A Process for Utilizing Disposable Face Masks in Hot Mix Asphalt (HMA) Pavement Construction

by

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July, 2022

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The COVID-19 pandemic has caused a tremendous rise in plastic waste pollution globally. Pollution instigated by plastic has been one of the greatest threats to our world even before the Coronavirus outbreak. It is believed that plastic pollution has worsened due to the disposing of millions of personal protective equipment (PPE), such as surgical face masks. The use of plastic waste as a modifier has significantly lowered the temperature susceptibility of pavements, improved asphalt performance, and lowered construction costs, while the recycling of plastic waste has improved the environmental quality and preserved the non-renewable resources. To reduce pandemic-generated wastes and enhance the asphalt rutting resistance, disposable face mask is used as an as an efficient and non-costly modifier to hot mix asphalt (HMA) mixtures. The goal of the thesis is to bring an advancement to the field of transportation infrastructure by evaluating the performance of the flexible pavement using shredded face masks (SFM) as a modifier of HMA mixture and developing a cost estimating calculator to estimate the cost of asphalt pavement construction with mask. Modified HMA mixes with SFM content ranging from 0% to 1.5% were prepared and tested for rutting using Asphalt Pavement Analyzer (APA). It was found that by increasing the SFM content from 0% to 1.5%, the modified samples showed admirable resistance to permanent deformation as rutting depth values decreased from 3.0 mm to 0.93 mm. However, this study has resulted in the improvement of the rutting resistance of hot mix asphalt samples by

using shredded face masks (SFM) as a modifier of HMA. Specific contributions include the evaluation of face masks in hot mix asphalt (HMA), and the development of a safe collection procedure for disposable face masks and a cost estimation calculator in Excel to estimate the cost of asphalt pavement construction based with and without face masks. Finally, this research opens a new avenue for the development of sustainable asphalt pavements by reducing pollution and energy consumption and increases knowledge in these areas. The findings of this study provide valuable insights into future efforts by industry and government agencies to develop sustainable approaches for the transportation, energy, and environmental industries. Furthermore, this research could provide a solution to reduce the plastic waste that is polluting the environment due to the COVID-19 pandemic and reveals the scope of a cost-benefit analysis of the process so that economists can assess the socioeconomic benefits of using face masks in pavement construction.

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A Thesis

Presented to The Faculty of the Department of Construction Management

East Carolina University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Construction Management

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

The whole world is facing the problem of Covid-19 pandemic. Millions of people died by getting unconscious of using Personal Protection Equipment (PPE) (e.g., Face mask, face shield, hand gloves) (Saberian et. al., 2021). The use of face masks as part of the health campaign against the coronavirus has been so successful that it has become a necessity for global public health initiatives to prevent the spread of the virus (Royo-Bordonada et al., 2020). Though the use of face masks is incredibly needed, disposing them is threatening the environment. Daily, a large amount of waste is generated from the disposable of millions of masks. At the time of this writing no current figure is available for the total number of face masks used globally; in 2020, the total estimate of used face masks was more than 129 billion where a sharp 20% growth is expected in between 2020 to 2025 (Prata et. al., 2020). Collection of face masks is very challenging since face masks are littering parking lots, neighborhood streets, sidewalks, and parks which may lead to social, environmental, and animal issues (Prata et. al., 2020; Saberian et. al., 2021). Additionally, most face masks are made of polypropylene, which is non-biodegradable materials and will not break down in the environment for several hundred years (Dhawan et al., 2019; Henneberry, 2020) causing a solid waste problem in addition to microplastic contamination in marine and freshwater environments (Aragaw, 2020). While the use of plastic waste as a modifier has greatly enhanced the road's adhesion, lowered the thermal susceptibility of pavements, improved asphalt performance, and reduced construction costs, recycling plastic waste has improved the environment and maintained non-renewable resources (Rahat et al., 2022). Since disposable face masks are plastic, it can be a good construction substitute material to enhance the asphalt rutting resistance. In addition, a safe collection procedure for face masks, as well as proper cost estimations of construction process with modifiers, are vital considerations.

Rutting control on asphalt pavement is a major issue because of the amount of traffic, tire pressure, and axial strain on the surface (Saberian et al., 2021). After a few years, asphalt rutting is common. In a different perspective, it seems to be a depression in the wheel paths that is eroded on the edges when seen from above, or to put it another way, it displays densification and lateral deformation (Khan et al., 2013). Three forms of rutting are formed following the establishment: structural rutting, wheel path wear and densification, and asphalt concrete stability rutting (i.e., deformation) (Saberian et al., 2018; Wang, 2016). As traffic numbers, traffic flows, and pressures have grown in recent years, so has the possibility of tire rutting. Pavement rutting occurs when fine and coarse aggregate particles of different shapes and sizes are deformed over time due to the shape, toughness, and angularity of the aggregate. Furthermore, it may be due to poorly designed mixes and inadequate asphalt binders, such as a binder that does not meet AASHTO M320 (AASHTO, 2017) or AASHTO M332 (AASHTO, 2020) standards, or an excess amount of asphalt binder in the mix. Heat, solar radiation, air oxygen, and traffic are some of the factors that cause asphalt binder to be destroyed. Consequently, road surfaces become unreliable. Therefore, asphalt binder must be replaced or modified to meet road requirements (Roberts et. al., 1996).

Some modifiers, such as polymers and plastics, may be used to make the asphalt binder more rigid in order to prevent cracking due to stress, while softening the asphalt binder to resist temperature-related fluctuations in stiffness (Speight, 2015). For the construction of flexible pavements, plastic wastes have recently proven to be an effective modifier to asphalt binder (Almeida et al., 2021; Veropalumbo et al., 2021) because they do not produce any toxic gas during heating and tend to form a film covering the aggregate and Plastics Coated Aggregates (PCA) when spread on hot aggregate at 160°C (Rajasekaran, S., et al. 2013). In addition, the use of polymers as asphalt binder in flexible pavements has been found to increase the engineering properties of these pavements (i.e., Marshall stability, water resistance, and resistant to crack propagation) (Esfandabad et al., 2020; Haider et al., 2020; Needhidasan and Agarwal, 2020). For this reason, recycling and repurposing COVID-19 generated wastes, such as single-use face masks, solid waste plastics, and industrial by-products (e.g., asphalt shingles, glass, ash), can dramatically alleviate environmental issues and add financial value. Additionally, this method may be employed in asphalt applications, where it can be used as a component in hot-mix asphalt (HMA).

According to Bai & Sutanto (2002), recycling is the most widely accepted method of plastic waste management and a vital part of sustainable waste management. Nevertheless, recycling of plastic waste is a multifaceted process that involves collection, processing, storage, transport, treatment, and application. Waste collection, and transportation operations account for about 70% of total process costs (Greco et al., 2015; Tavares et al., 2009). A proper collection method, as well as an accurate cost estimation, are essential to determine the most cost-effective waste collection (Huang et al., 2011; Jacobsen et al., 2013). As a result, plastic waste collection could be more efficient. By adding disposable face masks to hot mix asphalt (HMA) to modify the mechanical properties and improve the performance of the pavement, this study provides a novel method for reducing pandemic-generated waste. Since, it has become a challenge of collecting the COVID-19 generated plastic waste (i.e., face mask, face shield, gloves), and estimating the cost of the process. Face masks has been used by mass people and millions of face mask are throwing out as waste everywhere, including hospitals, residential, educational, and commercial zones. As the medical plastic wastes are incinerated after collection (Tejaswini et al., 2022; Chowdhury et al., 2022), it is not possible to recycle for further use. Due to some restrictions on the collection and recycling of disposable masks, this thesis was carried out on new masks.

However, for the practical application of recycled disposable masks as a modifier of HMA pavement to improve rutting resistance in the future, a safe collection method for masks and cost estimation calculator to estimate the total process has been developed in this study. To prepare disposable face masks, the metal strips on the nose and the ear loops were removed and the masks were shredded. For testing how the mask behaves in the HMA solution, the shredded face masks were first heated to 160^0C for 10 minutes and then cooled to room temperature to solidify. A series of experiments on the volumetric properties and mechanical properties (i.e., rutting) were conducted using blends of different percentages of the shredded face mask (SFM) added to the normal HMA mixtures. Finally, a cost estimation calculator was developed in excel to calculate the cost of the process.

1.1 Problem Statement

The use of plastic waste as a modifier has significantly lowered the temperature susceptibility of pavements, improved asphalt performance, and lowered construction costs, while the recycling of plastic waste has improved the environmental quality and preserved the non-renewable resources. To reduce pandemic-generated wastes, enhance the asphalt rutting resistance, and estimate the cost of the total process of construction; a face mask collection procedure and cost estimating calculator is developed to collect disposable face mask and estimate the cost of the total process of construction for using face masks as a modifier of hot mix asphalt (HMA) mixtures.

1.2 Goal and Objectives

The goal of the thesis was to bring an advancement to the field of transportation infrastructure by evaluating the performance of the flexible pavement using SFM as a modifier of

HMA mixture and developing a cost estimating calculator to estimate the cost of asphalt pavement construction with mask. To achieve the goal, the following objectives are undertaken:

1. Develop face mask safe collection procedures from non-medical sources
2. Prepare the face masks for laboratory experiments and incorporate them with HMA samples to conduct superpave mix design and Asphalt Pavement Analyzer test (APA).
3. Develop a cost estimation calculator to estimate the cost associated with the collection, preparation and application of face makes.

The research calls attention to the following research questions:

- How can the collection procedure be effectively used for collecting disposable face masks?
- What are the optimum percentages of asphalt binder in the modified samples and optimum percentage of modifiers that provides high performance as compared to virgin binder?
- How much the cost of total process with face masks deviated from the cost of total process without face masks?
- What are the environmental and economic benefits of using SFM as modifier in HMA?

1.3 Study Limitation

This thesis is limited to the evaluation of the rutting resistance of SFM modified HMA with their volumetric properties, theoretical development of mask collection procedure from non-medical sources, and cost estimating calculator of the entire process based on the rates from local agencies (Greenville, NC). The samples were used to see the volumetric properties and the rutting resistance performance of HMA using Superpave test and asphalt pavement analyzer test. Although the modified samples were designed and tested for only rutting resistance performance, these types of samples can also be used to evaluate the performance of HMA against other pavement distress (i.e., alligator cracking, longitudinal cracking, flexural cracking), in the granular base/subbase to see the improvement and rheological properties of HMA. Besides other plastic wastes can be used to modify the HMA samples for evaluating the rutting resistance. Furthermore, a pilot application can be carried out to observe the effectiveness of the collection procedure, and cost can be estimated using the uniform national rates to see how the cost of the process with face mask deviates for the national rates.

1.4 Organization of the Thesis

This thesis is organized into five chapters: (1) Introduction; (2) Literature Review; (3) Materials and Methodology; (4) Results and Discussions; and (5) Conclusions, and Recommendations. Chapter 2 provides a literature review of recycled plastic waste application in construction industry, different types of distresses of asphalt pavement, different types of modifiers that are being used to improve the quality of hot mix asphalt (HMA), use of disposable face masks as a modifier in construction, and collection processing, and cost estimation of recycled plastic waste. Chapter 3 outlines the overall procedure of face mask collection and preparation, sample preparation, mix designs, testing methods, data analysis and cost estimation. Chapter 4 presents the results and discussions of the procedures and tests carried out in Chapter 3. Chapter 5 provides the overall conclusions, and recommendations resulting from the study.

CHAPTER 2: LITERATURE REVIEW

The purpose of this chapter is to understand the applications of recycled materials and plastic wastes in the construction industry especially in the road sectors and how advantages can be taken of the wastes generated by COVID-19 pandemic to improve asphalt. Additionally, studies on the use of modifiers in hot mix asphalt were reviewed to gain an insight on what has been studied. Within the context of the thesis, the first section of this chapter provides a review of the applications of recycled materials and plastic wastes in the construction industry. The second section focuses on the types of pavement distress for asphalt pavements. The third section provides a review of the modifiers have been used in hot mix asphalt to improve the performance. The fourth section discusses the use of the disposable face mask as a modifier in the construction Industry. The fifth section provides a review of the cost estimation of solid waste collection. This chapter enables identifying the gaps that are present in the literature and immensely helped in the development of this study.

