Şükrü ŞAKA
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THE USE OF WASTE PLASTICS IN ASPHALT MIXTURES

A THESIS

SUBMITTED TO THE DEPARTMENT OF SUSTAINABLE URBAN INFRASTRUCTURE ENGINEERING

AND THE GRADUATE SCHOOL OF ENGINEERING AND SCIENCE OF ABDULLAH GUL UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF SCIENCE

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SCIENTIFIC ETHICS COMPLIANCE

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

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M.Sc. thesis titled The Use of Waste Plastics in Asphalt Mixtures has been prepared in accordance with the Thesis Writing Guidelines of the Abdullah Gül University, Graduate School of Engineering & Science.

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ACCEPTANCE AND APPROVAL

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ABSTRACT

THE USE OF WASTE PLASTICS IN ASPHALT MIXTURES

Şükrü ŞAKA

MSc. in Sustaınable Urban Infrastructure Engineering Department

Advisor: Prof. Dr. Burak UZAL

May 2022

Within the scope of this study, the use of waste plastics in asphalt mixtures for surface layer of pavements was evaluated considering the specification limits in the Highways Technical Specifications of Turkiye General Directorate of Higways. Waste plastic data collected in Talas region has been used, a circular economy model has been created and its contributions have been evaluated. Polyethylene type of waste plastics as high and low density were used to replace bitumen in hot asphalt mixtures with 7.5 to 12.5% by weight of bitumen. The optimum binder content currently used by the Talas municipality was kept constant as (5%). In the context of Highways Technical Specifications, Marshall stability and flow values of the mixtures with and without waste plastics were determined and 10% replacement level were selected to use for further testing due its maximum stability and proper flow value (2-4 mm). Air voids, voids filled with bitumen, voids in mineral aggregates parameters on asphalt mixtures as well as softening point and flash point of bituminous binders were also determined. In addition, environmental impacts of asphalt mixtures with and without waste plastic replacement were examined via life cycle assessment methodology in the scope of cradle-to-gate.10% replacement of bitumen with waste plastics increased stability, air voids, voids in mineral aggregates and decreased flow and void filled with bitumen of asphalt mixtures as compared with the control. Softening point and flash point of bitumen increased with waste plastic replacement. Considering the environmental impact of with and without waste plastic replacement asphalt mixtures, abiotic depletion, ozone layer depletion, terrestrial ecotoxicity, and eutrophication values increased. Abiotic depletion (fossil fuels), global warming, freshwater aquatic, marine aquatic ecotoxicity, photochemical oxidation, acidification, and human toxicity values decreased. The cost of waste plastic replacement asphalt mixtures can reduce the costs of production, and laying costs.

Keywords: asphalt, life cycle assessment, stability, waste plastic, circular economy

ÖZET

ASFALT KARIŞIMLARINDA ATIK PLASTİKLERİN KULLANIMI

Şükrü ŞAKA
Sürdürülebilir Kentsel Altyapı Mühendisliği Anabilim Dalı Yüksek Lisans
Tez Yöneticisi: Prof. Dr. Burak UZAL
May 2022

Bu çalışma kapsamında, Türkiye Karayolları Genel Müdürlüğü Karayolları Teknik Şartnamesi'nde yer alan spesifikasyon limitleri dikkate alınarak atık plastiklerin asfalt karışımlarında aşınma tabakası içerisinde kullanımı değerlendirilmiştir.Talas bölgesinde toplanan atık plastik verileri kullanılmış olup, döngüsel ekonomi modeli oluşturulmuş ve katkıları değerlendirilmiştir. Bitüm ağırlığının %7,5 ve %12,5 oranları arasında plastik ikamesi ile bitümün yerine yüksek ve düşük yoğunluklu polietilen türü atık plastikler kullanılmıştır. Halihazırda Talas belediyesi tarafından kullanılan optimum bağlayıcı içeriği (%5) olarak sabit tutulmuştur.Teknik şartname kapsamında atık plastik içeren ve içermeyen karışımların Marshall stabilitesi ve akma değerleri belirlenmiştir. Maksimum stabilite ve uygun akış değeri (2-4 mm) nedeniyle testler için %10 ikame seviyesi seçilmiştir. Asfalt karışımlarda stabilite, akma, hava boşlukları, bitümle dolu boşluklar, mineral agregalar arası boşluklar gibi parametrelerinin yanı sıra bitümlü bağlayıcıların yumuşama ve parlama noktaları da incelenmiştir. Beşikten-kapıya yaşam döngü değerlendirmesi ile atık plastik ikameli ve plastiksiz asfalt karışımlarının çevresel etkileri karşılaştırılmıştır. Bitümün atık plastiklerle %10 oranında değiştirilmesi, kontrol numunesi ile karşılaştırıldığında, plastik ikameli asfaltların stabilitesini, hava boşluklarını, mineral agregalar arasındaki boşlukları arttırmış, akma ve bitümle dolu boşlukları azaltmıştır. Atık plastik ikamesi ile bitümün yumuşama ve parlama noktası artmıştır. İkameli ve plastiksiz asfalt karışımlarının çevresel etkileri karşılaştırıldığında, abiyotik tükenme, ozon tabakası incelmesi, karasal ekotoksisite ve ötrofikasyon değerleri artmıştır. Abiyotik tükenme(fosil yakıtlar), küresel ısınma, tatlı su-sucul, deniz-sucul ekotoksisite, fotokimyasal oksidasyon, asitlenme ve insan toksisite değerleri azalmıştır. Atık plastik ikamesi ile asfalt karışımlarının üretim ve serim maliyetleri azaltılabilir.

Anahtar Kelimeler: asfalt, yaşam döngü değerlendirmesi, stabilite, atık plastik, döngüsel ekonomi

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

PMA	Polymer Modified Asphalt
HMA	Hot Mix Asphalt
PMB	Polymer Modified Bitumen
LCA	Life Cycle Analyzes
SSD	Saturated Surface Dry
PET	Polyethylene Terephthalate
HDPE	High-Density Polyethylene
PVC	Polyvinyl Chloride
LDPE	Low-Density Polyethylene
PP	Polypropylene
PS	Polystyrene
AV	Air Voids
VMA	Voids in Mineral Aggregate
VFB	Void Filled with Bitumen
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact assessment
Gsa	Apparent Specific Gravity
Gsb	Bulk Specific Gravity
Gse	Effective Specific Gravity
SSD	Saturated surface dry
Gb	Bitumen Specific Gravity
Gsbm	Bulk Specific Gravity for The Combined Aggregate
Gsam	Apparent Specific Gravity for The Combined Aggregate
Gmm	Maximum specific gravity of compacted mixture
Gmb	Specific Gravity of Compacted Mix
IDT	Indirect Tensile strength

To my family

CHAPTER 1

1. INTRODUCTION

1.1 General

For developing countries such as Turkiye, the efficient use of resources or the use of them by making them more efficient is economically extremely important and reducing the foreign dependency rate is a very important parameter for the country's economy.

Road construction costs are projects with serious investments, and the harmful environmental effects that occur during production and construction are at a size that cannot be ignored. Therefore, studies are carried out to improve the properties of the binder bitumen or asphalt mixture used in road pavements and to reduce their costs.

Rapid urbanization and population growth, along with technological developments and industrialization, increase the pressure on the environment and humans in our country as well as all over the world. The increase in the needs of people with technology causes both natural resources to be destroyed more and every product produced ultimately turns into waste. For this reason, it is inevitable for the environment and human health to face serious threats, for this reason, sustainability is gaining importance day by day, efficiency is gaining more importance with each passing minute. The storage of various products obtained as waste or leaving them to nature creates great difficulties and brings great problems to society and environmental pollution.

Today, intensive studies are carried out on the evaluation of waste materials in the face of pollution caused by the unconscious use of existing resources, the insufficient level of waste management throughout the world, and the lack of awareness of human beings. For these reasons, it has been shown in various studies that waste plastic can be used in asphalt road construction and can improve asphalt properties when used.

As it is known, it is an undeniable fact that a good road network is a great prestige indicator for countries in terms of economic and welfare levels. The existence of a well-balanced road network with sufficient length and high physical and geometrical standards across countries is highly important and necessary for development for countries and environmental life.

Our country is at an advanced level in the transportation networks and has serious investments in this regard projects. Since we are a foreign-dependent country in oil, various alternatives are being studied to reduce the cost of road construction. The main ones of these alternatives are the reuse of waste materials in asphalt roads by decreasing bitumen amount, construction and improving asphalt properties, environmental protection. Intensive studies are carried out in order to reduce pollution and reintroduce waste materials to the country's economy.

While plastic production was only 2 million tons per year in 1950, today this value has approached 400 million tons and continues to increase in a parabolic way. The cumulative production total has exceeded 7 billion tons. Although its production is increasing day by day, the amount of recycling is not at sufficient levels throughout the world. Plastic pollution has reached significant proportions in today's world and it is predicted that if no precautions are taken, it may cause great problems in the future [1].

Therefore, the use of waste plastics in asphalt road construction can be a good solution for reducing plastic pollution and improving asphalt road properties. Within the scope of this study, a single type of aggregates 0-5 mm, 5-19 mm was used for the surface layer and the aggregates were supplied from Talas Municipality asphalt construction site. A single type of bitumen (50/70) was used and the bitumen was from Kırıkkale Tüpraş refinery. Recycled waste plastics were used as plastic. In addition, life cycle analysis (LCA) has been made for conventional type asphalt and plastic asphalt, and the environmental impacts that may occur in the environment have also been examined.

1.2 Purpose and Content of The Study

As can be seen from the researches and studies, it has been seen that the use of these waste plastics in asphalt road construction can provide benefits in terms of both improvement of road properties, economic gain and reduction of environmental pollution.

The main purpose of this study is to provide economic gain by reducing the need for bitumen with the use of plastic, and to show that environmental benefits can be achieved through life cycle analyses (LCA) for conventional type asphalt and plastic asphalt.

In addition, the use of waste plastics in hot mix asphalt is among the main purposes that asphalt mixtures of the same or better quality than conventional type asphalt can create within the limits of technical specifications.

In this study, Talas Municipality Asphalt plant laboratory and Abdullah Gül University Civil Engineering Department transportation laboratory were used.

CHAPTER 2

2. LITERATURE REVIEW

In this study, in order to examine the effect of waste plastics used as additional materials on hot bituminous mixes, first of all, a literature search was conducted for better recognition of bituminous hot mixes, aggregates, and plastics, and also about life cycle analysis. In this section, information about the research topics is given.

2.1 Bitumen

Bitumen are residual products obtained from the distillation of crude oil. They are primarily used for their waterproofing properties in the construction industry and for their binding properties in the road industry. Bitumen are thermoplastic materials and have significant limitations due to their temperature sensitivity [2].

Bitumen is one of the oldest known engineering materials. Due to its properties, it has been used as an adhesive, anti-leakage, preservative, waterproofing additive, and binder in road pavements for a long time. Bitumen; high viscosity, but viscosity is heat sensitive (it softens when heated, almost completely solidified) is a colloidal material that is completely or substantially soluble in toluene solvents such as trichloroethylene/tetrachloroethylene [3, 4].

2.2 Aggregates

In its most general definition, aggregate is the form of sand, gravel, crushed stone, slag and other mineral compounds combined in a binding medium (bitumen, portlant cement concrete, mortar, etc.). Aggregates are an important component responsible for the stability of the road pavement [5].

Aggregates are generally durable and hard materials, so they contribute to the high strength of the mix. Grading can add different properties to the mixture based on the largest particle size, water absorption capacity, unit weight, specific gravity, particle shape, type and amount of impurities on the surface, frost resistance and thermal properties. According to these properties, they can be used in different mixtures. [5, 6]

Aggregates to be used in the foundation and sub-base layers of flexible pavements should provide purposes such as transferring the load from the pavement to the ground in a safe and balanced manner, being resistant to environmental and traffic effects (durable, being high-grained). [5, 6].

2.2.1 Properties of Aggregates Used in Road Pavements

Aggregates to be used in the foundation and sub-base layers of flexible pavements should provide purposes such as transferring the load from the pavement to the ground in a safe and balanced manner, being resistant to environmental and traffic effects (durable, being high-grained) [5, 6].

Aggregate groups of different sizes give different properties to the coating mixtures. At this point, a good gradation significantly affects the properties of the mixture. For this reason, the aggregates, which are divided into three different groups according to their sizes as coarse aggregate, fine aggregate and mineral filler, should be examined separately.

- **Coarse aggregate** is the part of the aggregate mixture remaining on the 4.75 mm (No 4) sieve and consists of crushed stone, gravel or sifted gravel and their mixture, and materials with high strength should be included in the coarse aggregate, soft and low strength or unknown materials that will affect its properties should not exist. Coarse aggregate distribution significantly affects asphalt concrete properties, durability and stability [5, 7].
- **Fine aggregate** is the part of the aggregate mixture that passes through the 4.75 mm (No. 4) sieve and remains in the 0.075 mm (No. 200) sieve, and is an aggregate type consisting of crushed stone, gravel or sand. In the design of the mixture, the coarse aggregate forms the main skeleton structure, while the fine aggregate is formed by the coarse aggregate. It provides a denser mixture by filling the voids of the structure [5, 7].
- **Mineral fillers** are defined as aggregate material passing through a 0.075 mm sieve. Filler is used to increase the fine aggregate ratio in bituminous mixtures, to

reduce the amount of voids and to increase the resistance of asphalt concrete against deformation at high temperatures. Filler material is generally used between 3% and 9% in the bituminous mixture. Up to a certain extent, fillers change the fine aggregate gradation as it fills the voids, thus providing more contact points between the aggregate particles, helping to obtain denser mixtures [5, 7].

2.3 Plastics

Plastic materials are essential in modern societies. They are produced mainly from fossil-based resources. Plastic are man-made materials that can be shaped with the help of heat and pressure, and that can be obtained by breaking the bonds of simple groups called carbon (C), hydrogen (H), oxygen (O), nitrogen (N) based monomers and transforming them into a long and chained structure called polymer. Plastic is a material with a very long time to dissolve in nature and has a structure with highly harmful effects for the environment [8].Plastics are divided into four main groups: thermoplastics, elastomers, thermosets and polymer compounds. Macromolecular structures distinguish the class and physical properties of any plastic material. Elastomers and thermosets have soft and hard resilience, respectively; and its resins cannot be melted for recycling. However, thermoplastics are either amorphous or semi-crystalline and suitable for recycling [9, 10].

The fact that plastics have different structures will bring different properties on different plastics, for these reasons, the selection of the plastic-type that can be used is of great importance. Thermoplastics have been used in the study since they are a material suitable for recycling. Thermoplastic plastic types, densities, melting points and usage areas are shown in Table 2.1, Table 2.2 and Table 2.3, respectively.

THERMOPLASTICS: They soften when heated and can be easily shaped. If desired, it can be softened by heating again.

Polyethylene (HDPE and LDPE), Polyvinylchloride (PVC), Polypropylene (PP)

THERMOSETPLASTICS: They reach a permanent hardness above a certain temperature and do not soften when reheated. For example phenolics, epoxies, and some polyesters

ELASTOMERS: Natural rubber

Table 2. 1 Plastic types and structures [11]

Polymer types		Structure
♳PETE	Polyethylene terephthalate (PET)	Ethylene glycol and Dimethyl terephthalate
♴HDPE	High-density polyethylene(HDPE)	Ethylene (CH_2=CH_2)
♵PVC	Polyvinyl chloride(PVC)	Vinyl chloride (CH_2=CH-Cl)
♶LDPE	Low-density polyethylene(LDPE)	Ethylene (CH_2=CH_2)
♷PP	Polypropylene (PP)	Propylene (CH_3-CH=CH_2)
♸PS	Polystyrene(PS)	Styrene

Table 2. 2 Density and melting points of plastic types [11]

Polymer types	density (g/cm^3)	Melting temperature (°C)
high-density polyethylene (HDPE)	0.95–0.97	137
low-density polyethylene (LDPE)	0.92–0.93	110
polypropylene (PP)	0.90–0.91	176
polystyrene (PS)	1.0–1.1	—
polyvinyl chloride,(PVC)	1.3–1.6	—
polyethylene terephthalate (PET)	1.3–1.4	265

Table 2. 3 Plastic types usage areas [11]

Polymer types	Using Areas
♲PETE	Transparent Bottles,
♲HDPE	Milk Bottles, Wire and Cable Insulation, Toys
♲PVC	Pipe, Conduit, Home Siding, Window Frames
♲LDPE	Packaging Film, Grocery Bags, Agricultural Mulch
♲PP	Bottles, Food Containers, Toy
♲PS	Eating Utensils, Foamed Food Containers

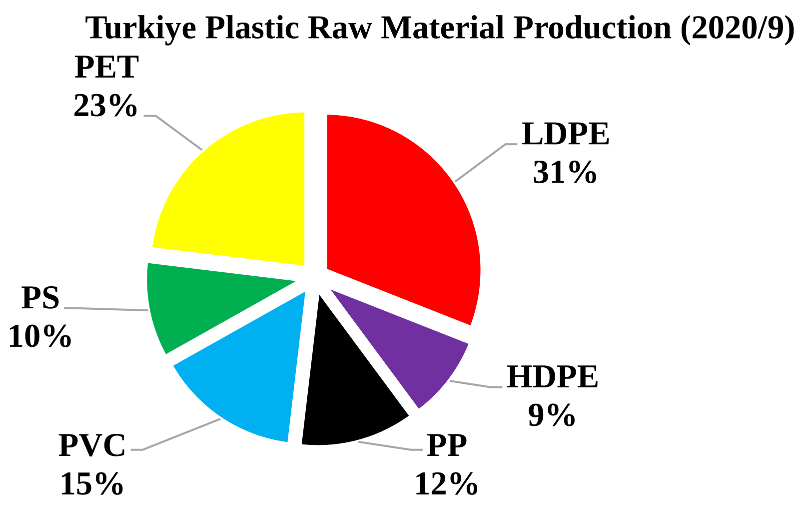

Figure 2. 1 Turkiye plastic raw material production [12]

It is estimated that, in 2020 in Turkiye, the plastics raw materials production realized about 1 million MT. In this period, 31% of the total plastic raw materials was LDPE 9% was HDPE, 15% was PVC, 12% was PP, 10% was PS and 23% was PET as shown in Figure 2.1 [12].

