PERFORMANCE INVESTIGATION OF HOT MIX ASPHALT USING CLOTH WASTE AS BITUMEN MODIFIER

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DEDICATION

I dedicate this work to my parents, teachers, and my soulmate

who have always provided me with inspiration, love,

and wisdom.

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(Engr. Irfan Ali)

ABSTRACT

In current era where development is on peak in every field, sustainability is the main point of consideration in infrastructure where as in pavement construction sustainability and durability are the main goals. Modification of bitumen with cheap waste material from different sources is concerned with sustainability, while mechanical properties like rutting resistance, resilient modulus etc. are performance parameters which are associated with durability. Numerous studies were performed on bitumen modifications using different wastes, but this study is a pioneer approach towards using Polyester (PET) and Acrylic (AC) cloth waste in HMA as bitumen modifier. This research work evaluates the rutting resistance, resilient modulus moisture susceptibility properties of cloth modified HMA mixtures. Different mixes were designed for Marshall Test using varying ratios (0.1%, 0.25%, 0.5%, 0.75%, 0.9% and 1%) of cloth waste on optimum bitumen content and highest optimum value of 0.75% was selected. For the evaluation of rutting resistance double wheel tracker test was performed, where indirect tension test was conducted to find the resilient modulus and for determination of resistance to water damage TSR test was performed in the laboratory. The rutting resistance and resilient modulus was improved with cloth addition and the resistance to moisture damage was slightly decreased this is because of a little increase in air voids. Furthermore, along with other advantages like sustainability and better performance properties, cloth modification was also found to be cost-effective for pavement construction.

Keywords

Hot Mix Asphalt (HMA); Cloth Waste; Bitumen Modifier; Dry Mixing; Rutting Resistance; Resilient Modulus; Moisture Susceptibility.

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CHAPTER 1: INTRODUCTION

1.1 Background

In modern fast developing world, the demographic and economic figures are growing day by day. And the intend of people to get high standard of living made a significant impact on automobile and fashion industry specifically on garment/apparel sector. With increase in apparel quantity the cloth waste is also increasing, as 92 million tons waste is produced on annual bases [1]. One of our basic needs is clothing and textiles. The textile and fashion industries have been pushed to acquire and bring in effect to manage waste in a sound way and disposal solutions as a result of the growing environmental issues linked to the massive amounts of textile waste dumped in landfills [2]. While the world is going towards sustainability and it's a problem for us to dumb these wastes in landfills. For achieving future goals, modern societies must find ingenious ways to reuse and dispose of the enormous amounts of waste they produce. There are many waste materials that have the potential to significantly supersede traditional materials at different stages in the construction of highways [3].

The infrastructure system of roads is a key aspect in strengthening a nation's economy, most significantly, the existing paved road's length, which is generally used as a measure of country's level of development. A transport system requires roads as its foundational component. They transport traffic and endure repeated loads, and the harmful effects of the climate cause a variety of pavement defects [4] .

On the other hand, the increments in traffic count affect the road condition. The road construction industry is faced with the challenge of developing and constructing asphalt materials with high performance to meet the ever-increasing demand of surging traffic volume and loadings [5] . The decline in performance and useful service life is due to some unwanted factors such as permanent deformation, fatigue thermal cracking, caused by an increment in traffic volume, environmental conditions and human errors at different stages [6]. So due consideration should be given to mitigate rutting, fatigue, and water damage defects in roads. In developed countries asphalt pavements is the most surfacing choice for the road paving, According to the report of National Asphalt Pavement Association (NAPA) 2017 the annual HMA production in USA was about 375 million tons [7]. . Because of its good stability, durability and low moisture susceptibility, Asphalt concrete is most preferred type of pavement [8]. Studies are conducted to enhance the engineering properties of asphalt mixtures by using different additives, polymers, and fibers. From the result it has concluded that the addition of certain additives might significantly enhance the asphalt concrete's performance while bringing fruitful change in construction cost [9].

1.2 Problem Statement

For highway construction asphalt pavement is the most preferred choice for surface's paving. But loss of serviceability and stability due to continuous exposure to some deteriorating factors like heavy cyclic loading, change in environmental conditions etc. are the main concerned problems. Highway agencies are forced to transition from reconstruction of pavement to pavement rehabilitation and preservation programs due to rising traffic demands and a lack of resources. It is crucial to adopt such cutting-edge techniques like road networking, pavement recycling and incorporation of additives etc. that would enable Pakistan to provide its road users with upgraded and higher-performing transport infrastructure facilities while reducing the adverse effects of development on the environment.

Being one of our basic necessities the apparel sector is a key element of every market. While preparing apparel the garment factories produces waste in considerable amount, which is of non-biodegradable nature. And this cloth waste is either burned that produces harmful gases or dumped in landfills which takes years to be decomposed in soil. Now a days studies are conducting on modification of bitumen with different types of substituting polymers.

The current issue is to manage the cloth waste in a better way instead of dumping or burning. In this study, the cloth waste of synthetic nature which have a long life will be utilized to modify bitumen, the most significant and expensive component of asphalt mixture, and its performance will be evaluated.

1.3 Research Objective

The objectives of this research are as follows:

- To evaluate the use of waste synthetic polymer cloth in HMA as bitumen modifier.
- Evaluation of the rut resistance of asphalt mixtures using cloth waste.
- Investigating the effect of bitumen modification with synthetic cloth on resilient modulus of Asphalt mixtures.
- Analyzing the impact on moisture susceptibility of Asphalt mixtures by using cloth waste as bitumen modifier.
- Cost analysis of cloth modified and virgin asphalt pavements.

1.4 Scope of the Research

The ever blooming apparel sector and rapidly increasing population of Pakistan, both call for the best utilization or disposal of cloth waste. The main factors that are responsible for the deterioration and poor service life of roads are vehicular loadings and environmental effects. Currently, Pakistan is witnessing a revolution in transportation, with major development in highways by constructing underpasses, overhead bridges and widening of already built roads. Different studies are conducting to find the best suitable material as additive or modifier that can improve the rutting resistance and stability, and resistance to environmental factors etc. and also helps in cost reduction. As a result, environment friendly, sustainable, and cost-effective pavements are built. My proposal is centered on modifying bitumen with waste synthetic cloth waste. This will have a favorable impact on the environment as well as significant reduction in costs and improve the performance of HMA pavements.

