USE OF WASTE PLASTIC BOTTLES AS A MODIFIER IN BITUMINOUS PAVEMENTS

FINAL YEAR PROJECT UG 2012

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This is to certify that

The Final Year Project Titled

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Has been accepted towards the requirements
for the undergraduate degree

In

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DEDICATED TO OUR PARENTS AND TEACHERS, WHO HELPED AND INSPIRED US THROUGHOUT OUR LIFE.

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All thanks and praises to ALMIGHTY ALLAH who gave us the patience and perseverance and guided us to complete our Bachelor's Degree. We are extremely thankful to our Parents for their consistent prayers and to our family for their support throughout the entire length of our course and research work.

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ABSTRACT

The production and use of plastic bottles is increasing tremendously with passing time. These plastic bottles become a problem when they are disposed off as they are non-biodegradable. This means that the waste plastic, when dumped, does not decompose naturally and stays in the environment affecting the ecological system. Burning of this waste, too, harms the environment as it releases harmful dioxins which are hazardous to human health. The emission of CO^2 is a major concern for environmentalists and world community as it is a primary greenhouse gas. Pakistan, with its high population and no proper recycling mechanism, faces this problem of plastic bottle littering.

One of the solutions to the above mentioned problem is to use waste plastic bottles as a modifier in flexible pavements. Waste plastic bottles are shredded into smaller size and wet or dry mixing with aggregate bitumen blend can be performed. This study focuses on the use of waste plastic as a modifier to enhance the individual properties of aggregate and bitumen and the strength and durability of bituminous mixture. Moreover, this waste plastic when effectively utilized will reduce the impact on the environment.

Aggregate was coated with shredded waste plastic and different tests were performed. Results showed a decrease in Impact Value, Crushing Value and Abrasion Value. Aggregate Impact Value decreased from 20.95% to 11.91%, Crushing Value reduced from 21.34% to 14.14% and Los Angeles Abrasion Value dropped from 20.16% to 10.84%. Marshall Results at Optimum Bitumen Content (OBC) and Optimum Plastic Content (OPC) supported the use of plastic as Stability Value increased by 27.02% due to better adhesion provided by plastic between aggregate and bitumen and flow value also increased. The value of Air Voids came out to be 3.84% and VMA (Voids in Mineral Aggregate) and VFA (Voids Filled with Asphalt) had a value of 14.3% and 68.6% respectively, showing that it adhered to the specifications provided by ASTM.

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CHAPTER 1

1. Introduction

1.1 General

No doubt plastic is a wonderful invention, take a look around and you won't find anything which is made entirely of plastic or has some amount of plastic in it. From simple things like bottles, kitchen utensils and toys to the most complex computers and machines, plastic is used everywhere. It is safe to say that plastics are a vital part of our life. The most useful property of plastic is that it can be molded easily into any desired shape. Unlike metal which requires a considerable effort. The durability and sturdiness that plastic offers is superior to many materials out there (1). Also plastic is a cheap material when we compare it with materials like wood and metals. The reason behind is that plastic can be easily molded into desired shape by applying a relatively small amount of heat as compared to metal products (The melting point of cast iron is 1204 ^{0}C)(2). Plastic is also chemically resilient, means it does not react easily with chemicals making it suitable for preserving food and medical items(1).Plastics are durable materials and are used in building and construction. Use of plastics can be seen in window frames and plastic pipes etc.(3).

1.2 Problem Statement

Plastic might be one of the most useful materials available today but everything has its downside. No doubt many countries have strict regulations limiting the use and production of plastics. The production of plastic has been on a rise and 245 million metric tons of plastic was produced in 2008(4).Plastic is indestructible which means it can't be decomposed chemically completely. Plastic takes indefinite amount of time to decompose completely (5). Huge amounts of plastic wastes are being dumped in the oceans and the seas which pose a serious threat to the aquatic life. The fact that horrifies the most is that plastic wastes will still be present after many years to come which are a serious threat for the future generations. This huge accumulation of plastic waste might render the affected parts of seas useless. When plastic is burned it produces several gases some of which are nitrogen oxides, sulfur oxides, VOCs (Volatile Organic Compounds) and polycyclic organic matter. These gases damage the ozone and are injurious to health (6).

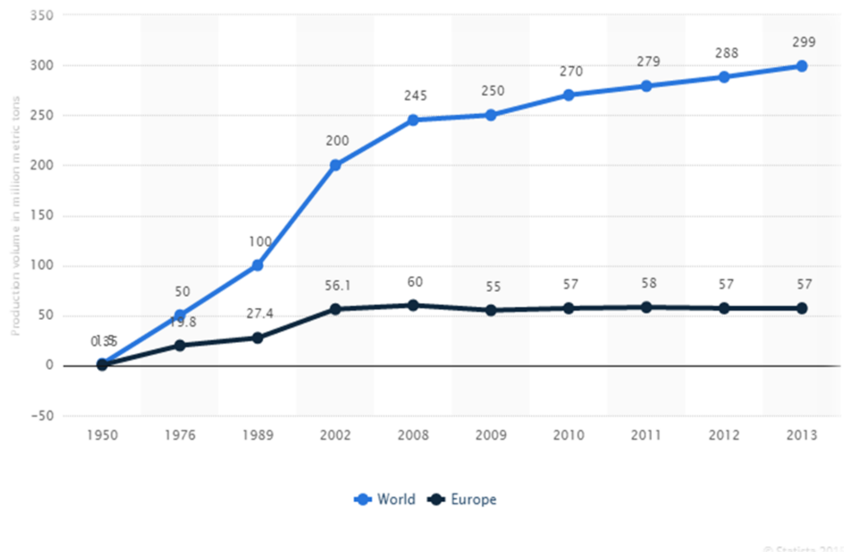

Figure 1: Yearly Production of Plastic

Now we shift our focus to the current condition of plastic in Pakistan. Like other countries plastic is widely used in Pakistan in many industries. Since Pakistan is an underdeveloped nation, the standard of living of a middle class family is not as high as other developed countries like America and Scandinavian countries etc. Therefore many items such as household items, kitchen utensils are made from plastic rather than wood or aluminum because plastic is cheaper. Also Pakistan is not primarily an industrial nation which means that industry regulations are poor and are not properly enforced which enables chemical factories to produce plastics overlooking the harmful effects it produces on the environment. Pakistan's plastic industry is growing at an average annual growth rate of 15% (7).

Soft drinks like Pepsi, 7up, Dew are extensively consumed in Pakistan. These soft drinks are filled in plastic bottles which are made up of a polymer called Polyethylene terephthalate or simply PET (8). Since there is no proper system for disposal of plastic waste in Pakistan, these bottles are usually dumped in landfills and water bodies where they pollute the environment. In Pakistan, solid waste generation is 0.612 kg/capita/day (7) and hence Pakistan has been ranked 15th as the worst plastic offenders by Climate Desk (9).