2.4 Hot Mix Asphalt (HMA)

Bituminous hot mix is a road pavement material obtained by mixing well proportioned bituminous binder, aggregate, and filler under quality control in terms of temperature, humidity, and composition in fixed mixing plants. Bituminous hot mix can be thought of as a system consisting of three components. Continuously graded aggregate is mixed in the mix design by granulometry in such a way that it contains sufficient material in all aggregate sizes from coarse aggregate to filling material, and hot mix asphalt (HMA) is given to the prepared hot mixture. Mixtures called HMA are the most advanced type of coating, they are used on heavy traffic roads, highways, airport runways, and their cost is high.

Basic properties of a good hot mix asphalt should have

- High stability
- Economic
- Durable
- Should not be fragile

Stability: It is the resistance of the bituminous coating against pressure, tensile and shear forces caused by wheel effects during continuous moving loads from vehicle traffic, long-term static loads and stresses caused by vehicles. The effects of bitumen and aggregate properties on stability are as important as the composition of the mixture. Another factor affecting the stability of the mixture is the hardness of the bitumen used, namely penetration. Penetration value is inversely proportional to consistency, as the bitumen softens, the penetration value increases. It can be said that the stability value of the coating will be higher when a bituminous binder with lower penetration is used. It can be adjusted with sufficient stability, different bitumen, and different aggregate granulometry, taking into account different climate, weather, and ground conditions [5-7].

Durability: The durability of an HMA blend is its resistance to traffic conditions, weather and temperature changes, and salt effects. It is an important parameter for asphalt life. High durability can be achieved by designing and compacting the mixture to provide high impermeability using good granulometry and quality aggregate and a good percentage of bitumen [5-7].

Workability: Adequate aggregate distribution in the desired consistency, it can be placed easily with compression. Mixtures containing too much coarse aggregate are not easily workable. A low percentage of fillers in the mixture leads to permeability and in this case has a negative effect on durability. If the percentage of filers is high, the durability of the mixture is low and it becomes very difficult to process [13].

Impermeability: It is determined by the percentage of air voids in the mixture. The interconnection of the voids in the mixture and the connection of the voids with the surface are the main factors affecting impermeability. The high percentage of voids in the mix design causes water and air to enter the mix easily, causing oxidation and segregation of the aggregates [5-7].

Flexibility: It is the resistance to withstand the problems that occur on the base floor without cracking. Lack of flexibility causes road surface cracks [5-7].

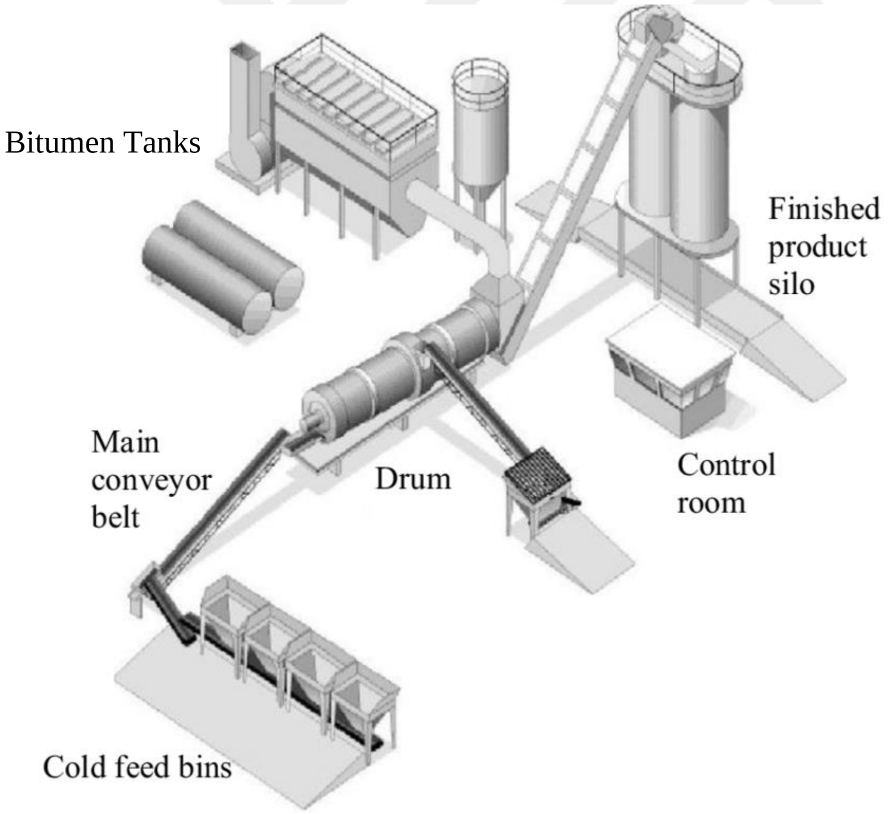

Figure 2. 2 Asphalt production scheme [14]

Aggregates are placed in the cold feed bins section with the help of a scoop according to their dimensions. Cold aggregates are sent to the dryer drum section with the help of a belt, where they are heated to an average of 160-170 degrees with the help of high heat. Heated aggregates are taken to the product silo with the help of an elevator. Bitumen at a temperature of 160 degrees is drawn from the bitumen tanks to the product silo. In the mixer room in the product silo section, the heated aggregate and bitumen are mixed within a certain period of time and after the mixture is loaded on trucks from this section and transported to the construction site. Asphalt production scheme is clearly shown in Figure 2.2.

2.5 Asphalt Mixtures Containing Waste Plastics

Pollution problems arise due to reasons such as rapid population growth and uncontrolled urbanization in the world. Plastic pollution has an important place among these problems and is increasing day by day. Although some methods (Recycling, Landfill, Incineration) are used to prevent plastic pollution or manage waste pollution. However, these methods are insufficient in themselves and alternative solutions are needed. Recycling stands out as the most environmentally friendly approach [1]. The use of waste plastics in asphalt road construction and the production of plastic roads are also included in the recycling method. Studies on this subject show that the use of waste plastics in asphalt road construction can both reduce environmental pollution and improve asphalt road properties. When approached on the basis of sustainability, considering that it will provide economic, ecological, and social benefits, it is seen that 3 basic principles can be met by using waste plastics in asphalt road construction.

The use of waste plastics in asphalt can be done by different methods. These methods can be carried out by mixing waste plastics into bitumen or by melting them on the hot aggregate surface.

Waste plastics to be used for plastic asphalt to be obtained by using waste plastics on asphalt are collected from various sources in the first stage, then other wastes are separated from the plastics and the separated plastics are cleaned and dried. The cleaned and dried plastics are broken into pieces of 3 to 10 mm size as shown in Figure 2.3, the broken plastics are ready for use.

Figure 2. 3 Shredded plastic

Advantages of plastic roads

- It reduces the need for bitumen by about 10%.
- It is an environmentally friendly approach.
- Extends road life.
- It increases road stability and performance.
- Use a higher proportion of plastic waste.
- It is an important approach to cleaning waste plastics.

2.5.1 Aggregate, Bitumen and Asphalt Design Tests of Mixtures Using Waste Plastic

Polymer modified bitumen (PMB) is obtained by mixing waste plastics with bitumen at certain temperatures and under suitable conditions.

Another method is obtained by adding waste plastics to the heated aggregate, forming molten plastic on the aggregate surface, and then adding bitumen.

Water Absorption Test: It is a test method used to determine the water absorption rate of the aggregates to be used, it is one of the important parameters for asphalt life. Low water absorption capacity can be considered as an increase in aggregate quality.

In the studies, PS, PP, PE, PET or mixed plastics were used. Plastics were used as replacements and additions, and the percentages of use vary in the studies. The percentages of use varied between 8% and 50%. And as a result of the studies, it was seen that the water absorption capacities decreased sharply by covering the aggregate surfaces with molten plastic, and some studies even stated that the water absorption capacities decreased to zero. It has been stated that the decrease in the water absorption capacity of the aggregates increases the quality of the aggregates, and the mixtures become more resistant to the formation of potholes, and thus their lifespan increases. [15-18].

By covering the aggregate surfaces with molten plastic, aggregates with water absorption capacity values outside the limits can be used, also the rate of pathole formation on asphalt can be reduced due to freeze-thaw effects.

Aggregate Impact Test: Coating of plastics improves aggregate impact value and improves aggregate quality by reducing surface. In addition, poor quality aggregates can be made useful by coating them with polymers. It can be considered as a good method to improve the quality of the flexible coating. In the studies, PS, PP, PE, PET or mixed plastics were used. Plastics were used as replacements and additions, and the percentages of use vary in the studies. The percentages of use varied between 1% and 50%. Studies have shown that by covering the surface of the aggregates with plastic, a decrease in impact values between 9% and 40% has been observed, and an increase in aggregate quality has been achieved, Figure 2.4 summarizes the impact of plastic use on the impact value of aggregates [15-20].

In the studies, it has been stated that the decrease in the aggregate impact value increases the quality of the aggregates, makes the aggregates more resistant to impacts, and acts as an impact absorber in heavy traffic loads, thus extending the service life. [15-20].

Due to the decrease in the impact values of aggregates whose surfaces are covered with molten plastic, poor quality aggregates or waste aggregates outside the impact limits can be used in asphalt road construction and the amount of raw materials taken from nature can be reduced.

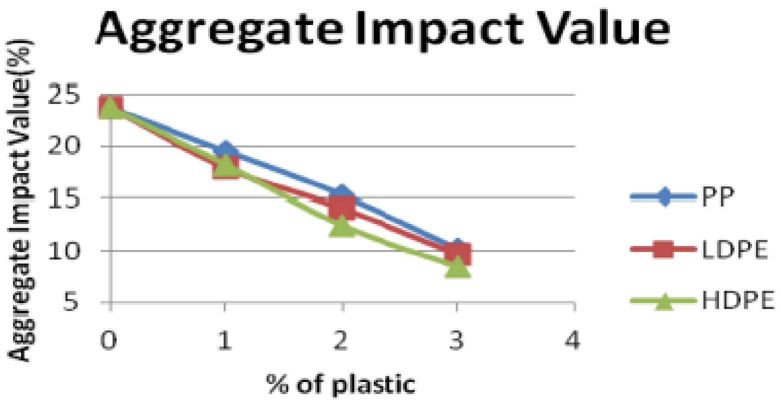

Figure 2. 4 Impact value with different % of plastic [20]

Los Angeles abrasion Test: The principle of the Los Angeles surface test is to find the percentage of surface caused by the relative frictional effect between the aggregate and the steel balls used as the abrasive load. These balls also have an impact effect during the test, and therefore their resistance to abrasion and impact is evaluated with this test [19].

In the studies, PS, PP, PE, PET or mixed plastics were used. Plastics were used as replacements and additions, and the percentages of use vary in the studies. The percentages of use varied between 1% and 50%. Studies have shown that by covering the aggregate surfaces with molten plastic, there is an improvement in Los Angeles values and the aggregate quality can be increased with this method. In studies with various plastics and different plastic percentages, it was stated that Los Angeles abrasion values decreased between 20% and 50% and Figure 2.5 summarizes the effect of the use of plastics on the Los Angeles abrasion value of aggregates. In the studies, it has been stated that with the decrease in the Los Angeles abrasion value, the asphalt mixtures become more resistant to the effects of wear under continuous loads, and the quality of the mixture and aggregate increased. [15-20].

Due to the decrease in the abrasion values of the aggregates whose surfaces are covered with molten plastic, poor quality aggregates or waste aggregates outside the abrasion limits can be used in asphalt road construction and the amount of raw materials taken from nature can be reduced.

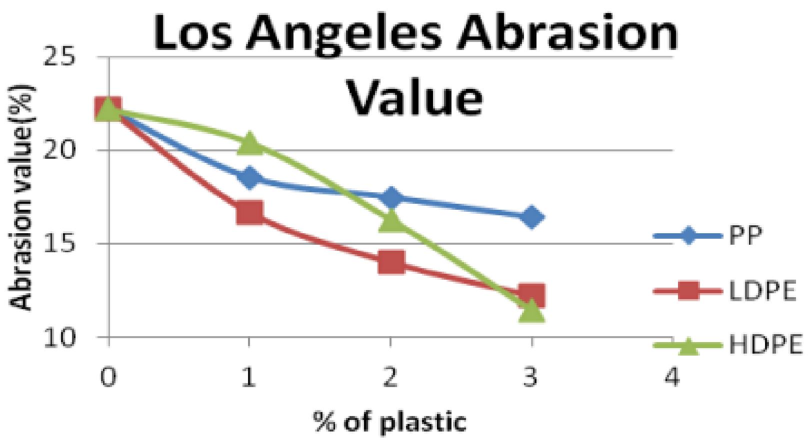

Figure 2. 5 Los angeles abrasion change with plastic [20]

Aggregate Crush Test: Aggregate with a lower crush value indicates a lower crushed fraction under load and gives the road longer service life. The weaker aggregate is crushed under the traffic load. It is clearly seen in the studies that plastic coated aggregates show lower crushing value than flat aggregates and can withstand traffic load more efficiently. In the studies, PP, PE, PET or mixed plastics were used. Plastics were used as replacements and additions, and the percentages of use vary in the studies. The percentages of use varied between 1% and 10%. Studies have shown that by covering the aggregate surfaces with molten plastic, there is an improvement in aggregate crush values and the aggregate quality can be increased with this method as shown in Figure 2.6. In studies with various plastics and different plastic percentages, it has been stated that crush values are reduced by about 40% to 50%. In the studies, it has been stated that with the decrease of aggregate crush value, asphalt mixtures become more resistant to traffic loads, the effect of crushed fraction is reduced, higher quality pavements can be obtained and thus the service life can be increased. [15, 16, 19, 20].

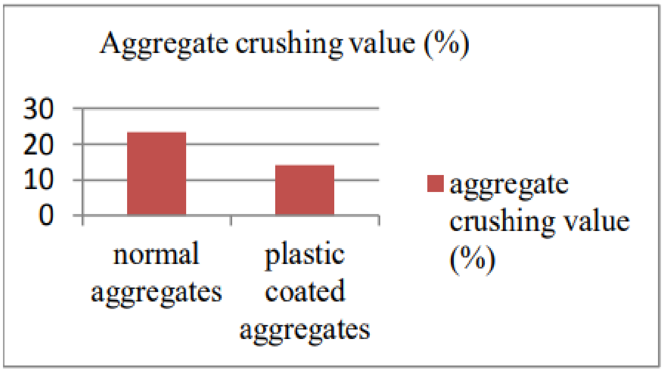

Figure 2. 6 Aggregate crushing value plastic relationship [19]

Stripping value: Stripping value gives the effects of moisture on the adhesion of the bituminous film to the surface particles of the aggregate. Plastic coating of aggregates makes water and moisture impermeable, and it is stated that the peeling effect can be obtained in this way. Stripping value has been shown to be zero in the studies. This shows that aggregates are more suitable for bituminous road construction than normal aggregates [15-17].

By covering the aggregates with plastic, the water and moisture permeability rate can be reduced and the peeling effect can be reduced, thus increasing the quality of the aggregate and thus increasing the service life, or low quality aggregates can be ready for use with this method.

Softening Point Test: The softening point is a test to determine the sensitivity of bitumen to temperature changes. The softening point is an important parameter that affects the formation of permanent deformation. PMB type bitumen obtained by mixing plastics in bitumen was used in the studies. Plastics such as PE, PET, PP or mixed plastics in different percentages were melted in bitumen and modified bitumen was obtained. In the studies, up to 20% of plastic was used and the softening point values increased between approximately 10 and 90 degrees on average in bitumen with different penetrations, Figure 2.7 and Figure 2.8 summarize the softening point change of bitumen using plastic. In the studies, it has been stated that the waste plastics mixed with bitumen enter into a chemical reaction and the softening point value increases, the temperature sensitivity of the bituminous mixtures decreases, they become more resistant to plastic deformations and the elastic recovery capacity increases. [19-24].

Depending on the increase in the softening point, the bleeding and softening problem can be reduced in hot climate conditions and more durable coatings can be produced.By reducing the bleeding problem, coatings with lower air voids rates can be produced, permeability values can be reduced and problems arising from permeability such as oxidation can be reduced.