2.1 Applications of Recycled Plastic Wastes in Construction Industry

Human activities have made a significant contribution to the yearly generated and discarded plastic wastes. Additionally, the enormous increase in face masks and face shield caused by the emergence of the COVID-19 pandemic has doubled the generated plastic wastes all around the world (Adyel, 2020). However, the high expenses of landfilling, and land-space consumption are significant barriers to waste management. One of the numerous solid wastes threatening the sustainability of our world is plastic waste (Jambeck et al., 2018) and about 300 million metric tons of plastic waste are produced annually (Singh & Sharma, 2016). Moreover, plastic pollution affects the natural environment and harms plants, animals, or humans. However, toxic plastic pollutants damage the environment and cause land, water, and air pollution. Although the recycling of plastics is considered complex, mechanical, chemical or thermal recycling of plastic waste is possible (Hahladakis & Iacovidou, 2019). On the other hand, with the increase of urbanization and population growth, the demand for different infrastructures will increase proportionally (Awoyera et al., 2016). Hence, the use of recycled plastic waste in a variety of construction applications seems to be an efficient approach to address this sustainability problem while also meeting future infrastructure demand. In addition to its effectiveness as a construction material, plastic waste should be affordable and sustainable. Researchers have conducted some research on recycled plastic waste in the construction industry and found Polyethylene terephthalates (PET), High density polyethylene (HDPE), Polyvinyl Chloride (PVC), Low density polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS) were the most used in Concrete, building plaster, Block, Mortar, Base/Subbase of Pavement, hot mix asphalt (HMA) (Almeshal et al., 2020; Proshad et al., 2017; Siddique et al., 2008; da Silva et al., 2021). Figure 2.1 shows construction applications of different plastics in different sectors (i.e., Concrete, building plaster, Block, Mortar, Base/Subbase of Pavement, hot mix asphalt (HMA)). From Figure 2.1 it can be said that PET is the most popular plastic in construction application (i.e., concrete, mortar, building plaster, block, pavements). Where PVC is the least applied plastic in construction (i.e., concrete, mortar). Moreover, HDPE, LDPE, PS, PP are also used frequently in the construction industry. By comparing Figure 2.1 and Figure 2.2 it can be said that recyclability is one of the main factors which influences the application of plastic in construction industry. Since the recyclability level PVC in is difficult they are being least applied in the construction industry where other plastics with easier recyclability is the most applied in construction industry.

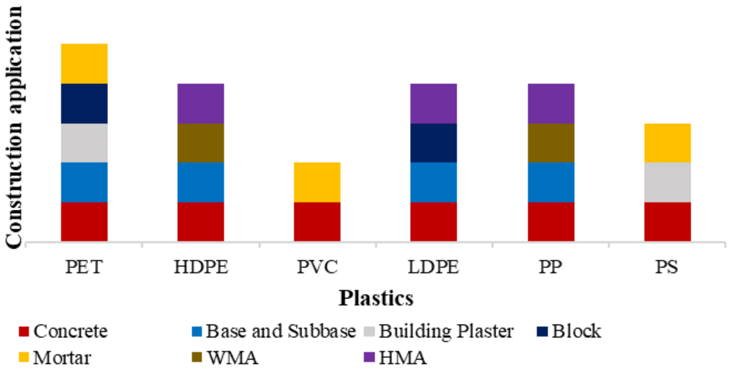


Figure 2.1: Construction Application of Different Plastics

Figure 2.2 represents the recyclability levels of different plastics for construction application. Basically, recyclability depends on different factors (i.e., cost of processing, availability, collection procedure). In most cases, the plastic which recyclability level is easier have high levels of application and the plastic which recyclability is difficult have low levels of application as shown in the Figure 2.2. From Figure 2.2 it can be said that PET, HDPE, PP and LDPE could be recycled easily but recyclability of PVC and PS is difficult. Polystyrene (PS)) has a high level of application despite their recyclability is very difficult because volume of PS is occupied by 94% of air content (Rahat et al., 2022). For this reason, it is very expensive to store or ship. Besides, being light in weight it can be easily contaminated with foods and other liquid so that it is very difficult to clean (Fortelný et al., 2004). This could be because PS is widely available, inexpensive to produce, and frequently used in the packaging of various products. On the other hand, 54% raw materials of PVC are chlorine and if it is used in construction application especially in concrete the construction could easily be affected by chloride attack (Sadat-Shojai & Bakhshandeh, 2011).

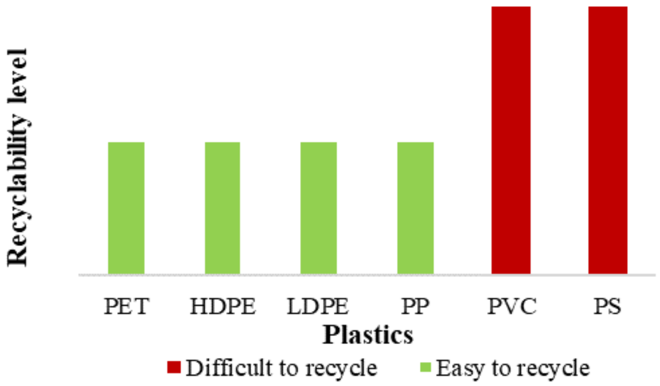


Figure 2.2: Recyclability Level of Different Plastics

Mixing plastic waste into concrete, mortar, building plaster, asphalt, Hot mix asphalt (HMA) and pavement base/subbase modification is a better choice for plastic waste disposal. Table 2.1 describes the application of plastic waste in the construction industry. The review focuses on the challenges and opportunities of plastic waste as construction material. It can be seen from Table 2.1, opportunities (improve performance, environment quality, reduce cost) and challenges (i.e., functionality, recycling plan, collection, separation, processing, field performance) are quite similar for all plastic application in construction (Ismail & AL-Hashmi, 2008; Batayneh et al., 2007; Hama & Hilal, 2017). Improvement of concrete overall quality, concrete cracking resistance, plaster tensile resistance and compressive strength of earth block is possible by using PET, PS and PVC (Ismail & AL-Hashmi, 2008; Batayneh et al., 2007; Hama & Hilal, 2017; Puri et al., 2013; Aciu et al., 2018). Besides, using Polyethylene Terephthalates (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS) it is possible to improve asphalt's mechanical properties, asphalt binder's viscosity, CBR and subgrade modulus (k_s) (Abu Abdo & Khater, 2018; Gibreil & Feng, 2017; Jha et al., 2014; Klinsky et al., 2008; Angelone et al., 2015; Arabani & Pedram, 2016). However, after all these opportunities researchers have found that the challenges have narrowed the scope of applications. The main challenges of using plastic waste are collection, field performance, separation and processing of the plastic waste (Ismail & AL-Hashmi, 2008; Batayneh et al., 2007; Hama & Hilal, 2017; Puri et al., 2013; Aciu et al., 2018; Abu Abdo & Khater, 2018; Gibreil & Feng, 2017; Jha et al., 2014; Klinsky et al., 2008; Angelone et al., 2015; Arabani & Pedram, 2016). Though there are separate bins are provided for recycled plastic waste disposal, most often the bins are contaminated by other wastes. Moreover, people are not using the bins for the disposal of plastic waste. For this reason, collection & separation procedure get complex, operation cost of this process increases. Furthermore, for using plastic waste in the construction it is required to process the material in smaller size by advanced process (i.e., grinding, pelleting, shredding), so expensive machines are required for this. Above all, researchers addressed environmental benefits and reduction of construction cost are the prime advantages of using plastic waste in the construction industry.

Table 2.1: Opportunities and Challenges of Plastic Waste Application in Construction Industry

Material	Application	Challenge	Opportunity	Author
PET	Concert, Building plaster HMA Block	Functionality, Recycling plan, collection, separation, processing	Improve performance, environment quality, reduce cost	Ismail & AL-Hashmi, (2008); Batayneh et al., (2007); Hama & Hilal, (2017); Khalid et al., (2018); Salim et al., (2019); Abu Abdo & Khater, (2018)
HDPE	HMA	Processing, functionality	Improve performance, environment quality, reduce cost	Gibreil & Feng, (2017); Jha et al., (2014); Angelone et al., (2015); Arabani & Pedram (2016)
LDPE	HMA Block	Processing Functionality	Improve performance, environment quality, reduce cost	Angelone et al., (2015); Suaryana et al., (2018); Kumi-Larbi et al., (2018)
PP	HMA	Processing, functionality	Improve performance, environment quality, reduce cost	Klinsky et al., (2008); Angelone et al., (2015); Wang et al., (2022)
PVC	Concrete Mortar	Processing, recyclability, functionality	Improve performance, environment quality, reduce cost	Puri et al., (2013); Aciu et al., (2018);

PS	Concert Building plaster Pavement	Processing, Functionality, Field performance	Improve performance, environment quality, reduce cost	Ismail & AL-Hashmi, (2008); Hama & Hilal, (2017); Salim et al., (2019); Mohajerani et al., (2017)

Ismail & AL-Hashmi, (2008) incorporated waste plastic into concrete mixes and conducted performing slump, fresh density, dry density, compressive strength, flexural strength, and toughness indices tests of concrete to evaluate the efficiency of recycling waste plastic in the concrete manufacturing process and found that microcrack development in concrete could be prevented. This study established that recycling plastic waste as a sand substitute aggregate in concrete is an effective strategy for lowering material costs and addressing some of plastics' solid waste issues. Batayneh et al., (2007) used 20% ground plastics and glass to replace fine aggregate in the concrete mix to evaluate the properties of the concrete through different laboratory tests (i.e., workability, unit weight, compressive strength, flexural strength, indirect tensile strength (splitting)) and found that substitution of fine aggregate by plastic waste improved concrete mixture strength.

Hama & Hilal, (2017) used plastic waste as partial replacement of fine aggregate in the self-compacting concrete (SSC) and found decreased flammability with linear burning rate of 4.36 mm/minute and increased tensile strength of 9.68 MPa. Khalid et al., (2018) conducted compressive strength, splitting tensile, fracture energy, and flexural beam tests on synthetic fibers embedded in a concrete matrix and found that increasing the fiber content of the concrete matrix increases its tensile strength. Salim et al., (2019) reinforced building plaster using waste plastic fiber and glass powder. However, adding waste glass powder enhanced the plaster's density while adding waste plastic fiber raised stress in flexion testing of reinforcement plaster beams. According to Benson & Khire, (1994) the use of plastic waste as a replacement for aggregate in base and subbase construction for pavements has been found to improve the shear, stiffness and bearing capacity of the pavement. Similarly, Jha et al., (2014) found that pavement strengthened with recycled plastic strips had better characteristics.

Similar to the application of recycled plastic waste in concrete and cement composites, recycled plastic waste can also be used in asphalt mixtures. Specifically, for asphalt pavement construction, Angelone et al., (2015) Conducted a study on environmentally friendly methods of recycling plastic waste in asphalt mixtures. The study included a laboratory comparison of dry processes and found that the use of recycled plastics in asphalt mixtures is a viable alternative that can reduce plastic waste and help protect the environment. Arabani & Pedram (2016) found that adding 10% recycled plastic bottles and recycled glass to the asphalt binder can improve elasticity and reversibility. Also, other characteristics of the asphalt samples like the modulus of resilience, creep, and fatigue resistance (which contribute to the asphalt mixture's durability) were improved.Suaryana et al., (2018) used plastic bag in asphalt mixture and conducted different laboratory tests to see the moisture sensitivity, rutting resistance and the fatigue life of the asphalt mixture and found the Marshall stability, the resilient modulus, stripping resistance, moisture sensitivity and rutting resistance of the mixture were improved. They mentioned that excessive use of plastic waste in the asphalt mixture could decrease the fatigue life of hot mix asphalt (HMA).

Abu Abdo & Khater, (2018) used asphalt binder and plastic powder obtained from grinding plastic bottles and found incorporating plastic powder with asphalt binder increased its viscosity and $G^*/\sin\delta$ values. Machsus et al., (2021) added plastic bottles to asphalt concrete- wearing course (AC-WC), a hot mix asphalt (HMA) type to evaluate the Marshall characteristics of the samples and the results indicated that plastic bottle waste increased the AC-WC combination strength, which correlates with increased stability. This study showed that plastic bottle waste and other local resources may be used as road paving material.

Although the use of plastic wastes for construction has several environmental and economic advantages, its widespread adoption still presents certain challenges. Based on the above reviewed studies, some of the main challenges and opportunities of using plastic wastes in construction industries. Challenges are categorized based on collection and processing, functionality, and field performance. One of the main challenges of plastic wastes is collecting and separating before recycling as these wastes are contaminated with other wastes as they are collected from different sources, as a result, these wastes are consisted hazardous and certain causation procedures are needed. Additionally, during the COVID-19 pandemic, no separate collection and separation method was used to collect used masks. The complicated chemical composition of some plastics such as PVC makes traditional recycling techniques unsuitable, as a result, advanced technology is needed, which may result in added cost. Plastic wastes need to be processed for using in construction in smaller size by grinding, pelleting, or shredding, therefore, advanced equipment is needed, which may require skilled manpower to operate and increase the cost of construction.