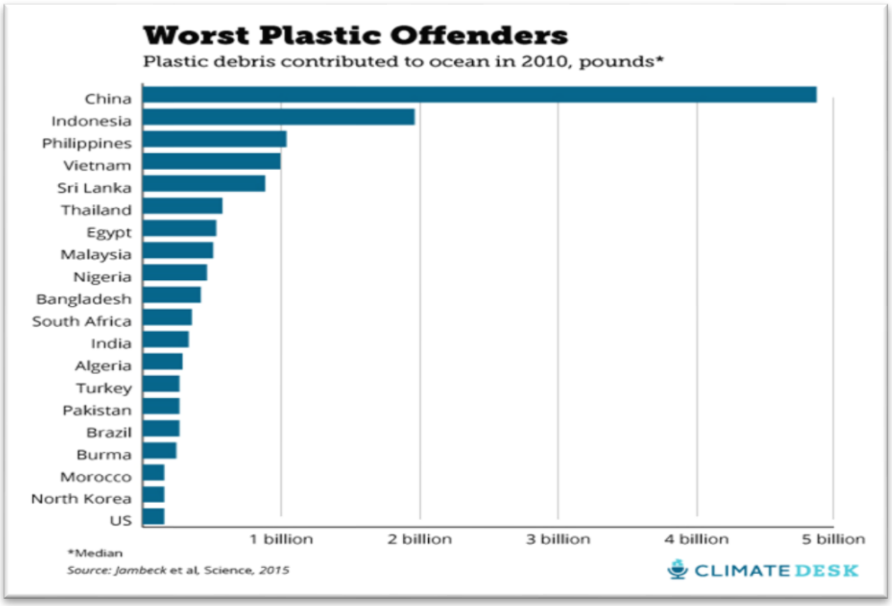

Figure 2: Worst Plastic Offenders

1.3 Purpose of Research

The growing consumption of plastic with the skyrocketing population in Pakistan demands for a proper disposal or utilization of plastic waste. If left unattended it can be a serious issue for our country and can have calamitous effects on public health. Use of waste plastic in Hot Mix asphalt has been studied in many countries, Oman and India (based on the research papers we have consulted for this project) to name a few but there hasn't been a considerable research on the effects of plastic on the properties of Hot Mix Asphalt (from now referred to HMA) in Pakistan.

Pakistan is currently going through a transportation revolution. Under the current government we have seen huge amounts revenue dedicated to the construction of underpasses and overhead bridges and repairing and widening of already built roads. If plastic is really enhancing the properties of roads built in Pakistan then now would be the ideal time to utilize plastic in roads and unlock its full potential. The recent agreement of providing economic corridor to China via Pakistan involves construction of 1100km long motorway between Lahore and Karachi (10) and overhauling and widening of Karakoram Highway between Rawalpindi and the Chinese border (11). With such a huge transportation revolution in Pakistan the positive impact of waste plastic on HMA will reduce the amount of waste produced and guarantee a safer environment free of plastic pollution for the people of Pakistan.

In the research papers reviewed it is noted that plastic coated aggregate is known to increase the Impact and Crushing value of aggregate. This is very good as plastic can be utilized to enhance the strength of poor aggregate. Use of plastic in bitumen is known to increase the flow value of bitumen as well as decrease the water permeability which is a big issue considering the damage caused to vehicles because of potholes which are formed due to poor drainage and accumulation of water on roads. The facts stated here will be backed by explanation in Chapter 2 which covers the literature review.

1.4 Research Objectives

The main objective of this research is to use waste plastic bottles effectively and efficiently in road construction thus decreasing the impact it has on the environment. Along with this, some other objectives are:

- To increase the strength of aggregates by effectively coating them with plastic.
- To increase the strength of Hot Mix Asphalt (HMA) that is its Marshal Stability value.
- To increase the Flow Value of Hot Mix Asphalt by using plastic as a modifier.
- To find the different parameters related to Marshal Test Method such as VMA (Voids in mineral aggregate), VFB (Voids filled with Bitumen), Air Voids (AV) at optimum bitumen.

CHAPTER 2

2. Literature Review

2.1 Necessity of Transportation

A functional and efficient transportation system is the backbone of any country's economy. Millions of people travel via road in our country. The deterioration in the standards of Pakistan Railway and the lack of vast and adequate public transportation system like the London Underground, Moscow Metro, Shanghai Metro, Indian Metro (8 Operational metro systems) (12). Yes there is metro and orange line which is under construction in Lahore but they are nowhere near the vastness and infrastructure of the above mentioned systems. Moreover, the already built roads in Pakistan are in a pretty bad shape. Apart from a few exceptions of developed cities like Islamabad, Lahore, Faisalabad and Karachi etc. the smaller cities are left with poor and faulty roads which are way past their life. This calls for immediate remedial measures and construction of new roads in Pakistan. A transportation revolution is necessary to fulfill the requirements of our growing population.

Figure 3: Traffic Congestion

Source: Dawn News

2.1.1 Present Conditions of Road in Pakistan

Coming back to our Final Year Project (FYP), the traditional methods are still being used in Pakistan although the recent renovation of Motorway (M2) saw new modern machinery and quite good handling of traffic construction; the local roads are still plagued by faulty construction. Poor construction methods, lack of adequate management of traffic during construction proves more of an annoyance than a blessing.

Figure 4: Deteriorated Road Surface

Use of additives in asphalt has been practiced all around the world. Just like concrete, asphalt is also tested with many additives in order to improve the quality. Additives like tires are extensively used in Phoenix City, Arizona USA in the early 60s (13).

2.2 Plastic: A Wonderful Invention

Plastic is one of the most commonly used materials in our daily life. There is no single day in todays' day and age where you don't encounter which is made up of plastic or has some amount of plastic in it. Plastic owes its usability and vastness to its ability to be shaped easily as desired and its durability as compared to other materials like wood which is prone to termites and climate and steel which is prone to rusting. Moreover plastic objects are way easier to manufacture and don't require a lot of skill and machinery, whereas steel requires a lot of energy to be molded into desired shape and wood requires accuracy and craftsmanship. That is why plastic is found in so many things around us and is so widely used.

2.2.1 Types of Plastic

The term plastic is used for various types of synthetic and semi-synthetic organic compounds which can be molded into desired shape and size by the application of heat. Plasticity can be explained as the property of materials due to which they deform and do not break. Plastics are widely used due to their low cost and high durability (14).There are many types of plastics. The thing about plastics is that all of them have varying properties and behavior, some of them can be a great barrier to moisture and gas, some of them are transparent and durable while some are strong enough to stop a bullet i.e. Kevlar . However two main types of plastics based on their deformation are (15).

1) Thermoplastics
2) Thermosets

Polyethylene Tetraphthalate (PET) lies in the category of first type of plastics.

2.2.1.1 Polyethylene Tetraphthalate (PET)

Polyethylene Tetraphthalate better known as PET is one of the most common plastics. Chemical formula for PET is $(C_{10}H_8O_4)_n$. It is mostly used in clothing and making containers for liquid and food. It is the most common type of polyester. PET is recyclable and is indicated by #1 as the recycling symbol. Because of its remarkable moisture resisting properties it is used in making food and beverage containers.

2.2.1.1 Physical Properties of PET

In its intrinsic state PET is a colorless, semi-crystalline resin. PET is very lightweight and forms a good barrier to moisture and gas. It can also act as a barrier to Alcohol but it requires additional barrier treatment. PET is strong and impact resistant.

Further physical properties are enlisted in the table below (16).

Table 1: Physical Properties of PET

Physical Property	Value
Density	0.0499 lbs/in^3
Water Absorption 24 hours	10%
Specific Gravity	1.38 g/cm^3
Flexural Strength	15000 psi
Melting Point	180-220 Celsius
Coefficient of Linear thermal expansion	3.9×10^{-5} in/in ^{0}F
Flammability	HB[1]
Rockwell Hardness	R117[2]
Flexural Modulus	400000 psi

2.2.1.1.1 PET Bottles

Most of the beverage bottles these days are made of PET. In Pakistan beverages like Pepsi, 7up, Coca Cola are widely available in PET bottles. With advancements in every field of science these days, chemists are experimenting newer ways to make PET lighter and more durable, enhancing economy and sustainability. This progress can be explained by the fact that in 1980 a 2.0 liter PET bottle weighed 68grams but now it only weighs 42 grams. Also the average weight of 0.5 liter PET is nearly half of what it weighed in 2000 i.e. 9.9 grams (17).

2.2.2 Disadvantages of Plastic

Despite having a lot of advantages, there are a few major drawbacks of using plastic. The major downside of plastic is that it can’t decompose. The chemical resilience of this material sometimes is the biggest problem with plastic. We might throw a plastic bottle out of our car window thinking about the consequences but that bottle will stay on the earth in the same chemical composition for hundreds of years. Plastic is a highly resilient chemical and it can resist acids bases and other chemicals.

