes the study's findings and issues, as well as the future research that must be conducted.

CHAPTER II

LITERATURE REVIEW

According to statistics, 10% to 15% of all accidents on the road are directly related to road conditions and weather. This percentage alone accounts for thousands of human injuries and fatalities as well as millions of dollars' worth of property damage every year. Ice accumulation on paved surfaces is not just an issue for cars; ice accumulation on sidewalks is responsible for several personal injuries due to slipping and falling[1]. Winter maintenance includes a variety of techniques to remove ice from pavements, including plowing, natural melting, traffic movement, and chemical treatment. Chemicals and fine aggregates serve as the primary deicing and anti-icing agents for most winter maintenance procedures for highways. Although sodium chloride is considered the most cost-effective material, the use of chloride can lead to corrosion of steel reinforcement, erosion of pavement and environmental pollution[2]. Simultaneously, mechanical equipment might result in outside damage and increased maintenance expenses [3]. These techniques are time-consuming, labor-intensive, and harmful to the environment [4], [5] since de-icing chemicals damage soil, surface runoff, and groundwater, therefore impacting the whole ecological system. It is predicted that by 2050, 50 percent of the world's arable land would be salinized, directly impacting the global food supply [6]. De-icing not only impacts the ecology, but also accelerates the pace of corrosion in infrastructure that is already aging [7]. Several innovative techniques for improving the removal of ice and snow from surfaces have been developed in replacement of these conventional methods. Numerous research efforts have been committed to creating cleaner and more sustainable methods for properly removing ice and snow from pavements, motivated by the economic, safety, and environmental implications of deicing chemicals. The use of superhydrophobic coatings on pavement surfaces [8]–[11] the incorporation of the electrically heated sheet/grille elements into the pavement [12], [13] and the application of heated pavement systems (HPS) [14]–[19] are some solutions developed for this purpose.

Researchers have been exploring more sustainable waste management and recycling methods. Recycling and reuse are the most effective waste management techniques. The pavement sector is a bright spot, since various types of waste are recycled into a variety of pavement applications, including rigid pavement, asphalt concrete, and bitumen. Several studies have been conducted to investigate the use of tire rubber in pavements. This chapter includes a comprehensive review of thermal snow melting technologies and a summary of the outcomes from several research studies that aimed to melt snow from pavement using various techniques. In addition, the benefits of various tire rubber applications in pavement from a sustainable approach.

1.6 Review on Heated Pavement Systems

1.6.1 Hydronic Heating Pavement Systems HHPS

The hydronic method works by heating water to melt ice and snow, heated fluid is circulated through pipes buried in pavement structures. The cooled fluid is heated each time it passes through the heat source[20]. Geothermal waters, boilers, and heat exchangers are all examples of heat sources. In areas where geothermal potential is high, geothermal water is thought to be highly effective[21]. One of the drawbacks of hydronic systems is that they are complex to create, require a large investment in terms of installation costs, and are difficult to repair if a fluid leak occurs[21]. HHPS was established in 1948 at the Klamath Falls Bridge, which is situated in Oregon, and it is still in use today[21]. For this project, the fluid was heated using geothermal well and sent through a heat exchanger to warm the bridge deck surfaces, melting ice and snow and improving skid resistance, hence reducing the number of car crashes. Recently, HHPS was erected on the aprons of the Greater Binghamton Airport in Binghamton. See Figure 3 utilizing geothermal wells as a heat source. The total area of the project was 3,200 ft2 (297 m2) at a cost of $ 1,600,000[22].

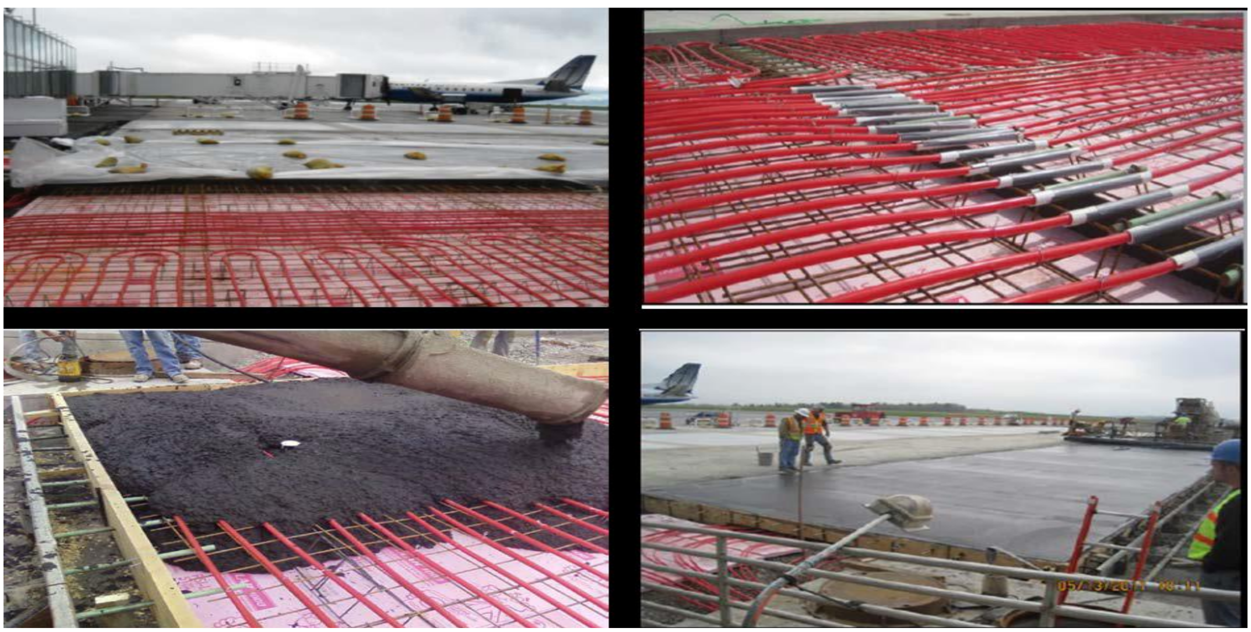


Figure 3: HHPS using geothermal source [22].

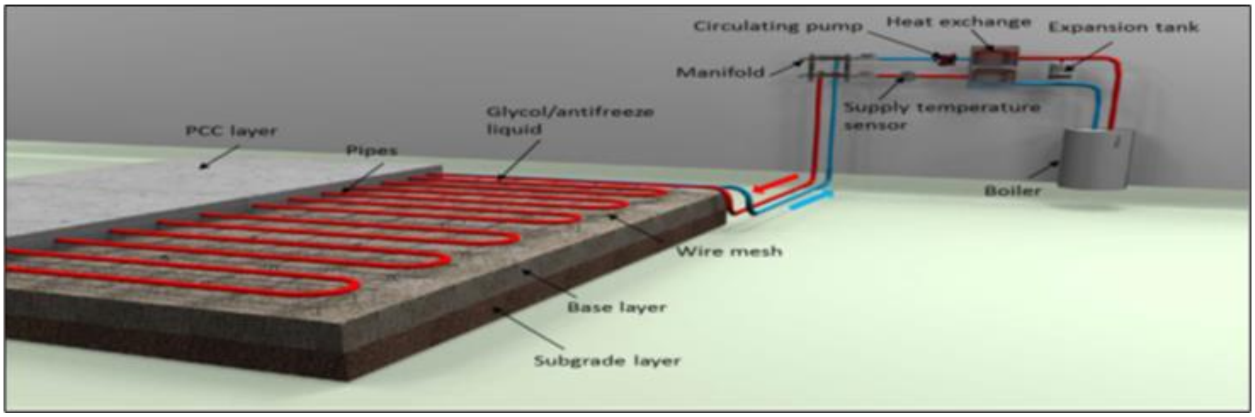


Figure 4: Detail of HHPS [24]

Gardermoen International Airport developed HHPS by using Aquifer Thermal Energy Storage (ATES) to heat and cool the aircraft parking space, which is 7,450 ft2 (700 m2) [23]. Additionally, the system was supported by an electric and oil-fired boiler to assist in raising the design load of 248 W/m2, since the ATES was unable to fulfill the intended load. As shown in Figure 4, the components of HHPS include heat transfer fluid, pipework, a fluid heater, pumps, and controllers [24]. By circulating hot fluid through pipes installed in concrete buildings, HHPS melts ice and snow. Each cycle, the cooled fluid is reheated by a heat source. Propylene glycol is a frequently used heat transfer fluid due to its inexpensive cost, high specific heat, and low viscosity[20].

1.6.2 Electrically Heated Pavement System (EHPS)

1.6.2.1 Heating using Electric Heating Cables. Using electricity as a source of heat to melt the snow is another technique of construction. Heating using Electric Heating Cables was an efficient method that significantly aided in mitigating the problem. Electric heating cables were placed on the approach to a highway drawbridge in Newark, New Jersey, in 1961, for snow removal and ice control [25].Figure 3 depicts the bridge approach highway in Newark, New Jersey, in 1961, with electric cables.

Figure 5: Electric cables in the bridge approach roadway, Newark, New Jersey 1961 [25]

The cables were put in two lanes of the bridge approach highway, which is 256 meters (840 feet) in length. The installation process consisted of four steps[26]: 1) placing a layer of coarse aggregate, 2) laying the heating cables, 3) manually spreading a 13 mm coat of sand-mix asphalt, and 4) paving machine laying a 38 mm final course. The installation cost around $54 per m2 ($5.0 per ft2). This price excludes transformers and service facilities. 378 and 430 W/m2 (35 and 40 W/ft2) of electricity were needed for the bridge and land fill regions, respectively. This amount of energy generated enough heat to melt 25 mm (1 in.) of snow each hour[26]. This project was eventually abandoned since the electric cables were torn out of the asphaltic concrete overlay by passing cars[26].

1.6.2.2 Electric conductive concrete pavement. (ECON). Among deicing techniques, electrically conductive pavement may be regarded as the most effective way for removing snow off roads, since it is a strategy that is inexpensive, efficient, ecologically friendly, and sustainable[27] . This is a specialized type of heated pavement system [4], [11], [19], [28] with a top concrete layer produced by adding electrically conductive material, such as carbon fibers [29]–[31] and steel shavings [26] into the concrete mixture [32] These systems not only improve the accessibility of transportation infrastructure, but also eliminate the need for enormous amounts of chemicals and vehicles powered by fossil fuels to remove snow and ice.

1.6.2.2.1 Components of electrically conductive concrete. The ECON system consists of an ECON layer (heating element), power supply, electrodes, electrical wiring, control system, polyvinyl chloride (PVC) conduit and temperature sensors to alert when the weather temperature drops to snow degree. All the preceding elements are the main components of the ECON HPS technology[20], [33]–[35]. The technology can be used as an overlay on top of a previous pavement system in good condition, or as the upper layer of a two-ladder paving system for new construction. Because it is essential to heat only the surface of the pavement where snow and ice accumulate, two-lift paving may be utilized to decrease construction material costs by lowering the ECON layer thickness[20], [33].

1.6.2.2.2 The working concept of electrically conductive concrete. Emerging material technology utilizes electrically conductive concrete for deicing. Conventional concrete does not carry electricity. The electric resistivity of normal-weight concrete varies from 6 to 11 KΩ m [36]. There are two ways that concrete may conduct electricity[16], [27] : electronically and electrolytically. Electronic conduction involves the movement of free electrons in a conducting media, while Electrolytic conduction includes the motion of ions in pore solution. In fresh concrete and during hydration, the movement of ions conducts electricity. In contrast, only free electrons may conduct electricity in hardened concrete with limited available moisture. Metals or other conductive fibers and particles must be included into the concrete matrix to provide a stable and sufficiently high electrical conductivity.

Table 1: Properties of Conductive Concrete with Steel Fibers and Shavings [16].

Properties	Test result
Unit weight	2397 kg/m^3
Compressive strength	35 MPa
Flexural strength	4.6 MPa
Modulus of elasticity	3634 MPa
Rapid freeze–thaw resistance	No failure during 312 cycles
Shrinkage	Less than ACI-209 by 20–30%
Permeability	0.004–0.007 cm^3/s
Thermal conductivity	7.8 W/m K
Electrical resistivity	500–1000 Ω cm

To conduct analysis on the properties of conductive concrete, we need to know the conductivity or resistivity of the materials. To determine the conductivity of concrete, it is necessary to comprehend the following properties: conductivity or resistance, distance, and the area of conductive concrete [27]. According to Equation 1's first Ohm law:

$$R = \frac{V}{I} \quad [37]$$

Electrical resistivity was derived from the second Ohm's equation in Equation 2:

$$\rho = \frac{RA}{L} \quad [2]$$

Electrical conductivity is the reciprocal of the electrical resistivity, as indicated in Equation 3:

$$\sigma = \frac{1}{\rho} \quad [32]$$

$$R = \frac{L}{\sigma A} \text{ [38]}$$

Where I represents the measured current, V represents the voltage, L represents the internal distance, A represents the conductive area, R represents the resistance, ρ represents the electrical resistivity, and σ represents the electrical conductivity. Joule's law is the combination of the rules governing the creation of heat and power by electricity. In addition, this rule, often known as the Joule effect, is stated as the heat produced by the passage of current through conductive materials. Where H is the heat production, I is the continuous current flow, R is the material resistance, and t is the period.

$$H = I^2 Rt \text{ [39].}$$

1.6.2.2.3 Existing electric conductive concrete pavement development. Thermal deicing has been the technology of choice for effective and eco-friendly snow melting solutions since the turn of the twentieth century. Which method uses heat from geothermal, solar, hydro and electric heat sources to melt snow and ice. Traditional deicing strategies have been given special consideration due to their effectiveness, eco-friendliness, safety and practicality. A relatively recent discovery in construction materials, electrically conductive concrete, is gaining widespread attention as a deicing technology. It is combined with dielectric aggregates, water, binders, and conductive elements to produce hybrid conductive materials [27]. Previous research investigations and studies on electrically conductive concrete pavement are summarized in Table 2.

Table 2: A summary of the studies conducted on electrically conductive concrete.

Research Team	Purpose	Ref.
Christopher Y. Tuan	The first implementation in the world of using electrically conductive concrete for deicing in the heated deck of Roca Spur Bridge.	[16]
Malakooti et al.	This research aimed to show the full-scale deployment of 10 ECON HPS slabs in the parking lot of the Iowa Department of Transportation headquarters in Ames, Iowa.	[33]
Hesham Abdualla	Determine the material selection, construction, and operating performance requirements for an ECON-based HPS.	[20]
Sassani et al.	This paper details the first use of an electrically conductive concrete (ECON) in a U.S. airport, including the mix design, manufacture, installation, and assessment of performance.	[34]
Lai Y, Liu Y, and Ma D	To minimize the detrimental effects of snow-melting chemicals on the construction, operation, environment, and safety of airports, a technique of melting snow using carbon fiber grille embedded in airport pavement is given in this research.	[35]
Wu J, Liu J, and Yang F	Testing three types of electrically conductive concrete composites using Carbon fiber, steel fiber, and steel fiber-graphite, and the elements that effect conductivity are investigated.	[2]
Chang et al.	In this project, an anti-ice concrete slab was constructed by supplying a conductive concrete pavement overlay with direct current energy from a solar energy system.	[13]
Hou Z, Li Z. and Wang J	Two strategies for increasing the electrical conductivity of carbon fiber electrically conductive concrete were addressed.	[40]

Table 2, cont.

Yehia and Tuan	A conductive concrete overlay is cast on the top of a bridge deck in this application for deicing or anti-icing.	[1]
Wu et al.	This study's primary objective is to examine the electrical and thermal characteristics of conductive concrete with varying graphite concentrations, specimen size, and applied voltages.	[41]
Rao et al.	This paper presents an experimental analysis of the thermal characteristics of an electric heating concrete containing steel fiber and graphite that is utilized for snow melting outside and inside radiant heating.	[42]
Shishegaran et al.	By adding steel wire rope and steel powder wastes into the concrete mix, this study seeks to do two things: (a) increase the conductivity and mechanical characteristics of conductive concrete; and (b) address environmental concerns related to recycling and reusing these materials.	[43]

1.6.3 Electrically Conductive Coating

To create a suitable electrically conductive composite, enough conductive materials and binders are required; as conductive materials, several carbonaceous materials, such as carbon nanofibers [44]], [45]], graphene [46], and carbon black [81], graphite powder [27] have been utilized in previous studies.

1.6.3.1 Electrically Conductive Coating components. The binders Conductive fillers must distribute uniformly during blending with binders to provide sufficient conductive channels inside the composite. This synthesis required a suitable binder and the ability to adhere well to substrates. Several types of polymers can be utilized as a binder in composites; for example, epoxy resin has been utilized as a binder and applied to different substrates, including Portland cement concrete (PCC) surface [5] and asphalt concrete pavement surface [8], [10]. Polyurethane (PU) polymer has attracted increased interest as a coating material in recent years due to its improved substrate adhesion. Waterborne polyurethane (WPU) has surpassed solvent-based polyurethanes in popularity due to its low toxicity, which favorably influences surface coating applications. In addition, WPU has exceptional characteristics, including flexibility, abrasion resistance, plasticity, and broad substrate application [47]–[49]. WPU has been used as adhesives and coatings on a variety of substrates, including plastics, leather, textiles, paper, rubber, and wood [50], [51]. Polyvinylidene fluoride, also known as PVDF, has been used as a binder in the process of forming superhydrophobic coatings on substrates [45], [52], and [53]. Despite its low strength and poor adhesion. **The conductive materials** to improve the thermal stability, mechanical toughness, and electrical conductivity of polyurethane-based compounds, various conductive fillers, such as glass fiber, carbon nanotube, carbon fiber, carbon black, and graphite, among others, were directly inserted into the polyurethane material, either on their own or in combination with one another. Graphite (GP) is considered to be less expensive than other fillers and to have shown exceptional conductivity and hardness [27]. Graphite powder (GP) with micrometer-sized particles may enhance network microstructure channels, hence facilitating the efficient passage of current through the composite. The composite containing WPU, and varying amounts of GP displayed superior electrical and thermal properties [27]**.**

1.7 Review of recycling rubber tires and its uses in civil engineering industry

The expansion of modern cities has a significant influence on the environment in terms of the depletion of natural resources for the manufacture of engineering building materials and the rise in the generation of garbage destined for landfills. As waste tires are disposed of in landfills, illegally dumped, or stockpiled, they contribute to a variety of environmental problems [54], [55] The direct disposal of discarded tires in landfills or stockpiles is no longer a viable option. Tire stockpiling generates several health, environmental, and economic problems through air, water, and soil pollution [56] and disease breeding environments [55]–[58] In addition, tires are made of incompressible, non-biodegradable materials, therefore their degradation process is exceedingly slow [59], [60] Globally, the disposal of used tires is a significant environmental issue [61]. Approximately one billion tires worldwide reach the end of their service life yearly, half of which are disposed to landfill [58]. Every year, nearly 1.5 billion tires are manufactured globally. Estimates indicate that by 2030, 1.2 billion tires will be discarded yearly [58]. There are now fifty-one million equivalent passenger tire units in stock in Australia are accumulated yearly. Only 5% of used tires are recycled into new products like scrap tires, tire chips, or tire derived aggregates (TDA) [62]. Tire burning was a common early method of disposal. In terms of effort and cost, this was the best option [58]. Nevertheless, this choice has significant drawbacks for the environment and human health as well as creates fire hazards. Once tire inventory fires begin, they are difficult to put out because each empty area around each tire extends the life of the combustion process by providing abundant oxygen, creating a flammable environment [58]. The combustion process also results in the uncontrolled release of potentially hazardous chemicals, including polyaromatic hydrocarbons, carbon monoxide, Sulphur dioxide, nitrogen dioxide, hydrogen chloride, butadiene, and various styrene and benzene compounds [56], [58]. The residue from the fire and the oil produced by the combustion of the tires contaminates the land and surrounding surface and ground waterways. In addition, uncontrolled fire dangers in tire stockpiles are a significant risk that should be considered, especially for tire stockpiles located near urban and residential areas. The recent tire stock fire in Melbourne, Australia, demonstrates the potential risk of toxic gases that could affect adjacent communities and waterways [63] . Another technique for disposing of used tires is to use tires as fuel for energy production [55], [64]. However, this method is not economically viable because of the higher cost of processing carbon black from tires and its poorer quality than petroleum products [58]. As the earth's natural resources are finite, the increasing demand for traditional quarry materials in pavement construction is one of the primary reasons why these materials have become exceedingly rare and expensive to extract. In addition, over half of all global building and demolition waste consists of demolition concrete wastes [63], [65], [66]. As the earth's natural resources are finite, the increasing demand for traditional quarry materials in pavement construction is one of the primary reasons why these materials have become very scarce and expensive to extract. In addition, more than half of the construction and demolition waste worldwide is demolition concrete waste [63], [65], [66].

Figure 6: an enormous number of tires are fired.

Figure 7: a substantial number of tires are stored in landfills.

1.7.1 Rubber tires components

The tires are made of a flexible elastomeric rubber material with a textile and metallic structural reinforcement. The rubber composition of a tire ranges between 46–48%, carbon black between 25–28%, steel inserts between 10–12%, oil and vulcanizing agents between 10–12%, and synthetic yarn and textile inserts between 3–6%. Although tires contain potentially useful components such as carbon black, organic oils, and steel, it is exceedingly difficult to extract these elements in a cost-effective manner.