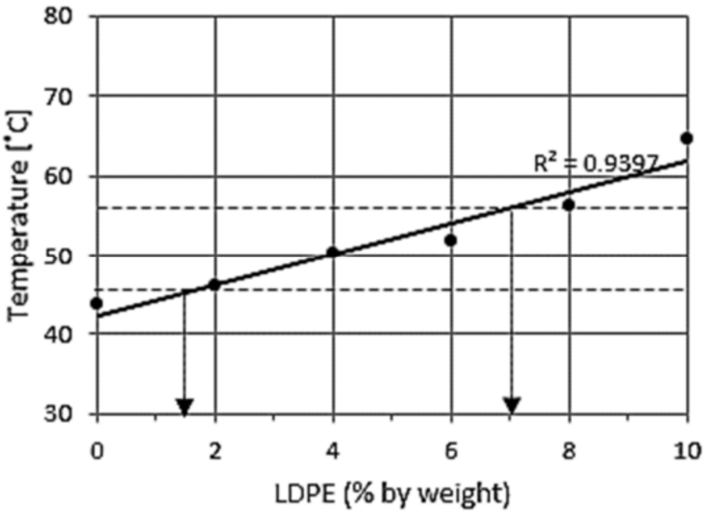

Figure 2. 7 Plastic effect on softening point [21]

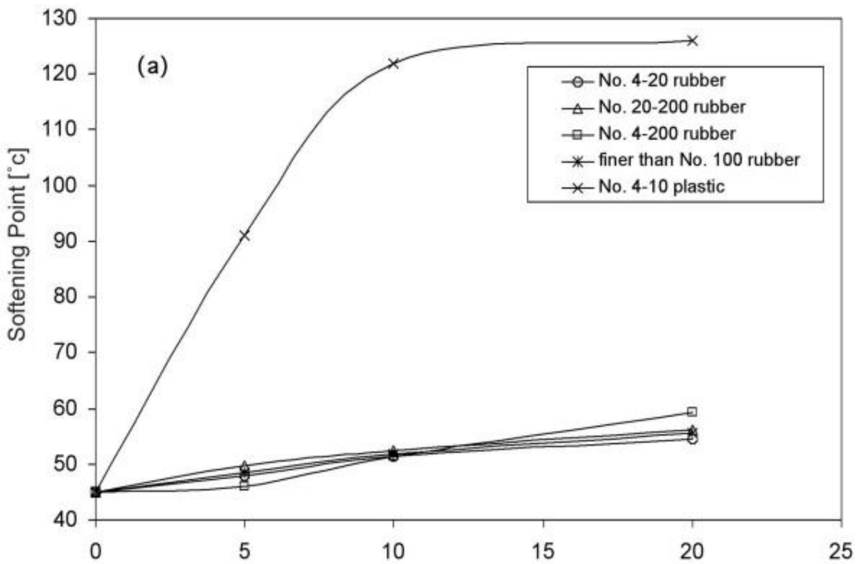

Figure 2. 8 Plastic effect on softening point [22]

Penetration Test : Penetration test is done to determine the hardness and consistency of bitumen. As the asphalt consistency increases, it binds the stones in the mixture to each other more strongly. Penetration value is inversely proportional to consistency. As the penetration increases, the asphalt softens. PMB bitumen is obtained by melting plastics such as PE, PET, PP or mixed plastics in different proportions into bitumen. In the studies, up to 20% plastic was used, and with the use of plastic in bitumen with different penetrations, there was a sharp decrease in the penetration value, and in some studies it was stated that the penetration value decreased to zero as shown in Figure 2.9. In the studies, it has been stated that the waste plastics mixed with bitumen react chemically and change the rheological properties of the bitumen, thus increasing the shear resistance at medium and high temperatures, increasing the binding force, and also bringing more stiffer. Also, it has been stated that the bitumen obtained by mixing waste plastics brings a more brittle structure. [19-24].

Bitumen is divided into certain penetration classes and according to these classes, it can be determined in which climatic conditions it can be used. The fact that the penetration values of bitumen are at the lowest level within the determined limits is an important factor to increase the binding quality of asphalt. However, falling below the limits makes the structure more fragile and shortens the life of the road, starting with the formation of cracks, in climatic regions where the temperature difference is high. In the studies carried out, decreases of 100% can be seen with the increase in the use of plastic. The percentage of plastic use can be reduced to keep it within limits. This means less waste plastic usage for plastic asphalts produced with PMB bitumen when compared to plastic asphalts obtained by covering the aggregate surface with molten plastic.

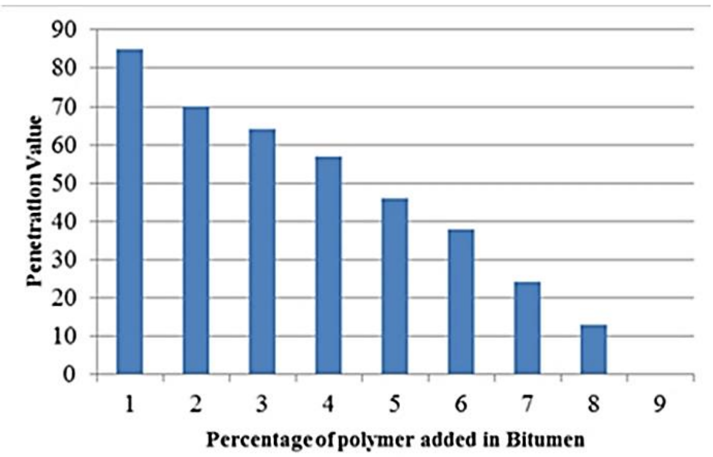

Figure 2. 9 Relationship between plastic and penetration value [23]

Flash Point and Fire Point: Flash point is the lowest temperature at which vapor of a substance glows temporarily on contact with a flame but does not continue to burn. PMB type bitumen obtained with the use of plastic showed a better performance in the flashing point as well as the softening point in the studies carried out compared to the unmodified form. It has been stated that it is an advantage to increase the flash point of bitumen against dangerous situations that may occur. With the use of plastics, an average 10% increase in the flash point value was obtained in the studies [23].

Ductility Test: The meaning of the word is “elongation”. Bitumen with high elongation ability has a superior bonding ability than bitumen with lower ductility value. On the other hand, bitumen with a very high ductility value is more sensitive to temperature changes. Therefore, the ductility values of various bitumen are limited.

In the studies, PE, PET, PP or mixed plastics types were used and in different proportions into bitumen and PMB type bitumen were obtained. In these studies, up to 20% plastic was used and it was stated that there was a sharp decrease in the ductility value with the use of plastic. The rate of decrease in ductility values has decreased from 15% to 100 % in some studies as shown in Figure 2.10, with the use of plastic in different percentages. In the studies, it has been stated that the ductility value of polymer modified bitumen obtained by mixing waste plastics with bitumen decrease, the bitumen become harder and brittle and its sensitivity to temperature decrease. [20-22].

As with the penetration values, the use of plastic significantly reduces the ductility value and this situation takes the bitumen values out of the limits. In order to keep it within the limits, the percentage of plastic use in PMB type bitumen is lower than when it is melted on the aggregate surface.This means less waste plastic usage for plastic asphalts produced with PMB bitumen when compared to plastic asphalts obtained by covering the aggregate surface with molten plastic.

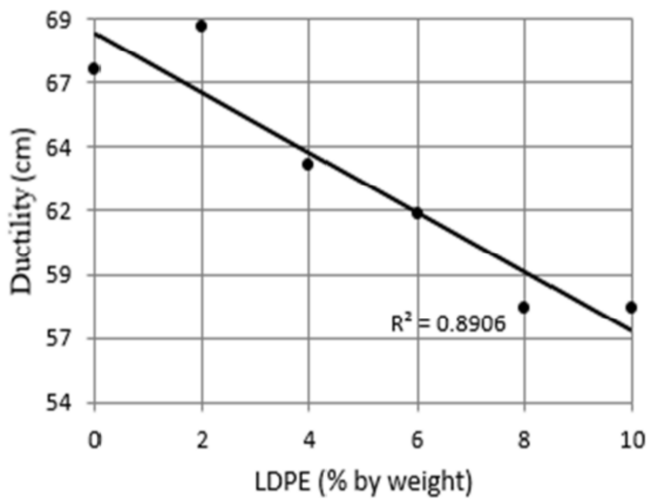

Figure 2. 10 Plastic effect on ductility [21]

Wheel Tracking Test The test is an important parameter used to determine the plastic deformation on asphalt. Also, such deformations are frequently encountered on asphalt roads.

In the studies, PET, PP, PE, and mixed plastics were used up to 20% of the bitumen weight on asphalt mixtures. In addition, the effects of elastomeric and plastomeric types of plastics were investigated in studies and it was stated that the formation of rutting could be reduced up to 90% with the use of plastics in asphalt mixtures. The decrease in rut depth with the use of plastic can be seen in Figure 2.11. In the studies, it has been stated that the rut depth values of the mixtures obtained with the use of plastic decreased, and thus the plastic mixture gained a more resistant structure against plastic deformations and also the dynamic stability value increased. [25-28].

The decrease in the rut depth value on the roads that serve under heavy tonnage vehicles or continuous traffic loads means that the life of the road can be extended. It is very important, especially for slopes or intersections where the braking region is high. At the same time, maintenance costs can be reduced for the repair of fluctuations on the roads.

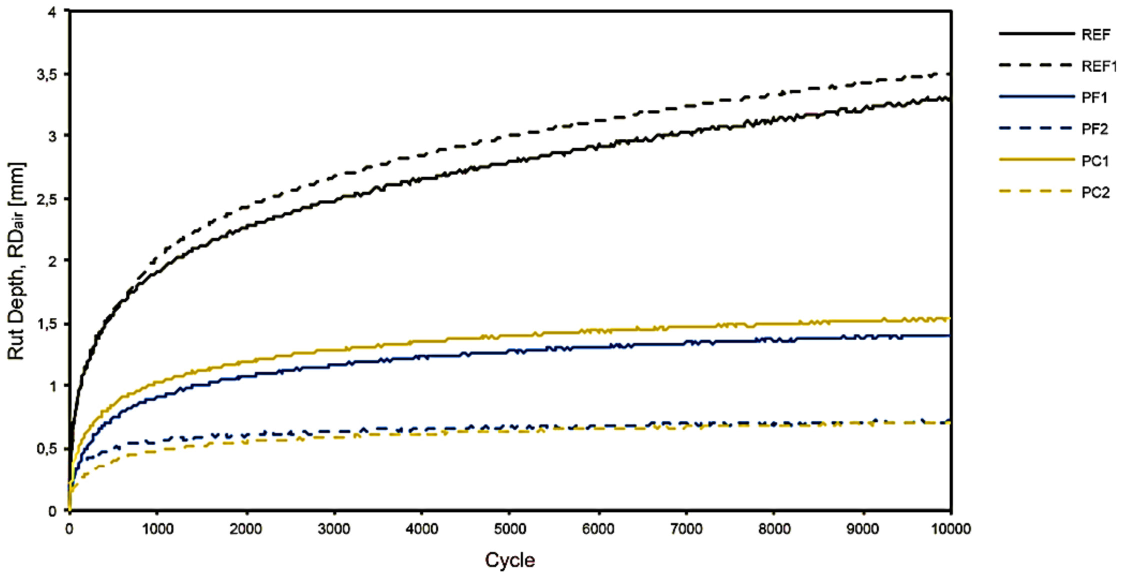

Figure 2. 11 Wheel tracking test Rut depth and plastic relationship [27]

Indirect Tensile Strength the IDT test is used to determine the tensile properties of asphalt mixes. It is an indicator of the asphalt's resistance to fatigue cracking and permanent deformation. In the studies, PET, PE, and mixed plastics were used up to 20% of the bitumen weight on asphalt mixtures. In addition, the effects of elastomeric and plastomeric types of plastics were investigated in studies. In most of the studies, it has been stated that the indirect tensile strength of plastics increases as shown in Figure 2.12 and can even increase up to 3 times, while in a limited number of studies, it is stated that the indirect tensile strength can decrease as shown in Figure 2.13 by approximately 25% with the use of plastics**.** In the studies, it has been stated that the IDT value is an indicator for cracking sensitivity and deformation, it is directly proportional to the use of plastics the bound force between aggregate and bitumen, and the durability of asphalt will increase with its increase. [25-27,29-32].

It can be said that the reason for the different results in the studies is related to the plastic percentages and plastic types used.For the drop rate, it should stay within the limits determined in the specifications and therefore the optimum plastic rate should be well determined.

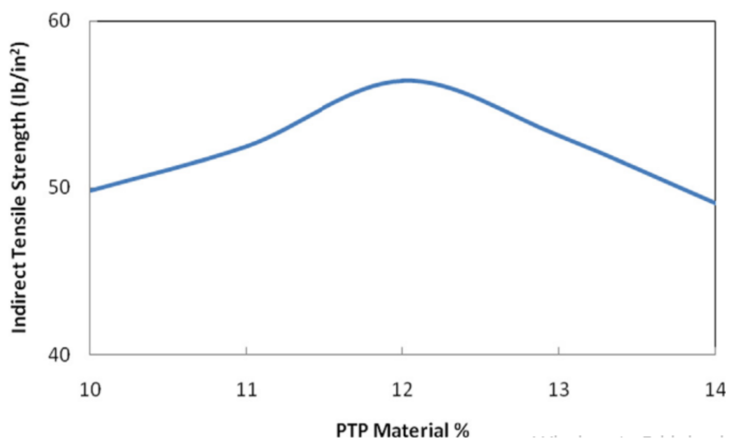

Figure 2. 12 Plastic effect on indirect tensile strength [27]

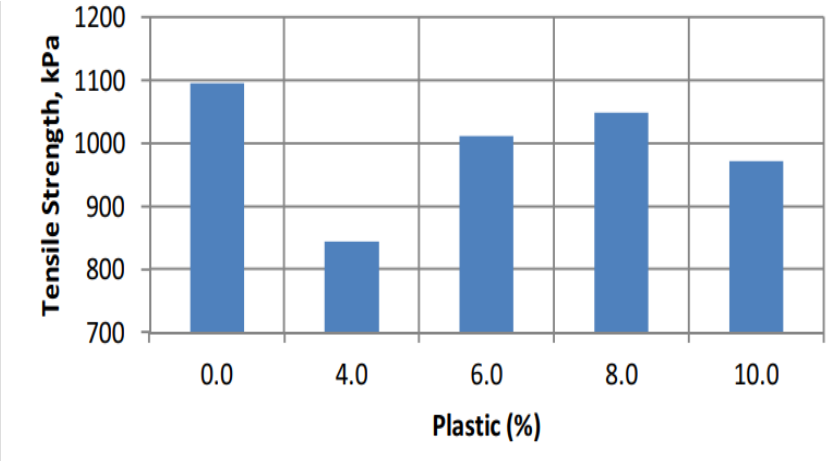

Figure 2. 13 Plastic effect on indirect tensile strength [29]

Marshall Stability Flow Test: The Marshall stability test is the most widely used method to determine stability, flow values and optimum binder content. It is one of the most widely applied test methods in the field.

In the studies, PET, PE, PP, mixed plastics were used up to 20% in asphalt mixture and the usage method was by bitumen weight or by aggregate weight. The use of plastics was by replacement or addition method. Studies have shown that the stability values is increasing between with the use of plastics are 10% to 300%. In addition, with the use of plastics, the stability does not increase continuously, after the optimum ratio is exceeded, the stability values decrease from the peak point was stated from studies. Figure 2.14 and Figure 2.15 summarize the stability change of bitumen using plastic. Optimum plastic percentages differ from study to study, and in the studies, the average optimum percentage is specified as between 7% and 12%. In the studies, it has been emphasized that in the mixtures obtained by using waste plastics, the plastic and bitumen reacted chemically at high temperatures and the rheological properties of the bitumen improved so the adhesion strength between the bitumen and aggregate increased and the stability values improved. Also, it has been stated that the improvement of the stability value is an improvement in shear strength and rutting. [32-47].

The increase in the stability value means the increase in the maximum load rate that the asphalt can carry, and it can be thought that the asphalt will serve more stable with this increase.

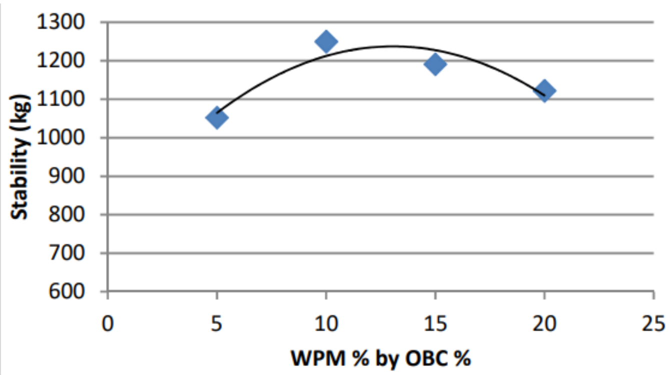

Figure 2. 14 Plastic effect on stability [32]

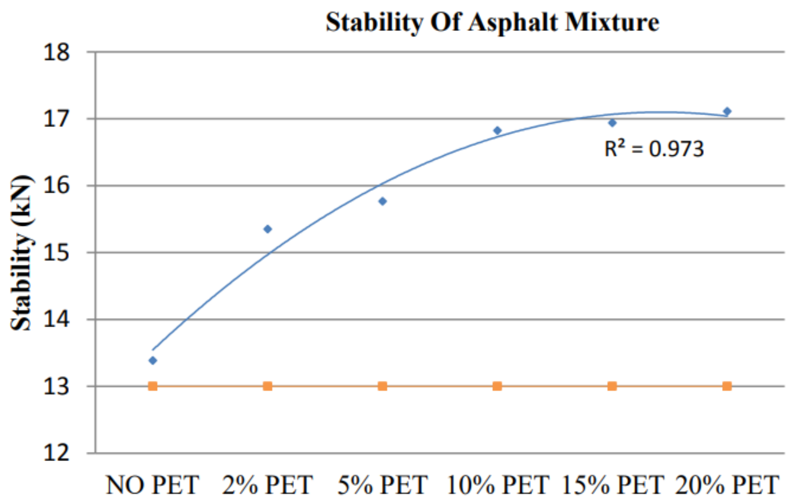

Figure 2. 15 Plastic effect on stability [38]

In addition, the effect of plastic thickness on stability and flow values was also investigated in a study Figure 2.16 and Figure 2.19 show the effect of plastic thickness on stability and flow [45].