Plastics contribute to 10% of discarded waste (18). They are a major source of pollution in the sea. According to a recent report it is estimated that there will be more plastic in oceans than fish in the year 2050 (19). This is an alarming fact. Some other facts and figures regarding the plastic pollution in sea are:

i. More than 8 million metric tons of plastic is dumped into oceans from land each year (20).
ii. More than 100,000 marine animals die annually by digesting or entangling in plastic bags each year (21).
iii. Approximately 4,600 turtles are being killed each year due to plastic pollution [22].

These are absolutely staggering facts and show the extent of pollution in the sea. It’s now or never for the human race to find an alternate solution or to use other techniques to dump plastics which don’t involve killing of aquatic life.

Figure 5 Plastic Pollution Facts

The excessive use of plastic in each and everything possible has increased the amount of waste being produced every year. Disposable materials that are made of plastic are a big threat to the environment. Some people have gone as far as eliminating plastic from their lives. In today's world it's not possible but it shows the extent of threat posed by pollution caused due to plastic. As mentioned above aquatic life is suffering from plastic pollution and for our own convenience and ease we are threatening the lives of aquatic animals. Moreover the hazard posed by plastic on the land shouldn't be ignored too. Plastic unlike other pollutants does not decompose so it poses a serious threat to environment. In some cities of Pakistan we still have uncovered sewerage drains, plastic shopping bags and bottles are clogged in these drains and reduce the efficiency of the drains and cause inconvenience to the people. There are piles of plastic pollution which are dumped all over around the city. Let's face it; our sanitary system is old and not up to speed with current requirements of the population. The day by day rise in population has also contributed in increase in waste plastic. The sanitary system can't take the full load of garbage so it is deposited in open lands where it serves as a breeding place for many insects and diseases. It's safe to say that plastic is a substance the Earth cannot digest.

2.2.3 Use of Plastic in Pakistan

In Pakistan plastic is widely used. Due to the lack of good quality industries and workmanship required for Steel and Wood the use of plastic is furthermore increased. And the fact that Pakistan is a poor country where products made up of glass, steel and wood are considered expensive and lavish and plastic is cheap and readily available.

Most of the plastic in our country is utilized in plastic PET (Polyethylene Tetraphthalate) bottles used for beverages like Pepsi, 7up and dew to name a few. Also plastic is widely used in making shopping bags. While other countries are discouraging the use of plastic bags in Pakistan plastic bags are used in abundance and their use are not regulated. There is no proper system of managing plastic waste which is increasing day by day. This is an alarming situation for our country. The yearly rise in temperature due to global warming and floods every year are signs of the environmental deterioration in Pakistan.

Figure 6: Waste Plastic Bottles

2.3 Use of additives in HMA

The properties of Hot Mix Asphalt (from now on referred to as HMA) can be altered by the use of additives. Crumb rubber, marble dust and plastic are some of the materials used in HMA.

For our Final Year Project we will be using Polyethylene Tetraphthalate (PET) bottles as a modifier in HMA. Tests were performed on aggregate, plastic coated aggregate, bitumen and HMA.

Figure 7 Shredded Plastic Bottles

2.2 Previous Research

Use of plastic in Asphalt has been practiced before. We have studied a number of research papers in which plastic was used as a modifier in HMA. Here we will discuss a few of them.

1) A research conducted by Moghaddam, Karim and Soltani conducted in 2013 utilized plastic bottles in HMA. The percentages of plastics used were 0.2, 0.4, 0.6, 0.8 and 1.0% by weight of aggregate. The performed the following tests on HMA.
   - Marshal stability and flow
   - Bulk specific gravity
   - Optimum asphalt content
   - Stiffness
   - Fatigue

The tests concluded that increase in stability and flow values, lower amount of plastic showed greater values of bulk specific gravity and stiffness and vice versa, mixtures containing waste plastic have lower OAC and have greater fatigue resistance.

2) Another research was carried out by Nasir, Ayoub, Zafarullah, Bilal, Amjad and Kakar in 2014 which employed plastic bags in HMA rather than PET bottles. The parameters checked were Marshal Stability and Flow value. The tests were performed on a wide range of plastic percentage i.e. 0, 3, 6, 9, 10, 11, 12, 15%. The research concluded that there is an increase in Marshal Stability in up to 10%, as the plastic percentage is increased at 6% plastic the flow value starts increasing again. At 10% the flow value is nearly as same as that at 0%. Hence the recommended percentage of plastic is 10% because beyond 10% the flow value starts increasing dramatically which then cancels the effect of increase in strength.

3) A research carried out in Oman by Kazmi and Rao used shredded polythene bags as a modifier in HMA. Percentages of plastic by weight used are 0, 5, 7, 9, 11%. According to their findings 9% shredded polythene bags by weight of sample is the optimum percentage to be used. They performed the following tests

   - Bulk density
   - Specific gravity
   - Marshal Stability
   - Flow value
   - Determination of Air Voids in sample

Rest of literature studied is comprehensively described in the table on the next page.

Table 2: Literature Review

Topic of Research	Objectives	% of Plastic	Tests Performed	Conclusion	Author and Year
Use of plastic waste in flexible pavements(23)	-Aggregate coating with plastic -Checking properties of bitumen mix specimen	2%, 4%, 6%, 8%, 10%	Specific Gravity, Impact Value, Crushing Value, Los Angeles Abrasion Test	Decrease in Impact Value, Crushing Value, Abrasion Value and water absorption. Increase in Specific Gravity	Miss Apurva J Chavan (2013)
Utilization of waste plastic materials as Bitumen Blends for road construction in Oman(24)	Effect of waste plastic on bulk density, stability, flow value and voids of asphalt mixture	0%, 5%, 7%, 9%, 11% by weight of sample	Marshal Stability, Flow Value, Bulk Density, Specific Gravity and void analysis	Waste Plastic can be used asa binding agent and 9% plastic by weight of sample is the optimum value	SukainaKazmi, DubasiGuvardanaRao (2015)
Optimum Use of Plastic Waste to enhance the Marshal Properties and Moisture resistance of HMA(25)	Effect of waste plastic bottles on marshal stability and waster resistance of asphalt mix	5%,10%,15%, 20%,25% by weight of aggregate	Marshal Stability, Bulk Density, Air Void Analysis, Index of Retained Strength	Increase in Marshal Stability and Index of Retained strength using plastic passing sieve #16	Hamed M Jassim, Omar T Mahmood, Sheelan A Ahmad. (2014)

Effective use of waste plastic as bitumen strength modifier(26)	Effect of waste plastic bags on Marshal Stability and Flow Value of asphalt mixture	0%,3%,6%,9%,10%,11%,12% and 15% of LDPE by weight of bitumen	Marshal Stability and Flow Value	Increase in Marshal Stability as plastic content increases. Increase in flow value upto 10% of plastic	S. Nasir, M. Ayob, S. Zafarullah, Ahmad Bilal, BadarAmjad, EhsanullahKakar. (2014)
Utilization of Waste Plastic Bottles in Asphalt Mixture(27)	Effect of waste plastic bottles on Marshal Properties. Determination of OAC on various % of plastic.	0%, 0.2%,0.4%,0.6% and 1% by weight of aggregate.	Marshal Stability and flow, Bulk Specific Gravity, Optimum Asphalt Content, Stiffness and Fatigue	Increase in stability and flow value. Lower plastic content showed greater bulk specific gravity. Stiffness decreases.	TaherBagheeMoghaddam, Mohamed RehanKarim, MehrtashSolatni. (2013)

CHAPTER 3

3. Material and Methodology

3.1 Sample Collection

3.1.1 Aggregate

The aggregate that was used in the experiments was collected from the quarrying site of Margalla Hills near Taxila. Different sizes of aggregate were collected in jute bags from one of the crushing units. However, this aggregate did not qualify for the use in wearing course as it failed the Crushing Value Test. Therefore, a new aggregate was needed. This time the aggregate was collected from the FWO plant on Lahore-Islamabad motorway (M2) which is using the same aggregate for pavement construction. This aggregate passed the different tests that have been specified by AASHTO to check for its use in wearing course.