1.7.2 Methods and procedures for recovering rubber waste.

Two main problems arise: the accumulation of substantial amounts of rubber tires waste and the generation of environmental pollution. Worn tire holes can expand rapidly, creating not only land use problems, but also environmental hazards as (dumps) spontaneously combust, resulting in long-term fires. Two solutions to these issues would be waste recycling and reuse, as well as waste material recovery.

The advantages of applying these two solutions can be:

- By temporarily storing used tires, the danger of contamination is reduced.
- Increasing the utilization rate of the used tires.
- Decreasing the use of raw materials, particularly those derived from nonrenewable sources, by using used tires as secondary raw materials.
- Repair and refurbish used rubber products to the same quality as the original.
- Reuse for other rubber products Recycling as the reintroduction of material into regenerated elastomeric compounds or rubber powder.
- Reuse as a source of different starting materials, such as carbon black or pyrolysis oil, as a fuel to generate thermal energy for the manufacture of cement or steel.
- Reuse as a material modifier, especially in road construction.

Figure 8: Tire derived materials

Figure 9: Tire processing

1.7.3 Previous studies on using rubber in civil engineering industry

There are different concerns regarding the introduction of rubber into pavement, whether concrete (rigid pavement) or asphalt (flexible pavement). It is difficult to produce a homogeneous mixture with a homogeneous rubber dispersion. This review investigates these issues in detail and provides a detailed look at how rubber is used in different civil, construction and pavements applications. Previous research investigations and studies on using rubber in civil engineering applications are summarized in Table 3.

Table 3: A summary of the studies conducted using rubber in civil engineering industry.

Research Team	Purpose	Ref.
Bulei et al.	The study discusses product components resulting from the crushing of old tires (powders) that can be used in the field of rubber-containing street furniture or building materials.	[67]
Arulrajah et al.	In this study, an experimental investigation is conducted to understand the compression behavior of concrete by substituting natural aggregates with recycled tire rubber in varying amounts, ranging from 10% to 50% by volume.	[68]
Girskas and Nagrockiene˙.	The study conducted several experiments to evaluate the compressive strength, water absorption, and ultrasonic pulse velocity of specimens made of concrete modified with rubber crumb.	[69]
Li et al.	This review discusses and analyzes the significant achievements of crumb rubber concrete (CRC) in the last 5 years, including its fresh concrete qualities, mechanical properties, durability, and other features.	[70]
Thomas and Chandra Gupta	This study summarizes the findings of an experimental investigation into the applicability of recycled tire rubber as a partial replacement for natural fine aggregate in high strength cement concrete.	[71]
Guo et al.	This research intends to enhance the performance of rubber concrete by applying various surface treatment and coating techniques. Specifically, two surface preparation procedures (NaOH and Silane Coupling Agent) and three coating techniques (coated with standard cement, blended cement with silica fume, and blended cement with sodium silicate) were used to increase rubber-cement bonding.	[72]

Table 3, cont.

Iman Mohammadi	This study established a link between the strength of rubberized concrete and three essential parameters, including the water-cement ratio (WC), the age of the concrete, and the rubber content, based on a significant number of experiments. Using this relationship, concrete makers may accurately predict the strength of rubberized concrete.	[73]
Hossain et al.	This study evaluates the feasibility of using large rubber blocks from crushed tires as aggregates in cold mixes in road construction. The purpose of the study was to produce block rubberized asphalt concrete mixtures for small-scale road construction using local aggregates, crushed tire rubber blocks and cationic emulsions.	[74]
Mohammed et al.	This study provides a review of the most current investigations on the fresh and hardened characteristics of rubber-crete. In addition, rubbercrete construction components and products have been emphasized. Additionally, the potential applications of rubbercrete have been considered.	[75]

CHAPTER III

RUBBER PREPARATION INTRODUCTION

The use of waste rubber tires on pavement has numerous benefits. First and foremost, it helps to reduce waste in landfills and the environment. Additionally, rubber tire waste provides an alternative to traditional materials used in pavement such as asphalt and concrete, leading to a more sustainable solution. The rubber also provides improved traction and durability to the pavement, resulting in safer road conditions and reducing the need for maintenance. Furthermore, the use of rubber tire waste in pavement helps to create jobs and stimulate local economies. Overall, using waste rubber tires in pavement is a smart, environmentally friendly, and economically viable solution for our roads.

In this chapter, a comprehensive explanation of the methodology used to introduce a new approach to sustainable construction, focused on creating electrically conductive pavements, is provided. The methodology starts with an overview of the system and its objectives, followed by a description of the system components and the steps taken to assemble it. The components include recycled rubber from tires, highly conductive wires for electrical circuit design, and rigid concrete pavement samples. The criteria for component selection are also discussed.

1.8 Heated pavement system description

Heated pavement systems can be created by adding conductive materials to the pavement surface, such as carbon fibers, metal wires, or other conductive elements. These materials are embedded into the pavement surface during construction and connected to a power source. When electricity is supplied to the pavement, the conductive materials generate heat, which melts snow and ice and prevents their accumulation. This method is particularly useful in areas with heavy snowfall or icy conditions, as it can improve safety and reduce the need for traditional de-icing methods. Heated pavement systems are also more environmentally friendly than salt or chemical de-icing agents, which can have negative effects on surrounding ecosystems. While the upfront cost of installing a heated pavement system can be high, it can provide long-term cost savings by reducing the need for maintenance and repairs associated with winter weather damage.

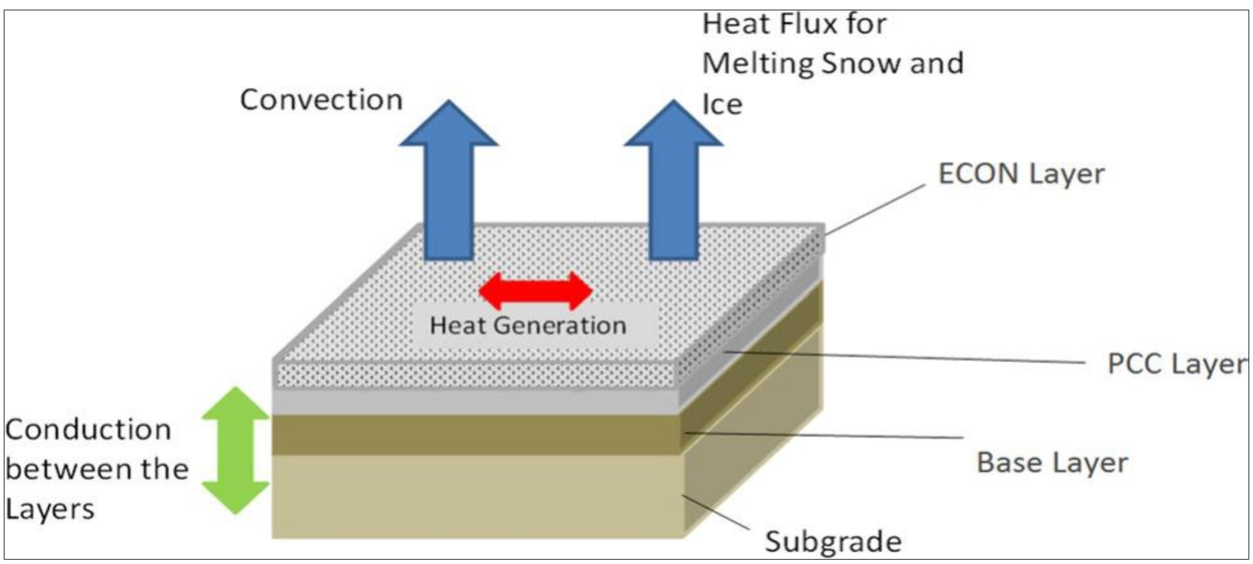


Figure 10: Schematic illustration of the electrically conductive rigid pavement system [76].

1.9 Rigid pavement overview

Rigid pavement is a type of pavement that is made up of a concrete slab that is constructed in a series of layers. The layers of a rigid pavement include the subgrade, which is the natural or prepared surface on which the concrete slab is placed, followed by the sub-base layer, which is a layer of granular material that is placed on top of the subgrade to provide a stable base for the concrete slab. The next layer is the base course, which is made up of high-quality concrete or stabilized soil and provides additional support for the concrete slab. Finally, the concrete slab is placed on top of the base course, forming the top layer of the rigid pavement. The concrete slab is designed to withstand heavy traffic loads and to distribute the load evenly across the pavement surface, resulting in a long-lasting and durable pavement structure.

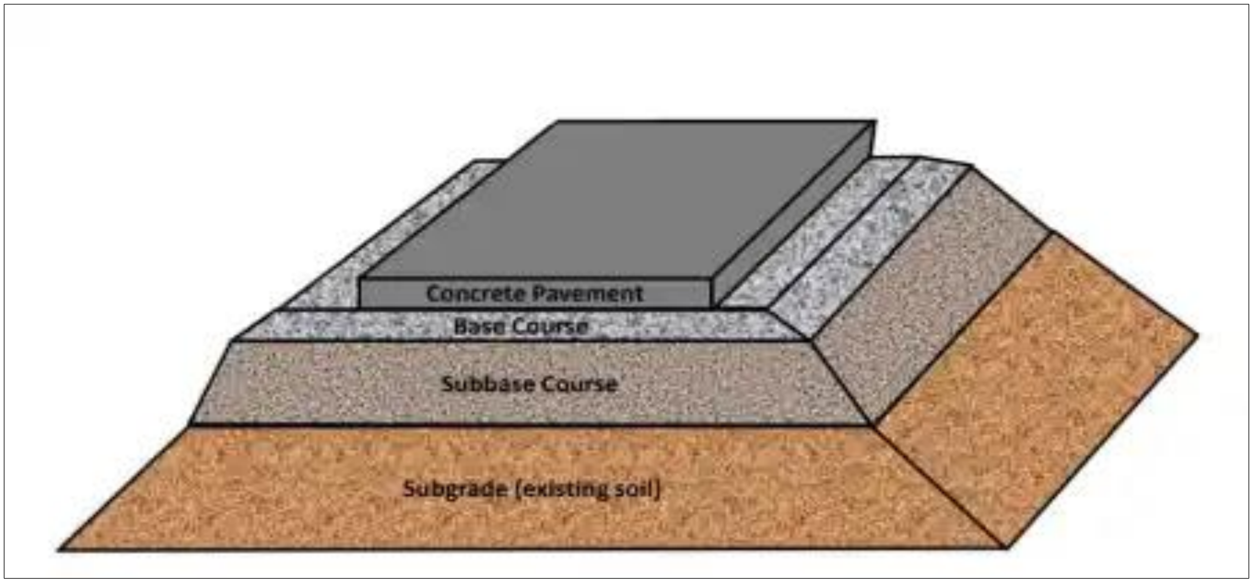


Figure 11: Typical Rigid Pavement Structure

1.10 Sustainability in heated pavement systems with using the waste of the rubber tires

Sustainability in construction is becoming increasingly important, and one area where sustainable practices can be implemented is in the installation of heated pavement systems. Heated pavement systems are used in areas that experience snow and ice accumulation, such as driveways, walkways, and parking lots, to reduce the need for manual snow removal and the use of de-icing chemicals. However, these systems can consume a lot of energy and have a significant environmental impact. To make them more sustainable, several measures can be taken, such as using renewable energy sources like solar or geothermal energy to power the system, using energy-efficient equipment and controls, and designing the system to only operate when necessary, such as when the temperature drops below a certain level or when precipitation is detected. Additionally, materials used in the construction of the pavement, such as the concrete and insulation, can be chosen to be environmentally friendly and have low embodied energy. Implementing these sustainable practices in the installation of heated pavement systems can help to reduce the environmental impact and promote sustainability in the construction industry. Using the waste of rubber tires in the heated pavement system is a sustainable point of view that can significantly reduce the environmental impact of the system. Rubber tires are a significant waste product, and they take a long time to decompose, causing environmental problems. However, using recycled rubber in the heated pavement system can help to reduce the amount of waste tires in landfills and minimize the environmental impact of the system. Recycled rubber can be used in various ways in the pavement system, such as adding it to the concrete mix or using it as insulation. Rubber is an excellent insulator and adding it to the pavement system can help to improve its thermal efficiency and reduce energy consumption. Additionally, rubberized pavement is more durable and has better skid resistance than traditional pavement, reducing the need for repairs and enhancing safety. Overall, incorporating waste rubber into the heated pavement system is a sustainable point of view that can help to reduce waste, save energy, and promote environmental sustainability.

1.11 Research conceptualization

This research was inspired by the invisible thermally conductive paint used to defrost and defog laminated car windshield glass. This study used a similar concept, which resulted in the creation of an innovative methodology for deicing pavements utilizing electrically conductive stripes. This approach is considered as a more sustainable construction option for safely and securely removing ice and snow from the pavement due to its low cost, little pavement damage, and environmental friendliness.

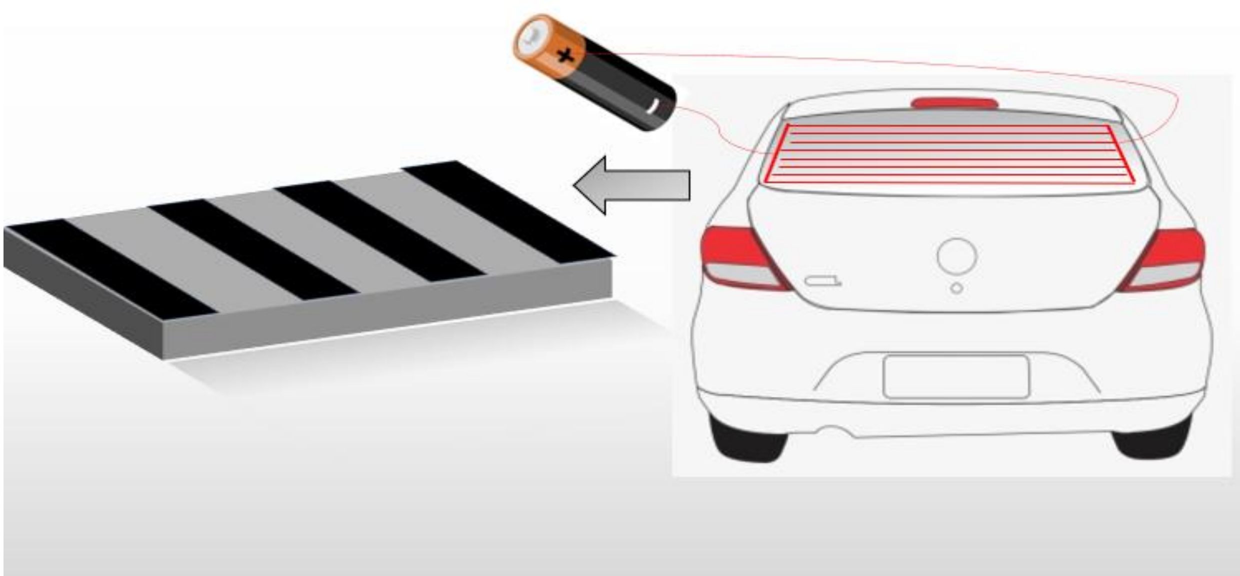


Figure 12: : The conception of a new method for electrically conductive pavement.

1.12 Pavement design

The American Concrete Institute (ACI) provides guidelines for the design and construction of concrete pavements, including rigid pavements . The mix design of the concrete is crucial in determining its strength and durability. The mix contains the right proportions of cement, aggregates, water, and any admixtures, in order to achieve the desired strength and workability. The concrete should be placed and finished according to industry best practices, taking into account factors such as concrete temperature, slump, and air content. The surface of the concrete should be properly finished to ensure that it is smooth and free of defects that could lead to premature pavement failure. Proper curing is critical to the strength and durability of the pavement. The pavement should be cured in accordance with industry standards, using methods such as wet curing or curing compounds to ensure that the concrete develops the required strength and durability over time.

1.13 System description

The rubber tires contain between 10 and 12 % of steel wires manufactured from high-carbon steel, which is a highly electrically conductive material. The aim of this study is to address the gap in earlier research on melting snow, which only focused on efficiency but neglected aspects such as cost, environmental impact, and sustainability. The study aims to suggest a new, environmentally friendly, and economical method for melting snow. The method is based on the use of waste rubber tires (WRT) instead of traditional materials like carbon black and carbon fiber. This approach would reduce the waste of tires generated every year and lower the time they are stored in landfills, mitigating their environmental harm. The study will examine the feasibility of using a mesh of steel wires embedded in WRT as an electrical and heat conducting element to create enough heat to melt snow on pavements, highways, bridges, and airport runways. The goals of the study are to solve the problem of snow accumulation, minimize the consumption of raw materials by using a sustainable source, and find new uses for WRT in the construction industry. As shown in figure 9 the system's concept was inspired by the utilization of the valuable steel wire mesh embedded into rubber tires. This study's approach is divided into three stages. **The first stage**: is to utilize the steel wire mesh embedded in the rubber as an electrically conductive material since an electric circuit is designed into it, so that, when the electric circuit is connected to a power source, heat can be produced as a result of electricity passing through the steel wire mesh embedded in the rubber, and the rubber sample will function as a heat source. **The second stage**: is to bury the rubber sample (the heat source) inside the concrete (the rigid pavement) at equal intervals of distance. **The third stage**: is testing the capability of the combined sample (rubber sample and concrete) for melting the ice.

Figure 12 provides a comprehensive explanation of the concept, along with a detailed breakdown of the steps involved. Figure 13 illustrates a simulated version of the concept in a real-world context, offering a visual representation of how it would appear in practice.

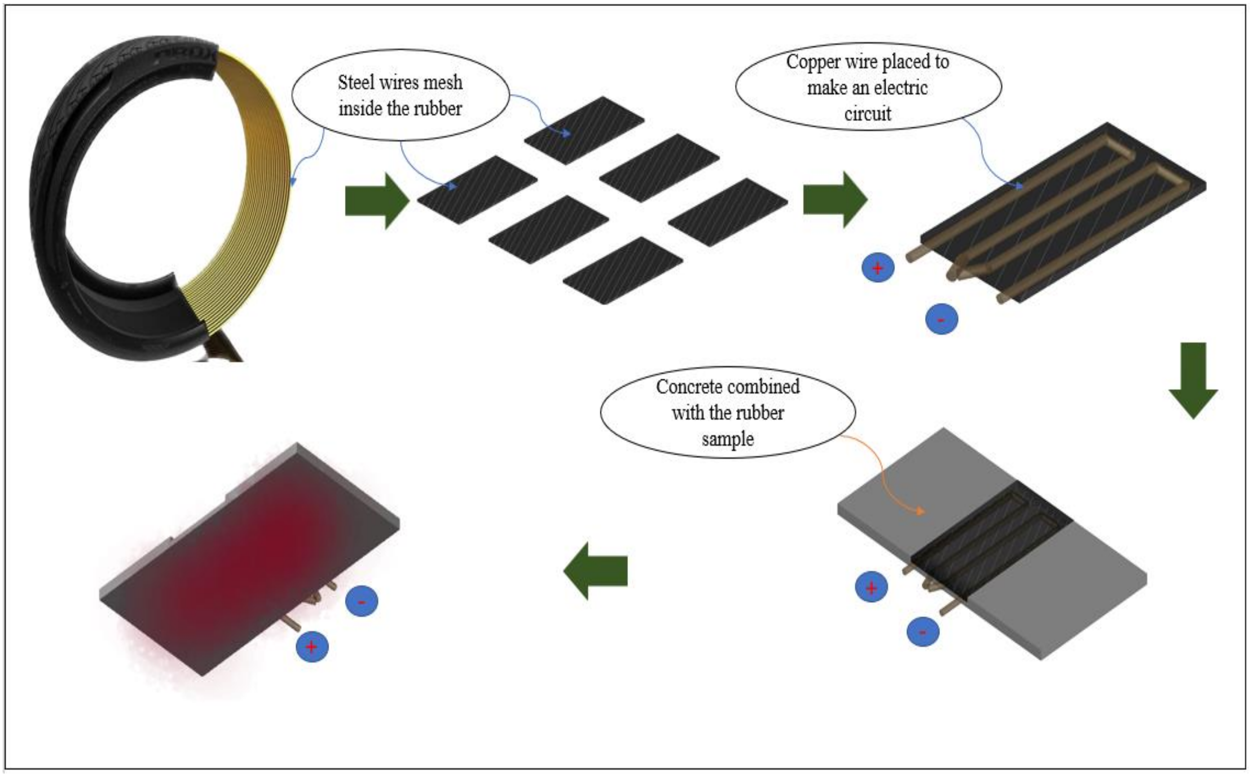


Figure 13: Simulation of the methodology and the main procedures of the study's approach.