Previous studies have been conducted with different recycled plastic waste in different sectors of construction industry to improve the environmental sustainability and make the construction process more economical. However, there are no recent studies found regarding plastic waste and COVID 19 plastic waste (e.g., disposable face mask) in Hot Mix Asphalt (HMA) to improve the rutting resistance of asphalt pavements. This study aims to use disposable face masks as a modifier of HMA to improve the rutting resistance of asphalt pavement.

2.2 Distress Associated with Asphalt Pavement

Asphalt pavements play an essential role in transportation, and those in excellent condition may offer vehicles with a safe and pleasant trip. During their service life, asphalt pavements, however, are subjected to the combined impacts of high and repetitive traffic loads, as well as the effects of the natural environment. There will be many kinds of distress as a result of this (i.e., rutting, block cracking, edge cracking, longitudinal cracking, top-down cracking, moisture damage, transverse cracking) (Liu et al., 2017; Gao et al., 2018). They may substantially decrease pavement performance and life. When cracks occur, water may enter the pavement structure and accelerate the degradation of the asphalt pavement.

2.2.1 Rutting

Rutting is one of the most severe distresses in asphalt pavements and may severely impair the pavement's performance and service life. Rutting should be taken seriously for some reasons (i.e., i. Rutting is a threat to high-speed automobiles if the pavement drainage system is not excellent; ii. Because of the increasing rutting depth, steering becomes more difficult and even unsafe at times; iii. Temperatures in cold climates may reduce the resistance of the pavement to slippage by covering the rutting with snow; iv. The performance of the pavement is harmed by rutting) (Johnson & Snopl, 2000). As a result, the rut depth is often used to determine the road surface's condition.

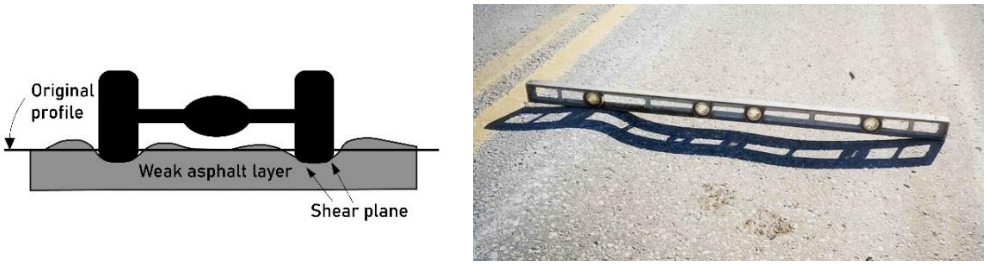


Figure 2.3: Rutting of Asphalt Pavement

2.2.2 Block Cracking

It occurs in the pattern of interconnected square or rectangular blocks on the surface of the pavement. These blocks typically range in size from 0.1 to 10 square meters and extend over most of the pavement surface area. The cracked area is measured in order to determine the severity of the cracking (Pierce et al., 2013).

Figure 2.4: Block Cracking of Asphalt Pavement

2.2.3 Edge Cracking

It occurs at the edge of the pavement due to poor drainage and insufficient support at the edge of the pavement. There are generally no more than 0.6 meters of cracking in a continuous or crescent shape along the pavement edges along the shoulder (Miller et al., 2003).

Figure 2.5: Edge Cracking of Asphalt Pavement

2.2.4 Longitudinal Cracking

It's most common in the middle of the street. If it appears in the wheel path or non-wheel path, it depends on where in the lane it is. Under repeated traffic loads, longitudinal cracks eventually evolve into alligator cracks. The linear measurement of the cracks is used to determine the severity of these cracks (Adlinge & Gupta, 2013).

Figure 2.6: Longitudinal Cracking of Asphalt Pavement

2.2.5 Top-Down Cracking

A new type of pavement distress has emerged in the last decade. This stress occurs on the surface or below the pavement. Top-down cracking occurs when critical tensile stress and strain conditions exist in the asphalt layers (Canestrari & Ingrassia, 2020). TDC often begins as a single fracture along the wheel path on the pavement. Then, as the applied loads grow, additional longitudinal fractures parallel to the original one develops at about 30-100 cm (sister cracks) and towards the center, there are longitudinally extending fractures which join at small angles. The surface of the pavement will seem to be broken into segments resembling bottom-up cracking (commonly known as "alligator cracking") (Svasdisant et al., 2002). Numerous factors contribute to the development of TDC (e.g., traffic loads, pavement structure, stiffness gradients, thermal effects, and the properties of HMA mixtures), but thick pavements are more probable to fail owing to TDC caused by tire-pavement contact stresses, particularly in the company of open-graded friction courses (OGFCs) (Canestrari & Ingrassia, 2020).

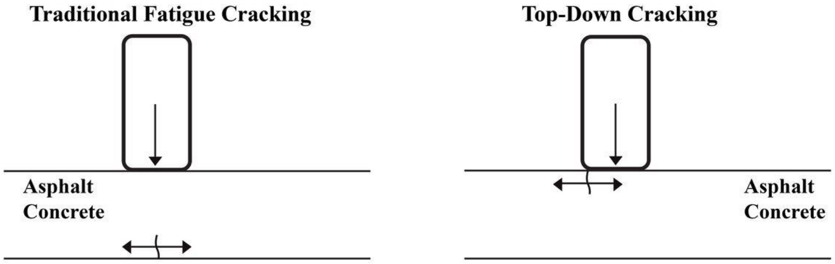


Figure 2.7: Traditional Fatigue and Top-Down Cracking of Asphalt Concrete

Figure 2.8: Alligator Cracking of Asphalt Pavement

2.2.6 Moisture Damage

Water penetrates the asphalt pavement's interior structure in various ways, causing moisture damage. Infiltration of road surface water into the internal structure of asphalt pavement occurs mostly via rainfall. Due to high groundwater, capillary activity may penetrate the internal structure of the asphalt pavement. Owing to the changing external temperature and humidity gradients, vapor is constantly inhaled and exhaled from the pavement structure. The continuous process keeps asphalt pavement breathing, while vapor may turn into liquid water by temperature change and collect in asphalt pavement. Therefore, water is closely related to asphalt pavement moisture damage and exists inside its structure (Wang et al., 2019).

Figure 2.9: Moisture Damage of Asphalt Pavement

2.2.7 Transverse Cracking

Asphalt pavements that have undergone repair or major maintenance are particularly prone to transverse cracking. Thermal cracking and reflecting cracking are the two types of transverse cracking that may be seen in most circumstances. In most cases, thermal cracking develops in the asphalt surface layer because of the thermal shrinkage of asphaltic concrete (AC), while reflective cracking begins in the chemically stabilized base and subsequently extends to the asphalt surface layer in a relatively short amount of time (Li et al., 2017). Cross-sectional cracking may affect the serviceability of a pavement by allowing water entering the structure, which in turn can hasten the degradation of a pavement.

Figure 2.10: Traditional Transverse Cracking of Asphalt Pavement

To improve asphalt pavement performance against such difficulties or problems, several modifiers have been used and proven effective. The following section will describe different types of modifiers that have been used in hot mix asphalt mixture to improve the performance of the asphalt pavements.

2.3 Modifiers of Hot Mix Asphalt (HMA)

Asphalt binder is used in hot mix asphalt (HMA) to bind the mineral materials that make up road surfaces (e.g., sand, gravel), to enhance the hydrophobic properties of concrete, and to fill holes. Asphalt binder as a surface is adversely affected by a variety of negative factors, including temperature rises, solar radiation, low oxygen levels in the air, and heavy traffic loads. In order to enhance HMA performance, asphalt binder must be modified to make it more resistant to rutting and thermal cracking, as well as less susceptible to fatigue damage, stripping, and temperature sensitivity due to deterioration of the asphalt binder. Modified HMA has been successfully used in high-stress environments (e.g., busy street intersections, airports, vehicle weigh stations, and racetracks). So, far different modifiers have been used in HMA to improve the performance of flexible pavements. Table 2.2 provides review of the most relevant studies on modifiers of hot mix asphalt found in the literature.

Table 2.2: Relevant Studies Reviewed in the Literature on Hot Mix Asphalt (HMA) Modifiers

Study	Modifier type	Tests Conducted	Potential Advantages
Alrajhi, (2012)	Polypropylene and Aramid fiber	Penetration, Softening Point, and Viscosity tests	Increased Viscosity and Decreased Thermal Crack
Mohammed et al., (2018)	Glass and Cellulose Fiber	Penetration, Softening Point, Viscosity and Double Edge Notch Tension Test Dynamic Shear Rheometer Test	Increased Viscosity, Increased Softening Point, Decreased Penetration
Klinsky et al., (2008)	Polypropylene and Aramid fiber	Moisture-Induced Damage, Resilient Modulus, Dynamic Modulus, Flow Number Test, Fatigue by Flexural Bending, Semi-Circular Test	Improved Rutting, Raveling, Fatigue, and Reflective Cracking
Qin et al., (2018)	Basalt Fiber	Leakage Test, Cone Penetration Test, Strip-Tensile Test Dynamic Shear Rheometer Test	Improved Adsorption, Strength Behavior, and Crack Resistance
Wu et al., (2008)	Polyester Fiber	Viscosity Test, Rheology Test, Dynamic Modulus Test, Indirect Tension Fatigue Test	Improved Fatigue Failure
Yao et al., (2011)	Polyacrylonitrile Fiber	Dynamic Shear Rheometer Test	Improved $G^*/\sin\delta$ Factor, Improved Strength, Improved Permanent Deformation
Morea & Zerbino, (2018)	Glass Fiber	Marshall Test, Wheel Tracking Test, Notched Beam Bending Test	Improved Rutting Resistance, Improved Fracture Behavior,
Park et al., (2015)	Steel Fiber	Indirect Tensile Strength Test	Increased Indirect Tensile Strength Increased Toughness
Jamal Khattak et al., (2013)	Carbon Nanofiber	Dynamic Modulus (E*) Test, Indirect Tensile Strength Test, Dynamic Fatigue Test, Scanning Electron Microscopy	Improved Nano- And Micro-Crack Bridging Mechanisms Adhesion Characteristics, Reduced Micro-Crack Localization and Propagation, Improved Fatigue Life Resistance to Permanent Deformation
Yazdani, (2018)	Styrene-Butadiene-Styrene Titanium Dioxide (TiO_2)	Rolling Thin Film Oven (RTFO) Test Pressure aging vessel (PAV) Test Dynamic Shear Rheometer (DSR) Test Asphalt pavement analyzer (APA) Disk Shaped Compact Tension Test (DCT)	Improved Rutting, Improved Low Temperature Cracking, Improved Fatigue Cracking

		Semi Circular Bend Test (SCB)	
Ziari et al., (2020)	Reclaimed Asphalt Pavement (RAP) Material	Semi Circular Bend Test (SCB)	Improved Cracking Resistance
Lee et al., (2008)	Crumb Rubber (CR)	Superpave Binder Tests	Improved Viscosity
Gibreil & Feng, (2017)	High-Density Polyethylene (HDPE), Crumb Rubber Powder (CRP)	Marshall Stability and Flow Test, Moisture Sensitivity Test, Wheel Tracking (Rutting)	Improved Mechanical Properties

In order to test the bitumen properties, Alrajhi, (2012) made asphalt mixtures with various amounts of polypropylene and aramid fibers and performed penetration, softening point, and viscosity tests. In the binder test results, three parts polypropylene and one part aramid were found to have the highest viscosity and the lowest thermal crack susceptibility. Mohammed et al., (2018) investigated the effect of glass and cellulose fibers in bitumen at 0.5%, 1.0%, and 2.0% by volume. With the addition of glass and cellulose fibers, it was found that the penetration value decreases. In addition, the addition of these fibers has been reported to increase the softening point and viscosity of the asphalt. Glass fibers reinforce the bitumen by forming a continuous network, whereas bitumen reinforced with cellulose fibers exhibits a slighter increase in viscosity, which could be due to the fibers' greater dispersion. According to Klinsky et al., (2008) polypropylene and aramid fibers in HMA may help asphalt pavements resist rutting, raveling, fatigue, and reflective cracking since they used polypropylene and aramid fibers in HMA to evaluate the performance of the HMA mixtures. Qin et al., (2018) investigated the effect of incorporating different proportions of basalt fibers into asphalt binders with different fiber lengths. The optimal fiber content was found to be between 5% and 7%. In terms of fiber length, 6 mm provided the best mix performance. A fiber content greater than 10% can create a clustering effect, reducing the homogeneity of the asphalt mix. The fibers improved the asphalt binder’s adsorption, strength behavior, and crack resistance the most. Wu et al., (2008) investigated the effect of polyester fiber on rheological characteristics and fatigue properties of asphalt. Fiber-modified asphalt mixtures were found to have 1.9, 2.9, and 3.6 times more cycles to fatigue failure at 0.5, 0.4, and 0.3 stress ratios (stress levels based on the asphalt mixture's splitting strength), respectively, when 0.3 % polyester fibers were incorporated.