1.5 Thesis Outline

Chapter 1: This chapter provides a brief history and impetus for the research on the performance evaluation of asphalt binder. It also provides a method to the problem statement, hypothesis, and research objectives.

Chapter 2: This chapter provides an overview of past research conducted on the selected topic. It also covers the rheological properties of asphalt mixtures, how to modify it, and the effects of various modifiers on the physical and performance properties of asphalt mixtures.

Chapter 3: This chapter explains the materials and methods used in characterizing asphalt binder with cloth and producing HMA samples for performance testing. Beside with Asphalt performance testing employing the best optimum amount of waste synthetic cloth by replacing bitumen.

Chapter 4: In this chapter the results of comprehensive laboratory testing were explained. And analysis performed with Microsoft Excel.

Chapter 5: This chapter presents the major conclusions drawn the findings of research investigation and recommendation for further studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The conveyance of people and goods from one place to another is referred as transportation. A transport system requires roads as its foundational component. The infrastructure system of roads is a key aspect in strengthening a nation's economy, most significantly, the existing paved road's length, which is generally used as a measure of country's level of development. The transport infrastructure has a direct impact on economic development, because it enables the movement of products and labour in efficient way to get high production. The decrease in labour and production time will result in an increase in regional productivity. Therefore, a country's economy needs a strong road transport system. Therefore investments in the new construction, expansion, and rehabilitation of road transport infrastructure are necessary and unavoidable.

The major issue is that the pavement does not reaches the end age in proposed time but too quickly because of heavy loading and abrupt change in traffic volume. With rising vehicular traffic and pavement age, the rate of pavement deterioration increases, resulting in a significant increase in rehabilitation and maintenance costs. If we do not do rehabilitation or other preventative maintenance actions at appropriate intervals, pavements will deteriorate rapidly, leaving only costly reconstruction as an alternative. To avoid costly constructions, it is cost-effective to conduct cost-effective maintenance and rehabilitation activities at appropriate times.

Environmental and economic considerations have spurred the recycling of synthetic polymer, steel, and a variety of other waste materials. Waste synthetic cloth is one of these waste products that can be utilized to modify asphalt binders and, to some extent, replace bitumen content. For this reason, two types of synthetic cloth of polyester nature (chiffon cloth) and Acrylic nature (umbrella cloth) will be studied and employed in this research.

2.2 Types of Pavements

The term "pavement" typically refers to the surface layer. Highway design, on the other hand, refers to the overall pavement thickness, which comprises the wearing (surfacing), base, and sub-base courses. It is a strong, long-lasting crust that is constructed over the natural subgrade to give cars a stable, level, or flat surface. It is a structure made of layers of materials above a naturally occurring subgrade, and its main purpose is to transmit and distribute the axle loads of cars to the subgrade.

There are two main types of pavements.

- Rigid pavement in which Portland cement are used as binding material to make the concrete slab, that are placed either directly on a granular subgrade or on a subbase made of granular material. Flexure of the slabs transmits load through to the underlying subgrade.
- Flexible pavement in which bitumen is used as binding material and laid in layers over the subgrade, a firm surface layer of granular material. The load is transferred through surface distribution from layer to layer.

Flexible pavements are preferred over concrete roads because they may be gradually improved as traffic volume increases and their surfaces can be crumbled and reclaimed for rehabilitation. Additionally, flexible pavements are less expensive to construct and maintain. In this research flexible pavement is focused so that we can modify the binding material.

2.3 Synthetic Cloth

Clothing is one of our basic necessities, which is made of fabric fibers. Basically there are two types of cloths, one is made of natural fibers like cotton and woolen cloths while the other is made of synthetic polymer fibers like Polyester, Aramid, Nylon, and Acrylic cloths etc. Synthetic fibers are manmade fibers which is prepared through chemical process of polymerization. Natural fabrics have are biodegradable in nature and have age of 5 to 20 years and decompose after discarded. On the other hand the synthetic fabrics have age ranges from 20 to 200 years depending on the type of fiber. They show different behavior to heat, natural fabrics take fire and turns into ash when comes in contact with flame, while synthetic fabrics show different behavior of melting through heating and conversion into a molten mass. The textile industry of Pakistan Is well developed and textile is one of our major exports. Though the apparel sector is on full bloom but the waste it produces is a major risk for environment. This waste is either dumped in landfills or burnt in houses and brick kilns. So disposal of this waste is a major issue. In synthetic fabrics polyester is the most widely used polymer fiber out of 62% total synthetic fibers. Polyester fibers are made from the condensation of petrochemicals through polymerization process.

The other famous synthetic fabric is Acrylic fabrics which are prepared using the synthetic material acrylonitrile. Acrylic fabric is a fossil fuel-based fiber since it is created by reacting specific chemicals with a variety of monomers that have a petroleum or coal base. Some properties of polyester fibers and acrylic fibers [10] are given as under.

Table 2. 1: Properties of Modifier Cloth

S. No	Description	polyester fiber	Acrylic fiber
1	Tenacity (gm/den)	2.2 - 9.5	2.0 - 3.6
2	Density	1.23 - 1.38	1.16 - 1.18
3	Melting point °C	220 - 296	215 - 255
4	Moisture regain %	0.1 - 0.4	1 - 2.5

2.4 Binder modification using Polymer and Fabric Fibers as Bitumen modifier

Road's infrastructure is an essential factor in a country's development so a lot of researches are conducted to enhance the engineering properties of asphalt mixtures while modifying one element with others or by using some natural artificial additives. With the concept of sustainability, different studies were conducted to find the best possible way to utilize the materials which are hazardous to environment. While to make durable and stress resistant pavements in cost effective way a lot of polymers were incorporated in asphalt pavement, and its physical and rheological properties were evaluated. Several additives and admixtures have recently been tested to improve the physical properties of binder. To increase bitumen performance, polymers, anti-stripping additives, chemical modifiers, antioxidants, extenders, oxidants, and hydrocarbons, and have all been utilized [11].