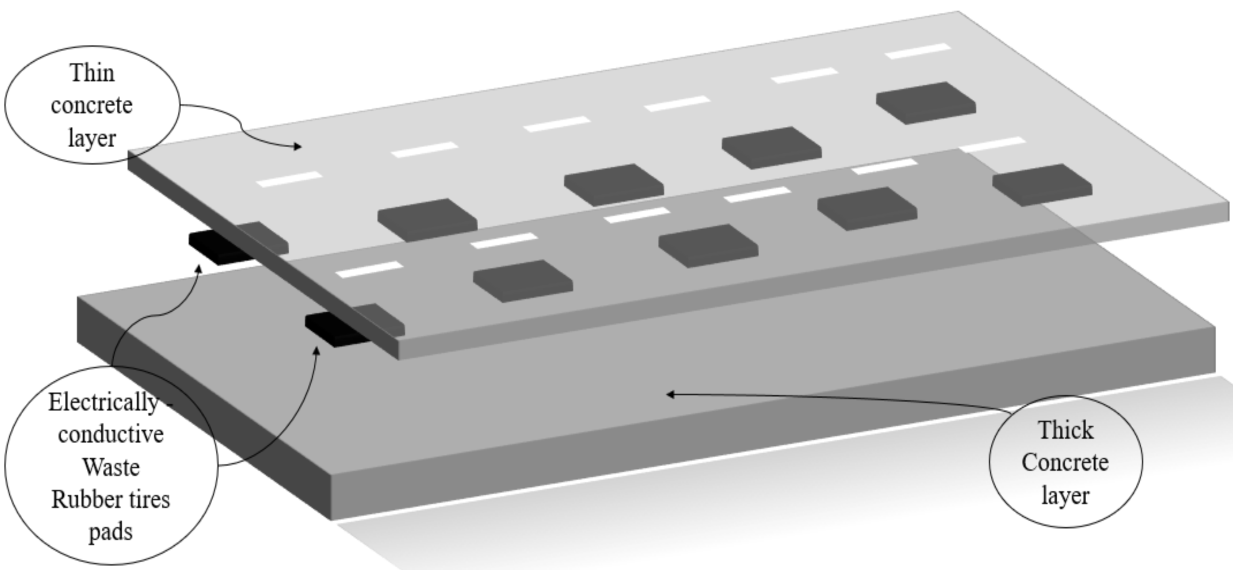


Figure 14: Simulation of the methodology of the study's approach in rigid pavement.

1.14 The first stage (rubber samples preparation)

This phase is titled "preparation of rubber samples," is comprised of four primary stages, which are as follows: 1) cutting the rubber to the desired size, 2) creating an electrical circuit and selecting materials, and 3) Classifying the rubber samples. 4) assessing the electrical conductivity and temperature increase of the rubber samples through testing.

1.14.1 Cutting the rubber to the desired size

To begin preparing for the experiments, a request was made to a tire shop for a used tire as indicated in figure 10a, then the tire was sent a steel wielding shop to be processed into eight equal parts to enable the subsequent procedure of slicing it into rectangles figure 14b, 14c. The eight sections were then brushed and cleaned, before being marked with the appropriate required dimensions as shown in figure 14d. Each piece of the eight pieces were cut into two types of dimensions, the first one is (5 cm width, 17.5 length), and the second type is (10 cm width, 17.5 length) as shown in figure 14d, 14e. It is important to note that only the tread area of the tire was marked since it contains most of the steel wire mesh while the sides do not.

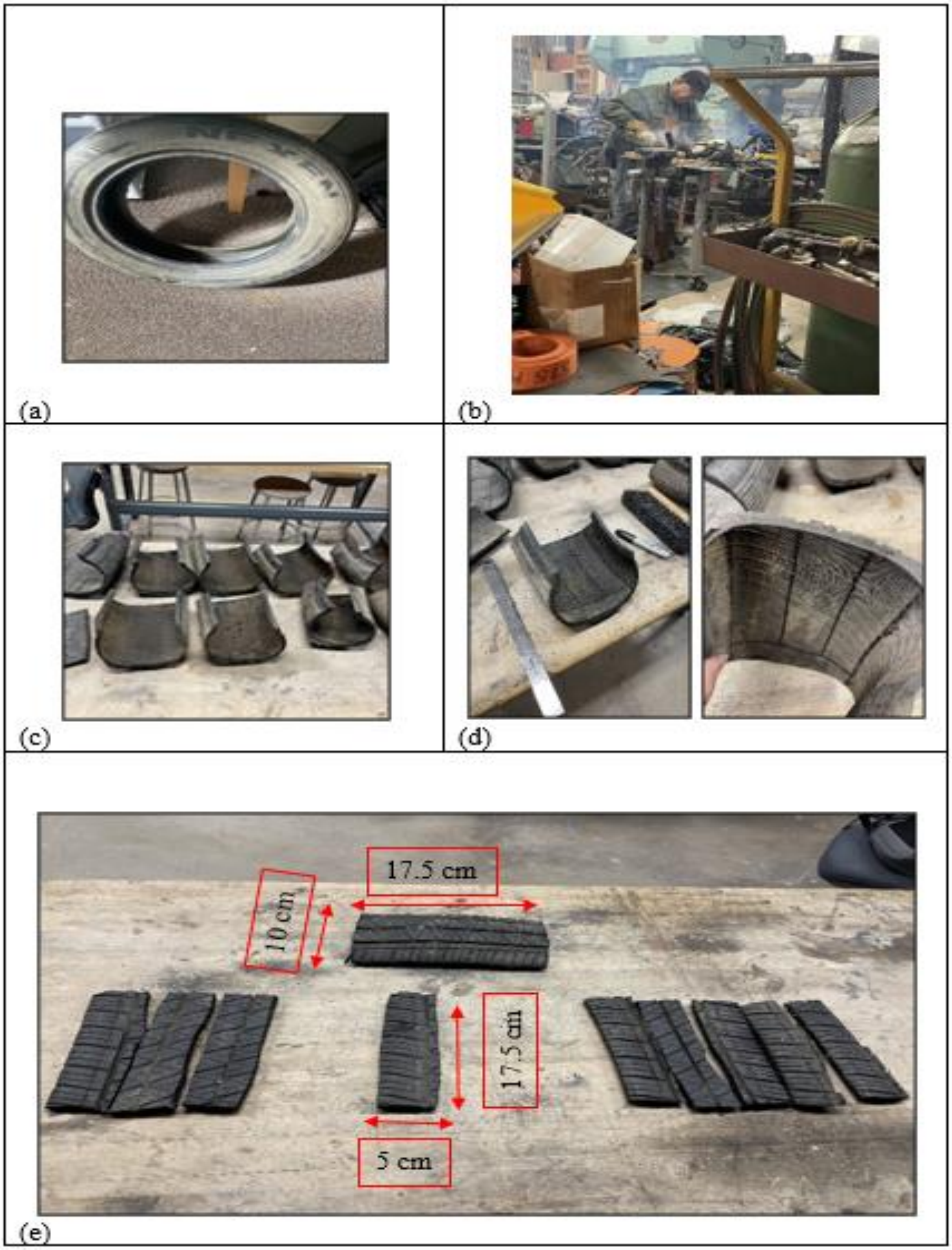


Figure 15: The main preparation steps for experimentation.

1.14.2 Creating an electrical circuit and selecting materials

1.14.2.1 Steel cords under the tread of the tire. The steel cords in a tire are typically made from high-tensile steel wire, which is a type of low-carbon steel that has been specially processed to increase its strength. High-tensile steel wire has a high strength-to-weight ratio and is able to withstand the stresses and strains of driving on the road, making it an ideal material for use in tire cords. The steel cords are typically made from multiple strands of high-tensile steel wire that are twisted together to form a cable-like structure as shown in figure 4a. The steel wire is then coated with zinc to prevent corrosion and improve adhesion to the surrounding rubber. The electrical conductivity of zinc-coated low-carbon steel can vary depending on the specific composition of the steel and the thickness and quality of the zinc coating. However, in general, the electrical conductivity of zinc-coated low-carbon steel is typically slightly lower than that of uncoated low-carbon steel. The electrical conductivity of low-carbon steel can range from about 6.99 × 10^6 S/m (Siemens per meter) for annealed low-carbon steel to about 2.07 × 10^6 S/m for cold-worked low-carbon steel. The presence of a zinc coating on the low-carbon steel can slightly reduce its electrical conductivity, but the exact reduction can vary depending on factors such as the thickness and quality of the zinc coating. In summary, while the electrical conductivity of zinc-coated low-carbon steel may be slightly lower than that of uncoated low-carbon steel, it is still a good conductor of electricity and can be used in various electrical applications.

1.14.2.2 Designing the electric circuit. To design an electric circuit within rubber samples, two types of conductors were utilized as shown in Figure 15: bare copper wire and galvanized steel wire. Copper wire is a good conductor of electricity with a high electrical conductivity of approximately 100% IACS. It also has low electrical resistance, allowing for efficient transmission of electrical energy. However, despite copper's high thermal conductivity it is still an expensive material, therefore, galvanized steel wire is also utilized in electrical circuit design due to its affordability and lower thermal conductivity and higher electrical resistance compared to bare copper wire.

Table 4: Prosperities of the two types of conductors (copper and galvanized steel)

Material	Electrical Resistivity	Melting point	Density	Heat conductivity
Copper	Approximately 100% IACS (International Annealed Copper Standard)	1084°C (1981°F).	8.96 g/cm3.	401 W/mK.
Galvanized steel	Typically, around 10-40% IACS (International Annealed Copper Standard)	1539°C (2798°F).	7.8 g/cm3.	50 to 60 W/mK.

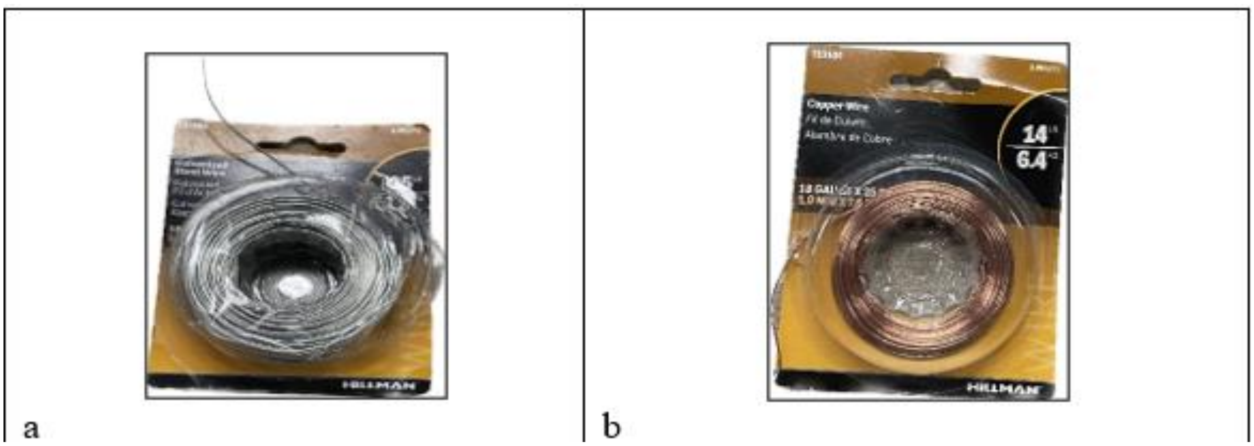


Figure 16: a) galvanized steel wire. b) copper wire, used for designing the electrical circuit.

1.14.3 Classifying the rubber samples

After the used tire was cut into the specified size as previously stated, the rectangular pieces were divided into two categories in preparation for the next experiments. The first category is the "**Exposed sample**" where the top layer of rubber was completely removed to access the steel wire mesh beneath. The second category is the "**Grooved sample**" where parallel grooves were created to reach the wire mesh without removing the entire top layer of rubber, which is a more efficient and time-saving approach as it eliminates the need for removing the entire top layer. Figure 16 shows the differences between the exposed sample and the grooved sample.

Figure 17: a) Exposed rubber sample. b) Grooved rubber sample.

1.14.3.1 **Exposed samples.** It was required to expose and remove the top rubber layer of the sample, as shown in figure 17, in order to accurately observe the heat distribution across the rubber sample. As can be seen in figure 17a, a mechanical instrument known as a vise was first utilized to firmly hold the sample, after which a saw was used to cut the sample precisely and slowly in order to detach the top layer of the rubber. The hammer driller tool shown in figure 20e was used to remove and clean the steel wire mesh after it was cut by the saw. Following that, the resistance for each steel wire in the mesh was measured using a multimeter to ensure that all the wires are electrically conductive and that there are no flaws in any of these wires, as shown in figure 13b, and it measured 0.8 Ω.

Figure 18: Exposing the rubber sample.

1.14.3.2 Grooved samples. It was determined that creating only longitudinal grooves within the rubber samples to reach the underlying steel wire mesh would be a more feasible and practical option, instead of completely removing the top layer of rubber. This would save time and prove to be more economical. The width of the grooves is roughly 0.5 cm. The design of the grooves was based on the appearance of the electric circuits within the rubber sample, with multiple shapes and designs being explored to ensure a balanced distribution of heat on both the top and back of the rubber sample. It worth noting that, The focus of this study was not to achieve the most ideal design for the electric circuit in the rubber sample, but rather to attain a balanced heat distribution on both the front and back sides of the rubber sample. Figure 18 shows different samples of the rectangular rubber samples after being grooved and the steel wire mesh was completelty exposed and cleaned from all the rubber layer on top of it.

Figure 19: Rubber samples with longitudinal grooves.

1.14.3.3 Steps of making the grooves. Figure 19a and 19b demonstrate the rubber sample being securely held in place by a mechanical device known as a vise attached to a boring machine. To create the grooves, a specific metal pin was utilized, as shown in figure 19c. The pin was moved carefully and gradually to reach the steel wire mesh within the rubber, taking care not to cause any damage to the mesh during the drilling process. Once the grooves were made, the hammer drill shown in figure 19d was used to fully remove the rubber layer from the steel wire mesh and ensure a smooth flow of current through the electric circuit without any defects or harm to the steel wire mesh.

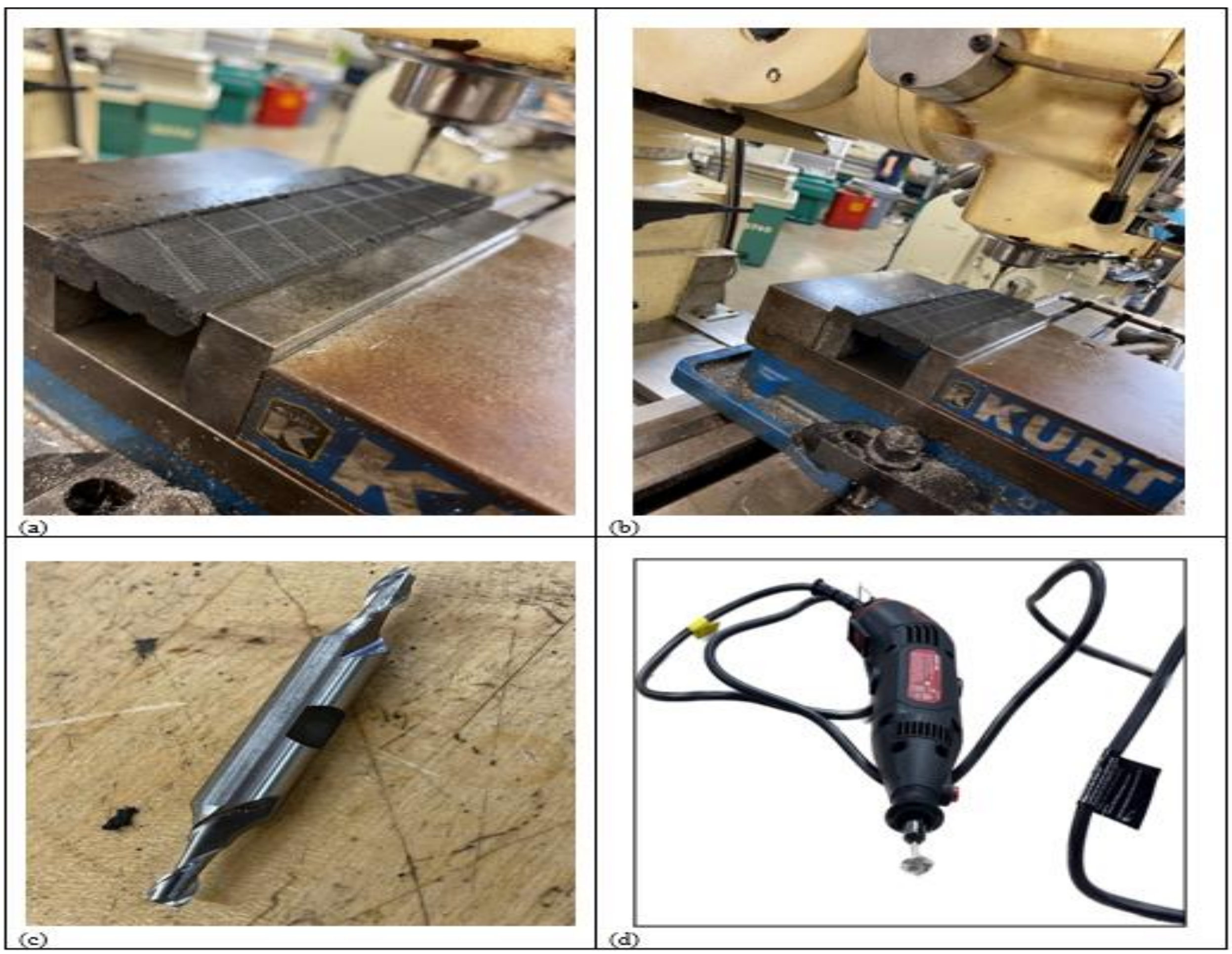


Figure 20: making Rubber samples with longitudinal grooves.

1.14.4 Electrical conductivity and temperature increase of the rubber samples.

1.14.4.1 Initial experimentation for the exposed sample. A thin rubber layer remained on some of the exposed steel wires, requiring the removal and cleaning of each steel wire using the hammer drill tool seen in figure 14e to ensure that they were all totally exposed. After ensuring that the sample was thoroughly exposed, it should be ready for heat observation experiments. Using the bared copper wire seen in figure 20f, an electrical circuit was created and put on top of the exposed sample. The copper wire was put in two parallel lines in order to force the electricity to flow through the inclined steel wire mesh, and then metal pins were utilized regularly along the copper wire to establish a strong connection between the two metals the copper and the steel, as seen in figure 21a. The indicated numbers 1,2,3, and 4 reflect the spots where the power supply (shown in figure 20c) should be connected to the circuit. The two points 2 and 4 were selected to be connected to the power supply and to close the circuit. The sample was then connected to the power supply seen in figure 21a, the experiment lasted for 10 minutes, and it was monitored by the stopwatch depicted in figure 20a, since this is a preliminary experiment and a proof of concept. The red dots shown in figure 21 reflect the locations where the temperature degrees were measured using the Infrared thermometer seen in Figure 20d.

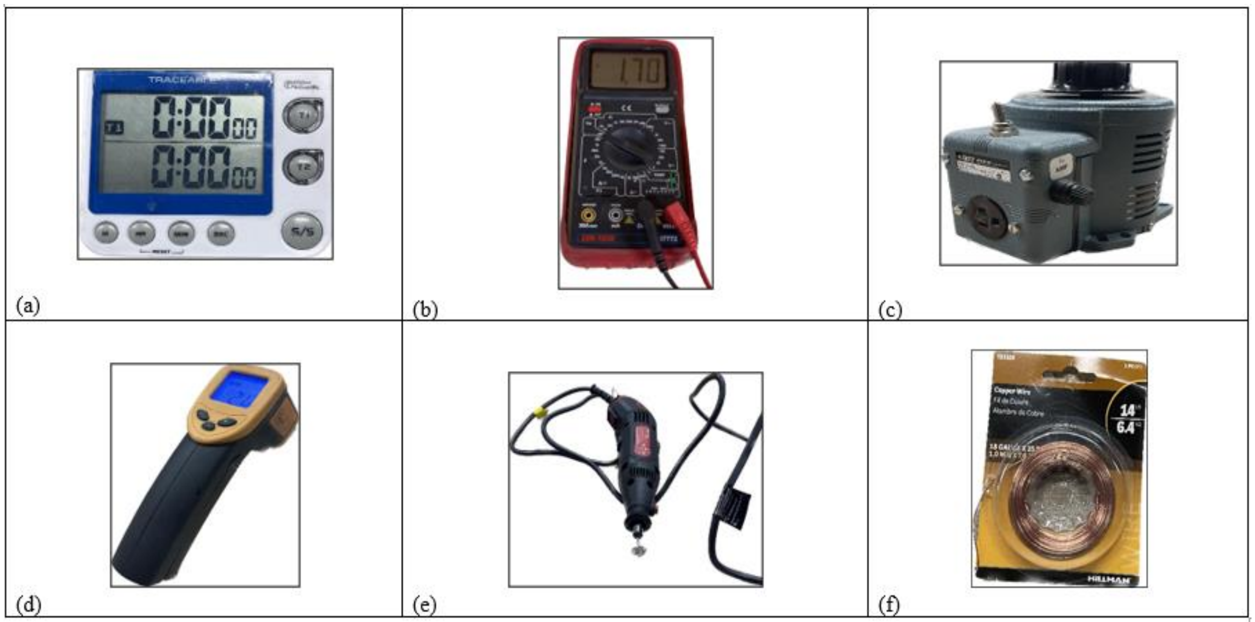


Figure 21: The measurement system and tools.