3.1.2 Bitumen

The bitumen used in this research is of grade 60/70 from Attock Refinery Limited, Rawalpindi, Pakistan.

3.1.3 Waste Plastic Bottles

Waste plastic bottles are easily available from dump yards/sites, garbage sites, recycling units and waste collectors. Shredded plastic was required with size less than 4.5 mm. There were a few shredding units in Islamabad and Rawalpindi and some were located in the suburbs of these major cities. However, the minimum size of shredded bottles available was of almost one inch which was greater than the required size. Therefore, the required material was ordered and delivered form Vehari. This fine sized plastic was sieved through sieve no 4. The material that was retained on sieve no. 4 was rejected and the passing material was washed several times and dried to remove the dust and impurities.

Figure 8 Shredded Waste Plastic from Vehari

3.2 Sample preparation and test procedures

3.2.1 Aggregate (With and Without Plastic)

The aggregate collected from motorway site plant consisted of coarse, fine and pan material. The size ranged from 0-10 mm and 10-20 mm. To carry out the various tests for finding the aggregate properties, the material was sieved through different sieve sizes and separated and stored in different drums. Before carrying out the tests, it was made sure that the aggregate has been oven dried.

Figure 9: Aggregate sieved into different drums

3.2.1.1 Impact Value Test

Aggregate Impact Value gives relative measure of resistance of an aggregate to a sudden shock or impact. The apparatus required for this test included Impact Testing Machine, tamping rod and sieves of sizes 1/2”, 3/8” and #8. Around 350g of aggregate passing through 1/2” sieve and retaining on 3/8” sieve was taken and filled in the mould of Impact Testing Machine in three layers, tamping each layer 25 times. The sample was transferred into the larger mould of the machine and 15 blows from a height of 38 cm were given with the hammer weighing 13.5 to 14 kg. The resulting aggregate was removed and passed through sieve #8. The impact value was measured by the percentage of aggregate passing through sieve #8. To find out the effect of plastic on aggregate, aggregate was heated to 170-180 ^{o}C. Shredded plastic was slowly added to the aggregate with constant mixing so that it completely coats the aggregate as it melts. Different percentages of plastic were added and the corresponding Impact Values were calculated.

Figure 10: Aggregate without Plastic Coating

Figure 11: Plastic Coated Aggregate

3.2.1.2 Crushing Value Test

To achieve a pavement with higher quality and strength, it is necessary for the aggregates to have enough strength to sustain traffic loads. The apparatus used for this test was steel cylinder with open ends, base plate, plunger having a piston diameter of 150 mm and a hole provided across it, so that a rod could be inserted for lifting it, cylindrical measure, balance, tamping rod, and a compressive testing machine. Aggregate was passed through a set of sieves and that passing through ½" and retaining on 3/8" was selected. Sample aggregate was washed, oven dried and weighed (W_1) and then added into that cylindrical measure in three layers, each layer being tamped 25 times. The sample is shifted into the steel cylinder with base plate in three layers and the plunger is inserted. It was then placed in compressing testing machine and load was applied at a uniform rate of 4 tons per minute until the total load was 40 tons. Crushed aggregate was then removed from the steel cylinder and passed through 1/16" sieve. The material that passed through this sieve was collected and weighed (W_2). Crushing value of aggregate was calculated by = W_2/W_1 x 100

3.2.1.3 Los Angeles Abrasion Test

This test determines hardness of road aggregate. Aggregate must be hard enough to resist wear due to heavy traffic loads. The apparatus used for this test included Los Angeles Abrasion machine, balance, set of sieves and steel balls. Testing methodology or grading B was adopted for this procedure. 2500 g of aggregate retained on ½" and 3/8" sieves each, which is a total of 5000g (W_1) of aggregate along with 11 steel balls or charges were placed in the Los Angeles abrasion machine. The machine was rotated at a speed of 30 to 33 Rpm for 500 revolutions. After that, the material was sieved through sieve #12. Weight of sample passing through it (W_2) was noted down. The abrasion value was found out by = $W_2/W_1 \times 100$

3.2.1.4 Water Absorption and Specific Gravity

Water Absorption and Specific Gravity test was performed according to the standard procedure specified by ASTM C127-15.

3.2.2 Bitumen

Samples were prepared to carry out the following tests for bitumen.

3.2.2.1 Penetration Test

Penetration test was performed according to standards and specifications of ASTM D5/D5M.

3.2.2.2 Softening Point

Softening Point of bitumen was found out using ASTM D36-06 methodology.

3.2.2.3 Flash and Fire Point

Flash and Fire point test was conducted as per D3143/D3143M-13 standards.

3.2.2.4Viscosity

Viscosity test for bitumen was performed as per ASTM D4402 guidelines.

3.2.2.5 Ductility

Ductility test was carried out following the specifications of ASTM D113-99.

3.2.3 Marshall Testing

To analyze the effect of plastic on bituminous pavement, it was necessary to find out its effects on different properties of an asphalt specimen. For that purpose, Marshall Method was adopted to design asphalt samples at different percentages of bitumen and then, select the Optimum Bitumen Content. Aggregate Gradation B was adopted to design the Marshall samples. A total of 1200 g of coarse aggregate, fine aggregate and filler were required to produce the desired thickness. These materials were proportioned according to the required grading standards as shown in the table on the next page.

Table 3: Aggregate weight distribution in Gradation B

Sample Size (inches)	Percentage Passing (% pass)	Percentage Retained (% ret)	Weight Retained (g)
¾"	100%	0%	0
½"	82.5%	17.5%	210
3/8"	70%	12.5%	150
No.4	50%	20%	240
No.8	30%	20%	240
No.50	10%	20%	240
No.200	5.5%	4.5%	54
Pan	___	5.5%	66
		Total Weight =	**100**

Three samples each were prepared at four different contents of bitumen by weight of aggregate which were 3.5%, 4%, 4.5% and 5% and the following tests and analysis were carried out

- Bulk Density Determination
- Stability and Flow Test
- Void Analysis
- Optimum Asphalt Content

3.2.3.1 Sample Preparation

1200g of aggregate, fine and course, and filler material were mixed together and heated to a temperature of 160-170 °C. Required amount of bitumen for the first batch was heated to 160°C and then added to the aggregate. Both the materials were thoroughly mixed at a temperature of 160-170 °C. When the bitumen had uniformly coated the aggregate and filler, the sample is placed into a preheated mould. 75 blows were given to the top and bottom side each with a standard hammer and then the sample was taken out of the mould with a sample extractor. Different specimens were prepared by adopting the similar procedure, varying the amount of bitumen with an increment of .5%.

Figure 12: Marshal Molds at different percentages of Bitumen

3.2.3.2 Bulk Specific Gravity

Bulk specific gravity of the specimen was found in accordance with ASTM D 2726. Three different weights were taken, Dry Weight (A), Saturated Surface Dry Weight (B), Weight in water (C). Bulk Specific Gravity was found using the following formula

$$G_{sb} = \frac{A}{(B - C)}$$

3.2.3.3 Stability and Flow Test

The specimen was immersed in water bath at a temperature of 60°C for 30 minutes. It was then placed in Marshall Stability testing machine with a loading rate of 5 mm per minute.

The total load in KN at which the sample failed was recorded as Marshall Stability. Flow Value is the total amount of deformation of 0.25 mm of units was recorded along with it at maximum load.