Yao et al., (2011) used the wet method to add Polyacrylonitrile fibers to asphalt concrete (4 % and % fibers by weight of the binder) to make it stronger. The Dynamic Shear Rheometer (DSR) test results for the fiber-modified asphalt mortar showed that the factor $G^*/\sin\delta$ went up when fibers were added. Because of that, the strength of the binder at high temperatures went up, and the permanent deformation went down. Morea & Zerbino, (2018) investigated the effect of glass macro fibers in asphalt concrete mixtures. In this case, the authors included fibers with a length greater than 35 mm. Based on the results obtained, 0.4% glass fiber by weight of the mixture was the optimal amount to improve rutting resistance, fracture behavior and the maximum stress determined in the bending test. Park et al. (2015) investigated the low-temperature cracking resistance of a steel-fiber-reinforced asphalt concrete mix design. A wide range of steel fiber variables, including aspect ratio (length/diameter), section type, and texture, were evaluated. An Indirect Tensile Strength (ITS) test at -20^0C showed that the addition of fibers increased both the ITS and the toughness of the asphalt concrete. The length of the fibers has a positive effect on the evaluated properties. Jamal Khattak et al., (2013) investigated the mechanistic properties of electrically conductive carbon nanofiber (CNF) modified hot mix asphalt. CNF was added to the HMA mixture in varying amounts. Viscoelasticity, strength, permanent deformation and fatigue were studied in indirect tension mode. Scanning Electron Microscopy (SEM) was used to examine the microstructure and morphology of fracture surfaces of HMA samples to better understand CNF micromechanical behavior in HMA mixes (SEM). The results of mechanical testing and SEM analysis showed that CNF has better nano- and micro-crack bridging mechanisms and adhesion characteristics, reducing micro-crack localization and propagation under tensile loadings. Moreover, The CNF modification improved fatigue life and resistance to permanent deformation.

Yazdani, (2018) Modified hot mix asphalt with elastic polymers (SBS-styrene-butadiene-styrene) and nano-TiO2 (titanium dioxide) and conducted various laboratory experiments to assess the mechanical properties of the modified samples. Rutting, low temperature cracking and fatigue cracking were all improved because of the study. Ziari et al., (2020) used RAP materials as a modifier of HMA mixture and investigated the cracking behavior of asphalt mixtures containing varying percentages of RAP and glass fibers using semi-circular bending (SCB) fracturing tests at temperatures of 15, 0, and 15 °C. The findings indicated that up to 0.12% glass fiber increases the resistance of all mixtures to crack initiation and propagation significantly. Lee et al., (2008) used Crumb Rubber (CR) in HMA mixture to improve the binder's temperature resistance. Viscosity and stiffness increased as the CR particles absorb oil from the asphalt binder. Asphalt binders and CR interact differently depending on the CR proportion, source, and size. The research examined the properties of CR binders in relation to CR processing methods and percentages. They prepared and aged 24 CR binders (three binder sources, two CR processing methods, Four CR percentages). A wide range of CR binders were tested for viscosity, performance, and cracking properties. Less low-temperature cracking and more viscosity were observed with increased CR percent in binders. Ambient CR binders were viscous and resistant to rutting and breaking.

Gibreil & Feng, (2017) evaluated the impacts of high-density polyethylene (HDPE) and crumb rubber powder (CRP) on the characteristics of hot mix asphalt. The physical characteristics of original and modified asphalt were measured for different HDPE and CRP contents. The results of Marshall stability and flow, moisture sensitivity, and wheel tracking (rutting) showed the improvement of the physical and mechanical characteristics and Marshall properties of asphalt for using HDPE and CRP as modifier of HMA. The resistance to moisture damage and persistent deformation improved substantially with the addition of HDPE and CRP.

Previous studies are based on different modifiers of HMA for the improvement of mechanical and volumetric properties of HMA. For this study, an innovated method that is based on the use the disposable face mask as a modifier of HMA was conducted to improve the rutting resistance of HMA pavement. The next section provides more discussion on disposable face masks.

2.4 Disposable Face Masks as A Modifier

During the pandemic of the COVID-19 face mask has become the most popular protective equipment among the people. For this reason, the amount of used face mask is increasing day by day and for the unconsciousness of people face masks are found here and there. So, face mask can save people from the COVID-19, but it will have a bad long-term impact on the environment as the most popular single used mask is made with non-biodegradable material. Disposable face mask is the most used and are made of polypropylene (Henneberry, 2020). As per the best knowledge of the author there are only two study has been conducted with face mask as construction material. Saberian et al., (2021) conducted a series of experiments, including modified compaction, on the shredded face mask blends at various percentages for highway base and subbase applications, as well as resilient modulus testing. RCA base blended with three different concentrations (i.e., one percent, two percent, and three percent) of shredded face mask provided the required stiffness and strength levels for paving/foundation an addition of the shredded face mask made the fibrous Recycled concrete aggregate blends even stronger and more pliable. When 1% SFM and RCA was included, the strength remained completely unconfined at 216 kPa, and the modulus increased significantly (314.35 MP). Even beyond 2%, the higher SFM caused a decrease in stiffness and strength. Kilmartin-Lynch et al., (2021) conducted some tests of concrete using face mask as a modifier. The masks have been inserted with volume at 0% (control), 0.10%, 0.15%, 0.20% and 0.25%, to test the overall quality of the concrete, with the test focus on pressure strength and indirect tensile strength, elasticity modulus and ultrasonic pulse velocity. With the addition of the single-use masks, the strength properties of the concrete settings were increased as well as the overall quality of the concrete increased. However, the trend of increasing force began to decline over 0.20 percent.

The previous studies are based on using adding disposable face masks as modifier to improve the performance of the concrete and base/subbase of pavement. This thesis aims to use disposable face mask as a modifier of HMA to improve the rutting resistance of HMA pavements. The next section will describe some existing methods of estimating plastic waste collection and processing cost.

2.5 Collection Processing, and Cost Estimation of Recycled Plastic Waste

Recycling is considered one of the most important solutions in the plastic waste management hierarchy to mitigate the environmental impact of post-consumer plastic waste at end-of-life (EoL) and end-of-use (EoU). To begin with, recycling aids in municipal solid waste management by diverting items with economic value from the mainstream of waste and lowering overall volumes of waste that must be collected and disposed of; consequently, recycled plastic may flow through many phases of their life cycle, allowing for more environmentally friendly production (Troschinetz & Mihelcic, 2009). The prevention approach of source reduction and reuse is considered the "most ecologically sound" technique for dealing with plastic waste (Zen & Siwar, 2015). Recycling was found to be the most widely accepted method of plastic waste management and a vital part of sustainable waste management (Bai & Sutanto, 2002). However, recycling of waste is a multi-faceted operation that comprises collection and storage, transportation, treatment, and trash disposal. Approximately 70% of total system costs can be attributed to waste collection and transportation operations (Greco et al., 2015; Tavares et al., 2009). In order to determine the most cost-effective waste collection, a proper collection method and an accurate cost estimation is important (Huang et al., 2011; Jacobsen et al., 2013). This can also improve the efficiency of waste collection. Several studies have examined the costs of managing plastic waste in different countries and have proposed methods and tools for analyzing the financial success of waste management.

D'Onza et al., (2016) used an approach called "full cost accounting (FCA)" assessing the cost of complete collection of various forms of waste in 68 Italian cities. They found their technology enabled cost-benefit studies and benchmarking, overcoming issues related to company-specific accounting decisions, earnings management practices, and purchasing policies. According to Greco et al. (2015), economies of scale and cost drivers are different for different forms of waste. Waste separation involves additional costs, and recycling does not always make up for them. However, monetary incentives aren't the only way to get people to recycle. Due to legislative mandates, several towns must review their solid waste management plans. On the other hand, Larsen et al. (2010) investigated how much recycling can be maximized by improving collection techniques while keeping in mind organizational and technological constraints, as well as the environmental and economic implications. They claim that promoting recycling can reduce collection and disposal costs by avoiding high incineration prices.

The previous studies are based on the estimation of the cost of collection and transportation operation of the recycled plastic waste. Hence, the aim of the thesis is to develop a cost estimating calculator to determine costs of disposable face mask collection, separation, and preparation of the face mask and face mask modified hot mix asphalt pavement. This calculator should be used as a fast method to determine costs of the process.

CHAPTER 3: METHODOLOGY

The purpose of this chapter is to outline the research methodology for developing face mask collection procedure, preparing materials preparation (i.e., face masks, hot mix asphalt composite), performing mixed design tests, and calculating the cost related to the use of face masks. Figure 3.1 illustrates the steps undertaken for the methodology. The following sections will address the methodology behind each step.

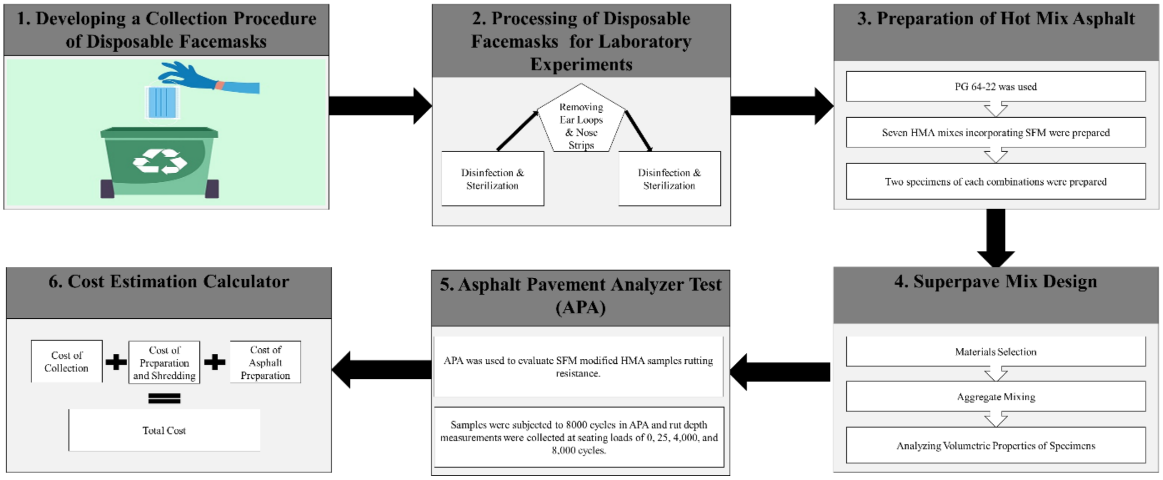


Figure 3.1: Thesis Methodology Roadmap

3.1 Developing a Collection Procedure of Disposable Face Masks

In this section a safely procedure for collecting face mask from sources other than hospitals is developed. Masks from hospitals were not included in this study because they should be given special consideration since they present potential bio-medical hazards. Usually, the medical masks from hospitals are collected in separate bags and then incinerated (Gidarakos et al., 2009). For this reason, the potential sources of disposable masks will be residential buildings, commercial and educational districts. Figure 3.2 illustrates the steps required to collect disposable face masks.