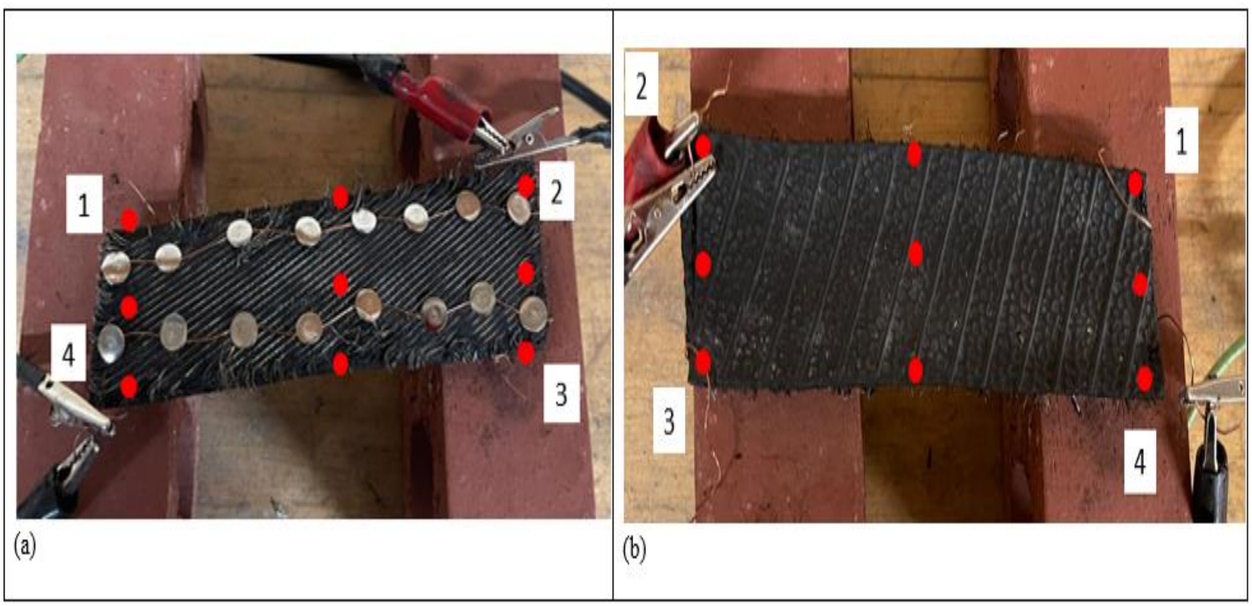


Figure 22: Testing the increase in temperature.

1.14.4.2 Experimental results and observations. The rubber sample's back side and the front side where the electric circuit was created are shown in Figure 21. One of the most crucial factors in this study is making sure that a sufficient excellent heat distribution is accomplished on both sides of the rubber sides. The rubber sample was split into three stripes with 3 points on each strip. These red points represent the places where temperatures were measured using the infrared thermometer depicted. It's important to note that in order to provide a fair comparison, the points' positions were flipped when the back side was measured. One of the most important factors, as previously indicated, is establishing a sufficient, good heat distribution on both sides of the rubber sides. As a result, temperatures were measured at the same locations on both sides. The test was conducted on each side for 10 minutes. Since the study places a strong emphasis on sustainability in all aspects of its methodology, particularly the economic aspects, one of its limitations is the amount of power it uses. Therefore, supplying 6 volts (Vs) was sufficient to produce the outcomes shown in table (5). A drop in the supplied volt was seen due to the internal resistance of the AC power supply, and it is donated with (Vd) as illustrated in table (5). The top, middle, and bottom strips each had three temperature readings for both sides the front side and the back side in Celsius table 5. Averages for each strip were obtained as shown in table (6) for better graphical representation. The electrical circuit's resistance was measured to be 0.8 **Ω**. Also, the room temperature, which was 22 °C as given in Table 5, was measured to illustrate the increase in temperature between the sample and the surrounding environment.

Table 5. The temperature readings of each strip for 10 minutes.

Front / Back	Measurments													
	Top °C			Middle °C			Bottom °C			R (Ω)	Vs (v)	Vd (v)	Troom °C	Duration (min)
F	68	55	63	82	56	37	30	29	26	0.8	6	2.5	22	10
B	29	58	55	27	44	56	25	26	31					

.

Table 6. The temperature's averages of the three strips top, middle, and bottom.

	Average Top °C	Average Middle °C	Average Bottom °C
Front	62	58.3	28.3
Back	47.3	43.3	27.3
T(room)	22	22	22

As seen in figure 22, the graph reveals that the temperatures of the three strips on both sides rise as time passes at a constant supply voltage of 6 volts in comparison with the room temperature which is 21 °C. After 10 minutes, the three top spots' average temperature was 62 °C on the front side, whereas the average temperature on the back side was 47.3 °C. It's important to note that whether at the front or the back, the top part averages were the highest. Since it might be claimed that the back side had a better heat distribution than the front side, the top average and the middle average were quite near to each other. In comparison to the top and middle areas, the average for the bottom, whether for the front or the back, was the lowest. Overall, as time goes on, all three strips top, middle, and bottom—both on the front and back, exceeded the room temperature of 22 °C.

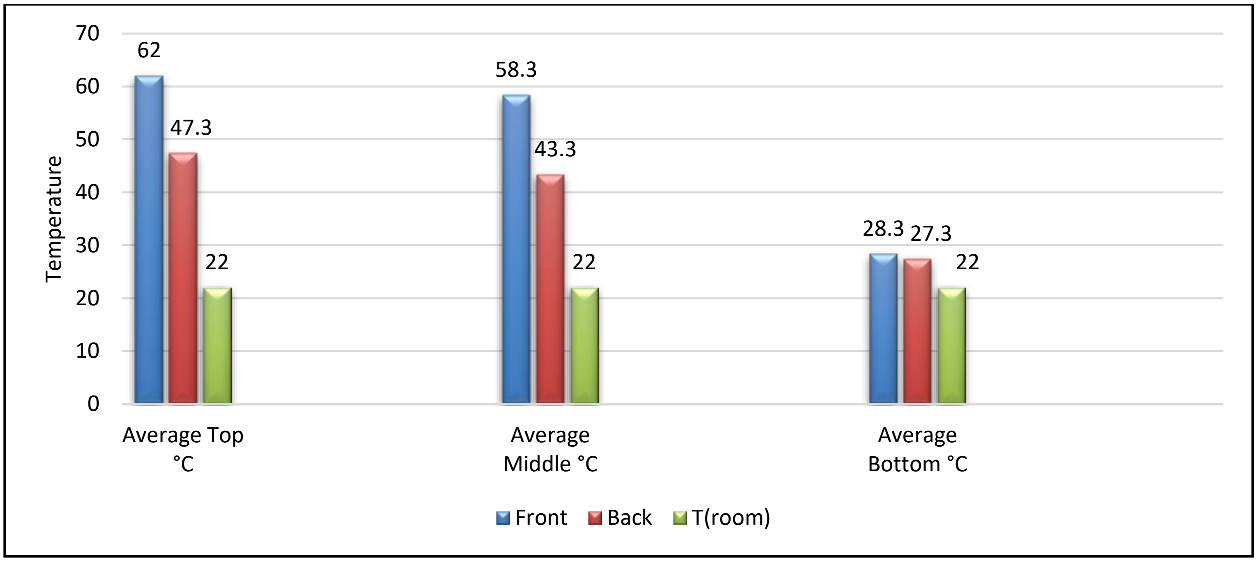


Figure 23: Initial observation for temperatures of an exposed rubber sample.

1.14.4.3 Initial experimentation for Two different grooved samples. The angle of the steel wire mesh inside a tire can vary depending on the specific design and intended use of the tire. However, in general, the steel wire mesh inside a tire is usually oriented at an angle of about 20-35 degrees from the vertical axis of the tire. This is known as the "bias angle" or "ply angle" of the tire, and it helps to provide strength and stability to the tire's structure. It's worth noting that some specialized tires, such as racing tires or heavy-duty off-road tires, may have different ply angles or use different materials for reinforcement. Additionally, the specific design and construction of a tire can have a significant impact on its performance and durability, so it's important to choose a tire that is well-suited to the intended application. Given the angle of the steel wire mesh in the tire, an L-shaped electrical circuit was constructed as depicted in figure 23. This figure shows that the electrical circuit consists of two metal pieces (made of either copper or galvanized steel) arranged in the shape of the letter L. This arrangement ensures that the flow of electricity is directed through the steel wire mesh exclusively. It is important to note that the grooves were created to match the shape of the electrical circuit, and the metal wires (either copper or galvanized steel) were then placed into these grooves, as illustrated in Figure 19. The success of the electric circuit, whether using copper or galvanized steel wires, largely depends on establishing a reliable connection between the metal wires and the steel wire mesh inside the rubber tire. This presented a significant challenge during the construction process, which is why metal pins were used to secure and ensure good contact between the wires and the steel mesh inside the tire. As depicted in Figure 23, once the electric circuits were constructed for both samples, they were ready to be tested for temperature increases by connecting them to an AC-power supply. Both the front and back sides of each sample were tested, with the aim of generating a satisfactory amount of heat and ensuring even distribution along both sides. To accomplish this goal, both sides of both samples were tested. The colored circles visible on each sample correspond to the precise locations where temperature readings were taken using an infrared thermometer. It is apparent that the colored circles on both samples are arranged into five horizontal lines or stripes, with each line containing five colored circles. The top strip has only one line of colored circles, while the middle strip has three lines, which is the highest number of colored circles on any of the strips. The bottom strip also has one line of colored circles. Importantly, each of the three parts (top, middle, and bottom) is colored differently, making them easily distinguishable from one another. Additionally, the same locations on the back side of both samples were marked to enable comparison with the corresponding points on the front side. The two samples underwent two rounds of testing. The first phase was an initial experiment that lasted only 10 minutes, during which the samples were connected to the power supply and the temperature increase was monitored. This increase was then compared to the ambient room temperature. In the second phase, the two samples were tested for a continuous period of 60 minutes while connected to the power supply. This test was intended to measure the maximum temperature that could be reached at a fixed voltage after one hour and to identify the limitations of the samples.

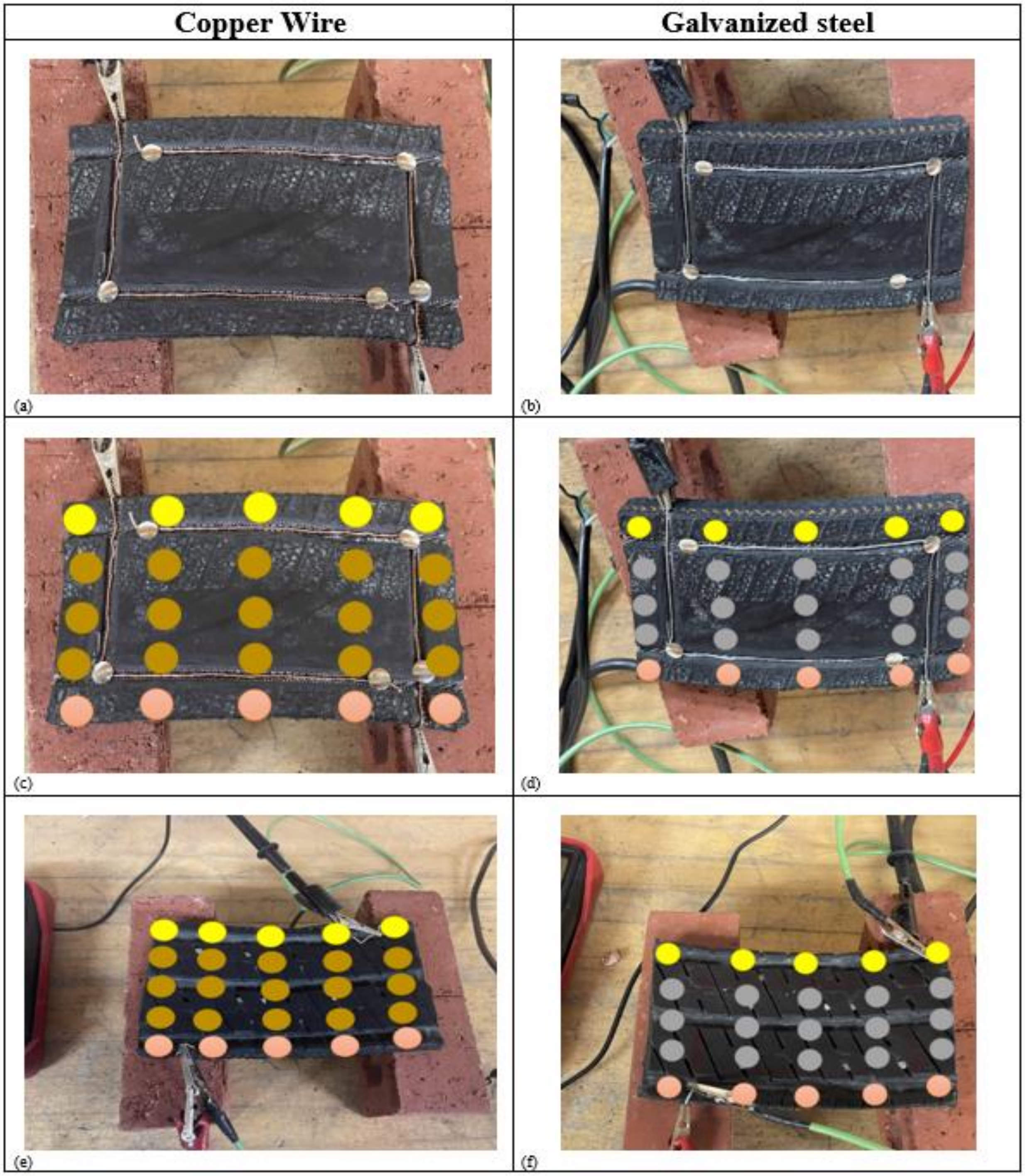


Figure 24: Testing two rubber samples using copper wire and galvanized steel wire.

1.14.4.4 Initial testing for 10 minutes. Prior to linking the samples to the power source, it was essential to gauge the circuit's resistance for both samples, which was found to be 0.8 Ω. After this step, the experiment was initiated by attaching each sample to an AC power supply, and a voltage of 6 volts (Vs) was supplied. It should be emphasized that a voltage drop (Vd) was observed due to the power supply's internal resistance, which was measured at 2.54 V. A stopwatch was employed to monitor the duration of 10 minutes. After a duration of 10 minutes, the temperature levels were noted based on the colored circles, as explained earlier. It is noteworthy that the middle section had the highest count of colored circles. The temperature readings for the top, middle, and bottom sections of both samples were recorded for both copper wire and galvanized steel wire on both front and back sides. Table 7 and Table 8 present these temperature values. Additionally, the average temperatures for the top, middle, and bottom sections were calculated to facilitate better graphical representation, which is displayed in Figure 24 and Figure 25. From Figure 24 and Figure 25, it is evident that the average temperatures achieved using copper wire are marginally greater than those obtained with galvanized steel wire. This indicates that copper reaches higher temperature levels faster than galvanized steel due to its superior thermal conductivity. Notably, both materials exhibited a significant increase in temperature from the initial room temperature of 22.7 degrees Celsius, despite being supplied with a low voltage of only 6 volts.

Table 7. Temperature testing of grooved rubber sample with copper.

Front/Back	Measurements														
	Top					Middle					Bottom				
F	**24.7**	**24.9**	**28.6**	**38.4**	**48**	**25.5**	**26.6**	**32.6**	**52**	**44.9**	**24.5**	**30.7**	**32.5**	**26**	**25.3**
						28.2	**34.4**	**50.3**	**32.9**	**31.6**					
						32.1	**69.6**	**44.1**	**27.7**	**27.5**					
B	**24.5**	**24.8**	**25.7**	**31**	**37.3**	**24.7**	**25.3**	**32**	**41.6**	**36.9**	**34.1**	**36.4**	**26.9**	**27.2**	**25.2**
						28.5	**27.2**	**39.1**	**33.7**	**31.5**					
						29.7	**40.3**	**29**	**27**	**27.4**					

	Average Top	Average middle	Average bottom
Front	32.9	37.3	27.8
Back	28.7	31.6	30.0
T(Room)	22.7	22.7	22.7

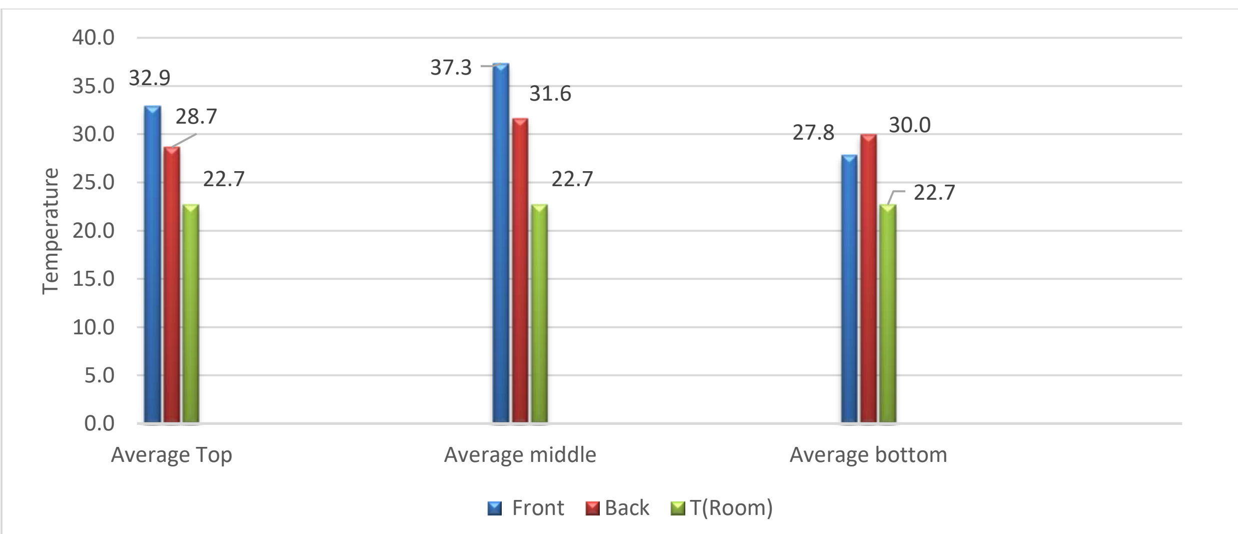


Figure 25: Temperature testing of a grooved rubber sample using the copper wire.

Table 8. Temperature testing of grooved rubber sample with galvanized steel.

Front/Back	Measurements														
	TOP					Middle					Bottom				
F	**25**	**24.1**	**29**	**32**	**45**	**26.7**	**30**	**34**	**45**	**32**	**23**	**23.1**	**21.4**	**21.5**	**22.5**
						38.4	**46.7**	**40.2**	**37.5**	**28.5**					
						51	**50.5**	**42.6**	**29**	**25**					
B	**23.7**	**23.3**	**24.5**	**31.8**	**30.9**	**27**	**26**	**28**	**32.5**	**33**	**22.8**	**23**	**24.3**	**22.6**	**22.5**
						31.5	**33.7**	**29.3**	**25.1**	**24.7**					
						30.8	**32.5**	**28**	**24**	**24.4**					

	Average Top	Average Middle	Average bottom
Front	**31.0**	**37.1**	**22.3**
Back	**26.8**	**28.7**	**23.0**
T(Room)	**22.7**	**22.7**	**22.7**

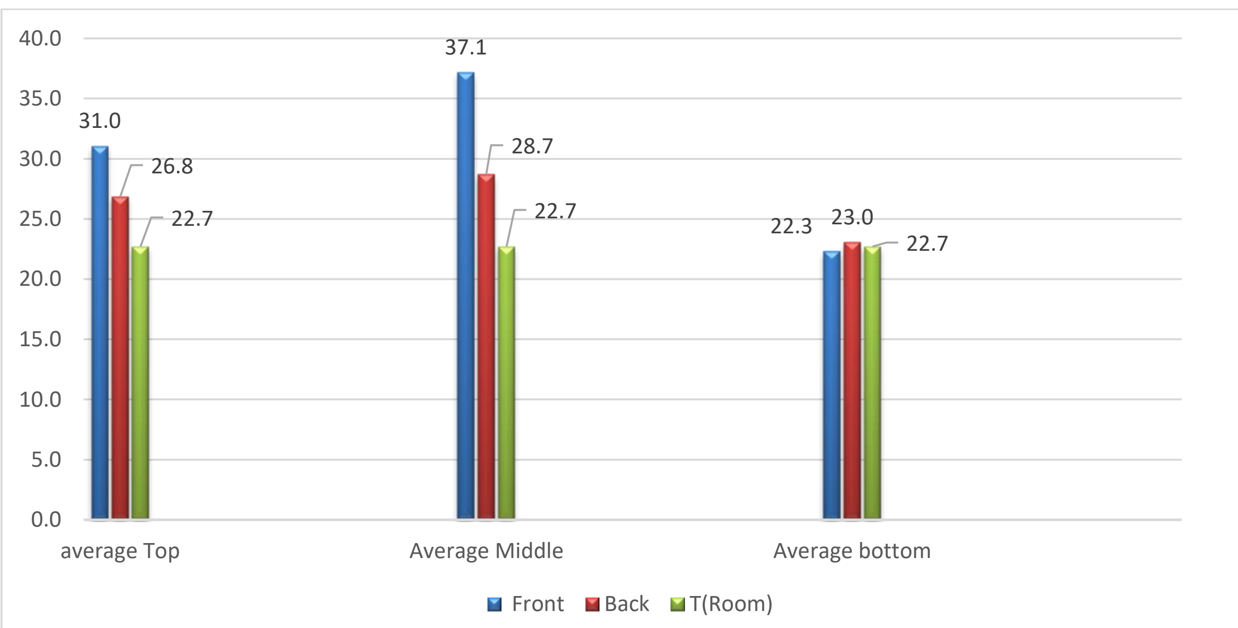
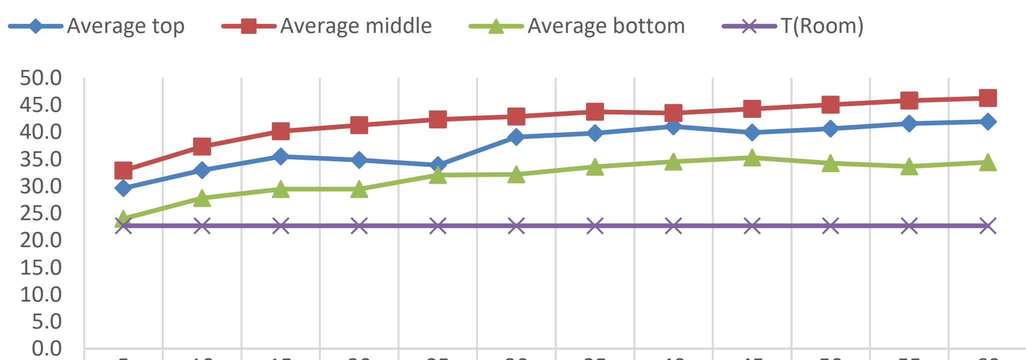


Figure 26: temperatures testing of a grooved rubber sample using the galvanized steel.