Klinsky, L. M. G [12] modified the bitumen with aramid fibers and polypropylene fiber mixture, in his study of performance properties of asphalt mixture suggested that 0.05% (By total weight of mix) addition significantly improve the resilient modulus values, rutting fatigue and reflective cracking resistance.

ASajjad, SMO Raza [13] worked on modification of bitumen by polyester waste from textile industry in different proportions from 0% to 10%. They concluded from their studies that the engineering properties of asphalt mixtures increases with the addition of polyester waste from textile industry when the ratio of modifier increases.

Al-Sabaeei, A., Napiah, [14] overviewed the properties of denim fibers that are used in pants cloths and stated that this will be a good modifier for bitumen in asphalt mix due to its nature. According to study of A.El, AAbbas [15] the addition of 0.35% (by total weight) waste polyester fiber increases the rutting resistance of asphalt mixture by 40%.

H Chen,Q Xu [16] in his research investigated the volumetric and mechanical properties of asphalt mixtures by using different fibers of lignin, asbestos, polyester and polyacrylonitrile (Acrylic). They evaluated that among these fibers acrylic and polyester fiber shows great increase in marshal stability and rutting resistance when used at 0.35% (total weight of the mixture).

During lab investigation Irfan, M. [17] conclude that crumb rubber modified asphalt mixture gives a huge improvement of 43% in resilient modulus and a slight improvement of 12% in permanent deformation

Karami, M., Nikraz, [18] worked on bitumen modification by Button Rock Asphalt in ratios 10%, 20%and 30% (by bitumen weight). They proposed an increase in resilient modulus when the medication increases but the most favorable ratio is 20% because of its low susceptibility to environmental temperature.

M Shukla, D Tiwari [23] worked on modification of bitumen with glass and polyester. According to their investigation of asphalt mix behavior modified with glass and polyester fiber by the modification results a great improvement in its rheological properties with a significant impact on resilient modulus of 38% and 36%.

In the case study of Somerset, Kentucky by Simpson et al [20] modified asphalt mixture with Polypropylene, Polyester fibers and polymer performance was investigated. They suggested great increment in high temperature resilient modulus by polyester fiber modified bitumen.

Y Zhu, Y Li [21] in his research used fibers of polyester, lignin, and basalt fibers with different percentages of RAP. He studied the rheological properties of the asphalt mixture and stated that the all the mechanical properties were effected positively but polyester fiber modification can greatly improve the resistance to moisture damage when used with RAP.

Al-Hadidy, et al [22] used three types of additives crumb rubber, polyester, and cellulose fibers in different ratios from 0.1% to 0.3%, to study its effect on performance properties of stone matrix asphalt. In his study they found that it affects the rheological properties greatly, but 0.19% (by weight of mixture) inclusion of polyester fiber enhanced the TSR by 37% it means a great resistance to water damage.

Putman, S.N., [23] incorporated waste tire and carpet waste fiber in SMA to compare its effect on rutting moisture susceptibility and toughness with the inclusion of polyester and cellulose fibers. From final results it was concluded that there is no significant difference in impact of rutting and moisture damage, however it is quite more than original ratio as more than 100% TSR value, while toughness was improved except for cellulose.

2.5 Performance Investigation

The description of rutting defect, moisture susceptibility and resilient modulus, as well as performance evaluation by several researchers who carried out performance testing on moisture susceptibility, rutting, and resilient modulus in the laboratory using the standard procedures, is explained.

2.5.1 Rutting

Rutting is the progressive development of a bowel-shaped indentation in the wheel tracks due to an increase in the number of loads applications, and is one of the most significant types of distress that impairs the pavement performance [24]. Rutting is regarded to be a major defect that often occurs on pavement structures due to the nonlinear, viscous, and plastic behavior of asphalt mixes [5].[25]. Rutting is an important parameter while making decision about pavement condition. Different researchers worked to study this property of asphalt mix and concluded some fruitful results by using different aggregates, addition of fibers and replacing some materials with others, to get a high quality pavement that can perform well under various conditions of loadings. Rutting is a flexible pavement's defect which primarily occurs along the wheel path at high temperatures.

Figure 2.1: Rutting Defect in Flexible Pavement (https://www.roadex.org)

The major elements which are responsible for rutting defect are;

- Excessive traffic and heavy loading than the designed condition.
- Pavement layers weren't properly and sufficiently compacted during construction.
- Human errors in mix design.
- Structure defects in lower layers due to which the materials were flown.
- Plastic deformation of asphalt mix.

Through (EN 12697-22) standard by using double wheel tracker machine Arminda, Almeida [26] assessed rutting behavior of HMA, with a procedure used for roller-compacted standard samples that were prepared in a laboratory and had dimensions of (370mm 300mm 40mm) (length width thickness). The method was based on repeatedly moving a typical loaded wheel

(700 5 N or 157 lb) back and forth on a slab formed of the material being evaluated. The test ends automatically after 5,000 load cycles, each of which consists of two passes, or it may end earlier if a rut depth of 20 mm is reached. The temperature is kept 50°C in accordance with the Portuguese Road Administration rules.

To find the rutting resistance of Asphalt mixtures, Quan Lv et al. [27] used HWT test. The HWT experiment was conducted in accordance with AASHTO T 324-11 standard, keeping temperature of 50°C. Superpave Gyratory Compactor (SGC) was used to compact cylindrical specimens to a height of 62 mm and a diameter of 150 mm. Two samples were merged to form one testing sample, which was then run through a steel rolling roller 52 times per minute. After each run through the linear variable differential transformer (LVDT), vertical deformation was measured. The test ends once there have been 20,000 passes, 10,000 cycles, or 20 mm of vertical deformation, whichever comes first. The Double Wheel Tracker (DWT) instrument, made by the CONTROLS firm, was used to conduct tests.