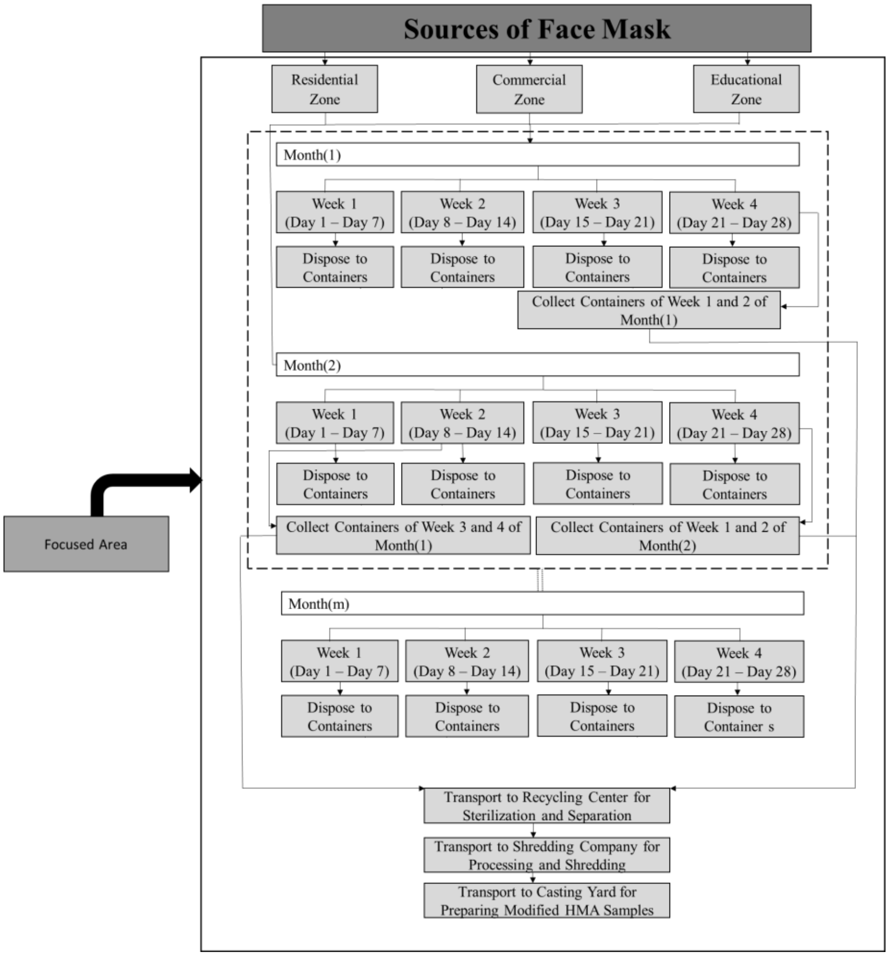


Figure 3.2: Collection Procedure of Disposable Face Masks

Residential, commercial, and educational zones will be focused area for collection. The collection sites will be designated by the solid waste management facility. Ciaccia, 2020 found that the presence of the COVID 19 virus in masks would not exceed 7 days. Therefore, to prevent the spread of the COVID 19 virus during collection, disposable face masks will be collected twice a month and a total cycle of 6 weeks from setting up to retrieving. All the containers will be setup at the starting of the procedure by the solid waste management facility and labeled with week and days where the week of setting up will be considered as Week 1. Containers of weeks 1 and 2 will be collected in week 4 and containers of Week 3 and 4 will be collected in week 2 of the following month and the cycle continued.

After collection from the sites, the masks will be transported to the recycling center for sterilization and separation. Disinfectants and sterilization procedures must be used for disinfecting of the face masks. Some common practices suggested by Kampf et al., (2020) are 62–71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite within 1 min of subjection to the masks. Xiang et al., (2020) used dry heat technology to the masks at 70°C for one hour. Because of its easy application and low cost, 0.5% hydrogen peroxide concertation for minimum exposure time of 1 minute will be used in the collection procedure.

Shredding company will be contacted earlier in the procedure to make sure make sure sanitized masks will be picked up either the day of sanitization or the next day of sanitization. Then, the masks will be transported to shredding company for removing ear loops and nose strips and shredding. Finally, the shredded disposable face masks will be transported to the casting yard for preparing modified hot mix asphalt (HMA) samples to carry out the laboratory tests to evaluate the rutting resistance of disposable face masks modified HMA samples.

To carry out the collection, sterilization, and separation of face masks several numbers of laborers will be required. The required number of labors will depend on number of collection points, containers, and volume of face masks.

3.2 Processing of Disposable Face Masks for Laboratory Experiments

Disposable shredded face masks (SFM) are used as a modifier in this thesis to enhance the performance of hot mix asphalt. However, as this study was conducted on new masks, in order to imitate the disinfection procedure and evaluate the physical changes in the treated face masks, the masks were disinfected by placing them in a 70^0C oven for 1 hour (Rivas, 2020; Xiang et al., 2020). Shredded face masks are shown in Figure 3.3 which were prepared to add in the HMA mixes as a modifier.

Figure 3.3: Shredded Face Masks to Be Added in the HMA Mixes as a Modifier

Prior to using the face masks, the nose metal strips, and ear loops were removed. In order to test the behavior of the mask in the HMA mixture, the main step of sample preparation was first melting the masks in oven for 10 minutes at 160^0C temperature. After that melted mask was taken out of the oven, it was cooled to room temperature to solidify. Face masks are shown in Figure 3.4 as they were disinfected and liquefied in an oven, which is shown in the figure.

(a) (b)

Figure 3.4: (a) Disinfection of Face Masks in the Oven, and (B) Melted Face Masks at 160^0C Temperature in the Oven

3.3 Preparation of Hot Mix Asphalt Sample

The asphalt grade used in this thesis was Superpave PG 64-22. Asphalt binder materials are graded using the performance graded (PG) method. As a part of the program for strategic highway research (SHRP), it was formed in the early 1990s. The Performance Grade (PG) standard provides a performance level for the asphalt binder, which will vary according to the ambient temperature 6^0C (Clayton et al., 2009). PG 64-22 is a Performance Grade (PG) asphalt binder that is governed by two factors: traffic and pavement temperature. To ensure that the pavement lasts as long as possible, the PG grade of asphalt binder is changed based on traffic circumstances and volume. A pavement with a design temperature of minus 22^0C may use this asphalt grade, which is appropriate for pavements with a design temperature of 64^0C. A total of two specimens were made for each combination in order to conduct this study. Coarse aggregate (CA), fine aggregate (FA), 15.4% Reclaimed Asphalt Pavement (RAP), and for the control mix design 7.6% asphalt cement were selected. Crushed Stone, manufactured sand, natural sand, baghouse fines, and RAP aggregates were also used. Similar mix was used for various percentages of SFM. RAP has been utilized for paving in hot mix asphalt (HMA) blends since the 1930s. The option of using the old asphalt binder in the new mixes, in contrast to the recycled aggregate or crushed portland concrete, reduces the needed (new) asphalt content, makes the use of RAP for HMA combinations more cost-effective (Huang et al., 2005).

Two specimens for each combination were prepared for this thesis. Coarse aggregate, fine aggregate, Reclaimed Asphalt Pavement (RAP), having 5.2% asphalt binder, and 7.6% asphalt content (AC) were chosen for the control mix design. Crushed stone manufactured sand, natural sand, and baghouse fines were also used. The same mix was used for different contents of SFM. Table 3.1 shows the aggregate gradation for RS 4.75A surface mix (control). The RAPs were collected from the same geographical location to ensure that the aggregate in the RAP had the same attributes as the new one. North Carolina Department of Transportation (NCDOT) permitted the use of RAP sources, which were then mixed with the asphalt binder PG 64-22. A total of seven HMA mixes including varying SFM percentages (i.e., 0 % (control mix), 0.25%, 0.50%, 0.75 %, 1.00%, 1.25%, and 1.5% by weight of the mixes) were investigated in this study. Figure 3.5 depicts the mixing of SFM and asphalt binder for HMA mixes.

Table 3.1. RS 4.75A Surface Mix Aggregate Gradation

Material	78M	UCL Base	Man. Sand	N Sand	BgHs Fines	RAP	Blend	Control Points
% MD	5.0	32.1	30.0	15.0	2.5	15.4	100	
% JMF	5.0	35.0	30.0	15.0		15.0	100	
Sieves (mm) 50.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
37.5	100.0	100.0	100.0	100.0	100.0	100.0	100	
25.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
19.0	100.0	100.0	100.0	100.0	100.0	100.0	100	
12.5	100.0	100.0	100.0	100.0	100.0	100.0	100	100
9.5	93.0	97.0	100.0	100.0	100.0	97.0	98	95-100
4.75	37.0	86.0	100.0	100.0	100.0	84.0	90	90-100
2.36	13.0	70.0	87.0	100.0	100.0	70.0	78	
1.18	4.0	48.0	61.0	99.0	100.0	59.0	60	30-60
0.600	3.0	34.0	43.0	90.0	100.0	48.0	47	
0.300	2.0	20.0	26.0	43.0	100.0	33.0	28	
0.150	1.0	13.0	5.0	7.0	96.0	14.0	11	
0.075	1.0	11.6	2.1	3.3	94.0	7.8	8.4	6.0-12.0
Ign.Furn.Corr.Factor								
Agg.Bulk Dry.S.G	2.435	2.543	2.592	2.656	2.520	2.605	2.578	
					Agg. Effective S.G.: 2.584			
Agg. Apparent S.G.	2.626	2.649	2.719	2.682	2.548	2.653	2.672	

Figure 3.5: The Shredded Face Mask (SFM) with HMA Virgin Materials and Reclaimed Asphalt Pavement (RAP)

3.4 Superpave Mix Design

Superior Performing Asphalt Pavements is an expression for Superpave. It is the product of the Strategic Highway Research Program's research on strategic highways. Superpave incorporates a novel method for designing and analyzing mixtures depending on the pavement's performance characteristics. This is a multi-dimensional approach that uses a layered approach to develop asphalt mixtures to achieve the desired results. There are three stages to the Superpave hot mix asphalt (HMA), (i.e., material selection, aggregate mixing, and specimen volumetric analysis utilizing the Superpave gyratory compactor SGC) (D'Angelo, J. A., 2001).

As previously mentioned in this thesis seven samples were prepared with the specification of RS 4.75 A with the same mixed formula with Superpave mix formula PG 64-22. One is a control mix without any SFM, while the other six have varying amounts of SFM, ranging from 0.25% to 1.50%. The samples have a diameter of 150 mm and a thickness of 75 mm. Superpave mix design is summarized in the following Table 3.2. Using the Superpave gyratory compactor (SGC), the composing materials were combined and quickly compressed at roughly 160^0C.

Table 3.2 Properties of Superpave Mix design

Specifications	% Asphalt Binder-Total Mix				
	7.6	7.0	7.5	8.0	8.5
Gmb @ Ndes (or Nmax)	2.284	2.188	2.200	2.211	2.222
Max. Specific Gravity(Gmm)	2.319	2.338	2.322	2.307	2.291
% Voids-Total Mix (VTM)	1.5	6.4	5.3	4.2	3.0
% Solids-Total Mix	98.5	93.6	94.7	95.8	97.0
% Effective Binder Content (Pbe)	7.5	6.9	7.4	7.9	8.4
Dust to Pbe Ratio ($P_{.075}$/Pbe)	1.12	1.22	1.14	1.06	1.00
By volume of Effective Pb	16.6	14.6	15.8	16.9	18.1
% Solids by Vol. of Agg. Only	81.9	79.0	78.9	78.9	78.9
% Voids in Mineral Agg. (VMA)	18.1	21.1	21.1	21.1	21.1
% Voids Filled w/Binder (VFA)	91.7	69.2	74.9	80.1	85.8
%Gmm @ Nini 6	91.5	87.2	88.0	88.8	89.8
% Gmm @ Ndes 50	98.5	93.6	94.8	95.8	97.0
% Gmm @ Nmax	98.5				
Sand Equivalent:	58.4			Pb in RAP	5.2
C. Agg. Angularity:	100/100			Pb from RAP	0.8
F. Agg. Angularity:	47.2			Pba	0.1
				ASH%	
				TSR%	83.8
				Ign. Furn. Calib.	0.29

3.5 Asphalt Pavement Analyzer Test (APA)

One of the most widely used equipment in the United States is the Asphalt Pavement Analyzer (APA), created by Pavement Technology Inc (PTI) (Uzarowski, 2010). HMA mixtures containing SFM were subjected to a series of laboratory experiments to determine their rutting resistance. NCDOT-approved laboratories conducted all tests. The American Association of State Highway and Transportation Officials and the American Society for Testing Materials were followed in the testing procedure (ASTM).

In this thesis, Asphalt Pavement Analyzer (APA) test was conducted. Four replicate samples (75mm height and 150mm diameter) were prepared for each mix design, and the average results were provided. Since pavement rutting occurs at higher temperatures, the test was conducted at the highest pavement temperature, which is the highest temperature in the PG grade. The specimens were conditioned and stabilized at the testing temperature for 5 to 6 hours before beginning the test. A total of 8000 cycles was performed on the samples at the APA. Seating loads of 0, 25, 4,000, and 8,000 cycles were used to measure rut depth.

Figure 3.6: APA Machine and Test Samples in APA Chamber

Figure 3.7: Sample of APA Test

3.6 Cost Estimation Calculator

This section focuses on the calculation of the cost associated with step 1 through step 5 of Figure 3.1. This includes the cost of the following activities in the process: collection, separation, preparation, shredding and application of disposable masks in hot mix asphalt (HMA) construction. A cost estimation calculator was developed in Microsoft Excel to calculate the associated cost. The cost of collection and separation was based on the cost from the Waste facility. This includes package of the following costs (labor cost required for setting up, pecking up, separation, and sanitization, transportation cost from and into the waste facility, materials cost required for sanitization and container price). Cost of preparation and shredding was based on the cost from the shredding company, where the cost is considered as a package that is based on number and size of containers. The package cost includes the cost of transportation from the waste management facility to the shredding company and from shredding company to the asphalt casting yard.