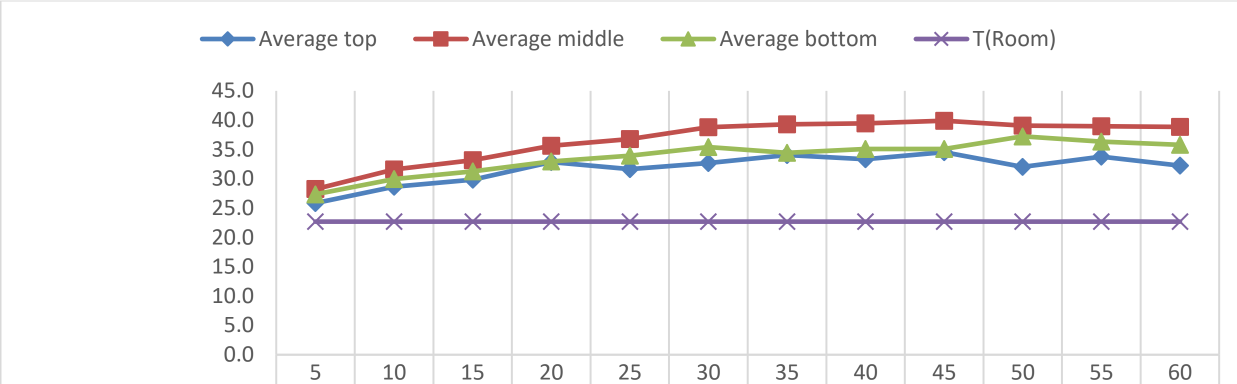
1.14.4.5 Testing the two samples for a continuous 60 minutes. L-shape electric circuit (Copper wire)

The graphs presented in figures 26 and 27 depict the temperature increase of a grooved rubber sample, with an L-shaped design, connected to an electric circuit made of copper wire (as shown in figure 23a). The experiment lasted for an hour, during which the sample was continuously supplied with a low voltage of 2 volts from an AC power supply. The reference point for the experiment was the room temperature, which was measured to be 22.7 degrees Celsius. The temperature readings for the top, middle, and bottom strips of the rubber sample gradually increased above the room temperature for both the front and back sides. The middle strip had the largest area of the rubber sample, as indicated by the highest number of colored circles, and therefore required precise observation. After an hour of the experiment, the average temperature of the middle strip reached 46.3 degrees Celsius for the front side and 38.9 degrees Celsius for the back side. The overall temperature of the sample was almost double that of the room temperature.



	5	10	15	20	25	30	35	40	45	50	55	60
Average top	29.6	32.9	35.5	34.8	33.9	39.1	39.8	41.1	39.9	40.6	41.6	41.9
Average middle	32.9	37.3	40.1	41.3	42.3	42.9	43.8	43.5	44.3	45.0	45.8	46.3
Average bottom	24.0	27.8	29.5	29.4	32.1	32.2	33.6	34.6	35.3	34.3	33.6	34.4
T(Room)	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7

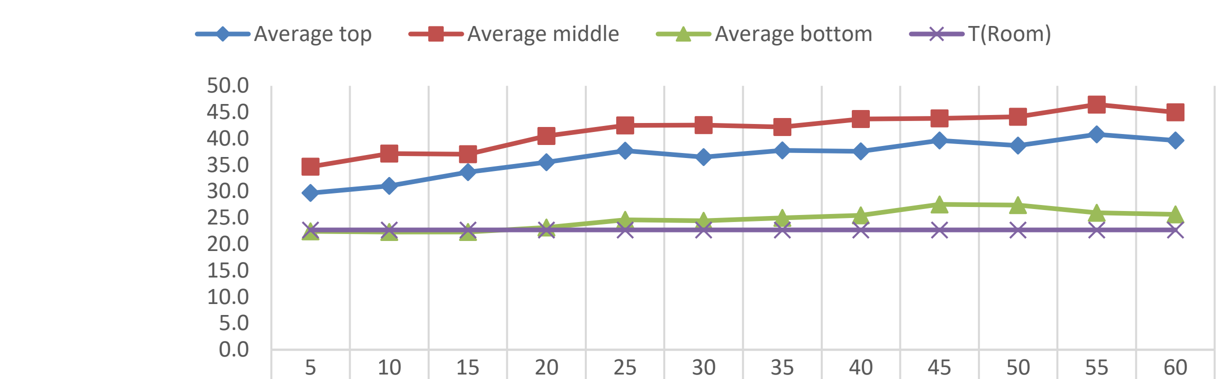
Figure 27: Observation for temperatures of the front side using copper wire for 60 minutes.



	5	10	15	20	25	30	35	40	45	50	55	60
Average top	25.9	28.7	29.8	32.9	31.6	32.7	34.0	33.3	34.5	32.0	33.8	32.3
Average middle	28.2	31.6	33.2	35.6	36.8	38.8	39.3	39.5	39.9	39.0	38.9	38.9
Average bottom	27.4	30.0	31.3	32.9	34.0	35.4	34.4	35.1	35.1	37.2	36.3	35.8
T(Room)	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7

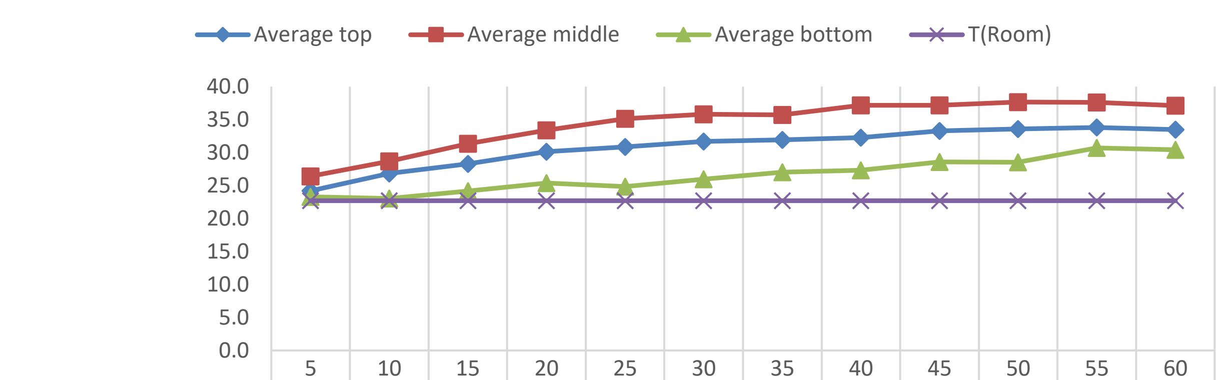
Figure 27: Observation for temperatures of the back side using copper wire for 60 minutes.

L-shape electric circuit (Galvanized steel wire). Figures 28 and 29 display the temperature elevation of a grooved rubber sample with an L-shaped design, connected to an electric circuit constructed with galvanized steel wire (as demonstrated in figure 6c). The experiment ran for an hour, and throughout that time, the sample was consistently supplied with a low voltage of 2 volts from an AC power supply. The reference point for the experiment was the room temperature, which was determined to be 21 degrees Celsius. The temperature readings for the top, middle, and bottom strips of the rubber sample gradually increased above the room temperature for both the front and back sides. The middle strip had the most extensive area of the rubber sample, as shown by the greatest number of colored circles, and consequently necessitated accurate observation. After one hour of the experiment, the average temperature of the middle strip reached 45 degrees Celsius for the front side and 37.1 degrees Celsius for the back side. The temperature of the sample as a whole was almost twice that of the room temperature.



	5	10	15	20	25	30	35	40	45	50	55	60
Average top	29.7	31.0	33.6	35.5	37.7	36.5	37.8	37.6	39.6	38.7	40.8	39.7
Average middle	34.7	37.1	37.1	40.5	42.5	42.6	42.2	43.7	43.8	44.1	46.5	45.0
Average bottom	22.5	22.3	22.3	23.1	24.6	24.4	25.0	25.4	27.5	27.4	25.9	25.6
T(Room)	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7

Figure 28: Observation for temperatures of the front side using galvanized steel wire for 60 minutes.



	5	10	15	20	25	30	35	40	45	50	55	60
Average top	24.2	26.8	28.3	30.1	30.8	31.7	31.9	32.3	33.3	33.6	33.8	33.5
Average middle	26.4	28.7	31.4	33.4	35.1	35.8	35.7	37.2	37.2	37.7	37.6	37.1
Average bottom	23.3	23.0	24.2	25.4	24.8	26.0	27.0	27.3	28.6	28.5	30.7	30.4
T(Room)	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7

Figure 29: Observation for temperatures of the back side using galvanized steel wire for 60 minutes.

U-shape electric circuit. Figure 30 presents another electric circuit design in the shape of the letter "U". Figures 31 and 32 demonstrate a notable increase in temperature for both the front and back sides of the rubber sample. The averages of the temperature readings for the top, middle, and bottom strips surpassed 60 degrees Celsius after a continuous one-hour connection to an AC power supply at the same voltage of 2 volts. It is apparent that this circuit design showed a significant difference in temperature rise compared to the L-shaped designs. Consequently, this design was selected for use in the second phase, which involved embedding the rubber sample into the concrete.

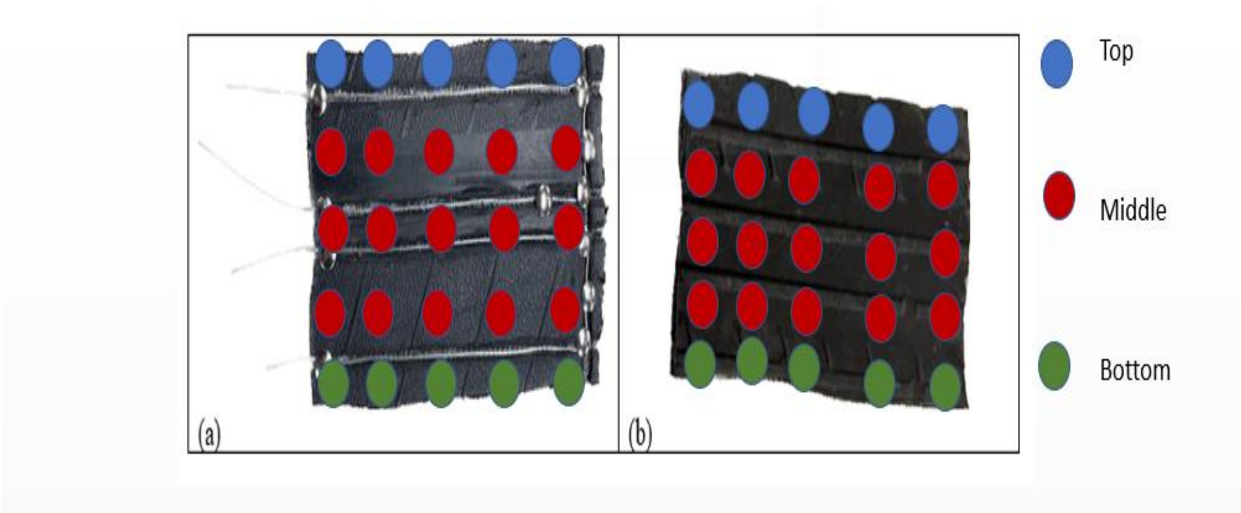
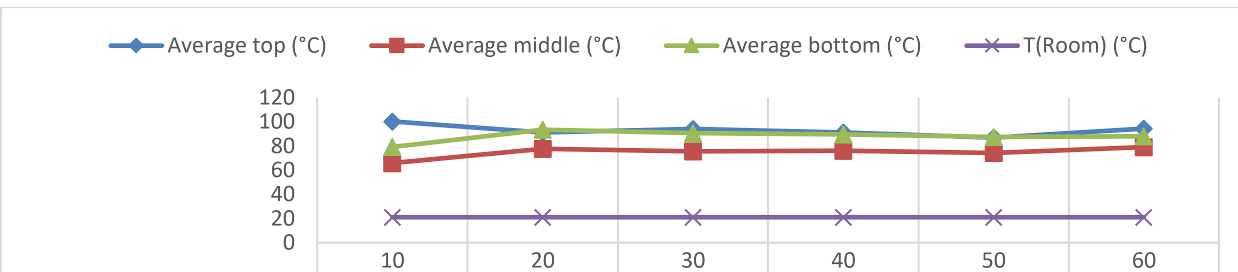
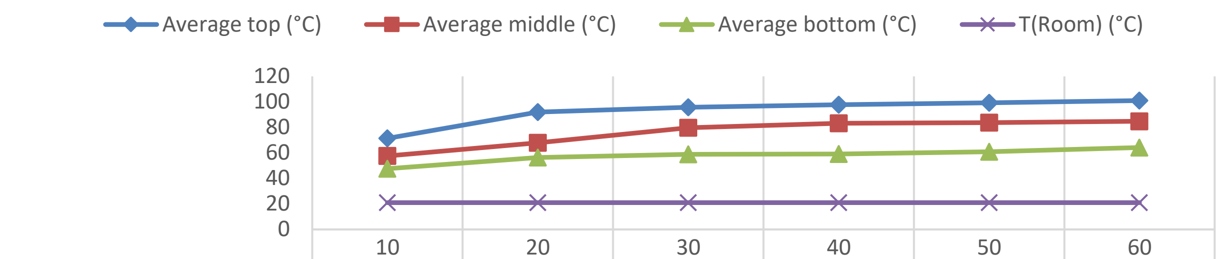


Figure 30: Testing the rise in temperature for each rubber sample for both side the front and the back side.



	10	20	30	40	50	60
Average top (°C)	100.2	91.2	94.1	91.2	86.8	94.2
Average middle (°C)	65.8	77.7	75.4	76.0	74.2	79.0
Average bottom (°C)	79.1	93.4	90.6	89.6	87.4	88.0
T(Room) (°C)	21	21	21	21	21	21

Figure 31: Front side (Galvanized steel - U design)



	10	20	30	40	50	60
Average top (°C)	71.4	92	95.8	97.8	99.2	101
Average middle (°C)	57.6	68	79.8	83.2	83.6	84.8
Average bottom (°C)	47.6	56.4	58.8	59	60.8	64.2
T(Room) (°C)	21	21	21	21	21	21

Figure 32: Back side (Galvanized steel - U design)

1.15 Observations for using a closed U-shape electric circuit

As previously stated, a crucial aspect is to ensure proper heat and temperature increase on both sides of the rubber sample. The outcomes for the U-design shape were obtained under the condition that the galvanized steel wire (forming the electric circuit) was connected. The rationale behind closing the electric circuit is based on the proven fact that the resistivity of galvanized steel is greater than that of the steel wire mesh embedded within the rubber tire. In accordance with the equation R = (ρ * L) / A, where R denotes the resistance, ρ (rho) signifies the resistivity, L represents the length of the conductor, and A denotes the cross-sectional area of the conductor, all these parameters were calculated and measured for the identical length of galvanized steel and the steel wire mesh utilized in the rubber sample. **The tire-steel wire** exhibited a resistance (R) of 1.2 ohms, with the length (L) of the conductor measured at 0.0762 meters. The diameter (D) of the conductor was determined to be 1.44 * 10^-4 meters, resulting in a cross-sectional area (A) of 1.62 * 10^-8 square meters as shown in figure 33. The resistance (R) for **the galvanized steel** was determined to be 1.1 ohms, while the length (L) measured 0.0762 meters. The diameter (D) of the conductor was determined to be 0.00107 meters, leading to a cross-sectional area (A) of 8.99 *

10^-7 square meters as shown in figure 34. Therefore, the electrical resistivity (ρ) for the tire-steel wire is calculated to be 2.55 * 10^-7, while the galvanized steel wire exhibits an electrical resistivity of 129.7 * 10^-7. Which means the electrical resistivity value for galvanized steel wire, which is 129.7 * 10^-7, is larger than the electrical resistivity value for the tire-steel wire, which is 2.55 * 10^-7. Undoubtedly, the disparity in electrical resistivity between the galvanized steel wire (measuring 129.7 * 10^-7) and the tire-steel wire (measuring 2.55 * 10^-7) will have a significant impact on the flow of current and subsequent heat distribution.

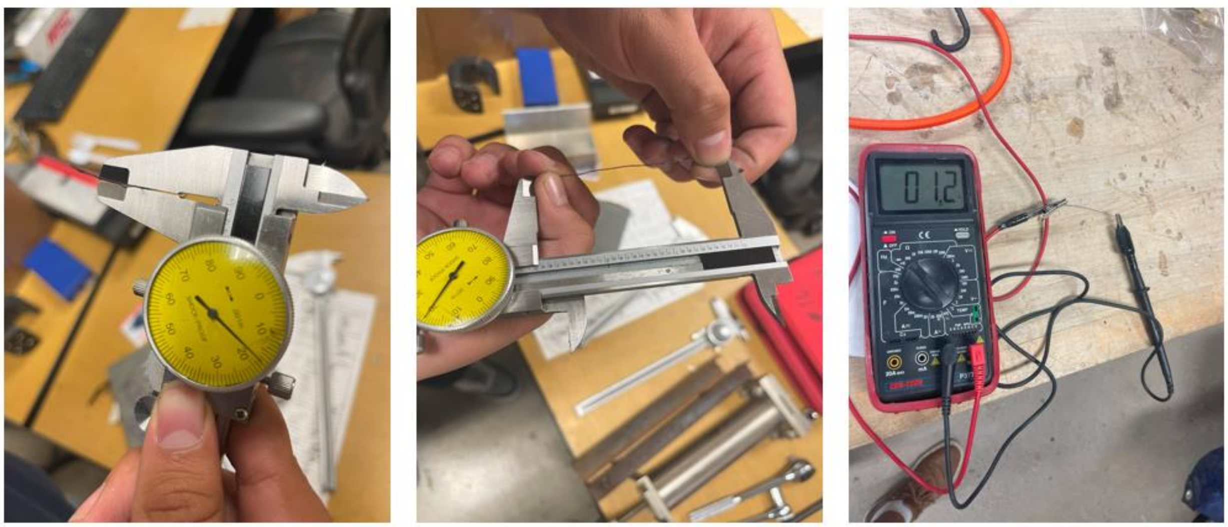


Figure 33. calculating the electric resistivity for one string of the steel wire mesh of the tire.

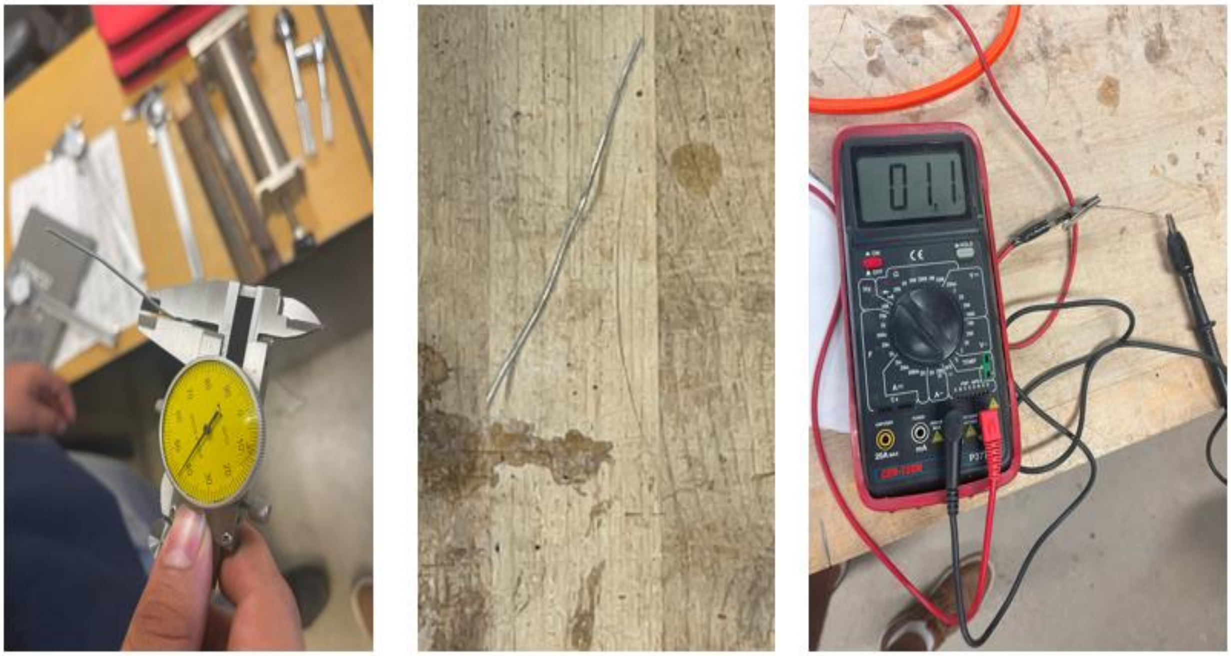


Figure 34. calculating the electric resistivity for the galvanized steel.