Both of these machines are linked with a desktop. And the designed software develop the deformation curve as the tracker wheel moves back and forth it records the deformation. On the basis of slope curve the rutting and stripping resistance can be evaluated.

2.5.2 Resilient Modulus

The Resilient modulus (Mr) is a material rudimentary property, which quantifies the stiffness of a material. It gives a method for describing the stiffness of materials under different stresses, moisture, and density conditions. Resilient modulus is a measure of response of asphalt concrete to dynamic stresses and associated strains and is an essential factor while designing the flexible pavements through mechanistic approach [28]**.** It represents the behavior of pavement materials when exposed to cyclic loadings (simulating traffic loading). It is the ratio of applied peak deviator stress to recoverable axial strain [29].

According to ASTM-D4123-82, using an IPC Universal Testing Machine UTM-5P the Resilient Modulus of the HMA mixtures is found by performing the indirect tensile resilient modulus test following Standard Test method of Indirect Tension Test for of Bituminous Mixtures. And the test results analysis is typically used to determine whether the addition of any additives substantially changes the stiffness properties of the asphalt mixture [30].

An important factor to take into account while planning pavement and assessing its performance is the stiffness of an asphalt mixture. To ascertain the stiffness of various types of asphalt mixtures and specimens, the resilient modulus test in accordance to standard ASTM D7369 is conducted [31].

2.5.3 Moisture Susceptibility

Moisture damage is defined as the induced reduction in the strength and durability as a result of damaging effects of moisture in asphalt mixtures. This deterioration occurs due to two mechanisms either due to failure of bonding in between bitumen or mastic, fine aggregates and coarse aggregates in asphalt mix or mastic weakening due to moisture presence [32]. And this damage makes a way to premature defects when further water permeates in the adhesion layers.

Due to the low compaction temperature used to produce HMA and the drying of the aggregate inadequately, moisture susceptibility is mostly brought on by moisture that becomes trapped inside the aggregates of the asphalt mix, making them vulnerable to moisture-induced damage [33].

According to the Washington State Department of Transportation, an efficient performance test for assessing moisture sensitivity in the pavement sector is the indirect tensile strength ratio. By doing an indirect tensile strength test on marshal specimens that have been conditioned and un-conditioned, and then calculating their ratio, moisture susceptibility may be calculated [34].

Figure 2.2: Observed Water damage of Flexible Pavement

The performance testing that is globally used for the moisture susceptibility determination in laboratory is indirect tensile Strength Tests (ITS). In accordance to AASHTO T 283-14 standard**,** by measuring the tensile strength of asphaltic mix samples (Marshal Samples), both unconditioned and conditioned, moisture sensitivity can be assessed. The sample is loaded in diametrically until it cracks or can support no more weight; the more loads the sample can withstand, the stronger the pavement will be.

Through using Hamburg wheel-tracker machine the moisture damage can also be evaluated but the most favorable one is ITS method.

2.6 Chapter Summary

In this chapter overview about transportation infrastructure, types of pavement and environment concerns were given. After that the informations about cloth and the waste produces by garment sector were presented. As this is a pioneer approach no researcher has picked completely the same cloth material but various researches about modification of bitumen by fabrics fibers giving fruitful results were discussed. A review about different test methods adapted in the past to evaluate performance properties of rutting, resilient modulus and moisture susceptibility was given. The most popular technique for assessing moisture susceptibility is to do tensile strength ratio test using Universal Testing Machine. According to current research, Double Wheel Tracker (DWT) apparatus is frequently used to assess HMA's resistance to rutting. And to evaluate the resilient modulus of Asphalt mixtures the indirect tension test is used. Though this test is unacceptable about latest ASTM standards and was cancelled down but still used globally for resilient modulus evaluation.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the methodology used to accomplish the research objectives. The methodology involved obtaining all necessary materials from multiple local sources, performing initial tests according to corresponding standards on selected materials, preparing samples to determine the optimum bitumen content (OBC), as well as performing various performance tests using specified standards. These tests are thoroughly explained so as to provide an accurate understanding of the research methodology. In addition to investigating Performance properties of virgin HMA mixtures, specimens with incorporation of acrylic and polyester cloth at various percentages by total weight of mix were also tested during this study. Through volumetric analysis using marshal mix design the optimum bitumen content was found. The incorporation of both type of cloth waste in shredded form was performed through dry mixing technique. After the OBC determination the marshal samples with varying percentages of cloth waste was again tested to compare the properties with original virgin ratio and to find the highest optimum ratio for bitumen modification by cloth waste. And ratio of 0.75% (by total weight of mix) was considered the best one. Using the optimum values of bitumen from marshal mix design, performance samples of virgin HMA and cloth modified HMA were cast for required testing (rutting resistance, resilient modulus, and moisture susceptibility). In order to find the rutting resistance in terms of deformation the HDWT machine was employed. For the determination of moisture susceptibly in terms of TSR value, the indirect tensile strength test at wet and dry conditions was conducted on universal testing machine. The indirect tension test was performed according to ASTM D-7369-20 standard was performed for resilient modulus using the same UTM machine while changing the assembly. The array shown represents the complete methodology adopted in this research.