The Total cost of the process (*TC*) is calculated as addition of three parts and is given in Equation 3.1.

$$TC = (C_C + C_{PS}) * TNc + C_{AP} \qquad 3.1$$

where, C_C is the cost of collection, C_{PS} is the cost of mask preparation and shredding, and C_{AP} is the cost of asphalt preparation. C_C includes labor cost required for setting up, pecking up, separation, and sanitization, transportation cost from and into the waste facility, materials cost required for sanitization, and container price, and *TNc* is the total number of containers. C_C is given in Equation 3.2.

$$C_C = P_c + C_{Sa} + C_L + \frac{C_T}{TNc} \qquad 3.2$$

where, P_c is the price of container, C_{Sa} is the cost of sanitization per container, TN_C is the total number contains, C_T is the transportation cost, C_L is labor cost. P_c is obtained based on the market price. C_{Sa} is calculated as $C_{Sa} = N_{Sa} \times P_{Sa}$. Where, N_{Sa} is number of sanitizer bottle used, and P_{Sa} is unit price of sanitizer obtained based on market price. TN_C is calculated as $TN_C = TN_{CT} \times W_M$. where, TN_{CT} is total number of containers required to collect face masks per ton, W_M is weight of face masks required for construction. TN_{CT} is calculated as $TN_{CT} = \frac{N_{CU}}{W_{CM}}$. where, N_{CU} is number of containers used per cycle, and W_{CM} the weight of collected masks per cycle. C_L is calculated as $C_L = N_L \times W_L \times t$. Where, N_L is number of labors required for setting up, picking up, separation and sanitization; W_L is wage of labor per hour, and t is the total number of hours.

C_{PS} is calculated based on the price provided by shredding company for each container with addition of 8% miscellaneous cost (i.e., fuel, toll). C_{PS} is given in Equation 3.3.

$$C_{PS} = (C_{CON}) + 0.08 \times (C_{CON}) \qquad 3.3$$

where, C_{CON} is cost provided by shredding company as a package.

C_{AP} is calculated using two scenarios (construction with face masks and without face masks) and is based on total weight of asphalt (TW_A), weight of face masks (W_M) as percentage of TW_A and price of asphalt per ton (P_A). C_{AP} is given in Equation 3.4.

$$C_{AP} = (TW_A - W_M) \times P_A \qquad 3.4$$

where TW_A varies based on the volume of asphalt pavement (V_p), and unit weight of asphalt per ton (W_A) and is calculated as $TW_A = V_p \times W_A$, where V_p is calculated as $V_P = N_L \times L \times w \times T$. where, N_L is number of lanes, L is length of asphalt pavement, w is width of asphalt pavement, T is thickness of asphalt pavement. W_M is calculated as $W_M = 0.015 \times TW_A$, where 0.015 is the ratio W_M to TW_A that provides the best rutting resistance (Wang et al., 2022). For scenario without face mask, W_M equals zero.

CHAPTER 4: RESULTS

The goal of the thesis was to bring an advancement to the field of transportation infrastructure by evaluating the performance of the flexible pavement using SFM as a modifier of HMA mixture and developing a cost estimating calculator to estimate the cost of asphalt pavement construction with mask. This chapter discuses and presents the results obtained from the research methodology presented in Chapter 3. The collection procedure of disposable face masks is presented in Section 1 which includes setting up and picking up of containers, separation, sanitization, preparation, and shredding of the face masks. Preparation of face masks for laboratory experiments is presented in Section 2. The hot mix asphalt composite preparation, superpave mix design and asphalt pavement analyzer (APA) testing results is presented in Sections 3, 4 and 5 of this Chapter. Finally, the cost estimation calculator for estimating the cost of pavement construction with and without face masks is presented in Section 6.

4.1 Collection Procedure of Disposable Face Mask

Due to lack of accessibly to collection points because of COVID 19, the actual collection was not carried out, instead example of application was carried out. It should be mentioned that this example does not represent any actual work. For this example, three collection points, four large containers of 95 gal (Capacity of 0.40 Tons of masks) at each location (i.e.,12 containers in total), and arbitrary date (February 1st) would be chosen. The 12 containers would be assumed to be set up on February 1st, in the three collection points designated by the solid waste management agency and labelled with the week and days as following: (Feb 1- Feb- 7), (Feb 8- Feb 14), (Feb 15- Feb 21), (Feb 22- Feb 28). Containers of Weeks 1 and 2 labeled as (Feb 1- Feb- 7), (Feb 8- Feb 14), and Weeks 3 and 4 labeled as (Feb 15- Feb 21), (Feb 21- Feb 28), would be collected on February 28th, and March 14th, respectively at the three collection points and transported to the recycling center of the solid waste management agency for separation and sanitization. Figure 4.1 shows the steps that would be taken only for one collection point. Same steps should be followed for the other two collection points.

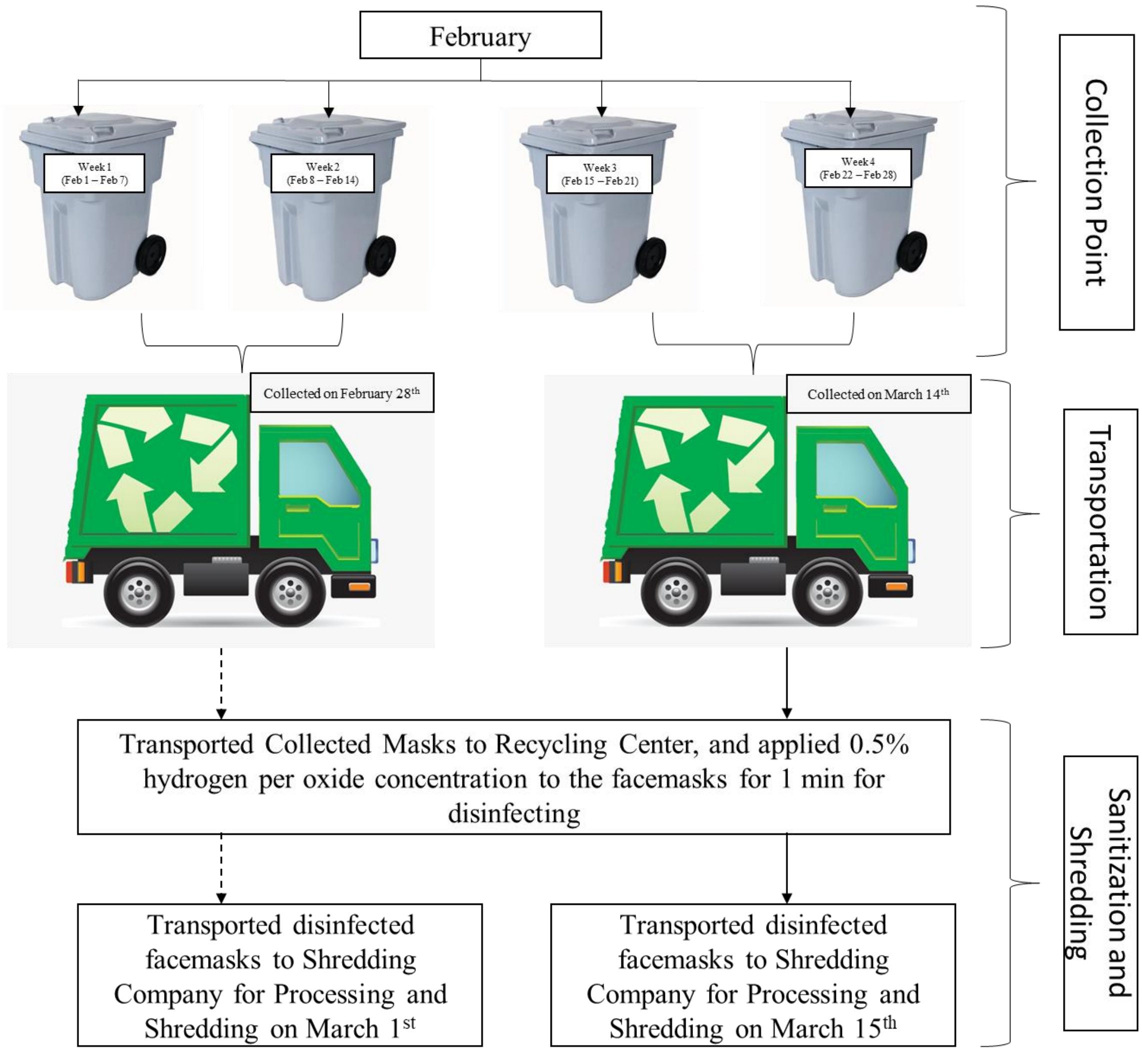


Figure 4.1: Flow Chart of the Example Application at Collection Point

For sanitization, one bottle (32 oz) hydrogen peroxide (H_2O_2) with 0.5% concentration applied for 1min would be needed for each container. Each container would take an average of 1 hour to set up, pick and sanitize. A $12/hour wage for labor is used to carry out the process.

Shredding company would be contacted, and the pickup date would be scheduled on the second day of sanitization. The disinfected masks of containers of Weeks 1 and 2 labeled as (Feb 1- Feb- 7), (Feb 8- Feb 14), and Weeks 3 and 4 labeled as (Feb 15- Feb 21), (Feb 21- Feb 28), would be picked up on March 1st and March 15th, respectively. No labor would be needed for shredding since the shredding company offered a package that includes the pickup from the recycling center, removal of ear loops and nose strips, shredding of the face masks and transportation to the casting yard.

4.2 Preparation of Disposable Face Mask for Laboratory Experiments

In this thesis, new face masks were used for the laboratory experiments due to safety concerns. The face masks began to melt after 10 minutes in the oven at 115.5^{0}C. Using a paper shredder, the hardened and cooled masks were shredded into pieces of 40 mm x 5 mm. The SFM size is not a significant influence in this case because the fiber is melted at the same mixing temperature as the binder.

4.3 Hot Mix Asphalt Sample

As discussed in section 3.3 Superpave PG 64-22 asphalt was used. Two specimens for each combination were prepared for this study. Coarse aggregate, fine aggregate, Reclaimed Asphalt Pavement (RAP), and AC were chosen for the control mix design. To prepare the mix design specifically 5% 78M stone, 32.1% UCL base, 30% manufactured sand, 15% natural sand, 2.5% baghouse fines, and 15.4% reclaimed asphalt pavement (RAP) aggregates were used. The same mix was used for different contents of shredded face mask (SFM). Among all the materials, the bulk dry specific gravity of 78M stone is the lowest, which is 2.435, and the volume dry specific gravity of natural sand is the highest, which is 2.656. All materials have the same effective specific gravity. For the HMA blend, the bulk dry specific gravity, effective specific gravity, and apparent specific gravity were 2.578, 2.584, and 2.672 respectively which are in range of standard value. Figure 4.2 shows the sample control mix prepared in this thesis.

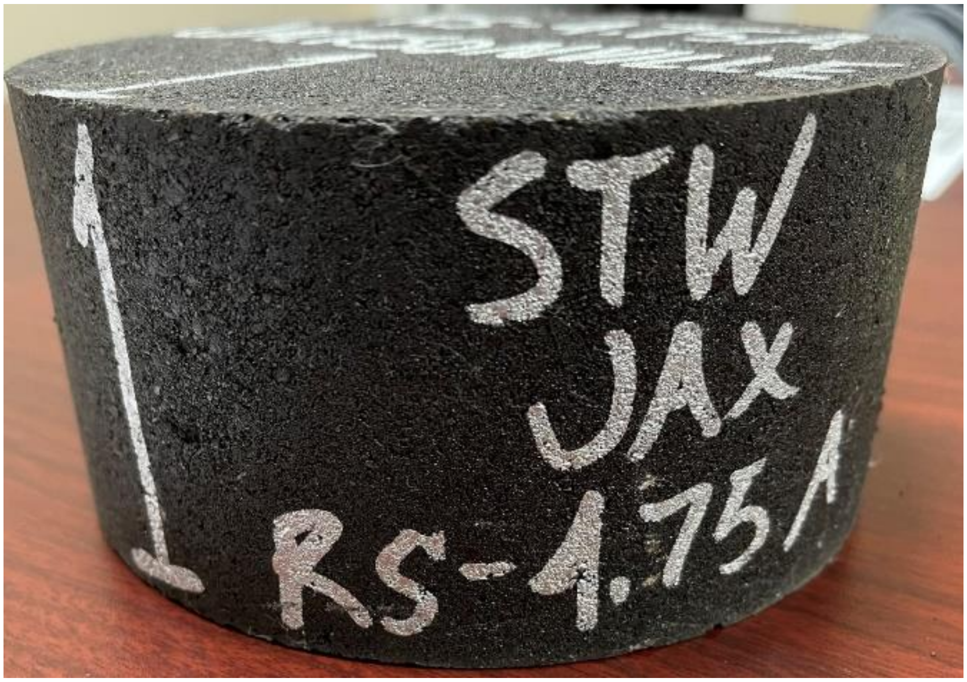


Figure 4.2: Control Hot Mix Asphalt Composite Sample

4.4 Superpave Mix Design

As discussed in the section 3.3 superpave mix design was carried out to evaluate the volumetric properties of control mix and different modified hot mix asphalt (HMA) samples. The optimum asphalt content was found to be 7.6% and 15.4% RAP for all mixtures. Voids in total mix (%VTM), voids filled with asphalt (%VFA), voids in mineral aggregates (%VMA) were found 5.0%, 76.0%, and 21.2% for all mixtures, respectively for all the mixtures. Table 4.1 shows Superpave volumetric properties RS 4.75A.