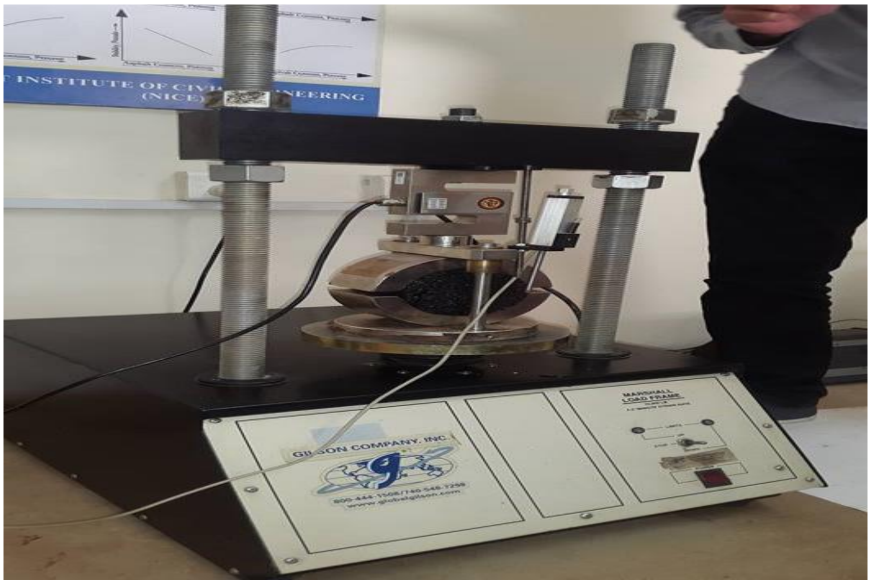

Figure 13: Marshall Stability and Flow Test

3.2.3.4 Theoretical Maximum Specific Gravity

The test was carried out using ASTM D 2041

3.2.3.5 Void Analysis

3.2.3.5.1 Air Voids (VA)

It is the total volume of air pockets that are present in the compacted specimen, expressed as the percentage of total volume of the compacted sample.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100$$

3.2.3.5.2 Voids in Mineral Aggregate (VMA)

It is the volume of inter granular voids present as air voids and effective asphalt content between the aggregate particles of a compacted specimen. VMA is calculated as

$$VMA = \left(1 - \frac{G_{mb}(1 - P_b)}{G_{sb}}\right) \times 100$$

3.2.3.5.3 Voids Filled with Asphalt (VFA)

It is the percentage of voids containing bitumen in mineral aggregate. It was found out by this equation

$$VFA = \frac{VMA - V_a}{VMA}$$

3.2.4 Plastic Coated Specimen

After finding out the Optimum Bitumen Content (OBC) from Marshall Testing, the next step was to evaluate the effect of plastic on Marshall Stability Value, Flow and other parameters.

The following formulation was used to form the samples

Optimum Bitumen Content (OBC) by the weight of aggregate

+

Optimum Plastic Content (OPC) by the weight of aggregate

+

Weight of aggregates according to Gradation B

Aggregate was heated till 170 °C and coated with plastic in a similar manner described earlier. When the whole plastic had melted and covered the aggregate, pre-heated bitumen at 160 °C was added and the sample was thoroughly mixed. After heating, it was placed in

Marshall Molds and Marshall Test was carried out later. 3 samples using this formulation were made for the purpose of accuracy.

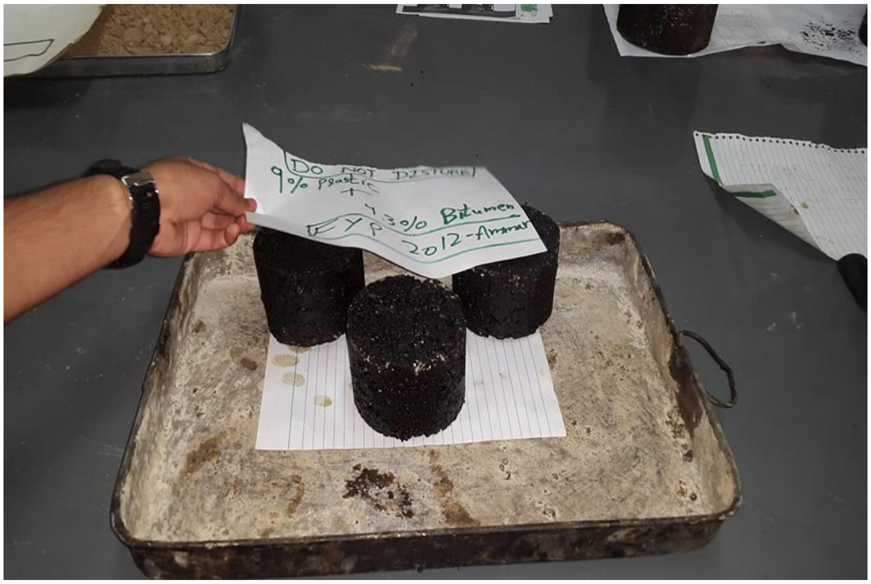

Figure 14: Marshall Molds after addition of Plastic

CHAPTER 4

4. Results and Discussion

4.1 Bitumen

The results for different tests carried out for bitumen are mentioned in the table below

Table 4: Different Tests for bitumen and their Results

Serial No.	Test Description	Specification	Permissible Value	Result	Remarks
1	Penetration Test	ASTM D3143/D3143M-13	250 MIN	279°C 302°C	Grade 60/70
2	Flash and Fire Point	ASTM D5/D5M	60-70	65	Grade 60/70
3	Softening Point	ASTM D36-06	49-56	50.8°C	Grade 60/70
4	Viscosity Test	ASTM D4402	.22-.45 pa.sec	262.5 cp or 2.625 p = .2625 pa.sec	Grade 60/70
5	Ductility Test	ASTM D113-99	100 MIN	123 cm	Grade 60/70

From the above mentioned results, it can be seen that the bitumen used was of grade 60/70 as it lied between the permissible values and fulfilled the criteria for the specific grade.

4.2 Aggregate

The results of the tests carried out for the first batch of aggregate were not satisfactory. Although the Impact Value and Abrasion Value were within the permissible limits but they were on the higher side. Also, the Crushing Value exceeded the desired limit of 30% as mentioned by ASTM C131 which showed that it failed the criteria for Crushing. This test was performed thrice but the results were no different as the value exceeded 30% every time. The second batch from FWO plant gave satisfactory results as it passed all the tests. Impact, Crushing and Abrasion values were less than the previous batch of aggregate showing that the aggregate was stronger and tougher. Summary of the results for different aggregate tests is mentioned in the tables below.

4.2.1 Without Plastic Coating (Sample 1 from Taxila)

Table 5: Aggregate Tests and Results (Sample 1)

Serial No.	Test Description	Specification	Permissible Value	Result	Remarks
1	Aggregate Impact Value	ASTMD5874	30%	25.85%	Good for pavement surface course
2	Aggregate Crushing Value	ASTM C131	30%	31.53%	Failed
3	Los Angeles Abrasion Test	ASTM C535-12	40%	23.18%	Ideal for base and sub-base course
4	Water Absorption and Specific Gravity	ASTM C127-15	WA< 2%	Gsb=2.49 WA= 1.46%	Not carried out

4.2.2 Sample 2 from FWO plant

Table 6: Aggregate Tests and Results (Sample 2)

Serial No.	Test Description	Specification	Permissible Value	Result	Remarks
1	Aggregate Impact Value	ASTMD5874	30%	20.95%	Strong
2	Aggregate Crushing Value	ASTM C131	30%	21.34%	Passed
3	Los Angeles Abrasion Test	ASTM C535-12	40%	22.16%	Ideal for base and sub-base course
4	Water Absorption and Specific Gravity	ASTM C127-15	WA< 2%	Gsb= 2.55 WA= 1.22%	Not carried out

4.2.3 Plastic Coated Aggregate

The purpose of this research was to find out the effects of shredded plastic on aggregate properties. The results of tests carried out on plastic coated aggregate support the findings of the previous research which stated that coating aggregate with plastic enhances its strength properties. From our research we found out that increase in plastic content was inversely related to Impact, Crushing and Abrasion values. Increasing the plastic content decreases these values, improving the quality of aggregates. However, beyond a certain limit of plastic content, there is no further decrease in these values. This optimum plastic content was found out to be 9% by weight of aggregate, which is quite close to that or previous researches.