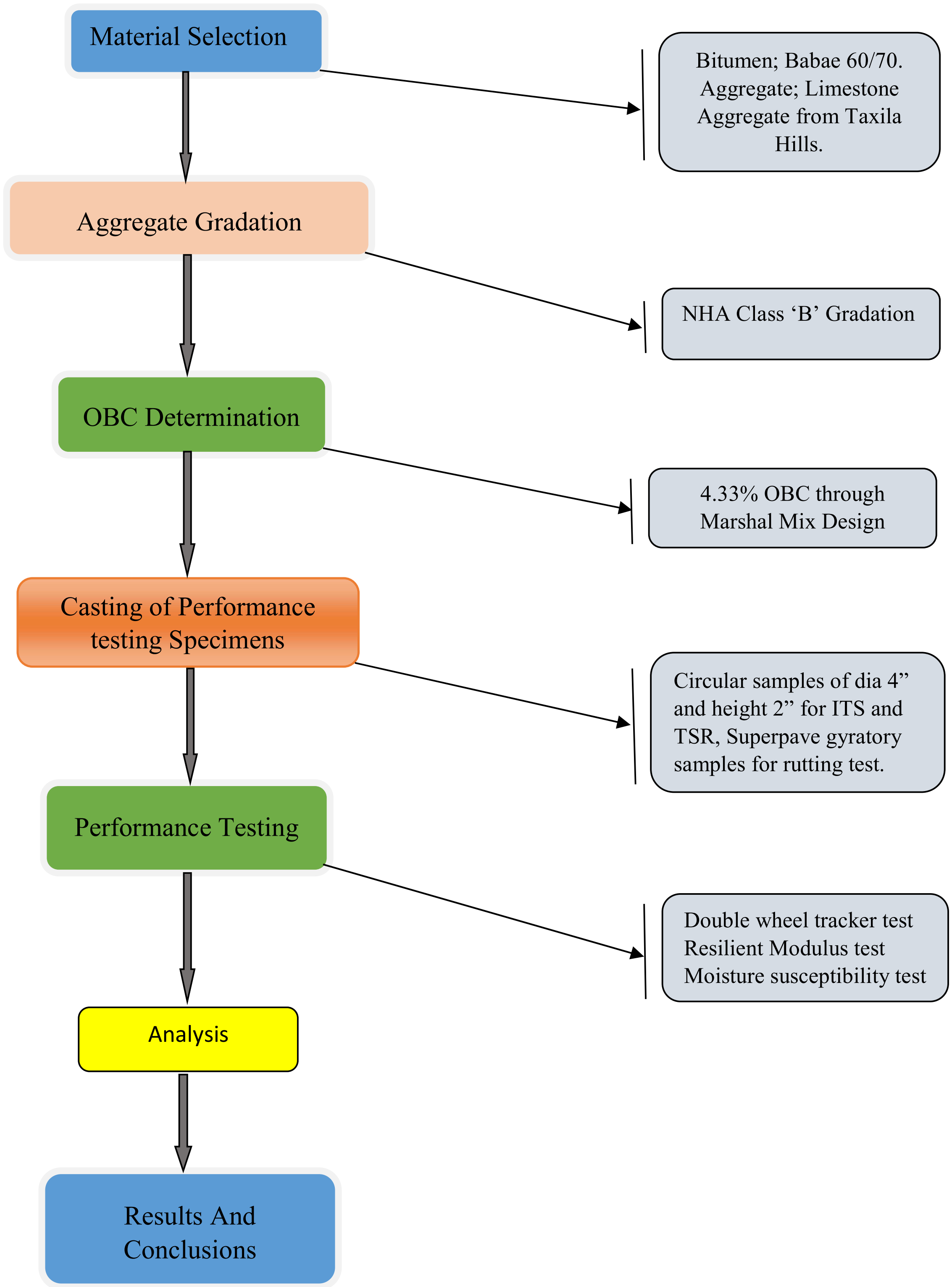


Figure 3.1: Stepwise Array of adopted Methodology

3.2 Materials Collection

Three different Materials including aggregates that were collected from Dhurnal crush plant, Babae bitumen of 6/70 grade from market was purchased and cloth waste (polyester and Acrylic nature) of garment factories were taken from Mardan Pakistan.

3.2.1 Aggregate

From the Margalla Hills near Taxila, Pakistan, virgin aggregates of limestone nature with various available sizes were collected. In flexible pavements the aggregate’s quality is of key importance because it take the overall load of the pavement and its lifecycle length is greatly dependent on the durability and strength of aggregate. In general, angular, and rough-textured aggregates have more ability of resisting stresses of cyclic traffic loadings that may induce permanent deformation in the pavements. Furthermore, the engineering properties were checked according to the concerned standards.

Figure 3. 1: Collected Limestone Aggregate

3.2.2 Binder

According to the performance in Pakistan's climatic conditions virgin bitumen of penetration grade 60/70 was selected for this research due to its suitability for moderate to cold temperature. So Babae bitumen of 60/70 grade was purchased from the market. To analyze conventional properties of binder basic tests were performed according to ASTM standards.

3.2.3 Waste Cloth- Modifier

As there are two types of cloth waste used in this research so waste in cut pieces form of Chiffon cloth (100% polyester nature) that is either thrown away in wastes or taken from the market for burning in houses and brick kilns was collected from an Abaya making garment firm and acrylic cloth waste from an umbrella making tailor in Mardan KPK, Pakistan. After that these waste cloth pieces were cleaned out. The cleaned cloth pieces were cut in shredded pieces of dimensions 12.5mm to 6.5mm using paper shredding machine. These were used as bitumen modifier while casting the performance specimens according to the optimum ratio. The collected and shredded pieces of chiffon and acrylic cloth are shown in figure.

Figure 3. 3: Collected and Shredded Cloth Pieces

3.3 Material Testing

To determine the index properties and suitability for use in road construction, the selected materials were analyzed in a laboratory according to specified standards.

3.4 Aggregate Tests

Aggregate refers to mineral materials like sand, gravel, and crushed stone that can either be naturally occurring or produced through manufacturing. Natural aggregate is typically harvested from large rock formations known as quarries, and then crushed to a size that's suitable for construction purpose. The basic strength characteristics of asphalt mixtures like hardness, toughness, durability, and voids volume etc. are determined by the size, shape, and texture of the surface as well as the gradation of aggregate. Some tests that are performed on aggregates in laboratory are.