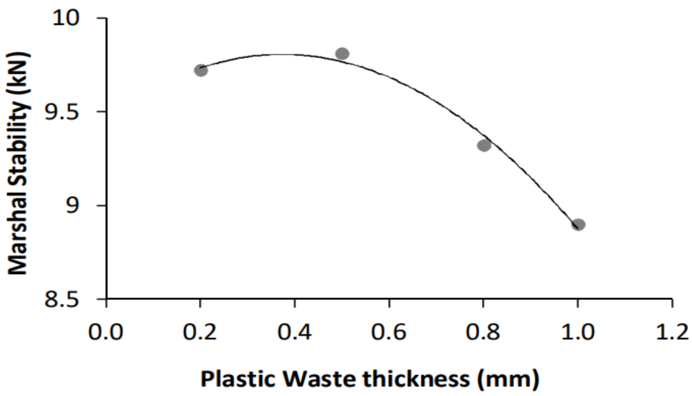

Figure 2. 16 Plastic thickness stability relationship [45]

Flow Test: In the studies, PET, PE, PP, mixed plastics were used up to 20% in asphalt mixture and the usage method was by bitumen weight or by aggregate weight. The use of plastics was by replacement or addition method. Studies have shown that the flow values generally increase with the use of plastics as shown in Figure 2.17, but a decrease is also observed in a limited number of studies as shown in Figure 2.18. Although the flow values showed a maximum increase of 197% in the studies, it was stated that there was a decrease of approximately 30% in a limited number of studies. In the studies, it has been stated that the flow value is a value that determines the behavior of asphalt pavements under traffic loads and reflects the plasticity and flexibility properties of asphalt. It has been stated that the use of plastics changes the chemical properties of the bitumen and therefore the flow values change and the decrease in the flow value makes the asphalt more rigid, on the other hand, the increase in the flow value causes high flexibility in the asphalt. In addition, in some studies, it has been stated that the changes in the flow value are seriously dependent on the structure of the plastic-type used and the plastic thickness. [32-35,37-47].

The increase in the flow value in asphalt mixtures increases the workability, while its decrease makes the asphalt more rigid. In this case, its increase and decrease have both advantages and disadvantages. Therefore, staying within the limits within the technical specifications is the optimum solution for asphalt design.

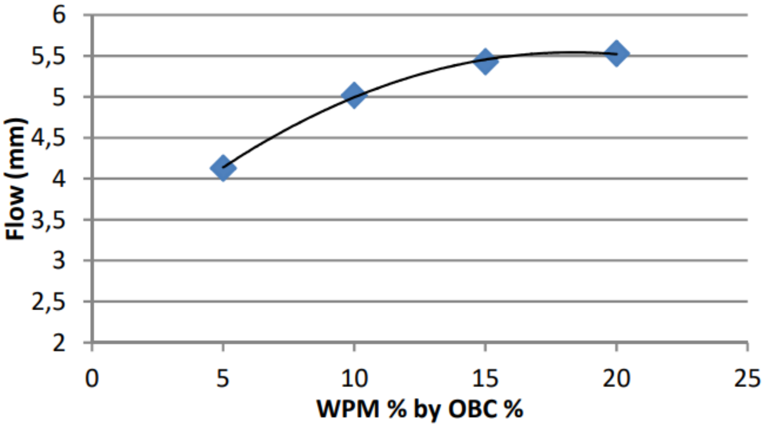

Figure 2. 17 Plastic effect on flow [32]

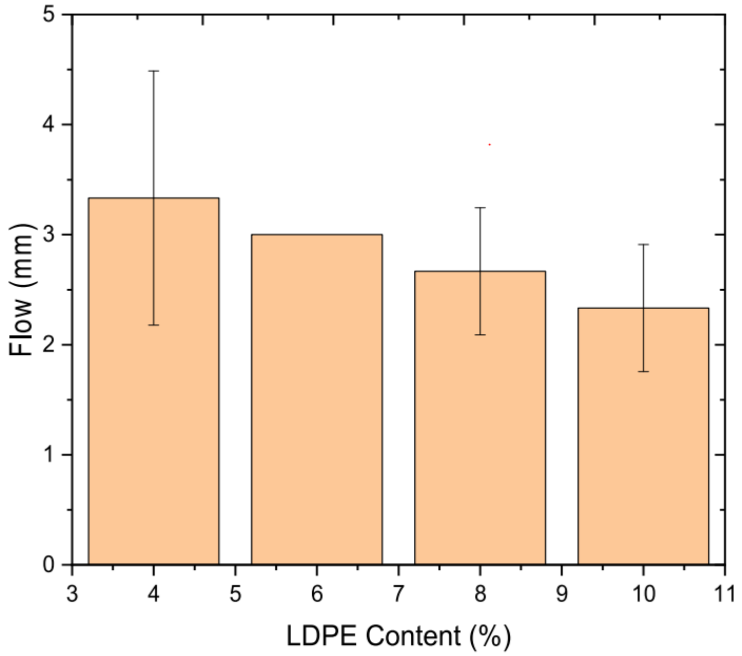

Figure 2. 18 Plastic effect on flow [37]

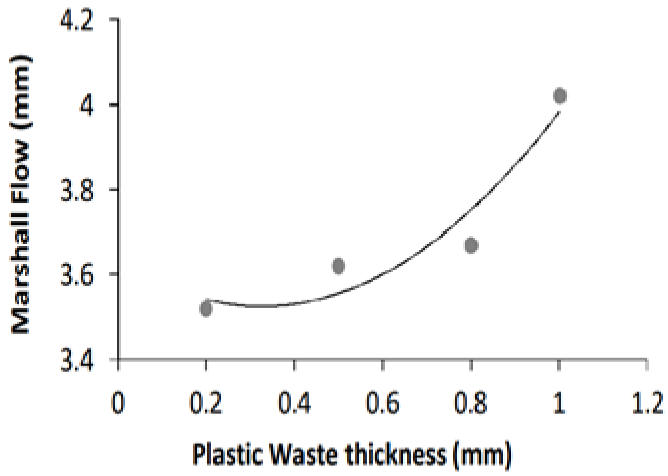

Figure 2. 19 Plastic thickness flow relationship [45]

Air Voids, Voids In The Mineral Aggregates, Void Filled With Bitumen: They are volumetric evaluation methods on asphalt and are important factors in many important parameters such as durability, porosity, asphalt life, cracks.

In the studies, PET, PE, PP, mixed plastics were used up to 20% in asphalt mixture and the usage method was by bitumen weight or by aggregate weight. The use of plastics was by replacement or addition method. Studies have shown that while the AV ratio in asphalt mixtures generally increases with the use of plastics as shown in Figure 2.20, a decrease has been observed in some studies as shown in Figure 2.21. While the maximum increase rate is approximately 300%, it has been stated in the studies that the decrease rate is at the maximum level of approximately 60%. In the studies, it was stated that the air voids ratio increased when the replacement method was used, and decreased when the additions method was used, as the binder ratio increased. It was also stated that the plastic thickness had an effect on air voids. It has been stated that the increase in air voids ratio affects permeability, oxidation, and water entry, and has a significant effect on freeze-thaw and crack and pothole formation. On the other hand, it was also emphasized that the decrease in air voids rate has a bleeding effect on asphalt. [32, 37-47].

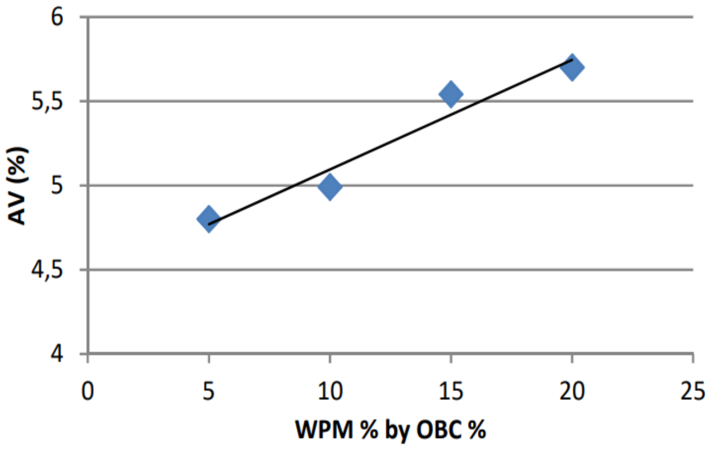

Figure 2. 20 Plastic effect on AV [32]

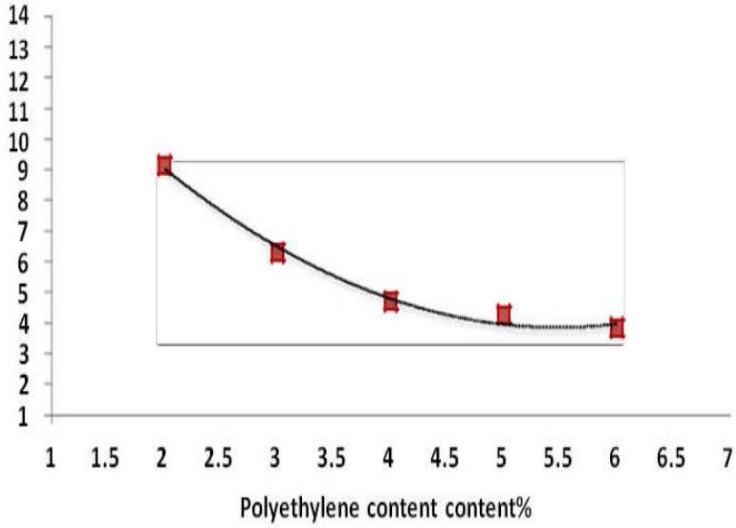

Figure 2. 21 Plastic effect on AV [42]

When the studies made in terms of VMA are examined, generally studies show have that increase is observed with the use of plastic as shown in Figure 2.22. The maximum increase rate is 16.5%. In the studies, it has been stated that the VMA ratio is highly affected by the air voids ratio and it is an important parameter for flexible pavements, which affects the asphalt durability and rutting value by forming a film layer between the binder and aggregate parts. [32, 37-41, 44, 46, 47].

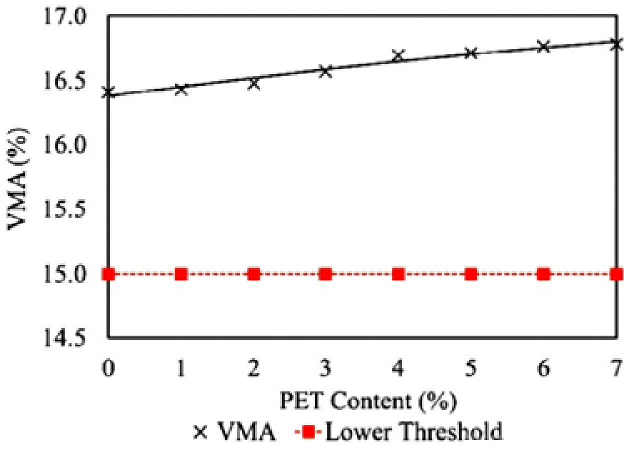

Figure 2. 22 Plastic effect on VMA [41]

When the studies conducted in terms of VFB are examined, an increase was observed with the use of plastic in general as shown in Figure 2.23 and as shown in Figure 2.24, while a decrease was observed in some studies. While the increase rate is maximum 20%, the decrease rate is stated as approximately 60%. In the studies, it was stated that the VFB value was characterized as voids filled with binder and that it changed with the replacement or additions method and was affected by the ratio of air voids and VMA, and also it has been emphasized that it has been affected by the type of plastic used, the chemical reaction between the plastic and the bitumen, and the thickness of the plastic. [32, 37, 38, 41, 43, 44, 46, 47].

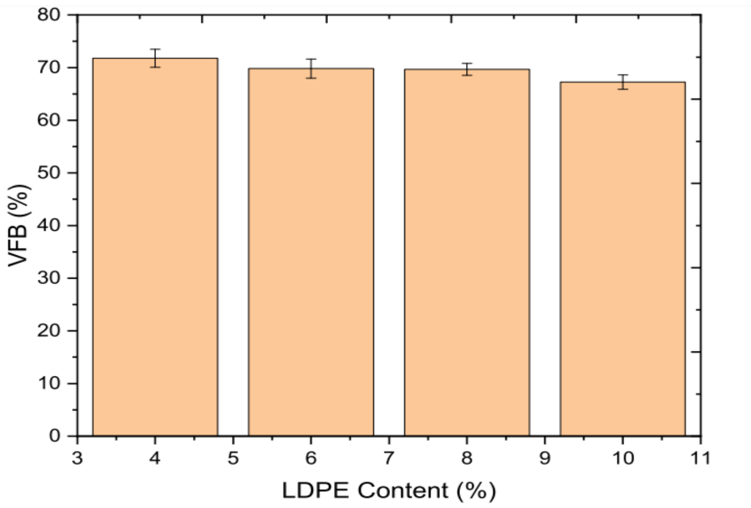

Figure 2. 23 Plastic effect on VFB [37]

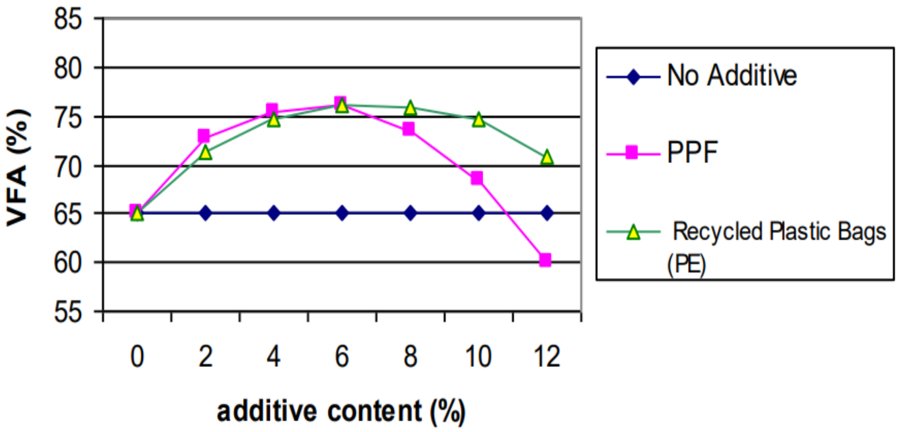

Figure 2. 24 Plastic effect on VFB [44]

2.6 Life Cycle Assessment (LCA) Methodology

Life cycle analysis (LCA) is a type of analysis to evaluate the environmental impact of products according to ISO 14040-14044 standards [48, 49]. It basically consists of 4 steps as shown in Figure 2.25.

1. Goal and scope definition,

2. Life cycle inventory (LCI),

3.Impact assessment (LCIA)

4. Interpreting the results

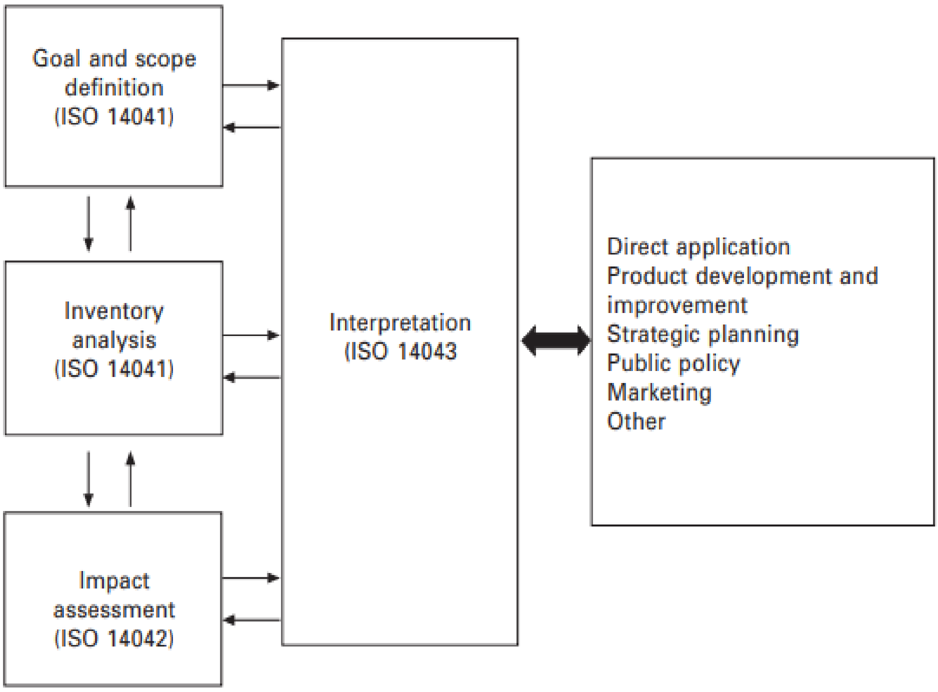

Figure 2. 25 LCA simple flowchart [50]

As a first step, the goal and scope definition should be defined in a clear, understandable, and simple manner that covers all stakeholders. For example, comparing two or more products that perform the same function, increasing the efficiency of existing products, or identifying opportunities for the development of a new product. The definition of the scope of an LCA study should be clear and concise on what is included in the modeled system and what evaluation methods will be used. Such as the functional unit, the system boundaries, the types of impact and the methodology of impact assessment. In the studies, asphalt mixtures obtained by using waste plastics, traditional asphalt mixtures, concrete pavements, recycled asphalt mixtures or crumb rubber modified asphalt mixtures were compared and efficiency, ecological effects and opportunities were stated as the definition of goal. As the scope definition, in some studies, ton, m^2, and meters were chosen as functional units, while in some studies, mile was chosen, and as the evaluation method in some studies, cradle-to-gate, cradle-to grave methods were chosen and system boundaries as shown in Figure 2.26 were created within this framework [50-58].