4.2.3.1 Aggregate Impact Value

Results showed that as the plastic contents increases, aggregate impact value decreases. The value continues to decrease till the optimum plastic content which was found to be 9 % of plastic by weight of aggregate. Beyond this value, there is no further decrease in Impact Value. Impact Value decreased from 20.95 % to 11.91 % proving that coating aggregate with plastic improved its toughness and ability to resist impact loading.

Plastic (%)	Impact Value (%)
0	20.95
3	17.37
6	14.23
9	11.91
12	11.88

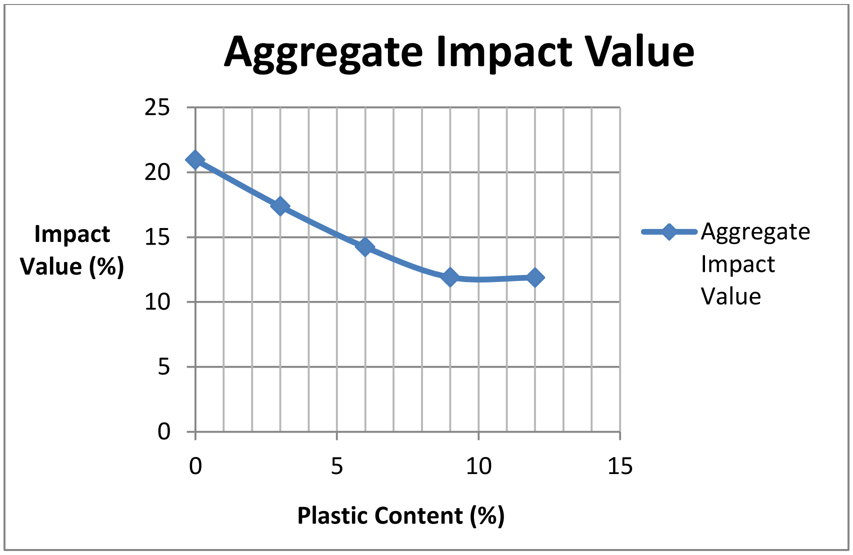

Figure 15: Variation of Impact Value with Plastic Content

4.2.3.2 Crushing Value of Aggregate

Similar results were observed with the Crushing Value of aggregate. Increase in plastic content decreased the crushing value. However, percentages decrease was less between 6 to 9 % beyond which there was no decrease in Crushing Value. Crushing Value dropped from 21.34 to 14.14 %, justifying that coating the aggregate with plastic increases its strength and making it strong enough to bear traffic loads.

Plastic (%)	Crushing Value (%)
0	21.34
3	18.17
6	14.99
9	14.14
12	14.1

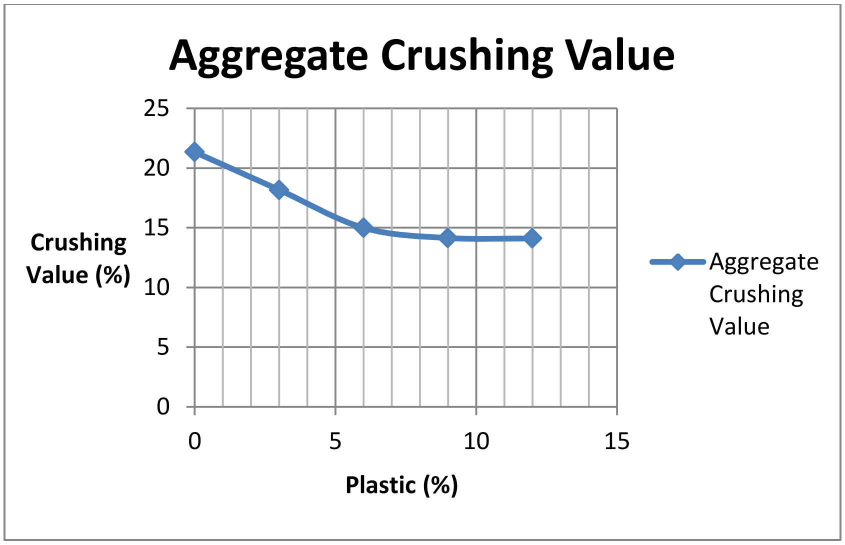

Figure 16 Variation of Crushing Value with Plastic Content

4.2.3.3 Los Angeles Abrasion Value

With an increase in plastic content, there was a decrease in abrasion value. This could be seen from the graph that the abrasion value reduced from 20.16% to 10.84%. Beyond the optimum 9% of plastic content, abrasion value remained constant. Thus, coating aggregates with plastic enhances their ability to sustain wear and tear under wheel loads.

Plastic (%)	Abrasion Value (%)
0	20.16
3	17.4
6	12.89
9	10.85
12	10.84

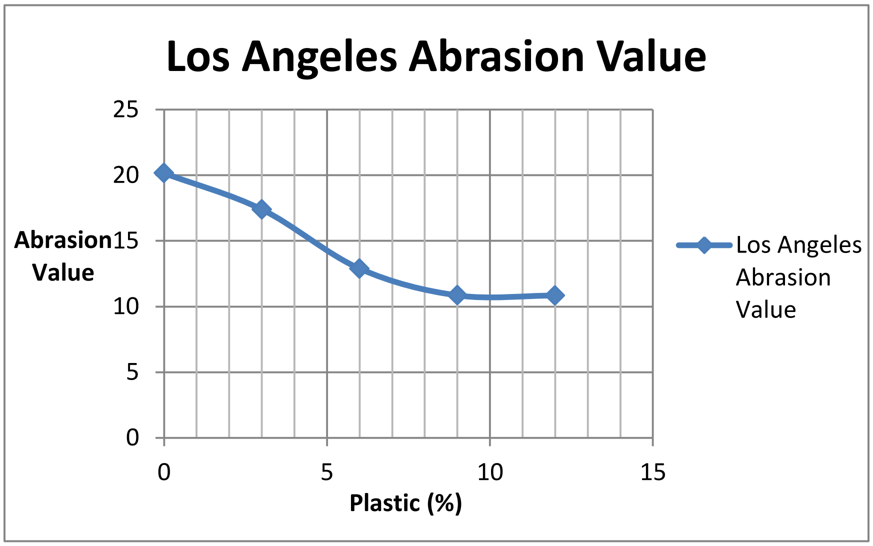

Figure 17 Variation of Abrasion Value with Plastic Content

4.3 Marshall Testing

4.3.1 Stability Value

The stability value increased till the optimum value of 4 % of bitumen. Further increase in bitumen content caused stability value to decrease. Maximum stability came out to be 11.739 KN.

Asphalt (%)	Stability Value (KN)
3.5	10.923
4.0	11.739
4.5	10.552
5.0	9.564

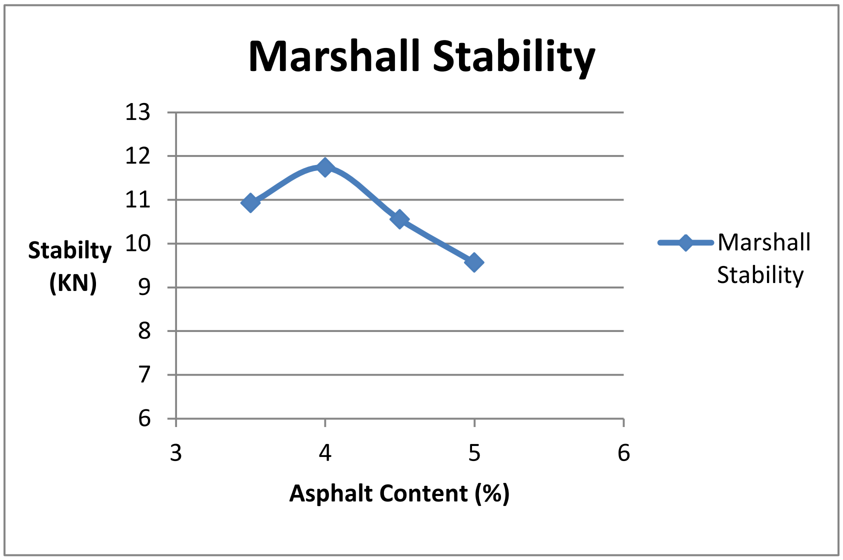

Figure 18: Stability Value vs Asphalt Content

4.3.2 Flow Value

As the asphalt content increases, flow value increases. Although flow should have been minimum at 4 % asphalt content since stability is maximum, yet it lies in the required range of 2-4 mm. This is because stability and flow are inversely related as shown by the results. At 5 % bitumen, stability value was minimum while flow value is maximum, exceeding the specified range.