Considering this information, the electric circuit was intentionally closed, as depicted in Figure 35. The figure illustrates two distinct scenarios or assumptions regarding the path of current flow when the circuit is closed and when it is open. It can be demonstrated that, when the circuit is closed, the current has the ability to traverse through a majority of the wires spanning across the rubber sample. In contrast, with an open circuit, the current is limited to passing only through the nearest tire-steel wire located at the beginning of the circuit.

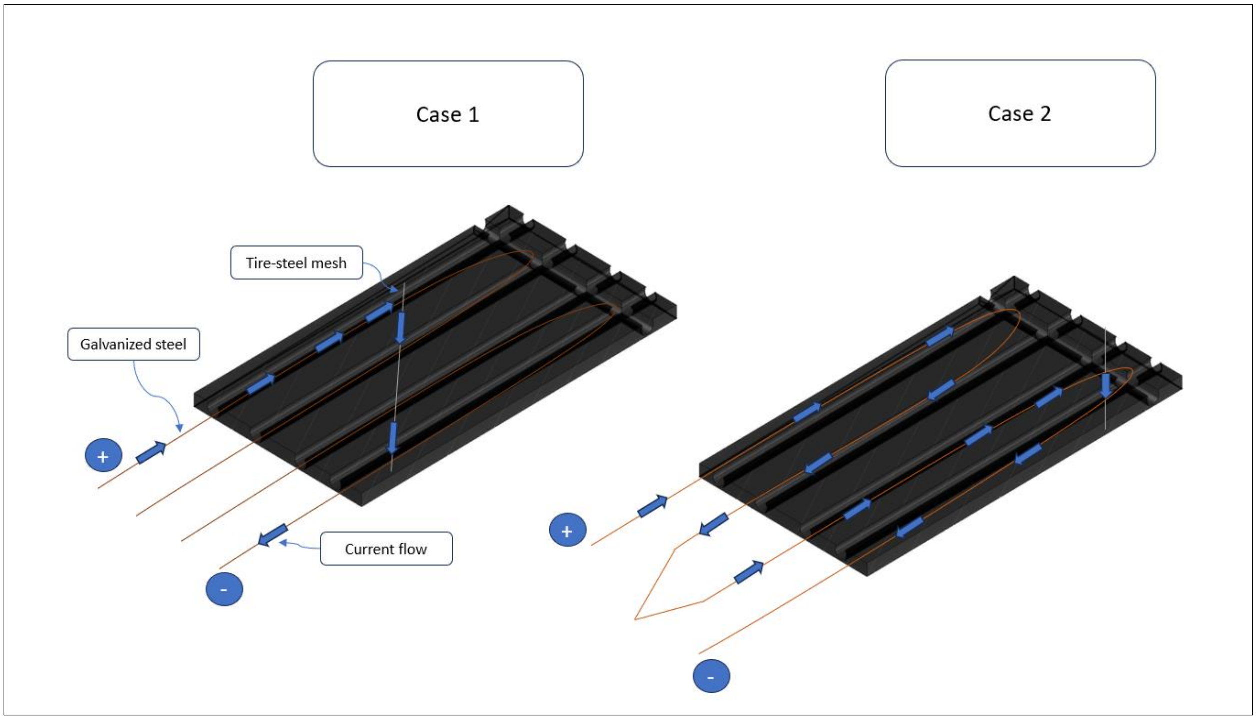


Figure 35. Special cases for current flo

CHAPTER IV

MODEL DEVELOPMENT INTRODUCTION

The primary aim of the study was to create a construction technique that is more environmentally friendly and can address the issue of snow accumulation on Rigid pavements. To replicate the conditions of snowy weather and rigid pavement, two samples made of a combination of conductive concrete and rubber were produced using ACI guidelines. The effectiveness of both samples in melting snow was evaluated through testing.

This chapter focuses on an effort to tackle the problem of snow accumulation on rigid pavements by utilizing waste from rubber tires. It begins by providing a clear explanation of the combined concrete-rubber samples and the research concept. It then proceeds to model the problem by examining the temperature increase in both samples and their ability to melt snow.

1.16 Model description

The concrete samples were not prepared until it was ensured that the rubber samples were able to generate adequate heat, which is depicted in Figure 34. As per the ACI 318 specifications and criteria, two concrete samples were produced. While the concrete was still wet, the rubber samples were embedded in it. Sample 1 had dimensions of 20 cm in width and 30 cm in length, with the rubber sample being buried in the center. On the other hand, Sample 2 had dimensions of 20 cm in width and 40 cm in length, with two rubber samples being buried at equal intervals of 5 cm from the edge and 10 cm in the center.

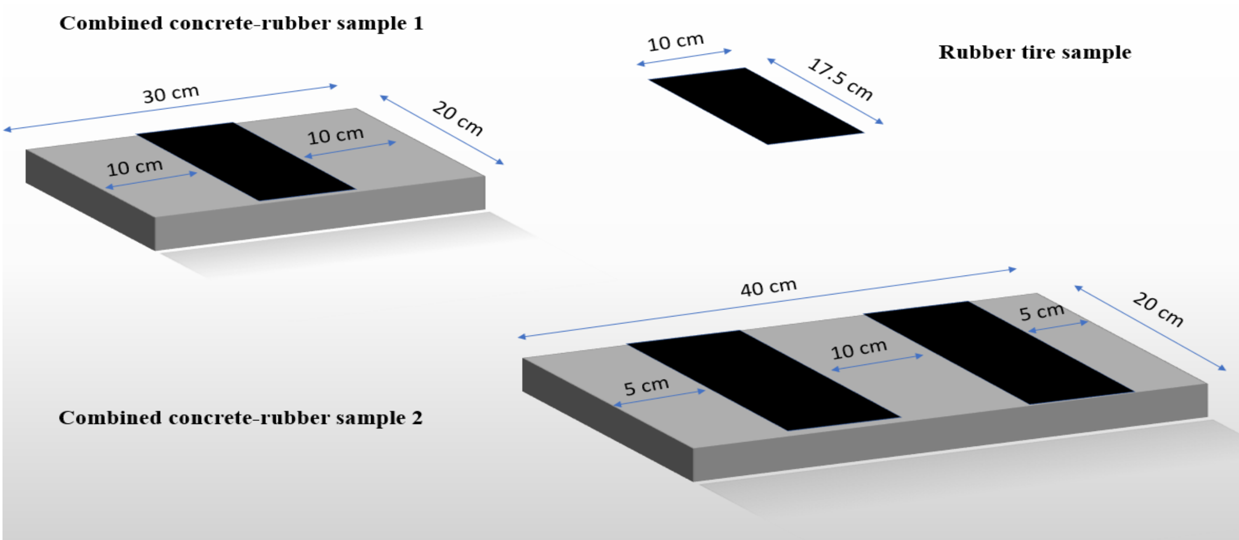


Figure 36: Simulation for the two combined concrete-rubber samples with dimensions.

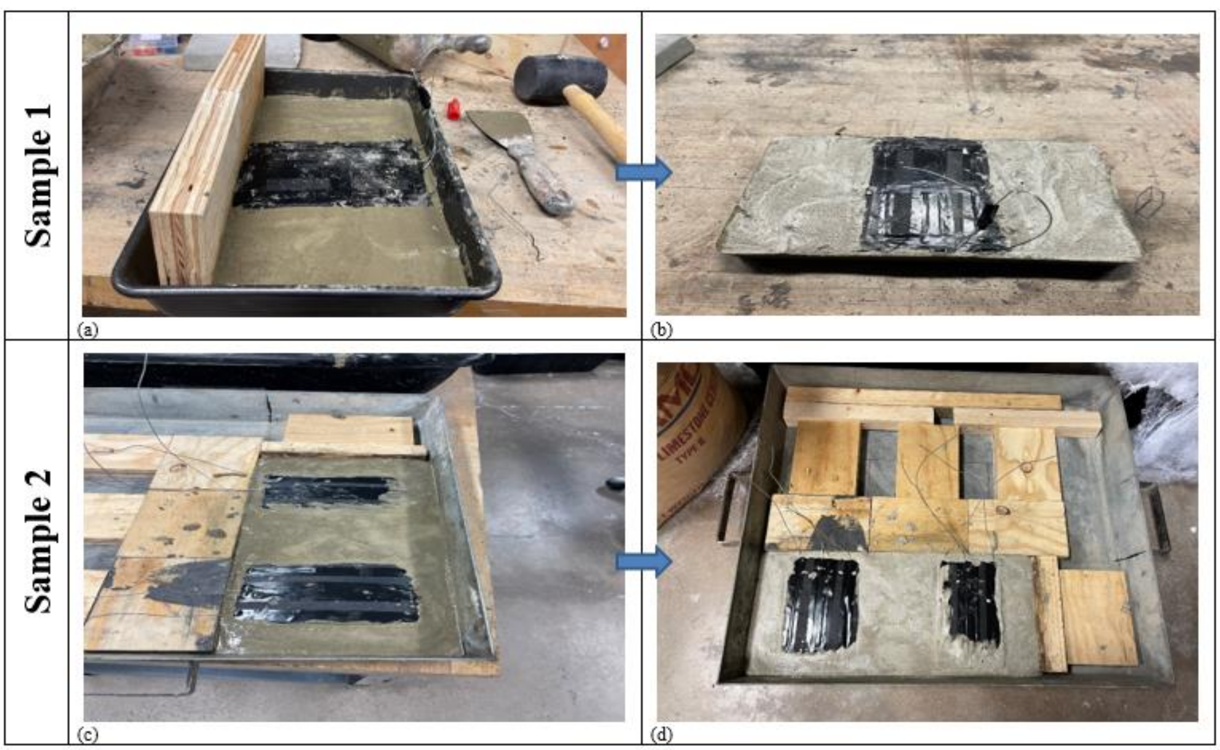


Figure 37: Two combined concrete-rubber samples.

1.16.1 Second stage: (Concrete-rubber samples testing)

The two concrete samples were prepared for testing using a similar method of marking them with colored circles. The temperature rise was observed across the entire surface of the concrete, assuming that this side would face the vehicles, while the rubber-faced side was placed facing downwards. Both samples had a LED light bulb attached to the circuits, serving as an indicator of the current flow. The top strip had blue circles, the middle strip had orange circles, and the bottom strip had green circles. These colored circles indicated the exact locations where the temperature was measured using an infrared thermometer, as previously mentioned.

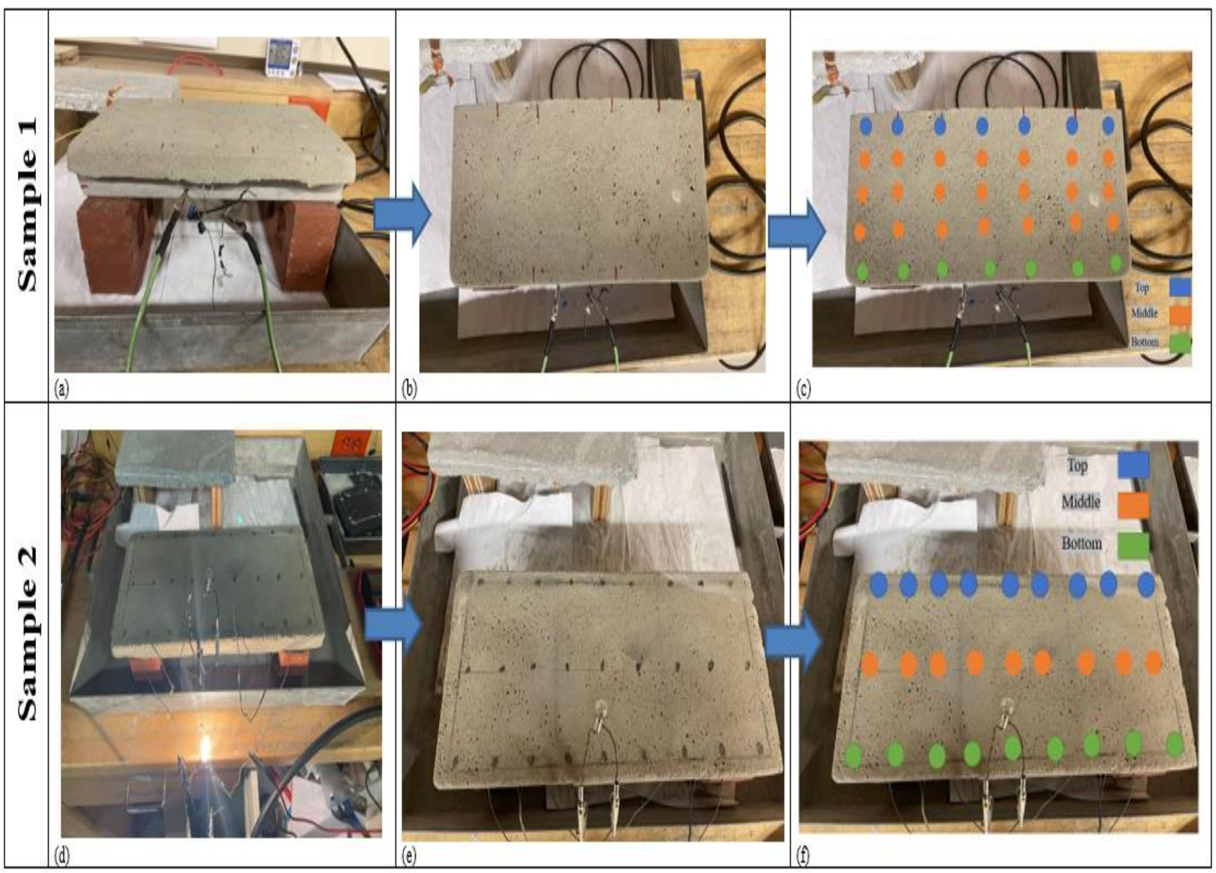


Figure 38: Testing the rise in temperature for two concrete-rubber samples after.

1.17 Experimentation results

1.17.1 Combined Concrete-rubber Sample 1

The second phase of the experiment involved observing the temperature rise across the entire surface of the concrete. As previously mentioned, the rubber sample designed in the shape of a U was chosen to be embedded into the concrete samples after ensuring that a high amount of heat was obtained and evenly distributed. Once the rubber sample was embedded, the concrete was flipped over, and only the side facing the vehicles was tested. Similar to the previous phase, colored circles were used to mark the top, middle, and bottom strips with blue, orange, and green circles, respectively. After one hour of activating the circuit and supplying with 6v, it can be observed that the top, middle, and bottom strips reached temperatures of 40, 38, and 36 degrees Celsius, respectively. Overall, a sufficient amount of heat was generated, and the distribution of heat across the concrete sample was satisfactory, all achieved by using only one rubber sample.

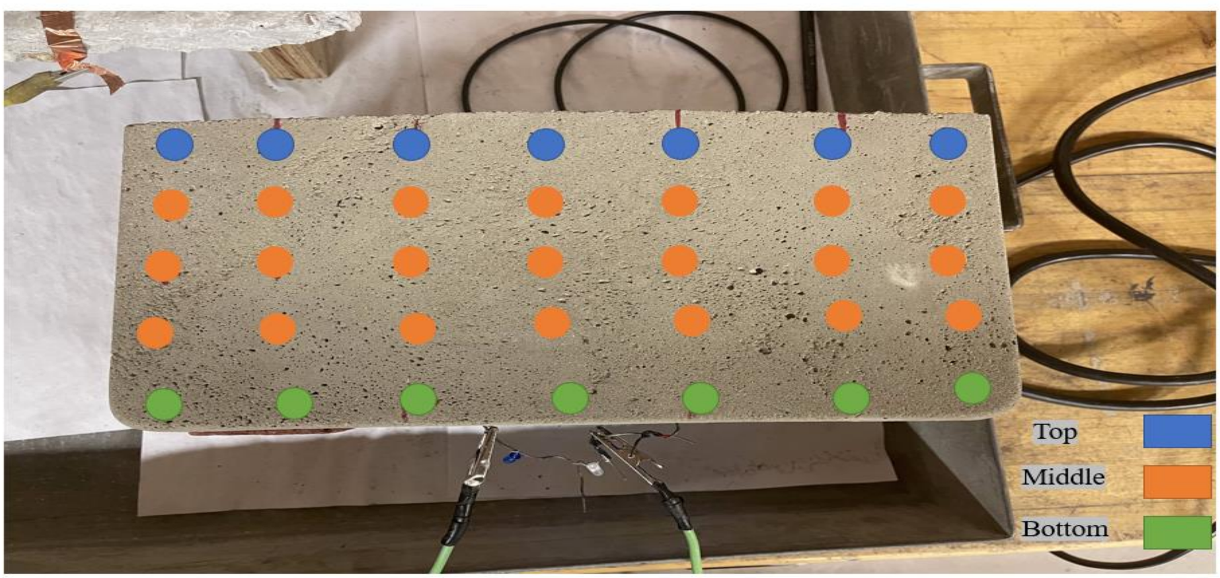
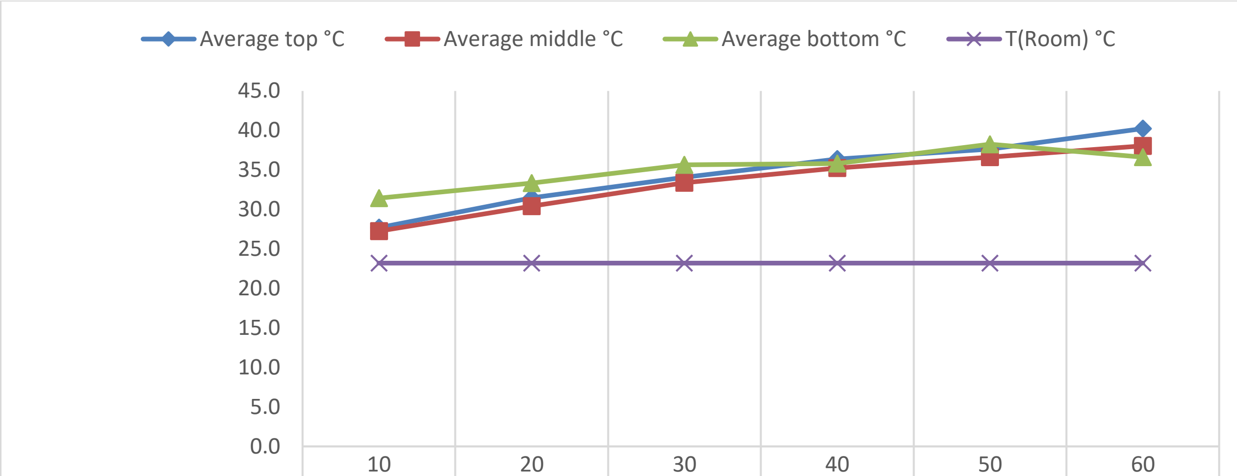


Figure 39: Combined concrete and rubber (using one rubber sample).



	10	20	30	40	50	60
Average top °C	27.7	31.5	34.1	36.4	37.6	40.2
Average middle °C	27.3	30.4	33.4	35.2	36.6	38.0
Average bottom °C	31.4	33.3	35.7	35.8	38.3	36.6
T(Room) °C	23.2	23.2	23.2	23.2	23.2	23.2

Figure 40: experimentation of the combined concrete-rubber (sample 1)

1.17.1.2 Combined Concrete-rubber Sample 2

For the second sample of combined concrete and rubber, two rubber samples designed in the shape of a U were embedded into the concrete sample. Sample 2 had a width that was 10 cm larger than Sample 1. The same marking method was used to observe the temperature rise. However, due to the larger size of the sample, it was necessary to increase the voltage to 15 volts to see how much the temperature would increase. After an hour of testing, it can be observed that the top, middle, and bottom strips reached temperatures of 43, 49, and 52 degrees Celsius, respectively, in comparison to the measured room temperature of 22.4 degrees Celsius. Overall, the use of two rubber samples in the U shape design showed a significant increase in temperature over an hour in concrete sample 2.