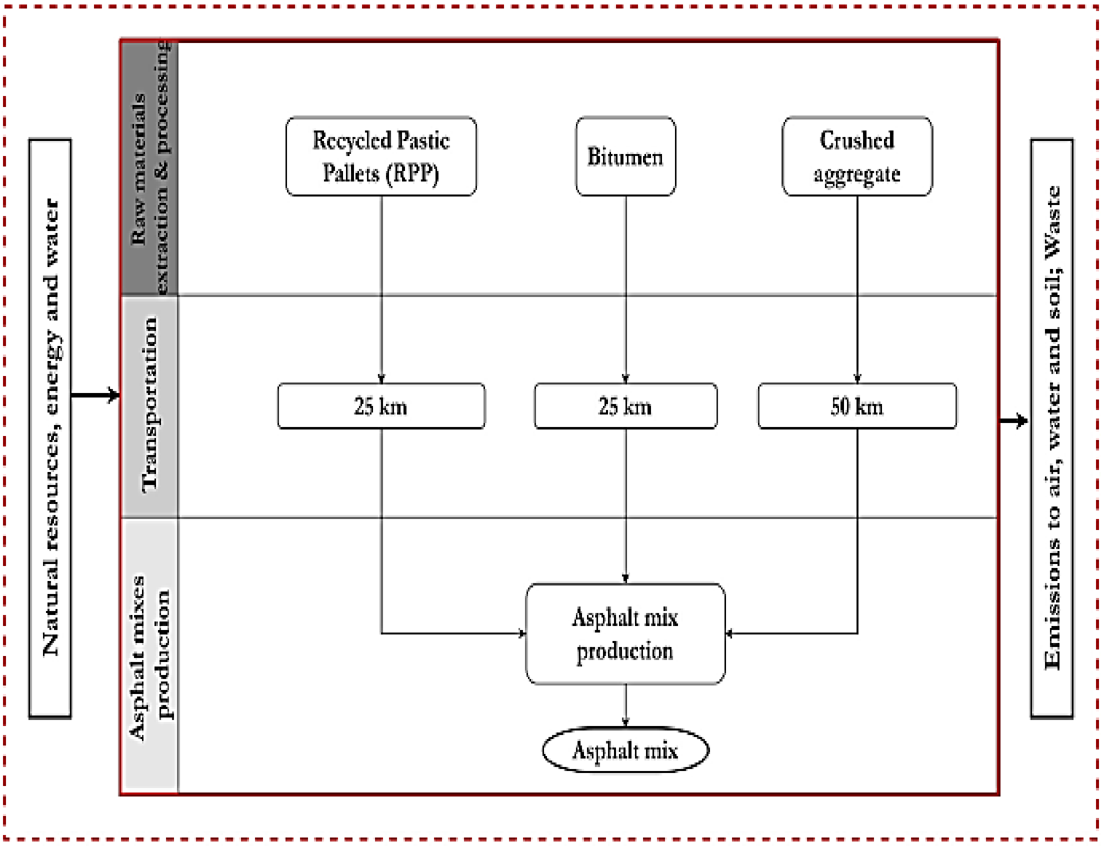

Figure 2. 26 System boundaries modelling the production of asphalt mixes [54]

Inventory analysis is the second step in an LCA. It includes data collection and calculation procedures to measure the relevant inputs and outputs of a product system. These inputs and outputs include the use of resources, and emissions to air, water, and soil. Raw material, material production, production of final product, use is a simple diagram of LCI. At this point, all processes have separate functional units and all processes are interconnected. When the Inventory analysis sections were examined in the studies, data collection, inputs and outputs, raw material, transportation data and regional database selections were collected in the light of the regions where the studies were carried out and these data were linked to each other [50-58].

Impact assessment is the third phase of the LCA where the environmental impacts of the system are evaluated. This step consists of three key elements: (1) selection of impact categories, category indicators, and characterization models, (2) classification, and (3) characterization. Examples of the impact categories are land use, climate change, ecotoxicological impacts, human toxicological impacts etc. In the studies carried out, environmental effects as impact assessment were examined and various categories such as ozone depletion, global warming, photochemical smog formation, acidification, eutrophication were evaluated according to ISO standards [50-58].

When examined impact assessment section in the studies, PE, thermoplastic elastomer, recycled pellets and mixed plastics were used, and it was stated that different results may occur when the results are evaluated as cradle to gate or cradle to grave. It has been stated that the main reason for this situation is the emissions that occur during the collection and recycling of plastics in the cradle-to-gate approach. In the studies, the ecological effect of cradle-to-gate approaches is more than traditional asphalt, and it has been stated that this situation can be overcome by reducing the asphalt thickness. In the cradle-to-grave approach, it was stated that environmental impacts were reduced also emissions could be further reduced by reducing the asphalt thickness [54, 56, 58].

Interpretation is the fourth stage of the LCA. It is the identification of important environmental problems, the evaluation of the results and the determination of recommendations based on the evaluated results [50-58].

CHAPTER 3

3. MATERIALS AND METHODS

Within the scope of the research, asphalt mixtures obtained by using aggregate, bitumen, and plastic used for asphalt surface layer were examined in accordance with the standards.

3.1 Materials

Asphalt mixtures are made up of two major components: aggregate and bitumen. Plastic is the third component of plastic asphalt mixtures, after aggregate and bitumen. Fine and coarse aggregates were obtained from the Talas Municipality asphalt construction site for this study. Bitumen is 50/70 type bitumen obtained from Kırıkkale Tüpraş refinery.

3.1.1 Aggregates

Aggregates were sieved within the limitations provided for the surface layer in the highway technical specifications, and specific gravity, water absorption, and moisture content tests were performed according to ASTM standards after giving the proper gradation curve. Type 1 type aggregate was used as aggregate. (Type 1): It is the type of surface with the largest grain size of 19 mm. It is applied in areas with heavy and continuous traffic.

3.1.1.1 Sieve Analysis

This test method aims to determine the particle size distribution of the aggregate by using the sieves whose qualifications are given in the standards. The experiment was conducted according to ASTM C 136-06 [59].

The test was carried out according to the limits between the granulometry limits specified as the Type-1 wear layer in the Highway Technical Specification. The aggregate sample is thoroughly mixed and brought to a homogeneous state. Sample separator equipment can be used to prepare adequate samples. As a result of the sieve analysis, 1000 kg asphalt distribution and gradation curve are given in Table 3.1, Table 3.2 and Figure 3.1, respectively.

Table 3. 1 Sieve analysis results

Sieve Size (mm)(in)(no)	Sieve (mm)	Passing % (Min)	Passing % (Max)	Passing %
19 (3/4")	19	100	100	100.0
12.5 (1/2")	12.5	88	100	95.6
9.5 (3/8")	9.5	72	90	87.4
4.75 (no:4)	4.75	42	52	51.7
2 (no:10)	2	25	35	29.3
0.425 (no:40)	0.425	10	20	12.7
0.180 (no:80)	0.18	7	14	8.0
0.075 (no :200)	0.075	3	8	3.0
Filler				

Table 3. 2 1000 kg asphalt mixing design

1000 KG ASPHALT DISTRIBUTION						
	KG	PERCENT %	1150 grams	7.5% Plastic	10% Plastic	%12.5% Plastic
BITUMEN	50	5	57.4	53.2	51.8	50.3
0-5 MM AGG	475	47.5	546.3	546.3	546.3	546.3
5-19 MM AGG	475	47.5	546.3	546.3	546.3	546.3
PLASTIC (g)				4.3	5.8	7.2

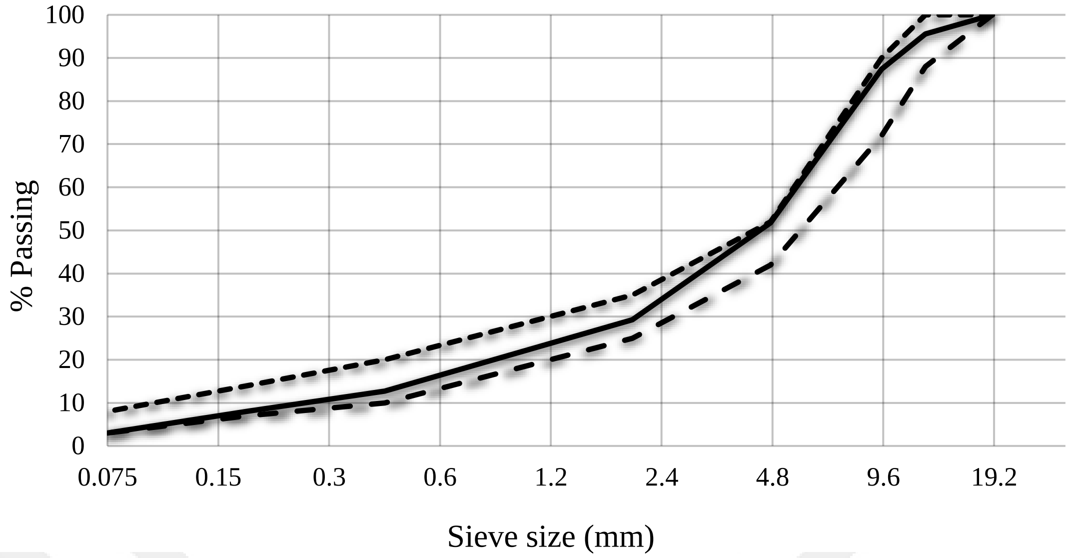

Figure 3. 1 Gradation curve of aggregates

3.1.1.2 Coarse Aggregates Specific Gravity and Absorption Tests

The Coarse Aggregates Specific Gravity and Absorption Test was conducted according to the ASTM C 127 standard. It is used to determine the specific gravity and water absorption rate of the coarse aggregates remaining on the 4.75 mm sieve. Two test samples were prepared and the average values were taken as a result [60].

As a result of the experiments, the coarse aggregates water absorption capacities, bulk specific gravity, SSD specific gravity, apparent specific gravity, effective specific gravity and moisture contents are given in Table 3.3.

Table 3. 3 Coarse aggregates specific gravity and absorption test results

Coarse Agg	Average
Water Absorption Capacity	0.90%
SSD Specific Gravity	2.64
Apparent Specific Gravity Gsa	2.68
Bulk Dry Specific Gravity Gsb	2.62
Effective Specific Gravity Gse	2.64
Moisture Content	0.18%

3.1.1.3 Fine Aggregates Specific Gravity and Absorption Tests

The Fine Aggregates Specific Gravity and Absorption Test was conducted according to the ASTM C 128 standard. It is used to determine the specific gravity and water absorption rate of the fine aggregates remaining on the between 0.075mm and 4.75 mm sieve. Two test samples were prepared and the average values were taken as a result [61].

As a result of the experiments, the coarse aggregates water absorption capacities, bulk specific gravity, SSD specific gravity, apparent specific gravity, effective specific gravity and moisture contents are given in Table 3.4.

Table 3. 4 Fine aggregates specific gravity and absorption test results

Fine Agg	Average
Water Absorption Capacity	1.5%
SSD Specific Gravity	2.70
Effective Specific Gravity Gse	2.71
Apparent Specific Gravity Gsa	2.77
Bulk Dry Specific Gravity Gsb	2.66
Moisture Content	1.1%

3.1.1.4 Specific Gravities of The Combined Aggregates

The specific gravity of the aggregate mixture obtained by combining coarse and fine aggregates according to the mixture design is shown in Table 3.5.

Table 3. 5 Total aggregate mix specific gravity results

	Coarse Agg	Fine Agg
Gsa	2.68	2.77
Gsb	2.62	2.66
Percentage of Coarse Aggregate %	48.26	
Percentage of Fine Aggregate %		51.74
Combined Aggregate Gsam	2.72	
Combined Aggregate Gsbm	2.64	
Combined Aggregate Gef	2.68	

3.1.2 Bitumen

According to the highways bitumen class selection table, the suitable bitumen class according to the climatic conditions of the Kayseri region is specified as 50/70, and for this reason, 50/70 penetration class bitumen was used in the study.

3.1.2.1 Bitumen Specific Gravity Test

Bitumen Specific Gravity Test was conducted according to the ASTM D 70 standard. The specific gravity of the bituminous material is the ratio of the weight of its volume in the air at a temperature of 25 °C to the weight of purified water at the same temperature and in the same volume [62]. The specific gravity of bitumen was found to be 1.023 gr / cm3.

3.1.3 Plastics

As plastic, plastics that can melt in asphalt mixtures, that is, whose melting temperature as shown in Table 3.6 is equal to or lower than the asphalt production temperature, LDPE and HDPE were selected and used.

Table 3.6 Density and melting points of plastic types [11]

plastic types	Density	melting points C°
(HDPE)	0.95–0.97	137
(LDPE)	0.92–0.93	110
(PP)	0.90–0.91	176
(PS)	1.0–1.1	—
(PVC)	1.3–1.6	—
(PET)	1.3–1.4	265

3.2 Methods

Two basic components for the production of hot mix asphalt (HMA) are aggregate and bitumen. HMA type asphalt is obtained by mixing the aggregate and bitumen heated up to 160 degrees Celsius according to the mixture design.

Plastic modified asphalt (PMA) is a type of asphalt obtained by mixing bitumen and aggregate with plastics.

The use of plastics in asphalt can be carried out by different methods. These methods are PMA type asphalt obtained by melting plastics in bitumen and using polymer modified bitumen (PMB) in asphalt mixtures or PMA type asphalts obtained by melting plastics on heated aggregates and then mixing them with bitumen.

At this point, when asphalt production is considered, plastics can be used by melting in hot bitumen in bitumen tanks or by melting on the aggregate surface at high temperature in the drying chamber. However, at this point, it has been observed that some problems may be encountered during field observations. Adding plastic to the heated bitumen melts the plastics, but the molten plastic collects on the bitumen surface due to the density difference, and a homogeneous mixture is not formed. For this reason, if it is desired to mix bitumen and plastic, there should be special mixer equipment in the bitumen tanks. As another method, it has been observed that the sieves in the drying chamber can become clogged when electrical or machine problems are encountered during the melting of plastics on the heated aggregate surfaces in the drying chamber.

Unlike the methods in the literature, such as obtaining polymer modified bitumen or covering the surface of aggregates with molten plastic first and then mixing them with bitumen, as a result of field observations, mixing plastic, bitumen and aggregate at the same time was seen as the most appropriate method for design tests and the mixtures were prepared by this method. Since the maximum temperature will be 160° Celsius during this method, the choice of plastic in terms of melting points is the most important factor for PMA type asphalt production. HDPE and LDPE were found suitable for this mixing method and the experiments were carried out on these plastics.

In the research, the ratio (5%) used as the optimum binder ratio by Talas Municipality was used and Marshall stability tests did not find the optimum binder ratio and continued with 5% binder ratio.Plastic mixtures with plastic substitutes of 7.5%, 10% and 12.5% of the bitumen weight were tested, the plastic ratio that gave maximum stability was determined, and the ongoing tests over this ratio were examined.

If it is PVC, it is not suitable for use in plastic asphalt because there is a risk of HCL formation [63-65].

As plastic, waste plastics collected from various regions are separated from other wastes and then cleaned and dried. The cleaned and dried plastics are shredded in sizes between 3 and 10 mm, and the shredded plastics can be used in asphalt.

Plastics were mixed in bitumen with a mixer with 600 revolutions per minute and the softening point and flash point values of the PMB type bitumen obtained were investigated. In addition, stability, flow, air voids, voids filled with bitumen, voids in mineral aggregates values of PMA type asphalt, which is obtained by mixing plastic, bitumen and aggregate at the same time, according to the asphalt design criteria of the highway technical specification, as shown in Table 3.7, were investigated.

Table 3. 7 Highway technical specifications asphalt design criteria

Experiment	Min	Max	Test Standard
Marshall test kg	900		TS EN 12697-34
Specimen preparation by impact compactor number of blows	75	75	TS EN 12697-30
Air Voids (AV) %	3	5	TS EN 12697-8
Voids Filled with Bitumen (VFB) %	65	75	TS EN 12697-8
Voids In Mineral Aggregates (VMA) %	14	16	TS EN 12697-8
Flow mm	2	4	TS EN 12697-34
Bitumen (by weight, to 100)	4	7	TS EN 12697-1
Indirect Tensile Strength Ratio, min. %	80		AASHTO T 283
Wheel tracking (At 30,000 cycles, 60 ° C), max. %		8	TS EN 12697-22

3.2.1 Softening Point Test

Softening point test was conducted according to TS-EN 1427. The softening point is done to determine the behavior and consistency of the bitumen against temperature. The softening point is in connection with the viscosity.

The heated bitumen is placed in the rings with the help of a syringe and left at room temperature for 30 minutes. The steel plate is lubricated as a thin film so that the rings do not stick. The beaker is filled with distilled or boiled water at an initial test temperature of 5 °C. and fixed to the test apparatus shown in Figure 3.2. The temperature is set to increase by 5 °C per minute and the experiment begins. The moment the bitumen in the test rings touches the substrate, the temperature at which the value is read is considered the softening point [66].

Figure 3. 2 Softening point test apparatus

3.2.2 Flash Point Test

Flash point test was carried out according to TS EN ISO 2592. Flash Point is a test to find the temperature at which bitumen glows but does not burn when in contact with a flame. The heated bitumen is filled up to the marked area on the test apparatus shown in Figure 3.3 and the test specimen is set. The rate of temperature rise should be between 5 °C and 17 °C per minute The moment when spark formation is seen on the bitumen surface with the help of flame is considered a flash point [67].

Figure 3. 3 Flash point test apparatus

3.2.3 Marshall Stability and Flow Test

Marshall Stability and Flow Test was conducted according to TS EN 12697-34. Test is an experiment to determine the optimum amount of bitumen to be used in asphalt. It gives information about the strength and flow properties of the prepared samples [68].