3.4.1 Shape Test of Aggregate

The flakiness and elongation of aggregate particles can be found through shape test. The shape test of aggregate is very important parameter because the performance characteristics, and workability is greatly influence by shape of the aggregates. For achieving the desired density the compaction effort is effected by the used aggregate shape. This test determines aggregate's quality and compatibility on the bases of shape to be used as coarse aggregate. It determines the fraction of elongated and flat particles or both in an aggregate sample. This test is performed according ASTM D 4791 standard [35], which classifies particles as flaky if their dimensions are less than 0.6 of their mean sieve sizes, and elongated if their length is greater than 1.8 of their mean sieve sizes. Collectively the elongation and flakiness indices are taken to be less than 30%. To make a better interlock the angular shape aggregates are the most desired one. Table 3.1 represent the results of the shape test which are in acceptable range.

Figure 3. 4: Apparatus And Shape Test of Aggregate

3.4.2 Impact Value Test

To check the resistance of aggregates to sudden impact loading impact value test can be used, as aggregate impact value characterizes relative strength to sudden shock. For the determination of impact value (2.36 mm), the testing assembly, tamping rod, and sieves of specified sizes (1/2", 3/8", and #8) were all the required tools to be used. 350g representative sample of aggregate was obtained from sieved material (1/2" sieve passed 3/8" sieve retained) and placed it in the Impact Testing Machine mould in three layers by tamping 25 times each individual layer with a rammer of weight 14 kg. The crushed material was sieved through #8 sieve after extraction from the mould. And its proportion was used to calculate the impact value of the aggregate.

Figure 3. 5: Impact Value Test Apparatus

3.4.3 Los Angeles (LA) Abrasion Test

The wear and tear resilience of aggregate caused by traffic loadings was assessed by performing abrasion test. It is mandatory that aggregate should pass the toughness criteria. The LOS Angeles machine, a set of sieves, steel balls, and a balance were utilized for testing. Approximately 5000g (W_1) of aggregate sample was fed in the Los Angeles Machine from representative sample with 11 steel balls, half of which (2500gm) were retained on a 1/2" sieve and half retained on a 3/8" sieve and the . After 500 revolutions, while rotating the drum at 30 revolution per minute, the material from the machine was removed and passed through a 1.7mm sieve, and the weight (W2) of the passing sample was recorded. Using following formula Abrasion value was calculated.

$$AV = W2 / W1 \times 100$$

Figure 3. 6: Loss Angeles Abrasion Machine & Testing

3.4.4 Aggregate Crushing Value

To build reliable pavement having better properties of durability, deformation resistance, and long lasting life, the aggregates must have sufficient strength to withstand traffic stresses. The crushing value test equipment's includes an open ends steel cylinder, a base plate, a plunger having a piston of a diameter 150 mm and a hole across it for raising through a rod, cylindrical measure, balance, tamping rod, and compressive testing machine. Selected aggregate sample of specified dimensions was oven dried after washing thoroughly and taken as (W_1), and then fed in the cylindrical measure in three layers while tamping 25 times each individual layer with tamping rod. The plunger was inserted after shifting the aggregates to steel cylinder with base plate, and then placed in the compression machine. It was loaded at uniform rate of 4 tons/minute till the load reaches to 40 tons. After crushing the aggregate sample was taken out and sieved with specified sieve (2.36mm). The passing weight was taken as (W_2), while using formula the aggregate crushing value was calculated.

$$ACV = W2/W1 \times 100$$

Figure 3. 7: Crushing Value Test of Aggregate

3.4.5 Specific Gravity and Water Absorption Test of Aggregate

The purpose of this test is to find the credibility of aggregate to be used in pavement construction. As specific gravity gives information about the strength of aggregate while water absorption gives idea about the porosity of aggregate, lighter the aggregates so smaller will be the strength and porosity is a critical parameter because of asphalt absorption by aggregate during mixing. Measurements of aggregate's specific gravity and water absorption were made in accordance with the methods and specifications defined in ASTM C 127-15 [36]. In this test, four different weights were taken: the weight of the aggregate and metal basket submerged in water (W_1), submerged weight of the metal basket (W_2), the weight of the aggregate in saturated surface dry condition (W_3), and the weight of the aggregate dried in an oven (W_4). Using these values the specific gravity and water absorption of the coarse aggregate was calculated through following formula;

$$\text{Specific gravity} = \frac{W_2 - W_1}{((W_4 - W_1)-(W_3 - W_2))}$$

$$\text{Water Absorption} = \frac{W_3 - W_4}{W_4} \times 100$$

The results obtained from the preliminary laboratory testing are tabulated as;

Table 3. 1: Physical Properties of Aggregate

S. No	Specifications	Standards	Results	Limits
1	Impact value	BS 812	16.10 %	≤ 30 %
2	Flakiness index	ASTM D 4791	11.21 %	≤ 15 %
3	Elongation index	ASTM D 4791	4.02 %	≤ 15 %
4	Specific gravity	ASTM C 127	2.66	-
5	Water absorption	ASTM C 127	0.60 %	≤ 3 %
6	Crushing strength	ASTM D 5821	26.25 %	≤ 30 %
7	Abrasion test	ASTM C 131	20.20 %	≤ 45 %

3.5 Asphalt Binder Tests

In hot mix asphalt the material component that act as binder is Asphalt. It is obtained from crude oil through petroleum distillation and having either dark brownish or black coloration. For use in pavement construction the knowledge about certain properties of bitumen is very important. Bitumen’s safety, purity and consistency are main parameters that define the quality which have direct impact on Asphalt mix’s performance. Moreover the bitumen properties are also influenced by age and temperature, because the consistency changes with temperature. Some tests that are performed on bitumen in laboratory are.

- Penetration test.

- Softening point test.
- Ductility test.
- Flash and Fire Point test.

3.5.5 Penetration Test

This test was performed according to standard AASHTO T 49-03 for checking the grade of bitumen. For grade determination the depth to which the standard needle that would vertically penetrate a sample of asphalt binder under specified conditions of, loading, and time duration was measured in tenths of millimeters as part of an asphalt binder penetration test. In soft bitumen the needle penetration is more than hard bitumen so it has higher penetration values than hard bitumen. In accordance to AASHTO T 49-03, the test was performed at room temperature of 25 C^o, with needle loading of 100 grams with time duration of 5 seconds. Following the completion of test on three specimens, three values were taken for each individual specimen. All the collected data were according to the criteria specified in the concerned standard and the results are tabulated in table 3.2.