Table 4.1 Volumetric Properties of Superpave RS 4.75A

	Control Mix	0.25% SFM	0.50% SFM	0.75% SFM	1.00% SFM	1.25% SFM	1.50% SFM
Diameter(mm)	150.00	150.00	150.00	150.00	150.00	150.00	150.00
Thickness(mm)	75.00	75.00	75.00	75.00	75.00	75.00	75.00
Dry Mass in Air	2897.92	2890.80	2891.80	2891.20	2892.55	2892.45	2894.75
SSD Mass in Air	2899.60	2892.15	2893.6	2893.50	2894.70	2894.45	2896.2
Bulk Sp. Gravity	2.213	2.193	2.195	2.191	2.192	2.192	2.197
% Air Voids	4.53	5.40	5.40	5.50	5.45	5.45	5.25
%VTM	5.0						
%VFA	76.0						
%VMA	21.2						
%AC	7.6						

The percentage of the total volume of the compacted paving mixture that is made up of tiny pockets of air between the coated aggregate particles is known as the total void in the mix. The air voids in shredded face mask (SFM) mixtures reduce when 1.5 % of SFM is incorporated into the mixture. The % air voids related to the SFM content in the asphalt mixture is shown in Figure 4.3.

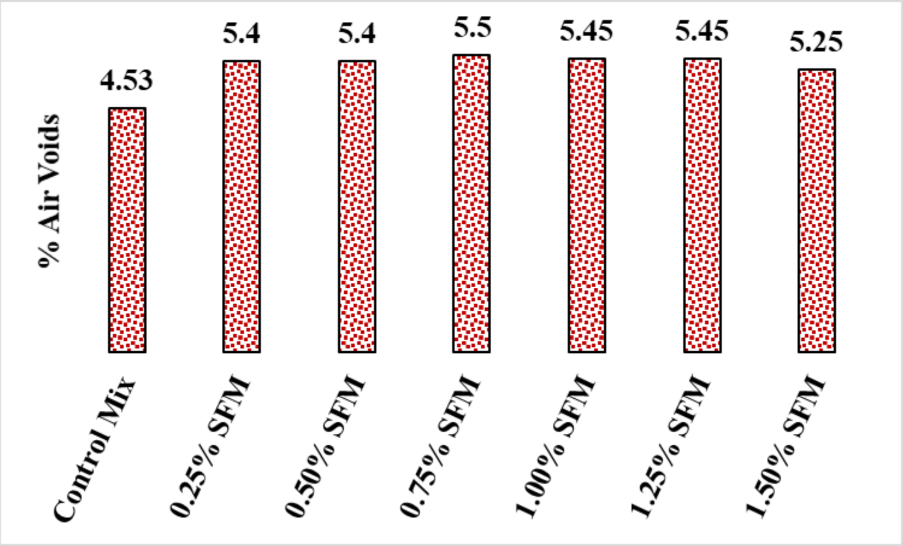


Figure 4.3: Comparison of % Air Voids Between the Control Mixes and Mixes with SFM

4.5 Asphalt Pavement Analyzer Test (APA)

Figure 4.4 illustrates the comparison of control and SFM mixed specimens using a bar chart. According to the figure, SFM has improved the rutting resistance of hot mix asphalt. With the increased SFM content, the rutting depth has been reduced from 3.16mm to 0.93mm, which is lower than the control mix and lower than the maximum specification for local traffic pavements and interstate highway pavements. Interstate highway pavement can have a maximum 4.5mm rut depth (30 million ESAL), while local traffic pavement can have a maximum rut depth of 11.5 mm (0.3 ESAL). The rut depth was 0.93 mm since 1.5 percent SFM was added to the mix. Based on these results, it can be determined that the SFM liquefied binds aggregates, reducing rutting depth and acting as the asphalt binder. It's fair to say that SFM-containing mixtures are more resistant to wheel passes in general.

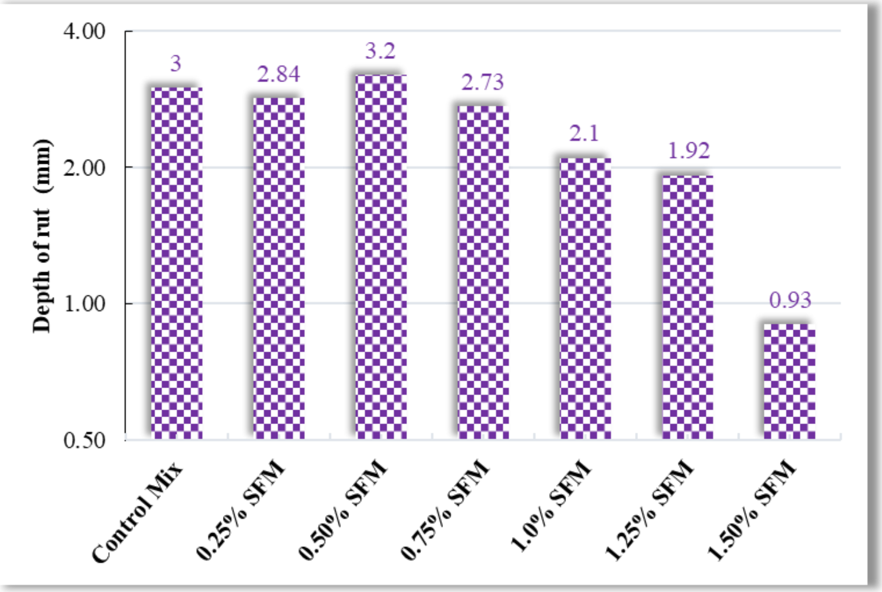
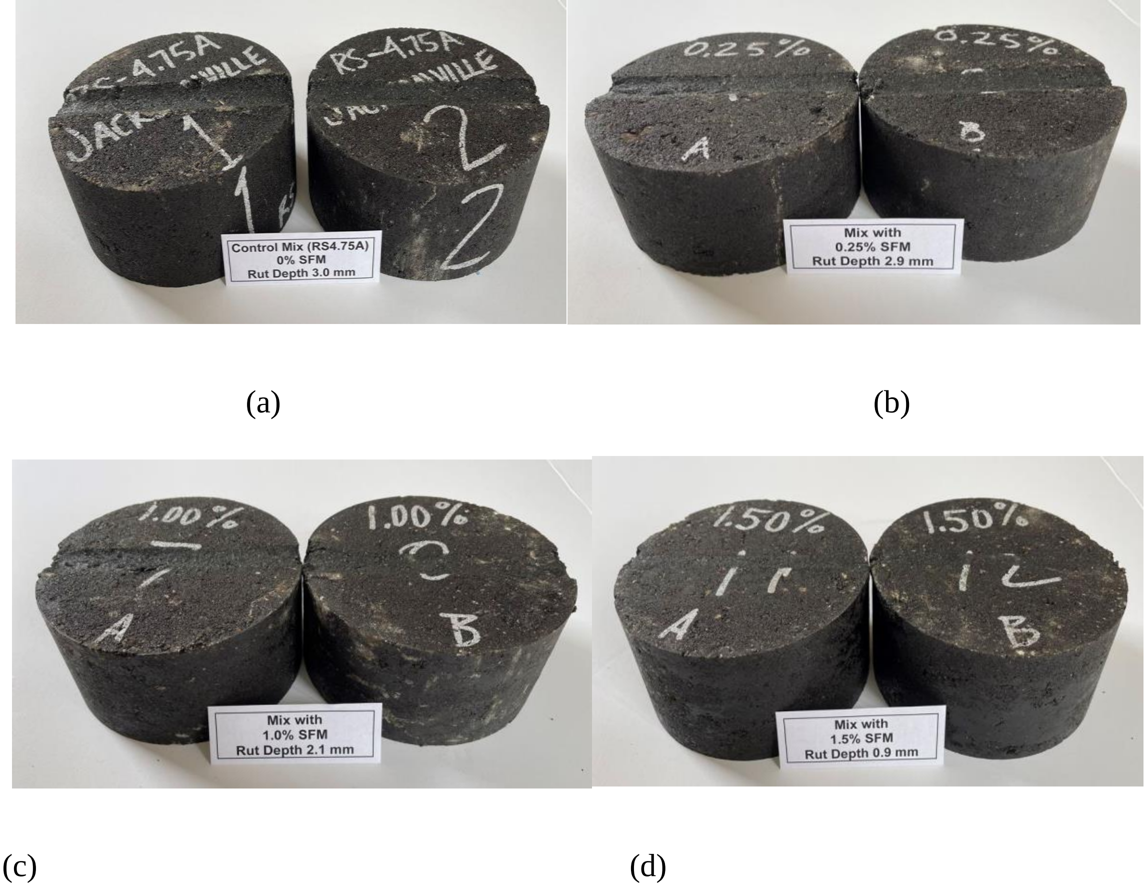


Figure 4.4: A Comparison of The Rut Depth Among the Control and the SFM mixes

Additionally, the incorporation of SFM resulted in stronger mixes and better adhesion between aggregates. A kilometer of pavement with a width of 3 m and a thickness of 50 mm asphalt will require approximately 5.4 tons of face masks (about 163,000 face masks) with a SFM content of 1.5 percent. As seen in Figure 4.5, rut depth was measured on samples of 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, and 1.50% SFM mix. In Figure 4.6, rut depths are shown for SFM modified samples at 0, 25, 4,000, and 8,000 cycles.



(a) (b)

(c) (d)

Figure 4.5: (a) 3.00 mm Rut Depth for Control Mix (0% SFM); (b) 2.9 mm Rut Depth for Mix with 0.25% SFM; (c) 2.1 mm Rut Depth for Mix with 1.0% SFM; and (d) 0.9 mm Rut Depth for Mix with 1.50% SFM

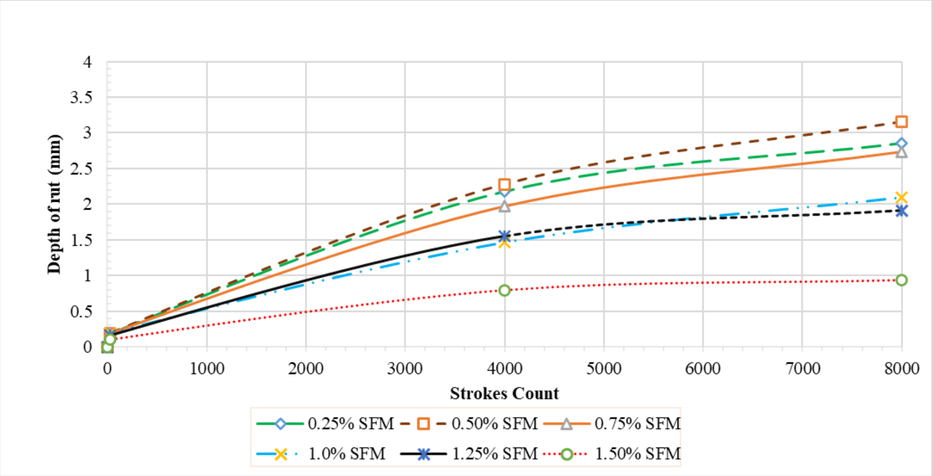


Figure 4.6: APA Test Results for Mixes with Various SFM Additions

The rutting test results indicate that the SFM-modified HMA can be used successfully as the binder layer to mitigate fatigue cracking, as shown in Figure 4.7.