- 1150 grams of the aggregate sample determined with appropriate gradation is prepared and the prepared aggregates are kept in an oven at 160°C for 24 hours.
- Tools such as molds and shovels to be used in the experiment should be heated to avoid heat loss.
- The aggregates removed from the oven are poured into the mixing bowl, the heated bitumen (160 C°) is added to the aggregate at the determined rate and the mixing begins in the mixing bowl. There should be a heating bowl under the mixer in order to maintain the temperature.
- The molds where the mixture will be poured are lubricated as a thin film layer, and greaseproof paper is placed on the mold base to prevent the asphalt from sticking.
- The mixture is poured into the ready molds by skewering with a shovel.
- The sample molds are placed in the Marshall rammer device and the compression process is completed by making 75 strokes on both sides.
- The papers on the upper and lower sides of the compressed samples are taken and left in a suitable place for cooling. The waiting time is approximately 2-3 hours.

- The samples that have cooled down are removed from the mold with the help of a jack and marked. The marked samples are kept at room temperature for one day.
- The heights of the samples are measured from 3 points with a caliper and the average is taken.
- The weights of the samples in air and water are noted.
- Afterwards, the samples are kept in a 60°C water bath for 30-45 minutes.
- The samples removed from the water bath are dried and placed in the Marshall stability device.
- As a result of the test, strength and flow values are obtained.
- At least 3 samples are prepared for each ratio and average results are taken.
- During the experiments, the mixing time was approximately 2 minutes. The mixing temperature should be 160.

The prepared test samples are shown in Figure 3.4. The stability value of the compacted surface layer mixture against the loads on it is called stability. The amount of bitumen and the aggregate gradation in the mixture are the most important factors. Flow value is a value that determines the behavior of asphalt pavements under traffic loads and reflects the plasticity and flexibility properties of asphalt.

Figure 3. 4 Test samples

3.2.4 Determination of Bulk Density of Mixtures

The bulk density determination tests were conducted according to TS EN 12697-6. The volumetric specific gravity value is obtained by dividing the weight of the prepared Marshall briquettes in air by the volume value found by subtracting the weight of SSD from the weight in water [69].

3.2.5 Determination of Void Characteristics of Mixtures

The void determination tests were conducted according to TS EN 12697-8. The voids in the mixtures are a very important part of the structure of the mixtures, they affect many factors such as durability, and service life [70].

3.2.5.1 Air Voids (AV)

Air voids can be made as a percentage of air voids between aggregate particles coated with bitumen. The low air voids cause vomiting in hot mix asphalt. Likewise, the voids in the mixture are an important factor affecting the impermeability, and the high percentage of voids causes the asphalt to deteriorate, such as water and air entering the asphalt, with the contribution of environmental effects (freeze-thaw) [71].

$$\mathrm{AV} = 100 * \frac{\mathrm{Gmm} - \mathrm{Gmb}}{\mathrm{Gmm}} \tag{3.1}$$

(Gmm) = Maximum specific gravity of compacted mixture

(Gmb) = Bulk specific gravity of compacted mixture

3.2.5.2 Voids Mineral Aggregates (VMA)

At the optimum bitumen and air void ratio, the percentage of voids between aggregates in the compacted pavement mixture is called the percentage of inter-aggregate voids (VMA) [71].

$$\mathrm{VMA} = 100 - [1 - \frac{\mathrm{Gmb} * (1 - \mathrm{Pb})}{\mathrm{Gsbm}}] \tag{3.2}$$

(Gmb) = Bulk specific gravity of compacted mixture

(Gsbm) = specific gravity of the aggregate mix

(Pb) = Percentage of asphalt in the mix

3.2.5.3 Voids Filled With Bitumen (VFB)

The asphalt-filled void ratio, known as the parameter for the compacted pavement mixture to approach a void-free structure under pressure. VFB is directly related to how much of the aggregate voids are filled with asphalt. It affects the impermeability [71].

$$\mathrm{VFB} = 100 * \frac{\mathrm{VMA} - \mathrm{AV}}{\mathrm{VMA}} \tag{3.3}$$

Voids Mineral Aggregates (*VMA*)

Air Voids (*AV*)

3.2.6 Life Cycle Assessment

The study was performed taking into account the ISO 14040/44 guidelines for LCA (ISO, 2006a; ISO, 2006b) [48, 49]. In this study, SimaPro software was used for LCA assessment. The assessment consists of four steps according to the guidelines. Goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation.

Also in this study, waste plastics collected in a local area were used instead of bitumen by reducing the bitumen ratio in asphalt. In this way, it is clearly seen in Figure 3.5 that resources are gained from recycling as much as possible by re-using waste plastics instead of production, use and disposal processes, and that wastes are transformed into new resources and contribute to the circular economy.

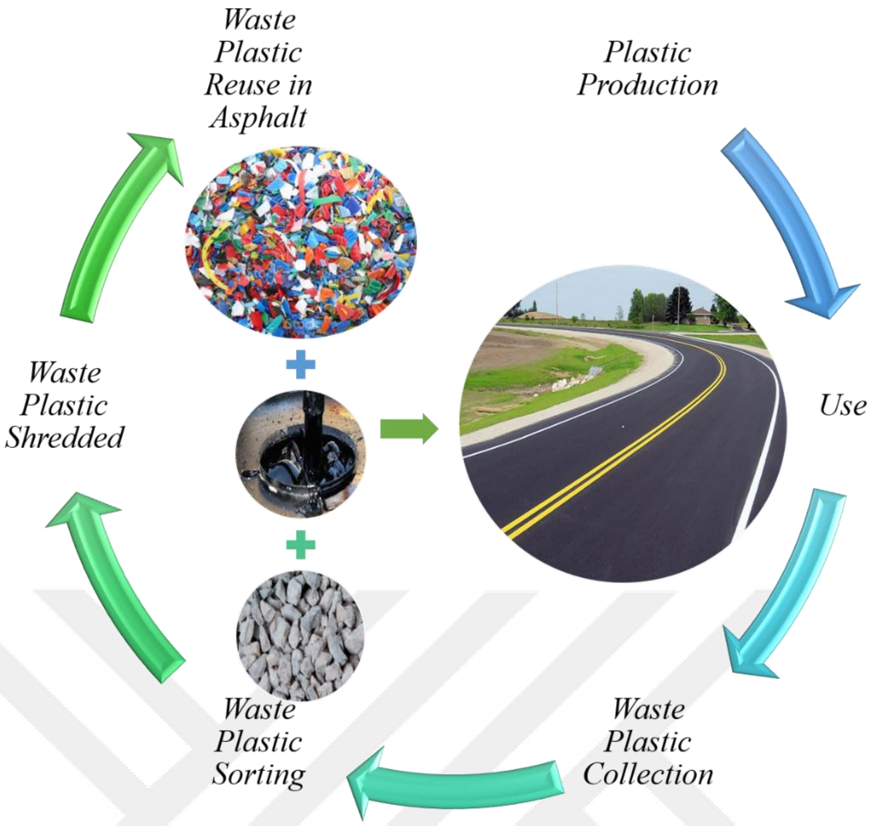

Figure 3. 5 Circular economy model of the use waste plastics in asphalt

3.2.6.1 Goal and Scope Definition

As goal definition, in this study, environmental impact comparison of HMA type asphalt mixture without plastic and 10% plastic replacement PMA type asphalt was determined. Within scope definition, the functional unit was selected as kg, and only the asphalt production phase was evaluated with the cradle-to-gate approach. The study does not include the use of effects of the products throughout their lifetime. System boundaries were created within this framework as shown in Figure 3.6 and Figure 3.7. The raw material production phase, transportation phase, and asphalt production phase was inputted as system boundaries to create environmental impacts. Each process was modeled, including not only the material it contains but also the energy and transportation required. CML-based evaluation method was used in SimaPro as the assessment method.

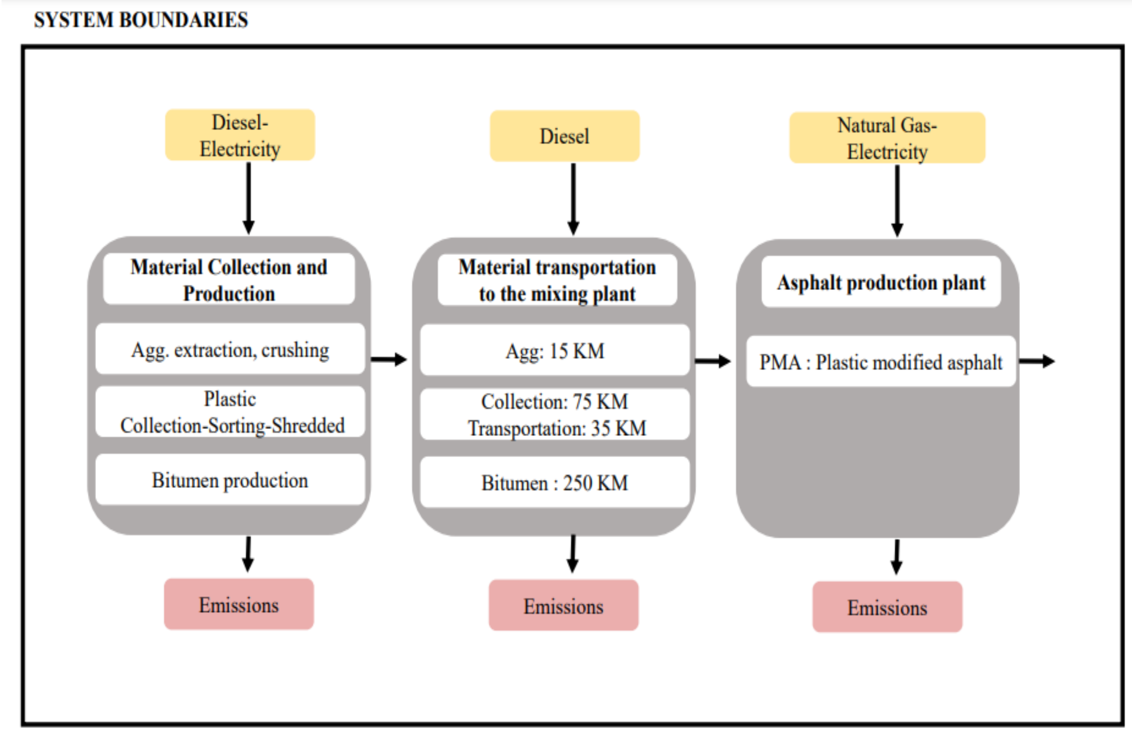

Figure 3. 6 System boundaries of HMA

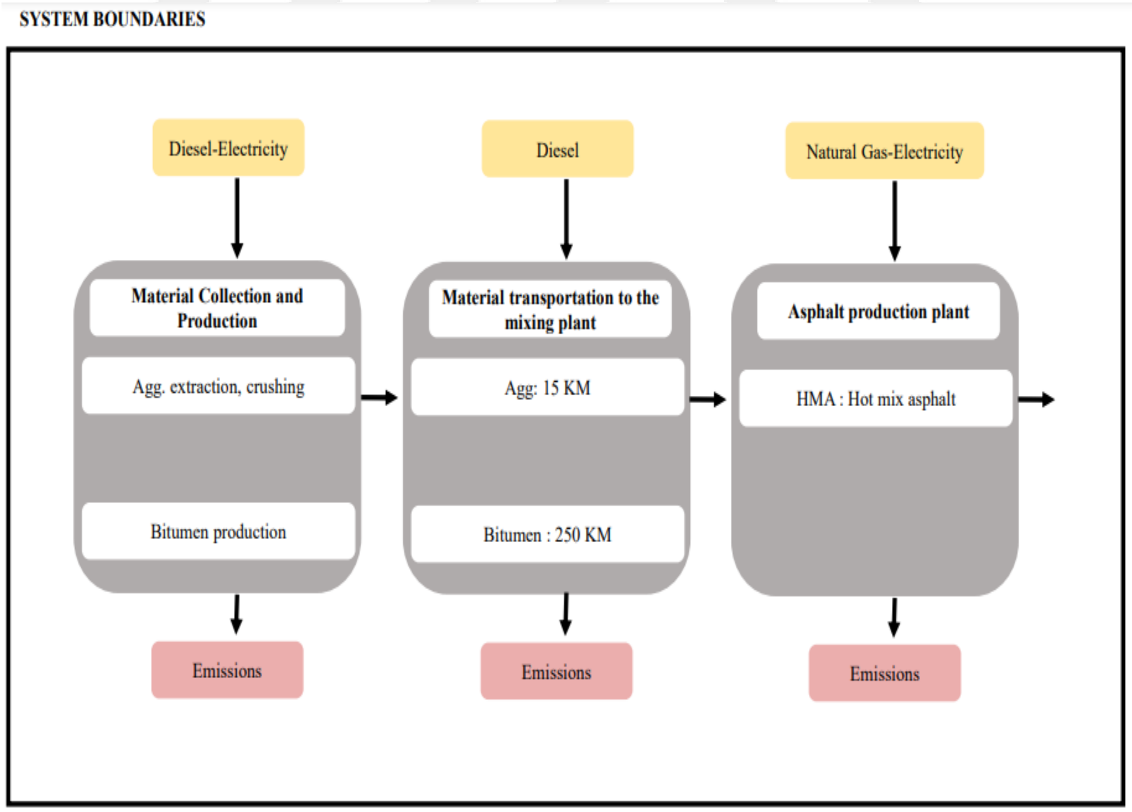

Figure 3. 7 System boundaries of HMA

3.2.6.2 Life Cycle Inventory

In order to determine the life cycle impacts of the asphalt mixtures the inventory should be clearly defined. Ecoinvent database was used since this database has many options for global information.

The production and transportation of the raw materials required for the production of HMA type asphalt, together with the electricity and natural gas consumption for the asphalt production, were calculated according to the functional unit of 1 kilogram as shown in Table 3.8 and were selected within this framework in the Ecoinvent database. Since there is no specific data such as bitumen, aggregate, and waste plastic processes for Turkey, rest of world (RoW) data was used in the inventory analysis section.

In PMA type asphalt, the collection and sorting processes of waste plastics were added according to HMA type asphalt, it was calculated according to 1 kilogram as shown in Table 3.9 and was selected in the Ecoinvent database within this framework. For PMA type asphalt, daily collected ton and transportation data of plastics from the local area were used, tkm data was calculated according to these data and defined in the inventory section.

In this context, these waste plastics are collected daily from the compartments built by the Talas Municipality in order to collect waste plastics more efficiently. Collected plastics go through a separation, cleaning, and shredding processes, as seen in Figure 3.8, Figure 3.9, and Figure 3.10.

Gravel crushed as coarse aggregate and sand as fine aggregate were selected and the transport distances were calculated as tkm and entered in the gravel crushed and sand tab for HMA and PMA. The transport input for HMA seen in Table 3.8 belongs to bitumen.The transport input for PMA seen in Table 3.9 belongs to bitumen and waste plastics.

Electricity and natural gas consumptions for asphalt production and the types of vehicles used during transportation are given in Table 3.8 and Table 3.9 for HMA and PMA, were obtained from Talas Municipality.

Figure 3. 8 Plastics collection compartments from buildings in Talas

Figure 3. 9 Plastic sorting and cleaning process

Figure 3. 10 Plastic shredding process

Table 3. 8 HMA type life cycle inventory

Inputs Materials/ Fuels	Amount	Unit
Conveyor belt {GLO}| market for | Cut-off, U	3.33E-08	m
industrial machine, heavy, unspecified {RoW}| market for industrial machine, heavy, unspecified | Cut-off, U	6.67E-06	kg
Transport, freight, lorry 16-32 metric ton, euro4 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	0.0125	tkm
Bitumen, at refinery/kg/US	0.05	kg
Gravel, crushed {RoW}| market for gravel, crushed_SUKRU | Cut-off, U	0.475	kg
sand {RoW}| market for sand_SUKRU | Cut-off, U	0.475	kg
Inputs Electricit / heat		
Electricity, medium voltage {TR}| market for | Cut-off, U	0.00651	kWh
Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | Cut-off, U	0.62	MJ

Table 3. 9 PMA 10 % plastic replacement type life cycle inventory

Inputs Materials/ Fuels	Amount	Unit
Conveyor belt {GLO}| market for | Cut-off, U	3.33E-08	m
industrial machine, heavy, unspecified {RoW}| market for industrial machine, heavy, unspecified | Cut-off, U	6.67E-06	kg
Transport, freight, lorry 16-32 metric ton, euro4 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	0.0125	tkm
Bitumen, at refinery/kg/US	0.05	kg
Gravel, crushed {RoW}| market for gravel, crushed_SUKRU | Cut-off, U	0.475	kg
sand {RoW}| market for sand_SUKRU | Cut-off, U	0.475	kg
Waste polyethylene, for recycling, sorted {RoW}| market for waste polyethylene, for recycling, sorted | Cut-off, U	0.005	kg
Transport, freight, lorry 16-32 metric ton, euro4 {RoW}| market for transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	0.00055	tkm
Inputs Electricit / heat		
Electricity, medium voltage {TR}| market for | Cut-off, U	0.00651	kWh
Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | Cut-off, U	0.62	MJ

3.2.6.3 Life Cycle Impact Assessment

Environmental effects during the production of 1 kg for HMA and PMA type asphalt with 10% plastic replacement were analyzed and CML-based impact assessment method was chosen. In the CML-based impact assessment method, abiotic depletion, ozone layer depletion, terrestrial ecotoxicity and eutrophication abiotic depletion (fossil fuels), global warming, human toxicity, fresh water aquatic ecotox., marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification categories were investigated.