Figure 3. 8: Penetration Test of Bitumen

3.5.2 Softening Point Test

The temperature at which the bitumen soften beyond which it start flow when heated under a specified load is known as softening point of bitumen. This test was performed according to standard ASTM D 36, through Ring and Ball apparatus. As bitumen is a viscoelastic substance and when heated its viscosity decreases and a time reaches when it does not support the 3.5 gms steel ball and start downward flow in submerged water and this temperature is taken as softening point. The bitumen was first heated at a temperature that allow it to flow while retaining its properties. It was then shaped as a horizontal disc while placing it in a mould. After being inserted in the apparatus, the balls were placed on the discs.it was then heated until the temperature reaches to a point where the binder allow the balls to fall through the specified distance of 25mm at the base of the jar. The results obtained are given in table 3.2.

Figure 3. 9: Ring And Ball Apparatus

3.5.3 Ductility Test

This test was performed according to standard ASTM D 113. Ductility represent the adhesion property and stretching ability of bitumen that how much it can elongate without breaking. It is defined as the distance in cm that a standard bitumen specimen (fitted in a briquette with a 1in 2 cross section) can be stretched without breaking at a certain speed of 5 cm per minute and at a set temperature of 25 ºC is known as the ductility of an asphalt binder. The specified range for ductility of a bitumen's specimen should be equal or higher than 100 cm. Three specimens of the selected bitumen were tested for ductility test and the average of all these was fulfilling the criteria of the standard. The obtained results are shown in table 3.2.

Figure 3. 10: Ductility Test

3.5.4 Flash and Fire Point Test

This test was performed according to standard ASTM D 92-12. The main purpose of this test is to observe the safety at site while working with HMA. The lowest temperature that causes the asphalt binder to suddenly flash when exposed to flame under certain conditions is referred to as the flash point. While when the surfaces catches fire for at least three seconds then this temperature is known as fire point. First of all the bitumen was heated at a temperature at which it sustain its properties, then it is poured in Cleveland Open-Cup. The

Cleveland Cup was then heated at a steady rate and a test flare was passing over it after some interval. With a uniform increase in temperature two instants reach at which the Cleveland cup's surface flashes and at other it catches fire these temperatures are noted and taken as flash and fire point of the bitumen. Three specimens were tested and average of all these results are taken and are shown in table 3.2.

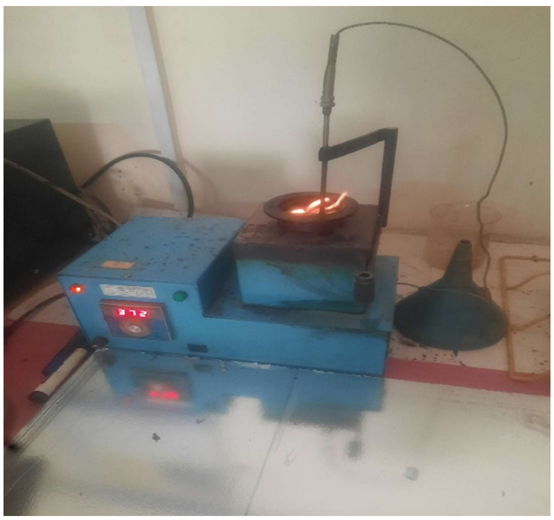


Figure 3. 11: Flash And Fire Point Test

The results obtained from the physical testing of the bitumen are tabulated as;

Table 3. 2: Physical Properties of Bitumen

S. No	Test Description	Specifications	Results	Limits
1	Softening point	ASTM D36 - 95	49.13 °C	49 – 56 °C
2	Flash point	ASTM D92	342 °C	Min 232 °C
3	Fire point	ASTM D 92	370.5 °C	Min 320 °C
4	Penetration Test	ASTM D 5- 06	64 pu	60 -70 pu
5	Ductility Test	ASTM 113-99	Over 100 cm	Over100 cm
6	Specific gravity	ASTM D 70	1.02	Over100 cm

3.6 Gradation Selection

This research study employed NHA Class B gradation, which was established by Pakistan's National Highways Authority (NHA) in 1998 and is frequently utilized for flexible pavement there. For wearing coarse class B gradation, the nominal maximum aggregate size is taken as 19mm (3/4"). From NHA gradation 'B' curve our selection was the midway between upper and lower limit that is shown in the figure 3.11, and tabulated as;

Table 3. 3:* NHA *Class B gradation

S. No	Sieve size (Passing mm)	NHA Specification of Class B gradation	Mid Selection	Retained (%)
1	19	100	100	0
02	12.5	75-90	82.5	17.5
03	9.5	60-80	70	12.5
04	4.75	40-60	50	20
05	2.38	20-40	30	20
06	1.18	5-15	10	20
07	0.075	3-8	5.5	4.5
08	pan	--	-----	5.5