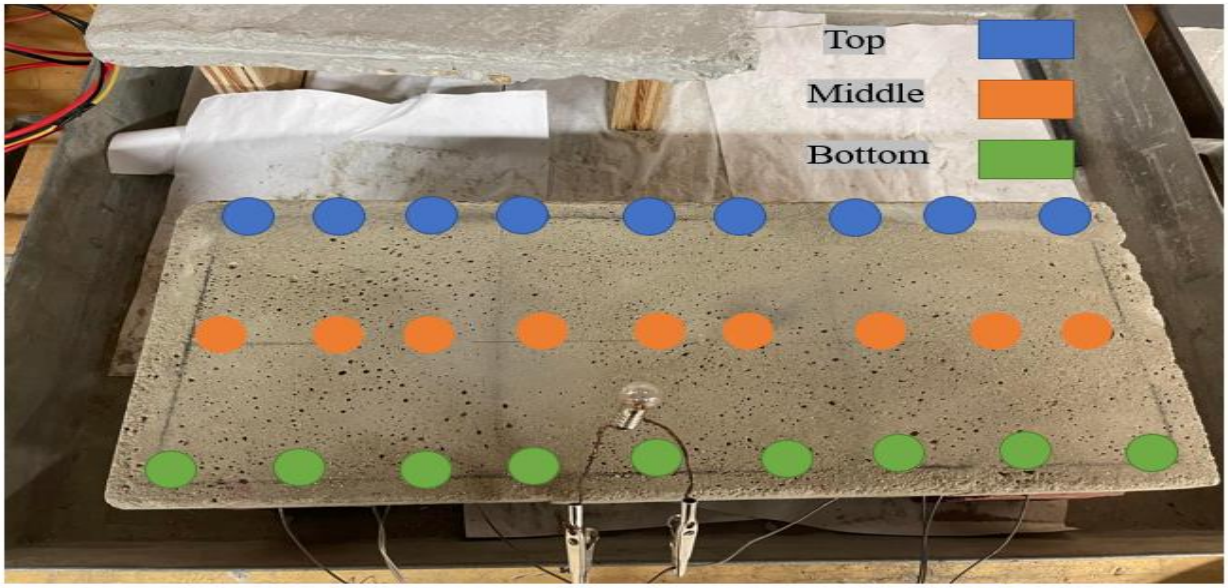
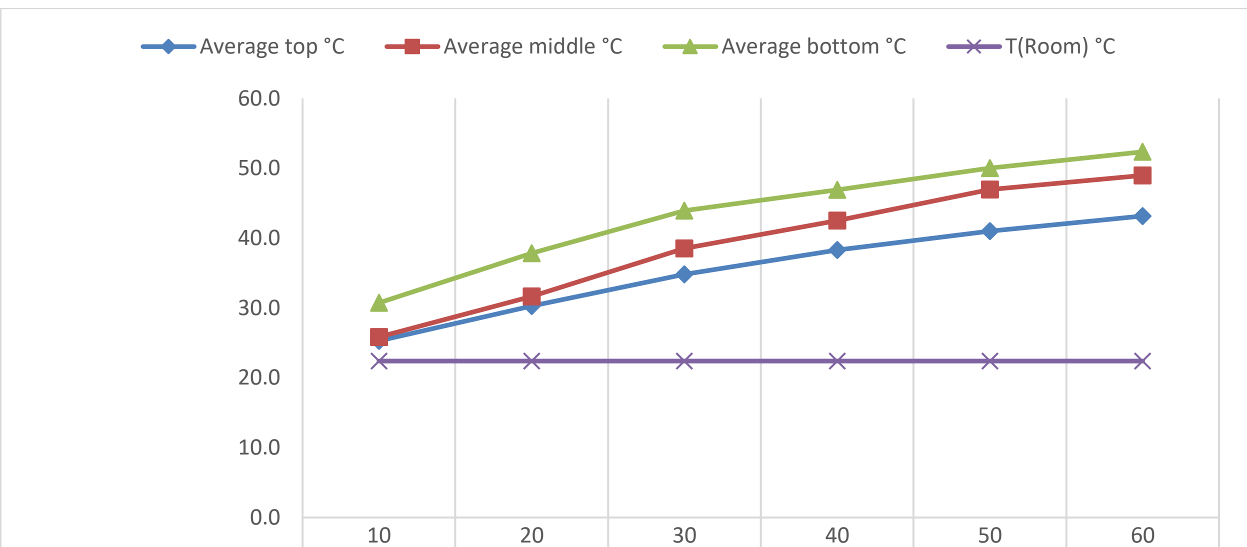


Figure 41: Combined concrete and rubber (using two rubber samples).



	10	20	30	40	50	60
Average top °C	25.3	30.3	34.8	38.3	41.0	43.2
Average middle °C	25.8	31.7	38.5	42.5	46.9	49.0
Average bottom °C	30.7	37.8	43.9	46.9	50.0	52.4
T(Room) °C	22.4	22.4	22.4	22.4	22.4	22.4

Figure 42: experimentation of the combined concrete and rubber (Sample 2).

1.18 Third stage: (Experimentation for melting the accumulated snow)

1.18.1 Combined Concrete-rubber Sample 1

The primary objective of this research is to evaluate the effectiveness of combined concrete and rubber samples in melting snow when it accumulates on a rigid pavement. Figure 22 depicts the experimental system components, which include two concrete samples. The front concrete sample, called sample 1, has previously undergone testing with a single rubber sample, and its temperature was recorded. Sample 1 is directly connected to the power supply, and it was supplied by 6v, and a LED light bulb serves as an indicator of the electric current flow. The back concrete sample serves as a control and is not connected to any electricity, allowing for the observation of snow melting by room temperature and electricity. The same number of ice cubes was placed on both concrete samples, and images were captured at different intervals to determine which sample melted the cubes more quickly. After 30 minutes, the ice cubes on sample 1 were almost completely melted, while the control sample retained its thickness and size. After an hour, the ice cubes on sample 1 had completely melted, whereas the control sample remained wet, with some ice cubes still retaining their size and thickness.

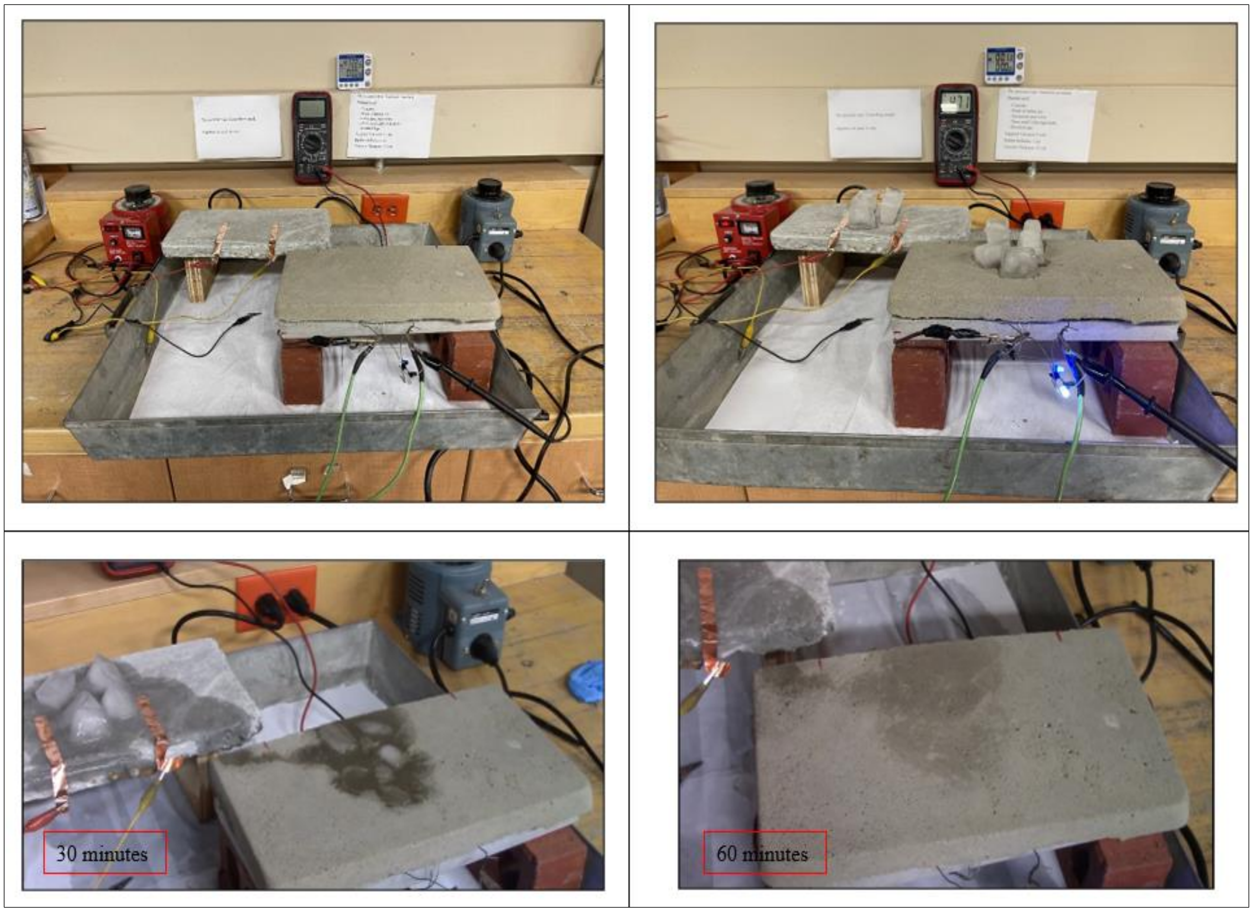


Figure 43: experimentation for concrete sample 1 to melt the snow (Ice cubes).

1.18.2 Combined Concrete-rubber Sample 2

Concrete sample 2, which features a U-shape design of two rubber samples, was also subject to testing. In order to accurately replicate real snow conditions, crushed ice cubes were spread on top of both the controlling sample (at the back) and concrete sample 2 in the front, as depicted in figure 23. Given that sample 2 was larger and had more resistance due to the two rubber samples, it was supplied with 15 volts of power. Similar to sample 1, a LED light bulb was attached to the circuit to indicate the efficiency and flow of the electric current. Images were taken at different time intervals to display the effects of temperature on melting the crushed ice. As shown in figure 24, the crushed ice on top of concrete sample 2 gradually disappeared, ultimately melting completely after 40 minutes, while the controlling sample retained the ice cubes.

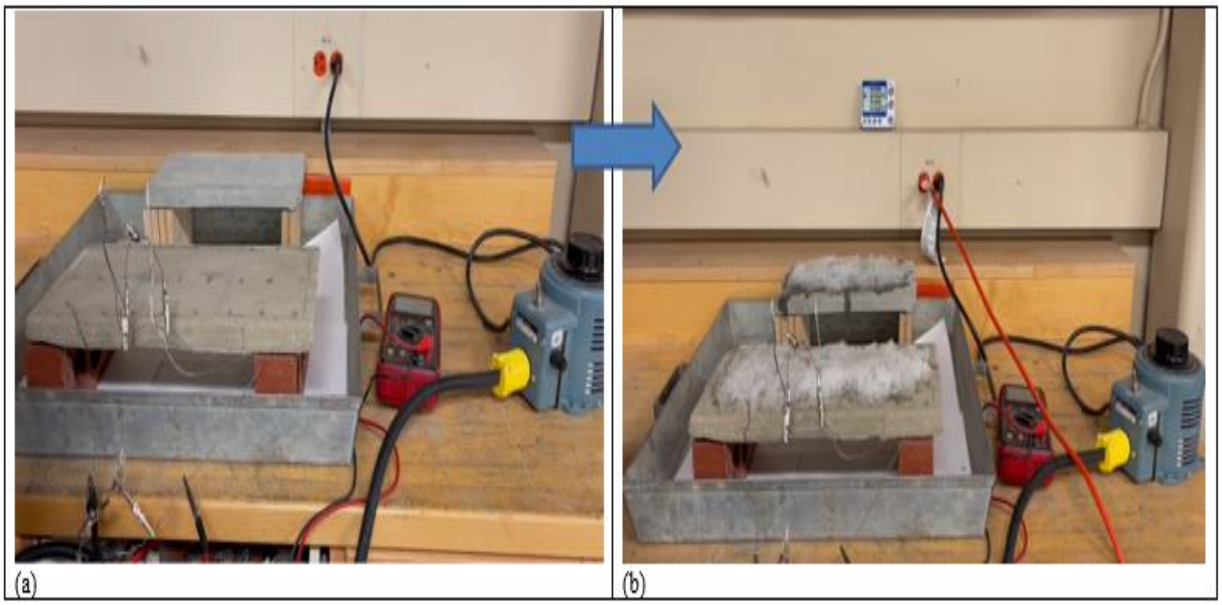


Figure 44: experimentation for concrete sample 2 to melt the snow (crushed Ice).

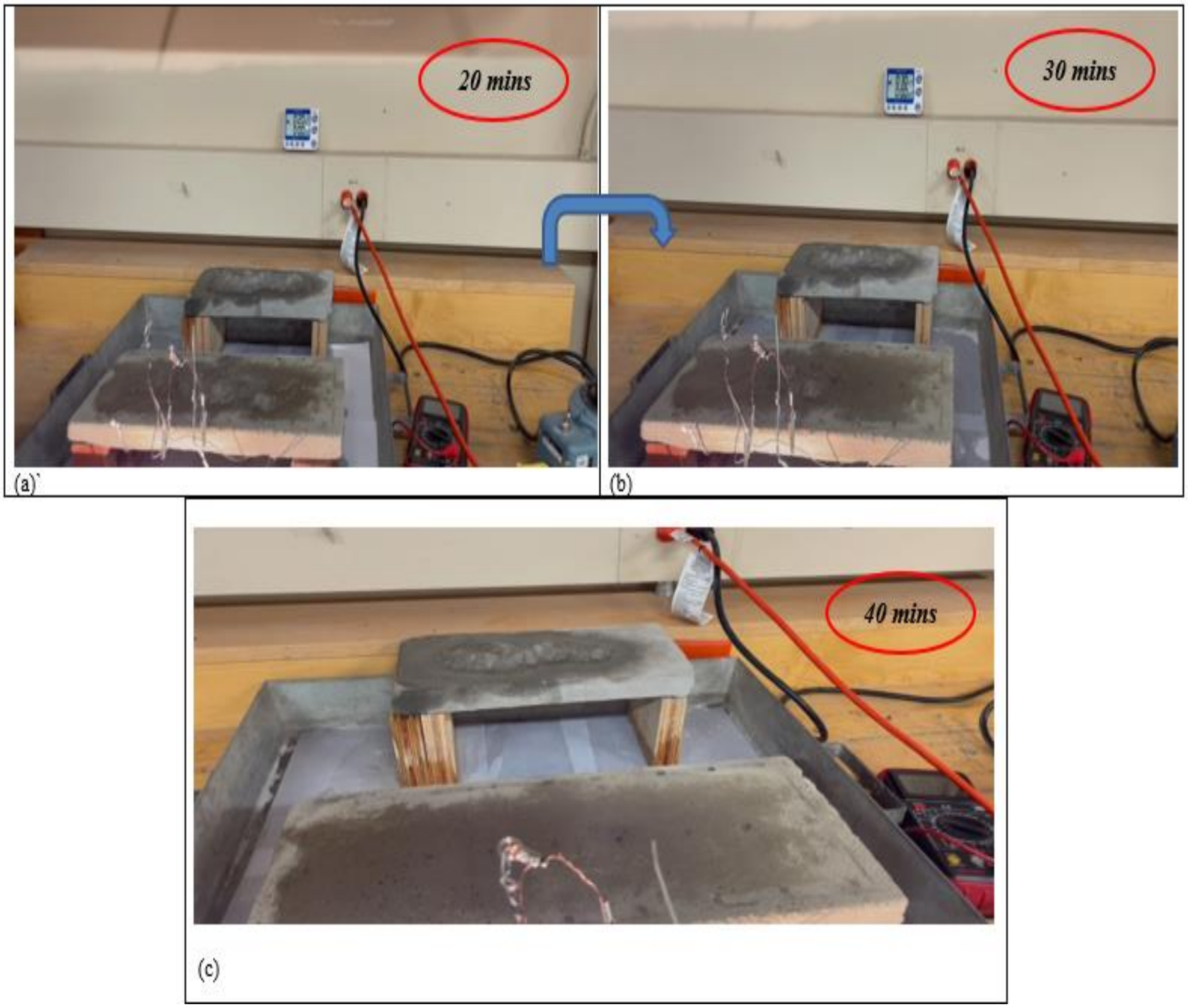


Figure 45: Observing the impact of the rise of temperature on melting the crushed Ice at different intervals.

Table 9: Important parameters for the rubber and concrete samples

Sample	Face	Mean	Standard deviation	Volt	Resistance	Current	Power
Grooved L-shape Galvanized steel	Front	37.3 C	11.8	6 v	0.8 Ω	7.5 A	45 W
	Back	32 C	6.6	6 v	0.8 Ω	7.5 A	
Grooved L-shape Copper	Front	39 C	13.4	6 v	0.7 Ω	8.6 A	51 W
	Back	35 C	7.7	6 v	0.7 Ω	8.6 A	
Grooved U-shape Galvanized	Front	82 C	24.5	6 v	0.8 Ω	7.5 A	45 W
	Back	73 C	23.8	6 v	0.8 Ω	7.5 A	45 W
Combined Concrete 1	Concrete face	34 C	11	6 v	0.8 Ω	7.5 A	45 W
Combined Concrete 2	Concrete face	39 C	11.2	15 v	0.8 Ω	18.75 A	281 W

From the comparison, it can be observed that the temperatures for the samples vary significantly. (Grooved U-shape Galvanized) has considerably higher mean temperatures compared to (Grooved L-shape Galvanized steel) and (Grooved L-shape Copper), indicating higher heat levels in that configuration. From this comparison, several differences can be observed between Combined Concrete 1 and Combined Concrete 2. Combined Concrete 2 has a higher mean temperature, higher voltage, significantly higher current, and much higher power compared to Combined Concrete 1. These differences indicate that Combined Concrete 2 experienced higher thermal conditions and electrical loads compared to Combined Concrete 1.

1.19 Sources of variation in heat

The distribution of heat on the rubber tire piece and its impact on the concrete surface can be influenced by a multitude of factors. One critical factor to consider is the degree to which the steel wire mesh is exposed from within the rubber layer. When the tire is cut into rectangular pieces, it is essential to examine whether any flaws or damages have occurred that could disrupt the continuity of the wire mesh. Such flaws or damages have the potential to hinder the smooth passage of current through the wire, subsequently affecting the distribution of heat. Establishing a strong and reliable contact between the wire and the steel wire mesh inside the tire is of utmost importance. A solid connection ensures efficient conduction of current and promotes the effective transfer of heat. However, achieving optimal contact can be challenging due to the presence of numerous curves in the wire. These curves create uneven surfaces and irregularities that obstruct the seamless interaction between the wire and the steel wire mesh. These imperfections in the wire's shape and the resulting lack of ideal contact between the two materials can hinder the efficient flow of electricity and heat. Therefore, the distribution of heat on the rubber tire piece becomes uneven, potentially leading to uneven heating of the concrete surface as well. Therefore, in order to achieve a more uniform heat distribution, it is crucial to address the challenges posed by the curves in the wire. Finding ways to minimize or eliminate these curves or implementing measures to enhance the contact between the wire and the steel wire mesh, could significantly improve the overall heat distribution and ensure a more effective transfer of energy from the tire to the concrete surface.

CHAPTER V

CONCLUSION

The article suggests an alternative approach to building electrically conductive pavement that is more environmentally friendly. This involves incorporating electric circuits into rubber tires, using the steel wire mesh embedded in them as a valuable material. These tires are then used as a heating element to warm the pavement surface.

To test this method, two samples of concrete and rubber were combined and studied. The results showed that this construction method, along with a noble strategy, was effective in providing sufficient heating to keep the surface temperature of the samples above freezing point and to melt snow. This approach is not only more cost-effective compared to other existing techniques but also offers greater technological advantages.

The main findings of the investigation can be summarized as:

The aim of this study is to evaluate the viability of a novel construction method for melting snow from pavement. The study introduces a new technique that utilizes waste rubber tires (WRT) to replace conventional materials such as carbon black and carbon fiber in ECON systems, altering the concrete layer properties and enhancing the electrical conductivity properties to generate heat for melting snow. Temperature changes were monitored and recorded over time for both the rubber and concrete samples, and observations and pictures were taken to document the combined samples' ability to melt snow. The following is a summary of the study's findings:

1. The low-carbon steel used in the steel wire mesh embedded in rubber tires has been proven to be electrically conductive.
2. A low voltage is capable of generating sufficient heat from both exposed and grooved rubber samples.
3. Grooved rubber samples are more effective and time-efficient compared to exposed samples as they do not require removal of the top rubber layer, which can be costly.
4. The heat distribution across the front and back surfaces of the rubber samples was satisfactory.
5. Copper, although a good conductor, was not used due to its tendency to cause a sudden rise in temperature, which could damage the sample. Galvanized steel was used instead to achieve a gradual temperature rise.
6. The U-design of the electric circuit was selected for use in concrete-rubber samples as it demonstrated a gradual temperature increase without damaging the sample.
7. The combined concrete-rubber samples showed impressive thermal and heat transmission capabilities.
8. The rubber samples remained intact and undamaged despite being exposed to high temperatures.
9. The approach of melting snow has been successfully demonstrated and achieved.

1.20 Limitations

Some limitations of this research work are described below:

1. The maximum voltage supply was limited to 15 volts to prevent damage to the power supply from overheating if the voltage is increased beyond that level.

2. Ensuring good contact between the wires of the electric circuit and the steel wire mesh inside the rubber tire was challenging, whether copper or galvanized steel was used. Using metal pins did not ensure full contact between the materials.

3. Creating grooves in the rubber samples was also challenging, as it was necessary to avoid cutting too deeply and damaging the steel wire mesh underneath.

4. The study did not focus on finding the best design for the electric circuit, as the primary goal was to prove the concept.

5. Due to the time-consuming process of cutting, grooving, and attaching the electric circuit to a rubber sample, only a limited number of concrete-rubber samples were tested.