CHAPTER 4

4. RESULTS AND DATA ANALYSIS

In this study, the main goal was to examine the effects of plastic substitution on asphalt mixtures. Therefore, the bitumen ratio was not changed, and the 5% as an optimum binder content currently used by Talas Municipality was used in the mixtures. Plastics were substituted at the rate of 7.5%, 10%, 12.5% of the bitumen weight, maximum stability and suitable flow value were provided by 10% plastic substitution. The value obtained for maximum stability was used as the plastic substitution ratio in further tests for asphalt design tests.

4.1 Marshall Stability Flow Results

Firstly, the experiments were carried out with 7.5%, 10%, 12.5% plastic substitution of bitumen weight, and these tests were determined as a preliminary test to obtain the maximum stability value. During these experiments, only stability and flow values were examined. The mixtures were mixed by hand, and the mixing time was 2 minutes on average, and the temperature of the mixture was 160°C on average. Binder percentage was kept constant in all tests as 5%. Marshall stability and flow preliminary test results can be seen in Table 4.1.

Table 4. 1 Marshall stability and flow preliminary test

Marshall stability test	Average Stability (kN)	Flow (mm)
Control	14.26	3.96
7.5% HDPE	20.32	2.69
10% HDPE	21.06	2.72
12.5% HDPE	16.04	4.00

PMA stability rate obtained by using 7.5% plastic is 42% compared to hot mix asphalt (HMA), PMA stability rate obtained by using10% plastic is 48% compared to hot mix asphalt (HMA), 12.5% plastic by using plastic The obtained PMA stability ratio shows an increase of 12% compared to the hot mix asphalt (HMA).

Plastics substituted in the mixture at different ratios showed an increase in asphalt stability with the substitution of waste plastics in all proportions. However, stability values decreased when the amount of plastic substituted by bitumen weight exceeded 10%. As a result of these experiments, the plastic mixture ratio was determined as 10% of the bitumen weight. After the plastic substitution rate was determined as 10%, tests were performed with HDPE and LDPE substitution again for stability and flow values. The mixtures were prepared by hand, the temperature of the mixture was kept between 160°-180°C and the mixing time was adjusted to an average of 10 minutes. The test results are given in table 4.2, Table 4.3 and Table 4.4 for control, HDPE and LDPE, respectively.

The stability value of PMA type asphalt obtained by using HDPE type plastics in asphalt, about 34% compared to conventional hot mix HMA asphalt, the stability value of PMA type asphalt obtained by using LDPE type plastics showed a better performance than conventional hot mix HMA asphalt by about 45%. The PMA type asphalt flow value obtained by using HDPE type plastics in asphalt showed a decrease of approximately 34% compared to conventional hot mix HMA asphalt, the PMA type asphalt flow value obtained using LDPE type plastics showed a decrease of approximately 45% compared to conventional hot mix HMA asphalt.

Table 4. 2 Marshall stability test results of control sample

Information	Control average	Standard deviation
Height (mm)	59.1	0.06
Volume (cm^3)	478.8	0.46
Flow (mm)	4.62	0.54
Correction Factor	1.13	0.00
Maximum Load (kN)	17.72	1.38
Stability (KN)	19.99	1.54
Bulk Density (g/cm^3)	2.39	0.00

Table 4. 3 Marshall stability test results of PMA (10%HDPE)

Information	%10 HDPE Average	Standard deviation
Height	59.50	0.10
Volume (cm³)	482.40	0.00
Flow (mm)	3.04	0.34
Correction Factor	1.11	0.00
Maximum Load (kN)	23.94	1.55
Stability	26.71	1.78
Bulk Density (g/cm³)	2.38	0.00

Table 4. 4 Marshall stability test results of PMA (10%LDPE)

Information	%10 LDPE Average	Standard deviation
Height	59.63	0.12
Volume (cm³)	482.40	0.00
Flow (mm)	2.53	0.37
Correction Factor	1.11	0.00
Maximum Load (kN)	26.26	0.53
Stability	29.16	0.71
Bulk Density (g/cm³)	2.38	0.01

As a result, the mixtures were prepared by a method different from the literature, and the mixing of plastic, bitumen and aggregate at the same time was chosen as the mixing method. It was observed that the mixing of bitumen and plastic at high temperatures changed the chemical properties of bitumen, similar to the studies carried out, and it was observed that it improved the properties of bitumen. It has been observed that the use of plastic, even with a different method, provides an increase in stability values. A decrease was observed in the flow value. This can be explained by the different mixing method and the thickness of the plastics used. The decrease in the flow value indicates that the mixture will have a more rigid structure, and as a disadvantage, there may be a decrease in the workability properties. At the same time, it was observed that increasing the mixing temperature and extending the mixing time had a positive effect on the stability. This shows that the plastics melted in the mixture react chemically with the bitumen and change the properties of the mixture.

4.2 AV-VMA-VFB Results

Air Voids (AV) of PMA type asphalt, which is obtained by using HDPE type plastics in asphalt, is approximately 11% compared to conventional hot mix HMA asphalt, air voids (AV) of PMA type asphalt obtained by using LDPE type plastics are approximately 13% compared to conventional hot mix HMA asphalt the increase has been observed.

Voids in mineral aggregates (VMA) of PMA type asphalt, which is obtained by using HDPE type plastics in asphalt, is approximately 3% compared to conventional hot mix HMA asphalt, Voids in mineral aggregates (VMA) of PMA type asphalt obtained by using LDPE type plastics are approximately 4% compared to conventional hot mix HMA asphalt the increase has been observed.

Voids Filled with Bitumen (VFB) of PMA type asphalt, which is obtained by using HDPE type plastics in asphalt, is approximately 3% compared to conventional hot mix HMA asphalt, Voids Filled with Bitumen (VFB) of PMA type asphalt obtained by using LDPE type plastics are approximately 3% compared to conventional hot mix HMA asphalt the decrease has been observed.

As a result, in the mixtures obtained by using plastics in asphalt mixtures, AV, and VMA values increased while VFB values decreased as shown in Table 4.5. The increase in the AV ratio in the mixture causes the permeability of the mixture to increase, making it more vulnerable to oxidation and freeze-thaw effects, but despite this increase, the AV value remains within the limits according to the design criteria. The increase in the AV value also directly affects the VMA value, indicating that the film layer thickness between the aggregate surface and the binder decreases and the VMA value increases. Although this is a disadvantage for asphalt durability, it has been observed that it remains within the limits according to asphalt design criteria. The decrease in VFB value shows that although the binder percentage does not change, the plastic used with the replacement method does not show the same fluidity as bitumen at high temperatures.

Table 4. 5 Control sample AV-VMA-VFB results

Samples	Control	10% HDPE	10% LDPE
Average Gsb	2.392	2.380	2.378
Gmm (Maximum specific gravity of compacted mixture)	2.4796	2.4773	2.4763
AV	3.52	3.91	3.97
VMA	13.81	14.24	14.33
VFB	74.49	72.54	72.29

4.3 Softening Point and Flash Point Results

The plastics were mixed with bitumen and the differences that may occur in the softening and flashing points were investigated. The mixing temperature was kept constant between 160 C° - 180 C° and the speed of the mixing device was 600 rpm per minute. The mixing time was set as one hour. During the softening point test, the bitumen was separated from the ring wall by rupture as shown in Figure 4.1, and this result showed that a higher speed device was required for a more homogeneous mixture where the mixture could not be fully achieved.

Figure 4. 1 Softening point test, the bitumen separated from the ring wall by rupture

The softening point value of polymer modified bitumen (PMB) obtained by mixing HDPE type plastics with bitumen is approximately 25% compared to 50/70 type bitumen, and the softening point value of polymer modified bitumen (PMB) obtained by mixing

LDPE type plastics with bitumen is about 50/70 type bitumen increased by 28% as shown in Table 4.6.

Table 4. 6 Control sample and PMA softening point results

Softening Point Test	Average C°
50/70 Bitumen	47.25
HDPE Modified Bitumen	59.1
LDPE Modified Bitumen	60.9

The flash point value of polymer modified bitumen (PMB) obtained by mixing HDPE and LDPE type plastics with bitumen showed an increase of approximately 8% compared to 50/70 type bitumen as shown in Figure 4.2.

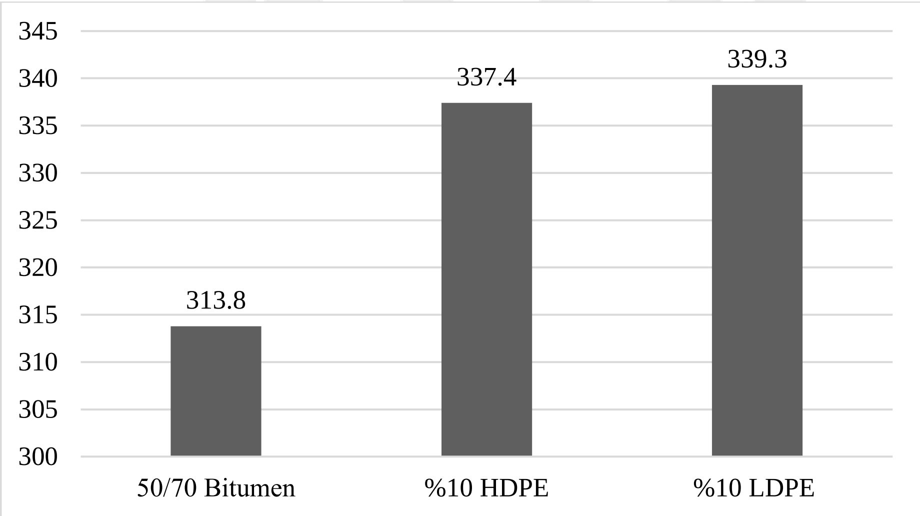

Figure 4. 2 Plastic-Flash Point results of mixtures

As a result, it has been observed that the softening and flash point values increase with the use of waste plastics, but healthier results can be obtained with a mixer at higher speed.

4.4 Life Cycle Impact Assessment Results

When the impact assessment results are examined, the environmental effects of 10% plastic replacement PMA type asphalt are higher than HMA type asphalt in abiotic depletion, ozone layer depletion, terrestrial ecotoxicity and eutrophication categories. On the other hand, abiotic depletion (fossil fuels), global warming, human toxicity, fresh water is seen that environmental effects are lower in aquatic ecotox., marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification impact categories. Impact results are given in Table 4.7 and percentage change values are given in Table 4.8.

Table 4. 7 HMA and PMA type asphalt impact assessment results for 1 kg asphalt

Impact category	Unit	Control {RoW}| production	PMA {RoW}| production
Abiotic depletion	kg Sb eq	8.24E-10	1.23E-09
Abiotic depletion (fossil fuels)	MJ	3.310524	3.065985
Global warming (GWP100a)	kg CO2 eq	0.081356	0.079579
Ozone layer depletion (ODP)	kg CFC-11 eq	4.37E-09	4.46E-09
Human toxicity	kg 1,4-DB eq	0.162582	0.147792
Fresh water aquatic ecotox.	kg 1,4-DB eq	0.060366	0.055669
Marine aquatic ecotoxicity	kg 1,4-DB eq	226.7534	206.6931
Terrestrial ecotoxicity	kg 1,4-DB eq	2.02E-05	2.65E-05
Photochemical oxidation	kg C2H4 eq	4.18E-05	3.85E-05
Acidification	kg SO2 eq	0.000455	0.000422
Eutrophication	kg PO4--- eq	5.50E-05	5.85E-05

Table 4. 8 PMA and HMA environmental impact change

Impact category	Change %
Abiotic depletion	+49
Abiotic depletion (fossil fuels)	-7
Global warming (GWP100a)	-2
Ozone layer depletion (ODP)	2
Human toxicity	-9
Fresh water aquatic ecotox.	-8
Marine aquatic ecotoxicity	-9
Terrestrial ecotoxicity	+31
Photochemical oxidation	-8
Acidification	-7
Eutrophication	+6

In this study, the cradle-to-gate approach was studied and it is thought that environmental impacts can be reduced to a greater extent due to the thought that the road life will increase in the cradle-to-grave approach. In addition, it is shown in Table 4.9 that a decrease can be seen in all effects, except abiotic depletion, on the asphalt roads to be built by reducing the asphalt thickness by 25%.

Table 4. 9 Impact change to be achieved by reducing the thickness (25%)

Impact category	Change %
Abiotic depletion	+12
Abiotic depletion (fossil fuels)	-31
Global warming (GWP100a)	-27
Ozone layer depletion (ODP)	-24
Human toxicity	-32
Fresh water aquatic ecotox.	-31
Marine aquatic ecotoxicity	-32
Terrestrial ecotoxicity	-2
Photochemical oxidation	-31
Acidification	-31
Eutrophication	-20

The reason for the high abiotic depletion values is thought to be due to the amount of water used for cleaning and separating waste plastics (especially waste plastics containing chemicals) after they are collected.

4.5 Plastic Asphalt Hot Mix Asphalt Cost and Comparison

HMA and PMA type asphalt components are shown in Table 4.10 and Table 4.11, respectively. With the use of waste plastics in asphalt, the need for bitumen decreases, while significant improvements are observed in asphalt properties.

Table 4.12 shows that with the use of plastic 10% by weight of bitumen in asphalt, a 1.3% cost saving in production and paving costs can be achieved. At the same time, within the scope of the study, it has been observed shown that the stability values of PMA type asphalts give approximately 40% and better results than HMA type asphalts. For this reason, it is foreseen that the asphalt thickness will be reduced by 25% and a total cost saving of 26% in production and paving will be achieved, as seen in Table 4.12. It has been clearly seen that asphalt can become more economical with the use of waste plastics.

Table 4. 10 Hot mix asphalt cost components

Hot Mix Asphalt Cost	Unit Price	Amount in the mixture	Cost TL
Bitumen Ton Price	8522 TL/TON	0.05 TON	426.10
Aggregate Ton Price	50 TL/TON	0.95 TON	47.50
Natural gas consumed for the production of 1 ton of asphalt	7 TL/m³	16.48 S/m³	115.38
Electricity consumed for the production of 1 ton of asphalt	2.29TL/KWh	6.50 KWh	14.90
Material cost per ton of asphalt (bitumen+agg)		1 TON	474
Energy consumption cost for producing 1 ton of asphalt (S/m³+KWh)			130
25 tons of asphalt transportation cost	20.45 TL/lt	9.54 lt	195
Paver fuel consumption for 1 ton asphalt paving	20.45 TL/lt	0.13 lt	2.7
Tire roller fuel consumption for 1 ton of asphalt paving	20.45 TL/lt	0.06 lt	1.2
Cylinder fuel consumption for 1 ton asphalt paving	20.45 TL/lt	0.09 lt	1.8
Cost of asphalt production and paving for 1 ton			**805**

Table 4. 11 Plastic asphalt cost components

Hot Mix Asphalt Cost	Unit Price	Amount in the mixture	Cost TL
Bitumen Ton Price	8522 TL/TON	0.045 TON	383.49
Aggregate Ton Price	50 TL/TON	0.95 TON	47.50
Plastic Ton Price	6500 TL/TON	0.005 TON	32.50
Natural gas consumed for the production of 1 ton of asphalt	7 TL/m³	16.48 S/m³	115.38
Electricity consumed for the production of 1 ton of asphalt	2.29TL/KWh	6.50 KWh	14.90
Material cost per ton of asphalt (bitumen+agg+plastic)		1 TON	463
Energy consumption cost for producing 1 ton of asphalt (S/ m³+KWh)			130
25 tons of asphalt transportation cost	20.45 TL/lt	9.54	195
Paver fuel consumption for 1 ton asphalt paving	20.45 TL/lt	0.13	2.7
Tire roller fuel consumption for 1 ton of asphalt paving	20.45 TL/lt	0.06	1.2
Cylinder fuel consumption for 1 ton asphalt paving	20.45 TL/lt	0.09	1.8
Cost of asphalt production and paving for 1 ton			**794**

Table 4. 12 PMA-HMA cost comparison

Comparison	Plastic asphalt (PMA)	Hot mix asphalt (HMA)
Cost of asphalt production and paving	794 TL / ton	805 TL / ton
Cost savings for asphalt of the same thickness	**1.3%**	
100 m x 10 m x 0.1 m HMA pavement tons	--	239
100 m x 10 m x 0.075 m PMA pavement tons	178.5	--
100 m x 10 m x 0.1 m HMA pavement cost	--	192,395 TL
100 m x 10 m x 0.075 m PMA pavement cost	141,817 TL	--
Cost savings when coating thickness is reduced by 25% without loss of stability	**26%**	

CHAPTER 5

5. CONCLUSIONS AND FUTURE PROSPECTS

5.1 Conclusions

In this thesis, the usage potentials and life cycle assessment of high and low density waste polyethylene plastics in asphalt were investigated. The aim of the study is to contribute to the production of more sustainable asphalt mixtures obtained with waste plastic substitute. The following conclusions can be drawn based on experimental studies.

1. In this study, unlike the methods found in the literature (plastic asphalt produced by covering the aggregate surface with molten plastic or plastic asphalt produced by obtaining polymer modified bitumen), plastic asphalt mixtures obtained by mixing aggregate, bitumen and plastic at the same time, evaluated according to asphalt design criteria. Asphalt design test results are similar to the literature.It has been observed that the applied mixing method has certain advantages when compared to the methods found in the literature. These advantages can be shown as the use of more waste plastic and thus lower environmental impacts compared to the polymer modified bitumen method. When compared to covering the aggregate surface with molten plastic, considering the real production conditions as a result of field research, when electrical or mechanical problems are encountered, it is thought to be a less risky production method against clogging problems in which plastic can be created in the machine.
2. According to Marshall stability and flow analysis, it was observed that the stability values of high and low density waste polyethylene used increased, but the stability values decreased after 10% plastic replacement of bitumen. In the flow analysis, it was observed that the high and low density waste polyethylenes used decreased the flow values. This shows that the asphalt mixture becomes more

durable with the increase in the stability values, the mixture becomes more rigid with the decrease in the flow value, and at the same time, the workability of the mixture decreases with the decrease in the flow value.