Asphalt (%)	Flow (mm)
3.5	3.259
4.0	3.691
4.5	3.952
5.0	4.486

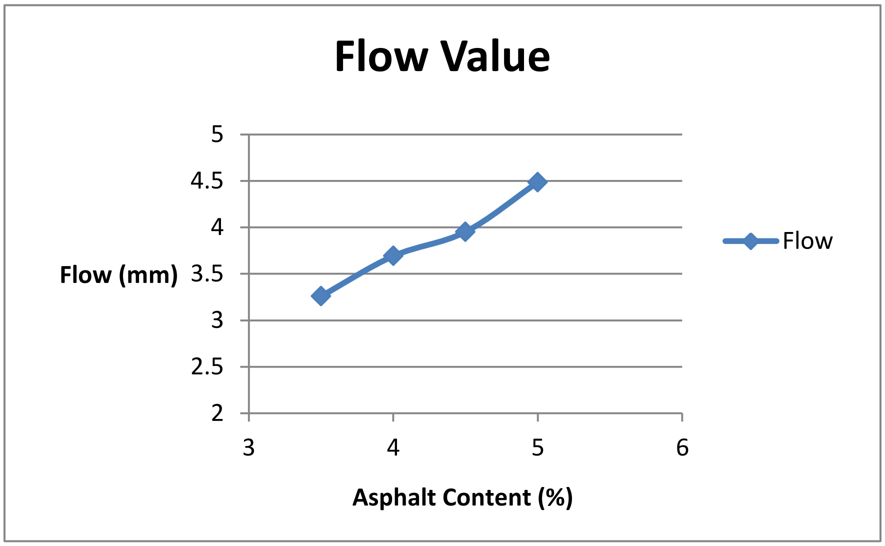

Figure 19: Flow Value vs Asphalt Content

4.3.3 Void Analysis

4.3.3.1 Air Voids (V_a)

The relation is quite simple, as the asphalt content increases percentage of air voids decreases. This is because more inter granular voids get filled with bitumen therefore reducing the volume of air voids present. Bitumen content of 4, 4.5 and 5% fulfilled the criteria of 3-5% of air voids.

Asphalt (%)	V_a (%)
3.5	6.94
4.0	5.09
4.5	3.72
5.0	3.01

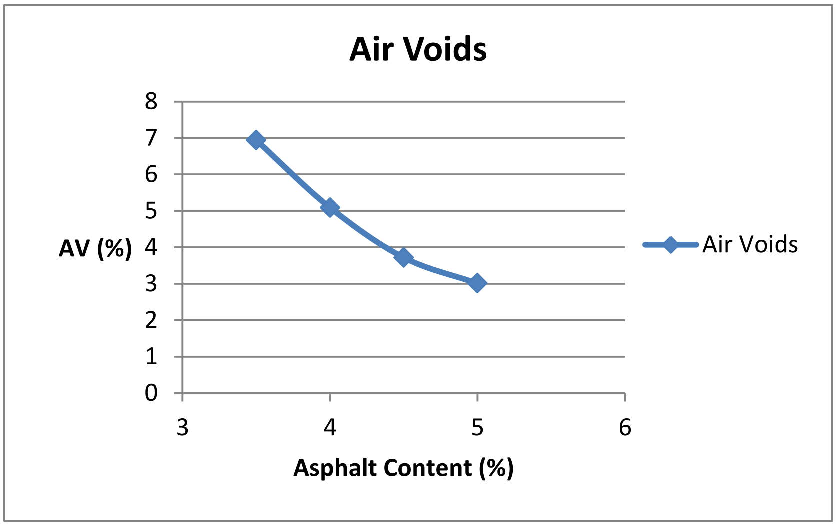

Figure 20: Air Voids vs Asphalt Content

4.3.3.2 Voids in Mineral Aggregate (VMA)

As the asphalt content increases, voids in mineral aggregate decrease. This is due to the fact that more bitumen is available to coat the aggregate particles. The value continues to decrease till the optimum value of 4.5% which shows that all the aggregate particles have been coated completely.

Asphalt (%)	VMA (%)
3.5	15.38
4.0	14.67
4.5	14.34
5.0	14.32

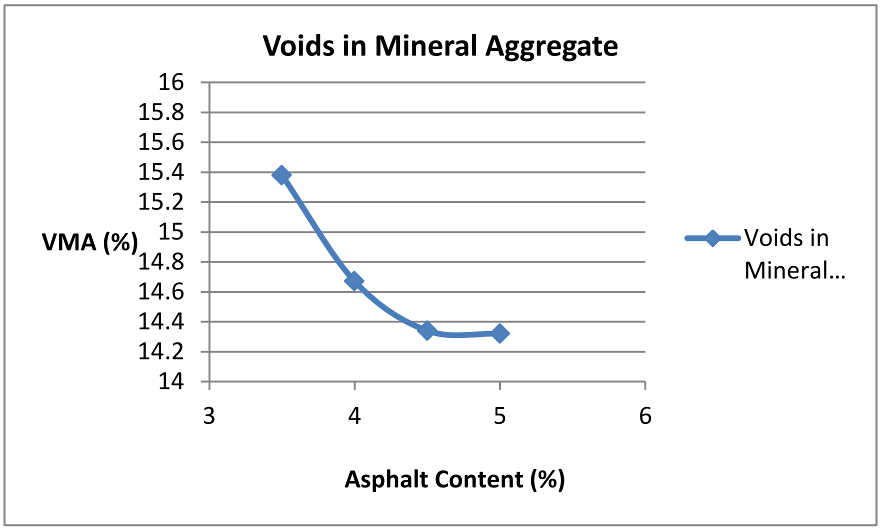

Figure 21: VMA vs. Asphalt Content

4.3.3.3 Voids Filled with Bitumen (VFA)

The relation between asphalt content and voids filled with bitumen is directly related. With an increase in percentage of asphalt, VFA increases. The reason being, more effective bitumen is available to fill the voids. Asphalt content of 3.5% fails to meet the criteria of 65% of VFA.