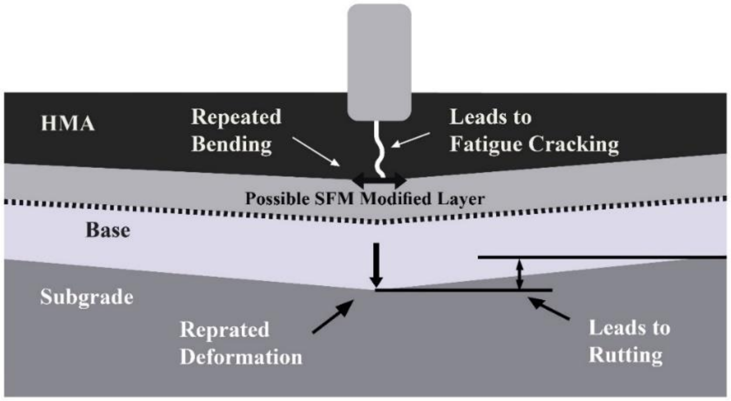


Figure 4.7: Asphalt Pavement Fatigue with SMF Modified HMA

SFM-modified HMA can be used in the maximum strain layer to create a perpetual (long-life) pavement system. The increase in traffic has made top-down cracking more popular than ever. Using the SFM-modified HMA will aid in reducing and delaying the development of top-down cracks. Because of this, the SFM can effectively ameliorate HMA distress in any temperature range.

4.6 Cost Estimation Calculator

As mentioned in Section 3.6, a cost estimating calculator was developed in Excel to estimate the cost of the process from collection to casting. The estimated cost of collection, preparation and shredding, and cost of asphalt paving with and without face masks was based on the example application provided in Section 4.1. The cost of collection, preparation, and shredding was estimated per container, and the number of containers required to collect one ton of face mask was estimated so that it would be easier to calculate different dimensions of HMA pavements. In this study, all the prices are based on the local price obtained from the solid waste management and shredding company in the city of Greenville, NC. The application of the calculator in other locations must consider the local prices of that particular geographical location.

Based on the Equation 3.2, C_C was calculated using market price of \$50 for a 95-gal container, market price of \$3 for sanitization bottle, \$12/hour wage for labor, and a \$175 transportation cost for (provided by Pitt County solid waste management facility) for the total of 12 containers, resulting in C_C equals to \$79.58 per container. Based on Equation 3.3, C_{PS} was calculated using \$100 cost for preparation and shredding per container. This cost was provided as a package by the Stericycle / Shred-it, a shredding company in Greenville that has a contract with ECU facility management, resulting in C_{PS} equals to \$108 per container, and this contributes the largest cost to the total cost of the process. Based on Equation 3.4, multiple cost of C_{AP} was calculated using six number of lanes (i.e., 1, 2, 3, 4, 5, 6), four lane lengths (i.e.,100 m, 250 m, 500 m, 1000 m), fixed lane width and thickness of 3.66 m and 0.05 m, respectively, price and unit weight of asphalt $86 per ton and 2.4 ton per cubic meter respectively, provided by St. Wooten Corporation.

Subtitling the calculations of Equations 3.2, 3.3 and 3.4 in Equation 3.1, TC was calculated for the two scenarios (i.e., with and without mask). Tables 4.2, 4.3, 4.4, and 4.5 show the cost estimating calculator for Cost of Collection (C_C), Cost of Mask Preparation and Shredding (CPS), Cost of Asphalt Preparation (C_{AP}), and the Total Cost (TC) of the process, respectively.

Table 4.2 Cost of Face Masks Collection

N_{CU}	P_C	TP_C	N_L	t (hr.)	W_L	C_L	C_T	N_{Sa}	P_{Sa}	C_{Sa}	W_{EC} (T)	W_{CM} (T)	N_{CT}	C_C
12	$50	$600	4	12	$12	$144	$175	12	$3	36	0.4	4.8	2.5	$80

*Note: N_{CU} = number of containers used per cycle, P_C = market price of container, TP_C = total market price of containers used per cycle, N_L = number of laborers, t = total number of hours, W_L = wage of labor per hour, C_L = labor cost, C_T = transportation cost, N_{Sa} = number of sanitizer bottle used, P_{Sa} = price of each sanitizer bottle, C_{Sa} = cost of sanitizer, W_{EC} = weight of masks in each container, W_{CM} = weight of collected masks per cycle, N_{CT} = number of containers require to collect 1-ton masks, C_C = cost of mask collection per container

Table 4.3 Cost of Face Masks Preparation and Shredding

No. of Container	Unit Cost of Preparation and Shredding/Container	Cost of Preparation and Shredding	Miscellaneous Cost	Mask Weight(T)	Cost of Preparation and Shredding ($) per Container
12	$100	$1200	$96	4.8	108

Table 4.4 Cost of Asphalt Preparation

L (m)	W (m)	T (m)	V_P (m3)	TW_A (T)	W_M (T)	TW_{EM} (T)	TN_C	TC_C	TC_{PS}	P_A	C_{APM}	C_{APWM}
1000	3.66	0.05	183	439	7	432	16	$1,311	$1779	$86	$37,754	$37,238
500	3.66	0.05	92	220	3	217	8	$655	$889	$86	$18,920	$18,576
250	3.66	0.05	46	110	2	108	4	$328	$445	$86	$10,074	$9,460
100	3.66	0.05	18	44	1	43	2	$131	$178	$86	$3,784	3,698

*Note: L = length of pavement section, W = width of pavement section, T = thickness of pavement section, V_P = volume of pavement section, TW_A = total weight of asphalt, W_M = total weight of masks, TW_{EM} = total weight of asphalt excluding masks, TN_C = total number of containers, TC_C = total cost of masks collection, TC_{PS} = total cost of masks preparation and shredding, P_A = price of asphalt per ton, C_{APM} = cost of asphalt preparation with masks, C_{APWM} = cost of asphalt preparation without masks

Table 4.5 Total Cost of the Process for Various Number of Lanes

No of Lanes	TC_{WM} (1000m)	TC_{M} (1000m)	TC_{WM} (500m)	TC_{M} (500m)	TC_{WM} (250m)	TC_{M} (250m)	TC_{WM} (100m)	TC_{M} (100m)
1	$40,328	$40,844	$20,120	$20,464	$10,233	$10,847	$4,007	$4,029
2	$80,656	$81,688	$40,240	$40,928	$20,466	$21,694	$8,014	$8,058
3	$120,984	$122,532	$60,360	$61,392	$30,699	$32,541	$12,021	$12,087
4	$161,312	$163,376	$80,480	$81,856	$40,932	$43,388	$16,028	$16,116
5	$201,640	$204,220	$100,600	$102,320	$51,165	$54,235	$20,035	$20,145
6	$241,968	$245,064	$120,720	$122,784	$61,398	$65,082	$24,042	$24,174

*Note: TC_{WM} = total cost without masks, TC_{M} = total cost with masks

Figure 4.8 shows *TC* for the two scenarios for number of lanes of 1, 2 3, 4, 5 and 6, lengths of 100 m, 250 m, 500 m and 1000 m, and width and thickness of 3.66 m and 0.05 m, respectively.

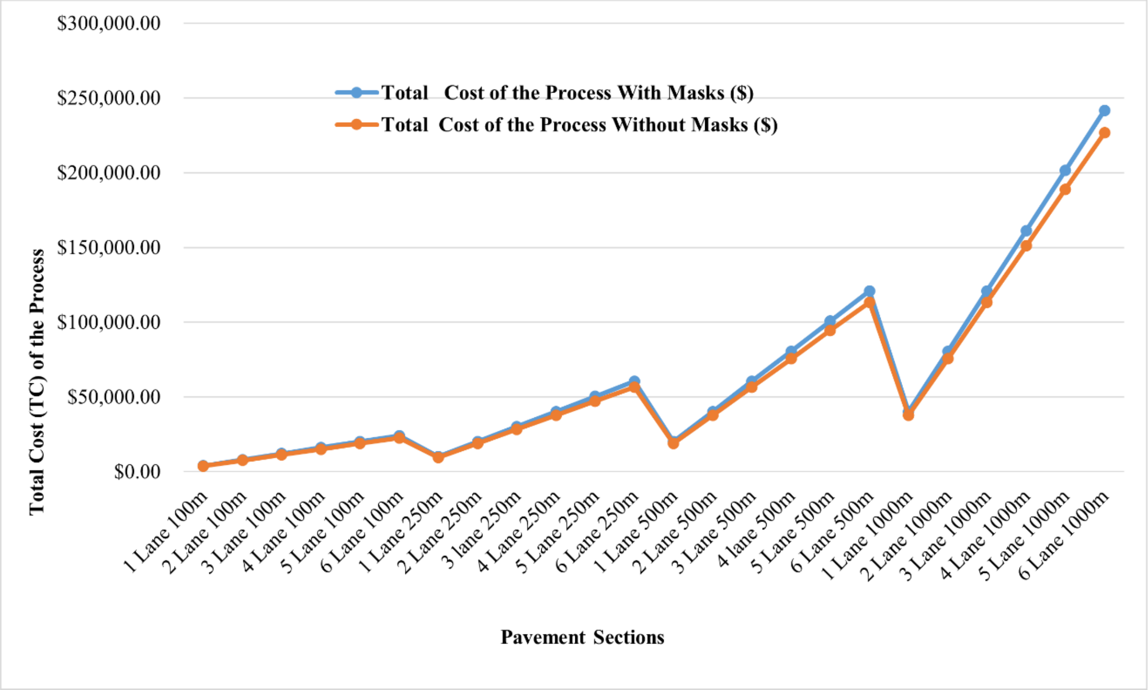


Figure 4.8 Total Cost of the Process for Various Pavement Sections

There is no large difference in *TC* for both scenarios for pavement sections with lengths of 100m, 250m, and 500m for the number of lanes 1, 2, 3, 4, and 5. However, a small deviation in *TC* demonstrating higher *TC* with face masks than without face masks begins at section 6 Lane

250m and increases at sections 5 Lane 500m, 6 Lane 500m, 5 Lane 1000m and, and 6 Lane 1000m, respectively. Although *TC* with face mask is higher at larger sections, it is expected that less maintenance would require for the pavement constructed with face masks because adding 1.5% of SFM to the hot mix asphalt mix allowed lowest level of rutting (Wang et al., 2022).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has resulted in the improvement of the rutting resistance of hot mix asphalt samples by using shredded face masks (SFM) as a modifier of HMA. Specific contributions include the evaluation of face masks in hot mix asphalt (HMA) as well as the development of a safe collection procedure for disposable face masks and a cost estimation calculator in Excel to estimate the cost of asphalt pavement construction based with and without face masks

The specific conclusions of this study are:

- Possibility to collect face masks without contracting COVID-19 following the collection procedure developed in this study.
- Ability to achieve the lowest possible rut depth by using 1.5 percent SFM in the mix, therefore, enhance the stiffness of the mixes, improve the adhesion between the aggregates, and provide greater resistance to the pavement exposed to traffic stress.
- Ability to reduce pavement maintenance and associated cost since rutting resistance improved by using SFM in HMA mixes
- Capability to estimate the cost of asphalt pavement with any additive using cost estimating calculator developed in this study.
- Capability to enhance the performance of the road network substantially by SFM and mitigate the negative environmental effects associated with the COVID-19 pandemic.

5.2 Recommendations and Future Research

This research opens up a new avenue for the development of sustainable asphalt pavements by reducing pollution and energy consumption and increases knowledge in these areas. The findings of this study provide valuable insights into future efforts by industry and government agencies to develop sustainable approaches for the transportation, energy and environmental industries. Furthermore, this research could provide a solution to reduce the plastic waste that is polluting the environment due to the COVID-19 pandemic. Additionally, this study reveals the scope of a cost-benefit analysis of the process so that economists can assess life cycle assessment and cost benefit analysis of using face masks in pavement construction. Due to the less maintenance cost over the life cycle, it is expected that the cost of using face mask in asphalt pavements will be less than the conventional method over the life cycle of the asphalt pavement (e.g., thirty years). Therefore, life cycle cost analysis (LCCA) is needed to evaluate the reduction in cost.

Since the major contribution of this study is confined to evaluate the rutting resistance of hot mix asphalt (HMA) pavement using shredded face masks (SFM) and develop a safe collection procedure for disposable face masks and a cost estimation calculator to estimate the cost of asphalt pavement construction using masks. However, there is still some room for future improvement. Further research should be carried out for improving the safe collection procedure in terms of functionality, cost and ability to collect masks from hospitals and health facilities as they are the main sources for masks.

The use of SFM in HMA to evaluate the performance of HMA against other distresses associated with asphalt pavement (i.e., block cracking, edge cracking, longitudinal cracking, moisture damage, top-down cracking, transverse cracking) should be investigated. Additionally, microstructure analysis could be conducted to characterize and evaluate the morphological features of the SFM modified HMA samples. Greater efforts should be made to research alternative plastic waste materials of COVID-19 disposable face masks to evaluate the mechanical performance of HMA samples in the future. Energy consumption on the use of masks and other plastics in the transportation industries should be evaluated. Cost benefit analysis to quantify all the unmeasurable costs associated with the application of disposable face masks in HMA pavement construction is highly needed.

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