3. According to the results of the determination of void characteristics of mixtures, an increase in the air voids and voids in mineral aggregate percentages of the mixtures and a slight decrease in the percentage of voids filled with bitumen were observed with the high and low density waste plastic replacement of bitumen. The increase in the air void ratio (AV-VMA) in the mixture increased the permeability of the asphalt mixture and it is thought that this situation reduces the durability of the mixture against oxidation and freeze-thaw effects. However, despite the increase in these values, it still remains within the limits of the technical specification.
4. According to the softening and flash point analyses, it was observed that the use of low and high-density waste polyethylene in bitumen modified the properties of the bitumen and increased the softening and flash point values of bitumen. It is thought that the increase in the softening point makes the mixture more durable in hot climatic conditions, while the increase in the flash point is thought to make the mixture safer in dangerous conditions.
5. According to the results of the life cycle analysis impact assessment, as a result of the comparison of the mixtures obtained with the substitution of high and low density waste polyethylene to bitumen with the mixtures without plastic substitute, an increase was observed in some categories (abiotic depletion (49%), ozone layer depletion (2%), terrestrial ecotoxicity (31%), and eutrophication (6%)), on the other hand (abiotic depletion from fossil fuels (7%), global warming (2%), human toxicity (9%), fresh water aquatic ecotox (8%), marine aquatic ecotoxicity (9%), photochemical oxidation (8%), acidification (7%)) categories a decrease was observed.
6. When examined in terms of costs, it has been observed that the production costs of asphalt mixtures with 10% plastic substitutes can be 1% less than asphalt mixtures without plastic substitutes, 26% less in the constructions to be made by reducing the asphalt paving thickness.

5.2 Social Impact

As a result of the study, it has been determined that the use of high and low density waste polyethylene as a 10% bitumen substitute increases the asphalt stability by 40% on average. It has been observed that it is possible to build more sustainable roads of the same quality with lower environmental impact and lower costs on the roads to be built by reducing the asphalt thickness.

5.3 Future Prospects

Polymer modified bitumen, which will be obtained by mixing high and low density waste polyethylene with bitumen, can be examined in more detail, or it can be examined in more detail on plastic coated aggregates obtained by melting plastics on heated aggregates. Thus, the effects of high and low density waste polyethylene on asphalt mixtures can be understood in more detail and the differences between normal asphalt mixtures can be revealed more clearly.

In order to better understand the effects of using waste plastics in asphalt, the effects can be seen in more detail by using plastics of different thicknesses.

Studies have shown that asphalt mixtures with higher stability can be obtained by replacing high and low density waste polyethylene with bitumen. In order to better observe the results of the use of plastic in asphalt mixtures, indirect tensile strength and wheel tracking tests should be performed from asphalt design tests.

In this study, the cradle-to-gate approach was adopted in the life cycle evaluation, and only the environmental effects that may arise during production were determined. By adopting the cradle-to-grave method, the environmental effects that may occur throughout the life of the asphalt mixtures can be investigated. In this way, more detailed results can be obtained.

BIBLIOGRAPHY

[1] Plastic Pollution, https://ourworldindata.org/plastic-pollution (25 February 2022).

[2] P. Nayler, “Encyclopedia of Materials:Science and Technology,” Elsevier (2001).

[3] D. Lesueur, “The colloidal structure of bitumen: Consequences on the rheology and on the mechanisms of bitumen modification,”Advances in colloid and interface science, vol. 145, pp. 42-82, (2009).

[4] I.Gökalp, H. M. Çetin, Y. Özinal, H. Gündoğan, And V. E. Uz, “Polimer modifiye bitüm modifikasyonuna etki eden parametreler üzerine bir literatür araştırması,” Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, vol. 8, pp. 954-964, (2019).

[5] Ü. Eren, "Asfaltitin asfalt betonunda mineral filler olarak kullanılması," Yüksek Lisans Tezi, Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü, Trabzon, (2008).

[6] A. Tunç, “Yol Malzemeleri ve Uygulamaları,” Nobel Akademik Yayıncılık, (2007).

[7] S. Ceylan, “Bitümlü sıcak karışımlarda filler olarak carboniferous-triassic kayaç tozlarının kullanılması ve etkisi,” Yüksek Lisans Tezi, Selçuk Üniversitesi Fen Bilimleri Enstitüsü, Konya, (2006).

[8] Plastic, https://www.britannica.com/science/plastic (22 March 2022)

[9] H. A. Maddah, “Polypropylene as a promising plastic: A review,” American Journal of Polymer Science, vol. 6, pp. 1-11, (2016).

[10] M.K. Eriksen, J. D. Christiansen, A. E. Daugaard, and T. F. Astrup, “Closing the loop for PET, PE and PP waste from households: Influence of material properties and product design for plastic recycling,” Waste Management, vol. 96, pp. 75-85, (2019).

[11] How Is Plastic Made? A Simple Step-By-Step Explanation, https://www.bpf.co.uk/plastipedia/how-is-plastic-made.aspx (02 March 2022).

[12] “Turkish Plastics Industry Follow-Up Report,” (2020).

[13] M. Önal, M. Kahramangil, “Deneyler, Bitümlü Karışımlar,” Karayolları Teknik Araştırma Dairesi Başkanlığı, (1993).

[14] O. Kabadurmus, O. Pathak, J.S. Smith, A.E. Smith, and H. Yapicioglu, "A simulation methodology for online process control of hot mix asphalt (HMA) production," Proceedings of the 2010 Winter Simulation Conference, pp. 1522-1533, (2010).

[15] M. A. J. Chavan, “Use of plastic waste in flexible pavements,” International Journal of Application or Innovation in Engineering and Management, vol. 2, pp. 540-552, (2013).

[16] R. Bajpai, M. A. Khan, O. B. Sami, P. K. Yadav, and P. K. Srivastava, “A study on the plastic waste treatment methods for road construction,” International Journal of Advance Research, Ideas and Innovations in Technology, vol. 3, pp. 559-566, (2017).

[17] P. N. A. Asare, F. A. Kuranchie, and E. A. Ofosu, “Evaluation of incorporating plastic wastes into asphalt materials for road construction in Ghana,” Cogent Environmental Science, vol. 5, p. 1576373, (2019).

[18] F. Adou, B. Ampadu, N. K. Agyepong, and O. N.A. Soli, “Assessing plastic waste usage as additives in flexible asphalt mix for road construction,” Civil and Environmental Research, vol. 10, pp. 32-38, (2018).

[19] R. Manju, S. Sathya, and K. Sheema, “Use of plastic waste in bituminous pavement,” International Journal of ChemTech Research vol.10, pp. 804-811, (2017).

[20] SK. Afroz Sultana, and K.S.B. Prasad, “Utilization of waste plastic as a strength modifier in surface course of flexible and rigid pavements,” International Journal of Engineering Research Application, vol. 2, pp. 1185-1191, (2012).

[21] F. Onyango, S. R. Wanjala, M. Ndege, and L. Masu, “Effect of rubber tyre and plastic wastes use in asphalt concrete pavement,” International Journal of Civil and Environmental Engineering, vol. 9, pp. 1403-1407, (2015).

[22] M. Tuncan, A. Tuncan, and A. Cetin, “The use of waste materials in asphalt concrete mixtures,” Waste management & research, vol. 21, pp. 83-92, (2003).

[23] H. Jan, M. Y. Aman, S. Khan, and F. Karim, “Performance of hot asphalt mixtures containing plastic bottles as additive,” MATEC web of Conferences, vol. 103, p. 09006, (2017).

[24] G. White, and F. Hall, “Laboratory comparison of wet-mixing and dry-mixing of recycled waste plastic for binder and asphalt modification,” Proceedings of the 100th Annual Meeting of the Transportation Research Board, pp. 5-29, (2021).

[25] G. White, and C. Magee, “ Laboratory evaluation of asphalt containing recycled plastic as a bitumen extender and modifier,” Journal of Traffic and Transportation Engineering, vol. 7, pp. 218-235, (2019).

[26] D. Movilla-Quesada, A.C. Raposeiras, L.T. Silva-Klein, P. Lastra-González, and D. Castro-Fresno, “Use of plastic scrap in asphalt mixtures added by dry method as a partial substitute for bitumen,” Waste Management, vol. 87, pp. 751-760, (2019).

[27] I. A. El-Naga, and M. Ragab, “Benefits of utilization the recycle polyethylene terephthalate waste plastic materials as a modifier to asphalt mixtures,” Construction and building Materials, vol. 219, pp. 81-90, (2019).

[28] O. Kamada, and M. Yamada, “Utilization of waste plastics in asphalt mixtures,” Memoirs of the Faculty of Engineering, Osaka City University, vol. 43, pp. 111-118, (2002).

[29] M. E. Abdullah, S. A. Abd Kader, R. Putra Jaya, H. Yaacob, N. Abdul Hassan, and C. N. Che Wan, “Effect of waste plastic as bitumen modified in asphalt mixture,” MATEC Web of Conferences, vol. 103, p. 09018, (2017).

[30] A. H. Mir , “Use of plastic waste in pavement construction: an example of creative waste management,” IOSR Journal of Engineering, vol. 5, pp. 57-67, (2015).

[31] H.R. Radeef, N. Abdul Hassan, A.R. Zainal Abidin, M.Z.H. Mahmud, H.F. Abbas, Z. al Saffar, S. Redha, “Impact of ageing and moisture damage on the fracture properties of plastic waste modified asphalt,” IOP Conference Series: Earth and Environmental Science, vol. 971, p. 012009 (2022).

[32] H. Naghawi, R. Al-Ajarmeh, R. Allouzi, A. AlKlub, K. Masarwah, A. AL-Quraini, and M. Abu-Sarhan , “Plastic waste utilization as asphalt binder modifier in asphalt concrete pavement,” International Journal of Civil and Environmental Engineering, vol. 12, pp. 566-571, (2018).

[33] S. S. Ali, N. Ijaz, N. Aman, and E. M. Noor, “Feasibility study of low density waste plastic in non-load bearing asphalt pavement in District Faisalabad,” Earth Sciences Pakistan, vol. 1, pp. 17-18, (2017).

[34] D. S. Mabui, M. W. Tjaronge, . S. A. Adisasmita, and M. Pasra, “Performance of porous asphalt containing modificated Buton asphalt and plastic waste,” Geomate Journal, vol. 18, pp. 118-123, (2020).

[35] S. Kazmi, and D. G. Rao, “Utilization of waste plastic materials as bitumen-blends for road construction in Oman,” Scholars Journal of Engineering and Technology, vol. 3, pp. 9-13, (2015).

[36] L. Costa, J. Peralta, J. R. Oliveira, and H.M. Silva, “A new life for cross-linked plastic waste as aggregates and binder modifier for asphalt mixtures,” Applied Sciences, vol. 7, p. 603, (2017).

[37] M. B. Genet, Z.B. Jembere, and A.L. Jembere, “Investigation and optimization of waste LDPE plastic as a modifier of asphalt mix for highway asphalt: Case of Ethiopian roads,” Case Studies in Chemical and Environmental Engineering, vol. 4, p. 100150, (2021).

[38] A.F. Ahmad, A.R. Razali, I.S.M. Razelan, S.S.A. Jalil, M.S.M. Noh, and A.A. Idris, “Utilization of polyethylene terephthalate (PET) in bituminous mixture for improved performance of roads,” IOP Conference Series: Materials Science and Engineering, vol. 203, p. 012005, (2017).

[39] E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and P. Shafigh, “Using waste plastic bottles as additive for stone mastic asphalt,” Materials & Design, vol. 32, pp. 4844-4849, (2011).

[40] M. Fonseca, S. Capitão, A. Almeida, and L. Picado-Santos , “Influence of plastic waste on the workability and mechanical behaviour of asphalt concrete,” Applied Sciences, vol. 12, p. 2146, (2022).

[41] M. Machsus, M. Khoiri, A. F. Mawardi, R. Basuki, J.H. Chen, and D. W. Hayati, “Improvement for asphalt mixture performance using plastic bottle waste,” Geomate Journal, vol. 20, pp. 139-146, (2021).

[42] F. A. Adday, “Utilizing of polyethylene and plastic wastes for paving asphalt modification,” International Journal of Current Research, vol. 11, pp. 491-498, (2019).

[43] A. A. Badejo, A. A. Adekunle, O. O. Adekoya, J. M. Ndambuki, K. W. Kupolati, B. S. Bada, and D. O. Omole, “Plastic waste as strength modifiers in asphalt for a sustainable environment,” African Journal of Science, Technology, Innovation and Development, vol. 9, pp. 173-177, (2017).

[44] S.A. Taih, “The effect of additives in hot asphalt mixtures,” Journal of Engineering and Sustainable Development (JEASD), vol. 15, pp. 131-150, (2011).

[45] H. M. Jassim, O. T. Mahmood, and S. A. Ahmed, “Optimum use of plastic waste to enhance the Marshall properties and moisture resistance of hot mix asphalt,” International Journal Engineering. Trends and Technology, vol. 7, pp. 18-25, (2014).

[46] M. A. El-Saikaly, “Study of the possibility to reuse waste plastic bags as a modifier for asphalt mixtures properties (Binder Course Layer),” M.Sc Thesis, In Faculty of Engineering Civil Engineering / Infrastructure The Islamic University of Gaza, Palestine, (2013).

[47] N. Suaryana, E. Nirwan, and Y. Ronny, “Plastic bag waste on hotmixture asphalt as modifier,” Key Engineering Materials, vol. 789, pp. 20-25, (2018).

[48] International Organization for Standardization, ISO International Standard 14040: Environmental management: life cycle assessment; Principles and Framework, ISO, 2006.

[49] International Organization for Standardization, ISO International Standard 14044: Environmental management: life cycle assessment; requirements and guidelines, ISO, 2006.

[50] S. Marinković, “Eco-efficient concrete,” Woodhead Publishing (2013).

[51] F. Colangelo, A. Forcina, . I. Farina, and A. Petrillo, “Life cycle assessment (LCA) of different kinds of concrete containing waste for sustainable construction,” Buildings, vol. 8, p. 70, (2018).

[52] R. Watson, B. Abbassi, and Z.S. Abu-Hamatteh, “Life cycle analysis of concrete and asphalt used in road pavements,” Environmental Engineering Research, vol. 25, pp. 52-61, (2020).

[53] M. Puccini, . P. Leandri, A.L. Tasca, L. Pistonesi, and M. Losa, “Improving the environmental sustainability of low noise pavements: comparative life cycle assessment of reclaimed asphalt and crumb rubber based warm mix technologies,” Coatings, vol. 9, p. 343, (2019).

[54] J. Santos, A. Pham, P. Stasinopoulos, and F. Giustozzi, “Recycling waste plastics in roads: A life-cycle assessment study using primary data,” Science of The Total Environment, vol. 751, p. 141842, (2021).

[55] F.G. Praticò, M.Giunta, M. Mistretta, and T.M. Gulotta, “Energy and environmental life cycle assessment of sustainable pavement materials and technologies for urban roads,” Sustainability, vol. 12, p. 704, (2020).

[56] M. Rangelov, H. Dylla, and N. Sivaneswaran, “Life-Cycle Assessment of Asphalt Pavements with Recycled Post-Consumer Polyethylene,” Transportation Research Record, vol. 2675, pp. 1393-1407, (2021).

[57] D. L. Vega A, J. Santos, and G. Martinez-Arguelles, “Life cycle assessment of hot mix asphalt with recycled concrete aggregates for road pavements construction,” International journal of pavement engineering, vol. 23, pp. 923-936, (2022).

[58] M. Vila-Cortavitarte, P. Lastra-Gonzalez, M. A. Calzada-Pérez, and I. Indacoechea-Vega, “Use of Recycled Plastics in Eco-Efficient Concrete,” Woodhead Publishing (2019).

[59] ASTM, “ASTM C 136-06: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates,” ASTM International, (2006).

[60] ASTM,”ASTM C127, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate,” ASTM International, (2004).

[61] ASTM, “ASTM C-128: Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate,” ASTM International, (2015).

[62] ASTM, “ASTM D70, Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer),” ASTM International, (2014).

[63] Heard about miracle "plastic roads"? Here's why it's not a solution to our plastic problem, https://www.thenewsminute.com/article/heard-about-miracle-plastic-roads-heres-why-its-not-solution-our-plastic-problem-36927 (04 March 2022).

[64] Can Plastic Roads be an Answer to the Global Plastic Waste Crisis?, https://www.jakson.com/blog/can-plastic-roads-be-an-answer-to-the-global-plastic-waste-crisis/ (04 March 2022).

[65] The plastic road ahead, https://www.canplastics.com/features/the-plastic-road-ahead/ (04 March 2022).

[66] TS EN 1427, Bitumen and bituminous binders - Determination of the softening point-Ring and Ball method, (2015).

[67] TS EN ISO 2592, Petroleum and related products - Determination of flash and fire points - Cleveland open cup method, (2017).

[68] TS EN 12697-34, Bituminous mixtures - Test methods - Part 34: Marshall test, (2020).

[69] D. Kaya, and A. Topal, "Marshall ve Superpave Tasarım Yöntemleri Arasındaki Farklılıkların Ilık Karışım Asfaltlar Açısından İncelenmesi," Celal Bayar University Journal of Science, vol. 12, pp. 289-302, (2016).

[70] TS EN 12697-8, Bituminous mixtures - Test methods for hot mix asphalt - Part 8: Determination of void characteristics of bituminous specimens, (2019).

[71] TS EN 12697-6, "Bituminous mixtures - Test methods - Part 6: Determination of bulk density of bituminous specimens," (2020).

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