Asphalt (%)	VFA (%)
3.5	54.88
4.0	65.3
4.5	74.06
5.0	78.98

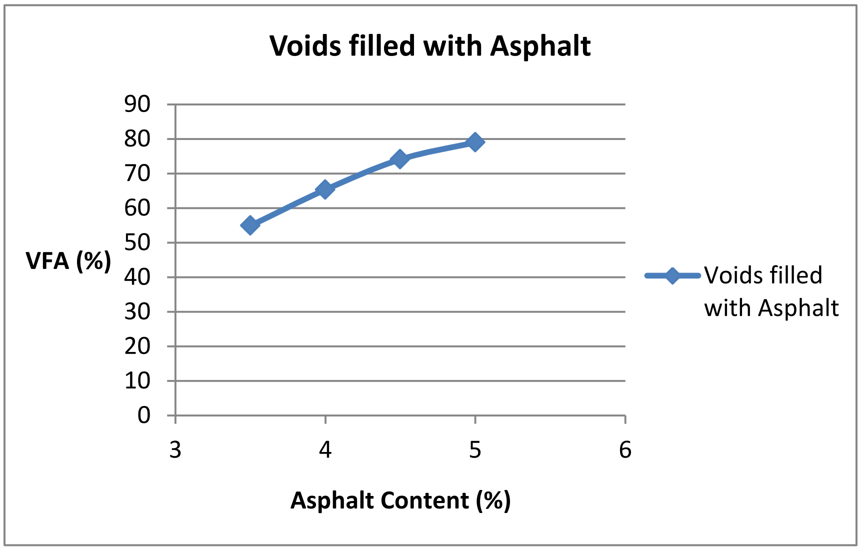

Figure 22: VFA vs. Asphalt Content

4.3.4 Optimum Bitumen Content (OBC)

Optimum Bitumen Content (OBC) is that percentage of bitumen that corresponds with 4% of Air Voids. According to our results OBC came out to be 4.2% by weight of aggregate. Other parameters that are consistent with this value of OBC are

Table 7: Marshall Parameters at OBC

Marshall Stability	**11.1 KN**
Flow	**3.75 mm**
Voids in Mineral Aggregate (VMA)	**14.5%**
Voids Filled with Asphalt (VFA)	**70%**

4.3.5 Plastic Coated Specimen

Optimum values of each modifier, that is plastic and bitumen were used for this sample.

9% plastic and 4.2% bitumen were added and mixed to make this specimen. Three samples were made and the average results are shown below

Table 8 Marshal Parameters at OPC and OBC

Marshall Stability	**15.21 KN**
Flow	**4.1 mm**
Air Voids	**3.84%**
Voids in Mineral Aggregate (VMA)	**14.3%**
Voids Filled with Bitumen (VFA)	**68.6%**

The results show an increase in Marshal Stability Value by 27% when compared with sample without plastic. Flow value also increased and slightly exceeded the limit of 4mm.This result is an indication of better adhesion provided by waste plastic between aggregate and asphalt. The increase in Flow Value might be due decrease in internal friction by addition of waste plastic into the mixture. Percentage of air voids, voids in mineral aggregate and voids filled with bitumen decreased with the addition of plastic. Decrease in air voids prevents the absorption of moisture and oxidation of bitumen due to the trapped air. Hence, plastic has the properties of a good binder and could be used by replacing a specific amount of asphalt binder with it. Further testing is required in this area to find out the amount of binder that could be replaced.

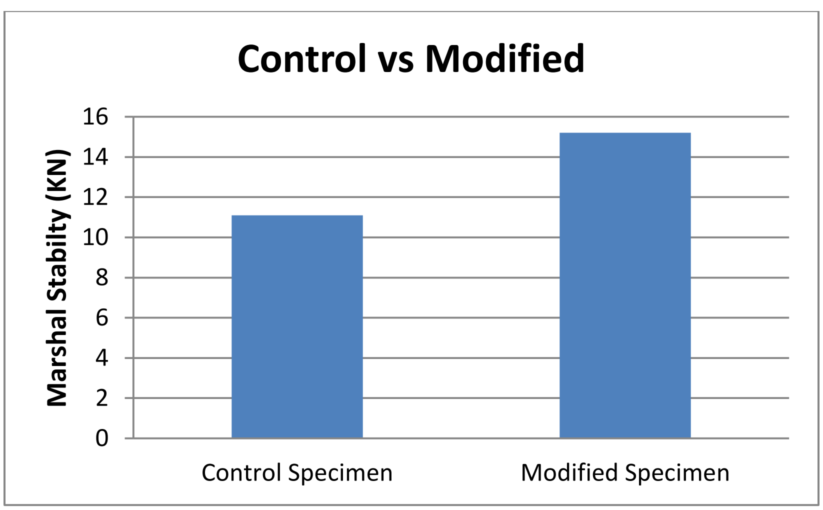

Figure 23: Stability Value Comparison

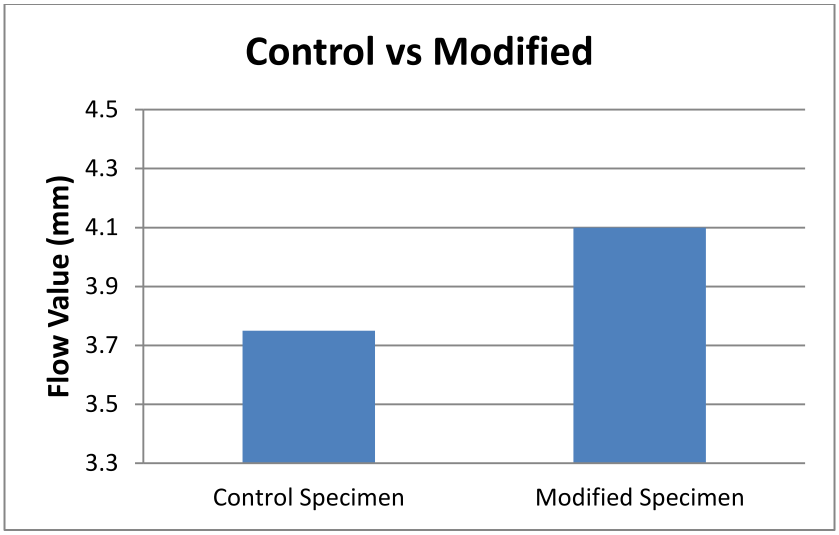

Figure 24: Flow Value Comparison

CHAPTER 5

5. Conclusions and Recommendations

The focus of this research was to analyze the effect of waste plastic bottles on asphaltic pavements. A lot of conclusions were drawn and there are further recommendations to broaden the scope of this area of research.

5.1 Conclusions

- Control specimen had an Aggregate Impact Value of 20.95%. It decreased to 11.91% for plastic percentage of 9%. So, there was a 43.15% decrease in impact value which means an increase aggregate's toughness and resistance to impact loading.
- Aggregate Crushing Value reduced from 21.34% to 14.14%. Value reduced by 33.74% at plastic percentage of 9%. This is an indication of aggregate, strong enough to bear traffic loads.
- Los Angeles Abrasion Value decreased from 20.16% to 10.84%. This value reduced by 46.23%, indicating an increase in the ability of aggregate to resist wear and tear.
- Marshal Stability and Flow Values of control specimen came out to be 11.1 KN and 3.75mm respectively. VMA was 14.5% and VFA was 70% at 4% air voids.
- Marshal Stability Value increased to 15.21 KN for plastic coated specimen. This value increased by 27.02% compared with the conventional mixture. Increase stability Value means stronger and greater load bearing pavements.
- Flow Value also increased to 4.1 mm due to decrease in internal friction and increase in flexibility by addition of waste plastic.
- Percentage of Air Voids, Voids in Mineral Aggregate and Voids Filled with Bitumen, all lied within the permissible ranges and adhered to the ASTM specifications.

- Decrease in Air Voids and Voids filled with bitumen showed that waste plastic could replace the need of bitumen, by some amount. However, detailed study and testing needs to be carried out for that purpose.

5.2 Recommendations

In order to enhance the properties of low quality or weak aggregate, waste plastic bottles could be used to coat them with plastic, thereby increasing their strength, durability and stiffness. This plastic could also be added in the mix for flexible pavements that have better strength, durability and flexibility. Waste plastic when used for this purpose would help in easing the burden on environment and will lead towards a greener and cleaner Pakistan.

Our recommendations for future study relating to this topic are

- Analyzing the properties of bitumen by adding shredded waste plastic bottles in it.
- Varying the amount of plastic and bitumen to determine the content of bitumen that could be replaced by plastic.
- Estimating the amount of money saved due the reduced amount of bitumen used and reduction in waste production by the use of plastic.
- Analyze the effect of plastic coating on the Stiffness and Fatigue life of asphalt mixtures.
- Using Super Pave Mix design and comparing the results with conventional method.

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