6. Real-time data records were not possible with the surface heating measurement device used in this study, as infrared heating measures only provide temperature data for a specific location rather than the entire testing surface area.

7. Despite variations in temperature in the lab setting, this research allowed the specimen's temperature to rise consistently.

1.21 Future work

Following works are suggested based on the current research work:

1. For future research, it is recommended to further investigate the use of materials such as copper and galvanized steel to determine which material can generate sufficient heat without damaging the material or the heating element.

2. Future studies should also focus on optimizing the electric circuit design to achieve a more uniform heat distribution across the rubber and concrete samples.

3. In order to determine the maximum temperature, rise and the extent of the heat distribution across the concrete-rubber samples, it is recommended to optimize the dimensions of the samples in future studies.

4. To fully understand the effectiveness of the proposed construction method, it is suggested that future research should conduct field-scale experiments.

5. When analyzing the cost-effectiveness of the proposed approach, it is important to consider both the operating and construction expenses to provide a comprehensive understanding of how it compares to other existing methods.

REFERENCES

[1] “Thin Conductive Concrete Overlay for Bridge Deck Deicing and Anti-Icing Sherif A. Yehia and Christopher Y. Tua”.

[2] J. Wu, J. Liu, and F. Yang, “Three-phase composite conductive concrete for pavement deicing,” *Constr Build Mater*, vol. 75, pp. 129–135, Jan. 2015, doi: 10.1016/j.conbuildmat.2014.11.004.

[3] W. A. Nixon and Strategic Highway Research Program (U.S.), *Improved cutting edges for ice removal*. Strategic Highway Research Program, National Research Council, 1993.

[4] H. Ceylan, K. Gopalakrishnan, S. Kim, W. Cord, and A. Uk, “Civil, Construction and Environmental Engineering Conference Presentations and Proceedings,” 2014. [Online]. Available: http://lib.dr.iastate.edu/ccee_conf/23

[5] A. Arabzadeh *et al.*, “Influence of Deicing Salts on the Water-Repellency of Portland Cement Concrete Coated with Polytetrafluoroethylene and Polyetheretherketone.”

[6] A. Jamil, S. Riaz, M. Ashraf, and M. R. Foolad, “Gene expression profiling of plants under salt stress,” *Critical Reviews in Plant Sciences*, vol. 30, no. 5. pp. 435–458, Sep. 2011. doi: 10.1080/07352689.2011.605739.

[7] S. Guo, R. Si, Q. Dai, Z. You, Y. Ma, and J. Wang, “A critical review of corrosion development and rust removal techniques on the structural/environmental performance of corroded steel bridges,” *Journal of Cleaner Production*, vol. 233. Elsevier Ltd, pp. 126–146, Oct. 01, 2019. doi: 10.1016/j.jclepro.2019.06.023.

[8] A. Arabzadeh, H. Ceylan, S. Kim, K. Gopalakrishnan, and A. Sassani, “Superhydrophobic coatings on asphalt concrete surfaces: Toward smart solutions for winter pavement maintenance,” *Transp Res Rec*, vol. 2551, pp. 10–17, 2016, doi: 10.3141/2551-02.

[9] A. Arabzadeh, H. Ceylan, ; Sunghwan Kim, K. Gopalakrishnan, and A. Sassani, "Fabrication of Polytetrafluoroethylene-Coated Asphalt Concrete Biomimetic Surfaces: A Nanomaterials-Based Pavement Winter Maintenance Approach," 2016.

[10] H. Ceylan, A. Arabzadeh, A. Sassani, S. Kim, and K. Gopalakrishnan, "Innovative Nano-engineered Asphalt Concrete for Ice and Snow Controls in Pavement Systems," Czech Technical University in Prague - Central Library, Jan. 2017. doi: 10.14311/ee.2016.388.

[11] A. Arabzadeh *et al.*, "Superhydrophobic coatings on Portland cement concrete surfaces," *Constr Build Mater*, vol. 141, pp. 393–401, Jun. 2017, doi: 10.1016/j.conbuildmat.2017.03.012.

[12] Y. Lai, Y. Liu, and D. Ma, "Automatically melting snow on airport cement concrete pavement with carbon fiber grille," *Cold Reg Sci Technol*, vol. 103, pp. 57–62, 2014, doi: 10.1016/j.coldregions.2014.03.008.

[13] C. Chang, M. Ho, G. Song, Y. L. Mo, and H. Li, "A feasibility study of self-heating concrete utilizing carbon nanofiber heating elements," *Smart Mater Struct*, vol. 18, no. 12, 2009, doi: 10.1088/0964-1726/18/12/127001.

[14] H. Ceylan *et al.*, "Self-Heating Electrically Conductive Concrete Demonstration Project tech transfer summary Self-Heating Electrically Conductive Concrete Demonstration Project PRINCIPAL INVESTIGATOR CO-PRINCIPAL INVESTIGATORS Objective and Goals," 2021.

[15] J. Gomis, O. Galao, V. Gomis, E. Zornoza, and P. Garcés, "Self-heating and deicing conductive cement. Experimental study and modeling," *Constr Build Mater*, vol. 75, pp. 442–449, May 2015, doi: 10.1016/j.conbuildmat.2014.11.042.

[16] C. Y. Tuan, "Implementation of Conductive Concrete for Deicing (Roca Bridge)," 2008. [Online]. Available: https://digitalcommons.unl.edu/ndor

[17] H. Xu, D. Wang, Y. Tan, J. Zhou, and M. Oeser, “Investigation of design alternatives for hydronic snow melting pavement systems in China,” *J Clean Prod*, vol. 170, pp. 1413–1422, Jan. 2018, doi: 10.1016/j.jclepro.2017.09.262.

[18] H. Wang, L. Liu, and Z. Chen, “Experimental investigation of hydronic snow melting process on the inclined pavement,” *Cold Reg Sci Technol*, vol. 63, no. 1–2, pp. 44–49, Aug. 2010, doi: 10.1016/j.coldregions.2010.04.007.

[19] P. Pan, S. Wu, Y. Xiao, and G. Liu, “A review on hydronic asphalt pavement for energy harvesting and snow melting,” *Renewable and Sustainable Energy Reviews*, vol. 48. Elsevier Ltd, pp. 624–634, Aug. 01, 2015. doi: 10.1016/j.rser.2015.04.029.

[20] H. Abdualla, “Design, construction, and performance of heated concrete pavements system.”

[21] J. W. Lund, “PAVEMENT SNOW MELTING.”

[22] D. R. Brill, “Heated Pavements & Nanotechnology for Airport Pavements SWIFT Conference 2016.”

[23] D. Barbagallo, “RPD 155 heated pavements,” FAA ANG-E262 REDAC Committee Meeting, Mar. 2013.

[24] ASHRAE., *ASHRAE Handbook - HVAC Applications American Society of Heating, Chapter 51 – Snow Melting and Freeze Protection*. American Society of Heating, Refrigerating and Air-Conditioning Engineers , 2015.

[25] D. J. Henderson, “Experimental Roadway Heating Project On a Bridge Approach.”

[26] C. Y. Tuan, “CONDUCTIVE CONCRETE FOR BRIDGE DECK DEICING AND ANTI-ICING A Final Report,” 2004.

[27] “TOWARD A MORE SUSTAINABLE CONSTRUCTION METHOD FOR ELECTRICALLY CONDUCTIVE HEATED PAVEMENT SYSTEMS,” 2021.

[28] P. Pan, S. Wu, F. Xiao, L. Pang, and Y. Xiao, “Conductive asphalt concrete: A review on structure design, performance, and practical applications,” *J Intell Mater Syst Struct*, vol. 26, no. 7, pp. 755–769, May 2015, doi: 10.1177/1045389X14530594.

[29] K. Gopalakrishnan, H. Ceylan, S. Kim, S. Yang, and H. Abdualla, “Electrically conductive mortar characterization for self-heating airfield concrete pavement mix design,” *International Journal of Pavement Research and Technology*, vol. 8, no. 5, pp. 315–324, Sep. 2015, doi: 10.6135/ijprt.org.tw/2015.8(5).315.

[30] A. Arabzadeh, A. Sassani, H. Ceylan, S. Kim, K. Gopalakrishnan, and P. C. Taylor, “Comparison between cement paste and asphalt mastic modified by carbonaceous materials: Electrical and thermal properties,” *Constr Build Mater*, vol. 213, pp. 121–130, Jul. 2019, doi: 10.1016/j.conbuildmat.2019.04.060.

[31] M. A. Notani, A. Arabzadeh, H. Ceylan, A. M. Asce, S. Kim, and K. Gopalakrishnan, “Effect of Carbon-Fiber Properties on Volumetrics and Ohmic Heating of Electrically Conductive Asphalt Concrete,” 2019, doi: 10.1061/(ASCE).

[32] A. Sassani *et al.*, “Carbon fiber-based electrically conductive concrete for salt-free deicing of pavements,” *J Clean Prod*, vol. 203, pp. 799–809, Dec. 2018, doi: 10.1016/j.jclepro.2018.08.315.

[33] A. Malakooti *et al.*, “Design and Full-scale Implementation of the Largest Operational Electrically Conductive Concrete Heated Pavement System,” *Constr Build Mater*, vol. 255, Sep. 2020, doi: 10.1016/j.conbuildmat.2020.119229.

[34] A. Sassani, H. Ceylan, S. Kim, A. Arabzadeh, P. C. Taylor, and K. Gopalakrishnan, “Development of Carbon Fiber-modified Electrically Conductive Concrete for Implementation in Des Moines International Airport,” *Case Studies in Construction Materials*, vol. 8, pp. 277–291, Jun. 2018, doi: 10.1016/j.cscm.2018.02.003.

[35] Y. Lai, Y. Liu, and D. Ma, "Automatically melting snow on airport cement concrete pavement with carbon fiber grille," *Cold Reg Sci Technol*, vol. 103, pp. 57–62, 2014, doi: 10.1016/j.coldregions.2014.03.008.

[36] H. W. Whittington B S ~ and T. C. Forde Beng, "The conduction of electricity through concrete."

[37] S. M. S. Sadati, K. Cetin, H. Ceylan, A. Sassani, and S. Kim, "Energy and thermal performance evaluation of an automated snow and ice removal system at airports using numerical modeling and field measurements," *Sustain Cities Soc*, vol. 43, pp. 238–250, Nov. 2018, doi: 10.1016/j.scs.2018.08.021.

[38] Y. Farnam, A. Wiese, D. Bentz, J. Davis, and J. Weiss, "Damage development in cementitious materials exposed to magnesium chloride deicing salt," *Constr Build Mater*, vol. 93, pp. 384–392, Jun. 2015, doi: 10.1016/j.conbuildmat.2015.06.004.

[39] H. Wang, C. Thakkar, X. Chen, and S. Murrel, "Life-cycle assessment of airport pavement design alternatives for energy and environmental impacts," *J Clean Prod*, vol. 133, pp. 163–171, Oct. 2016, doi: 10.1016/j.jclepro.2016.05.090.

[40] Z. Hou, Z. Li, and J. Wang, "Electrical conductivity of the carbon fiber conductive concrete," *Journal Wuhan University of Technology, Materials Science Edition*, vol. 22, no. 2, pp. 346–349, Jun. 2007, doi: 10.1007/s11595-005-2346-x.

[41] T. Wu, R. Huang, M. Chi, and T. Weng, "A study on electrical and thermal properties of conductive concrete," *Computers and Concrete*, vol. 12, no. 3, pp. 337–349, Sep. 2013, doi: 10.12989/cac.2013.12.3.337.

[42] R. Rao, H. Wang, H. Wang, C. Y. Tuan, and M. Ye, "Models for estimating the thermal properties of electric heating concrete containing steel fiber and graphite," *Compos B Eng*, vol. 164, pp. 116–120, May 2019, doi: 10.1016/j.compositesb.2018.11.053.

[43] A. Shishegaran, F. Daneshpajoh, H. Taghavizade, and S. Mirvalad, "Developing conductive concrete containing wire rope and steel powder wastes for route deicing," *Constr Build Mater*, vol. 232, Jan. 2020, doi: 10.1016/j.conbuildmat.2019.117184.

[44] B. O. Lee, W. J. Woo, H. S. Park, H. S. Hahm, J. P. Wu, and M. S. Kim, "Influence of aspect ratio and skin effect on EMI shielding of coating materials fabricated with carbon nanofiber/PVDF."

[45] A. Das, H. T. Hayvaci, M. K. Tiwari, I. S. Bayer, D. Erricolo, and C. M. Megaridis, "Superhydrophobic and conductive carbon nanofiber/PTFE composite coatings for EMI shielding," *J Colloid Interface Sci*, vol. 353, no. 1, pp. 311–315, Jan. 2011, doi: 10.1016/j.jcis.2010.09.017.

[46] C. Y. Lee, J. H. Bae, T. Y. Kim, S. H. Chang, and S. Y. Kim, "Using silane-functionalized graphene oxides for enhancing the interfacial bonding strength of carbon/epoxy composites," *Compos Part A Appl Sci Manuf*, vol. 75, pp. 11–17, 2015, doi: 10.1016/j.compositesa.2015.04.013.

[47] K. Golovin, M. Boban, J. M. Mabry, and A. Tuteja, "Designing Self-Healing Superhydrophobic Surfaces with Exceptional Mechanical Durability," *ACS Appl Mater Interfaces*, vol. 9, no. 12, pp. 11212–11223, Mar. 2017, doi: 10.1021/acsami.6b15491.

[48] L. Lei, L. Zhong, X. Lin, Y. Li, and Z. Xia, "Synthesis and characterization of waterborne polyurethane dispersions with different chain extenders for potential application in waterborne ink," *Chemical Engineering Journal*, vol. 253, pp. 518–525, Oct. 2014, doi: 10.1016/j.cej.2014.05.044.

[49] H. Du *et al.*, "Synthesis and characterization of waterborne polyurethane adhesive from MDI and HDI," *J Appl Polym Sci*, vol. 110, no. 3, pp. 1396–1402, Nov. 2008, doi: 10.1002/app.28805.

[50] J. Zhao *et al.*, “Synthesis of a waterborne polyurethane-fluorinated emulsion and its hydrophobic properties of coating films,” *Ind Eng Chem Res*, vol. 53, no. 49, pp. 19257–19264, Dec. 2014, doi: 10.1021/ie5040732.

[51] H. Kargarzadeh *et al.*, “Recent developments on nanocellulose reinforced polymer nanocomposites: A review,” *Polymer*, vol. 132. Elsevier Ltd, pp. 368–393, Dec. 06, 2017. doi: 10.1016/j.polymer.2017.09.043.

[52] A. Nahvi *et al.*, “Multi-objective Bayesian optimization of super hydrophobic coatings on asphalt concrete surfaces,” *J Comput Des Eng*, vol. 6, no. 4, pp. 693–704, Oct. 2019, doi: 10.1016/j.jcde.2018.11.005.

[53] M. K. Tiwari, I. S. Bayer, G. M. Jursich, T. M. Schutzius, and C. M. Megaridis, “Highly liquid-repellent, large-area, nanostructured poly(vinylidene fluoride)/poly(ethyl 2-cyanoacrylate) composite coatings: Particle filler effects,” *ACS Appl Mater Interfaces*, vol. 2, no. 4, pp. 1114–1119, Apr. 2010, doi: 10.1021/am900894n.

[54] B. Indraratna, Q. Sun, A. Heitor, and J. Grant, “Performance of Rubber Tire-Confined Capping Layer under Cyclic Loading for Railroad Conditions,” *Journal of Materials in Civil Engineering*, vol. 30, no. 3, Mar. 2018, doi: 10.1061/(asce)mt.1943-5533.0002199.

[55] C. Lee, ; Q Hung Truong, W. Lee, and J.-S. Lee, “Characteristics of Rubber-Sand Particle Mixtures according to Size Ratio”, doi: 10.1061/ASCEMT.1943-5533.0000027.

[56] B. S. Thomas and R. C. Gupta, “A comprehensive review on the applications of waste tire rubber in cement concrete,” *Renewable and Sustainable Energy Reviews*, vol. 54. Elsevier Ltd, pp. 1323–1333, Feb. 01, 2016. doi: 10.1016/j.rser.2015.10.092.

[57] W. Song *et al.*, “Improving Damping Properties of Railway Ballast by Addition of Tire-Derived Aggregate,” *Transp Res Rec*, vol. 2673, no. 5, pp. 299–307, May 2019, doi: 10.1177/0361198119839345.

[58] B. S. Thomas, R. C. Gupta, and V. J. Panicker, "Recycling of waste tire rubber as aggregate in concrete: Durability-related performance," *J Clean Prod*, vol. 112, pp. 504–513, Jan. 2016, doi: 10.1016/j.jclepro.2015.08.046.

[59] Y. Qi, B. Indraratna, A. Heitor, and J. S. Vinod, "Effect of Rubber Crumbs on the Cyclic Behavior of Steel Furnace Slag and Coal Wash Mixtures," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 144, no. 2, Feb. 2018, doi: 10.1061/(asce)gt.1943-5606.0001827.

[60] X. Shu and B. Huang, "Recycling of waste tire rubber in asphalt and portland cement concrete: An overview," *Constr Build Mater*, vol. 67, no. PART B, pp. 217–224, Sep. 2014, doi: 10.1016/j.conbuildmat.2013.11.027.

[61] H. Gong *et al.*, "Direct shear properties of railway ballast mixed with tire derived aggregates: Experimental and numerical investigations," *Constr Build Mater*, vol. 200, pp. 465–473, Mar. 2019, doi: 10.1016/j.conbuildmat.2018.11.284.

[62] H. Consulting, "Stocks and fate of end-of-life tyres - 2013-14 study." [Online]. Available: www.hyderconsulting.com

[63] Publication, "BEST PRACTICE ENVIRONMENTAL MANAGEMENT SITING, DESIGN, OPERATION AND REHABILITATION OF LANDFILLS," 2010.

[64] B. J. H Lee, R. Salgado, A. Bernal, and C. W. Lovell, "SHREDDED TIRES AND RUBBER-SAND AS LIGHTWEIGHT BACKFILL," 1999.

[65] H. Wu, H. Duan, L. Zheng, J. Wang, Y. Niu, and G. Zhang, "Demolition waste generation and recycling potentials in a rapidly developing flagship megacity of South China: Prospective scenarios and implications," *Constr Build Mater*, vol. 113, pp. 1007–1016, Jun. 2016, doi: 10.1016/j.conbuildmat.2016.03.130.

[66] F. Y. and B. H. Xiaoyang Jia, "Utilization of Construction and Demolition Wastes in Low-Volume Roads for Rural Areas in China," pp. 39–47, 2015.

[67] C. Bulei, M. P. Todor, T. Heput, and I. Kiss, “Directions for material recovery of used tires and their use in the production of new products intended for the industry of civil construction and pavements,” in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Jan. 2018. doi: 10.1088/1757-899X/294/1/012064.

[68] A. Arulrajah, A. Mohammadinia, F. Maghool, and S. Horpibulsuk, “Tire derived aggregates as a supplementary material with recycled demolition concrete for pavement applications,” *J Clean Prod*, vol. 230, pp. 129–136, Sep. 2019, doi: 10.1016/j.jclepro.2019.05.084.

[69] G. Girskas and D. Nagrockienė, “Crushed rubber waste impact of concrete basic properties,” *Constr Build Mater*, vol. 140, pp. 36–42, Jun. 2017, doi: 10.1016/j.conbuildmat.2017.02.107.

[70] Y. Li, S. Zhang, R. Wang, and F. Dang, “Potential use of waste tire rubber as aggregate in cement concrete – A comprehensive review,” *Construction and Building Materials*, vol. 225. Elsevier Ltd, pp. 1183–1201, Nov. 20, 2019. doi: 10.1016/j.conbuildmat.2019.07.198.

[71] B. S. Thomas and R. Chandra Gupta, “Properties of high strength concrete containing scrap tire rubber,” *J Clean Prod*, vol. 113, pp. 86–92, Feb. 2016, doi: 10.1016/j.jclepro.2015.11.019.

[72] S. Guo, Q. Dai, R. Si, X. Sun, and C. Lu, “Evaluation of properties and performance of rubber-modified concrete for recycling of waste scrap tire,” *J Clean Prod*, vol. 148, pp. 681–689, Apr. 2017, doi: 10.1016/j.jclepro.2017.02.046.

[73] I. Mohammadi, “Title: Investigation on the Use of Crumb Rubber Concrete (CRC) for Rigid Pavements,” 2014.

[74] M. Hossain, M. Sadeq, L. Funk, and R. Maag, “A STUDY OF CHUNK RUBBER FROM RECYCLED TIRES AS A ROAD CONSTRUCTION MATERIAL.”

[75] B. Mohammed, M. Adamu, N. Shafiq, and B. S. Mohammed, "A Review on The Effect of Crumb Rubber On The Properties of Rubbercrete," *Article in International Journal of Civil Engineering and Technology*, vol. 8, no. 9, pp. 599–615, 2017, [Online]. Available: http://www.iaeme.com/IJCIET/index.asp599http://http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=8&IType=9http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=9

[76] S. M. S. Sadati, K. S. Cetin, H. Ceylan, and S. Kim, "Energy-efficient design of a carbon fiber-based self-heating concrete pavement system through finite element analysis," *Clean Technol Environ Policy*, vol. 22, no. 5, pp. 1145–1155, Jul. 2020, doi: 10.1007/s10098-020-01857-4.

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