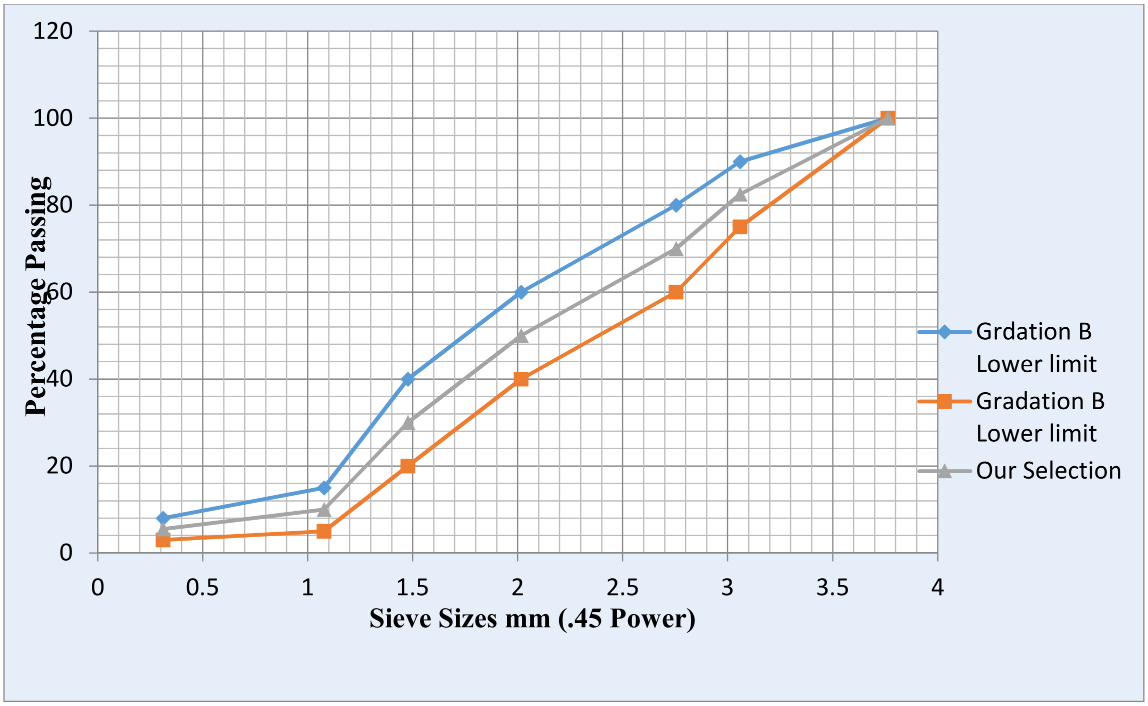


Figure 3. 12: NHA class-B gradation curve

3.7 Asphalt Mix Preparation

The basic concept in developing asphalt mixtures is that the pavement can perform well admired for a very long time if the best binder and aggregate combination is used. Because of the importance of aggregate structure in preventing deformation, mix design ought to incorporate a mix that can withstand consolidation under traffic stress while creating minute changes in air voids after construction. The HMA should have convenient mechanical properties to resist stresses that is creating due to moisture change, shear and tensile loadings, and this can be achieved by using suitable aggregate with proper gradation to bring required air void amount in the mix. In the laboratory, various methods have been developed to determine the proper proportions of mix components, but the Marshall of the Mississippi Department of Highway invented the methodology for designing asphalt mixtures in 1939. The recommended specification for this test is ASTM D 6926-20 [37]. It is only best to use for HMA having maximum aggregate size of upto 1 inch (25 mm). The modified approach is used if the mix's aggregate size is more than 1 inch.

Table 3. 4: Test Matrix

S. No	Bitumen Ratio (%)	No of Samples
1	3.5	3
2	4	3
3	4.5	3
4	5	3
5	5.5	3
	Total	15

3.8 Aggregate and binder Preparation

The aggregates were first separated into several containers after being sieved through a set of sieves according to specified sizes of NHA class B gradation. Then it were dried to consistent weights at 105°C to 110°C following sieve analysis. The Marshall mould has a height of 2.5 inches (63.5 mm) with diameter of 4 inches (101.6 mm), and an individual Marshall sample requires material having total weight of approximately 1200 gms. The amount of binder required to prepare the Marshall specimen was calculated as a percentage of total weight of the asphalt mix using below formula;

$$T = A + B$$

$$B = X / 100 (T)$$

Where;

T = Mixture's total mass, B = Total Binder's mass

A = Total Aggregate's mas, X = Bitumen percentage in the mix.

Figure 3. 13: Graded Aggregate

3.9 Mixing of Bitumen and aggregates

In accordance to ASTM D 6926 the mixing should be performed through mechanical or hand mixer to thoroughly mix the material. After being removed from the oven, the hot bitumen and aggregate had been put into the mixer. The binder should be blended at a temperature of 0.22 to 0.45 Pa.sec, as defined by the Superpave mix design (SP-2). As consequently, a temperature range of 160°C to 165°C was selected which complies with the NHA (Pakistan) Specifications temperature for the production of bituminous mixes.

Figure 3. 14: Automatic & Manual HMA mixing

3.10 Marshall Mix Compaction Procedure

The ASTM D-6926 standard suggests two hours conditioning of the mixes before compaction. Consequently, after mixing, the HMA mixture was put into pan and heated to 135°C in the oven for compaction. After the conditioning of two hours, the mix was compacted at 135°C using an Automatic Marshall Compactor. The cylinder, having 3 inches height with 4 inches inner diameter, is part of the mould assembly together with the base plate and the extension collar, which can be swapped on either end of the mould. Cleaning and preheating the mould at 135 °C in the oven, and insertion of a piece of filter paper having size of the mould's diameter at the bottom was done prior to loading. Using scoop and spatula, the mixture was then poured into the mould, and after pouring three layers, a piece of filter paper was placed on top. Using the mould holder to hold the mould assembly in the compaction pedestal it was then placed in automatic compaction machine. In accordance to the Marshall Mix Design criteria, a Marshall Compactor was used for compaction. It uses a motorized compactor having an 18-inch drop. For the heavy traffic criterion, Marshall Mix design was executed using 75 strokes on both side of the specimen.

After both sides had been compacted, the assembly was removed, and the sample was allowed to cool to the proper temperature before the extraction. An extraction jack was then used to remove the specimen from the mould. These removed samples were laid out on a level surface and given time to cool to the room's temperature.

Figure 3. 15: Compaction of Marshall Samples

3.11 Volumetric analysis and OBC determination

For determination of optimum Bitumen Content (OBC), the procedure endorsed was according to National Asphalt Pavement Association. The controlled HMA sample was prepared using the Marshall Mix Design ASTM D-6927 standard [30]. Using varying bitumen content of 3.0%, 3.5%, 4.0%, 4.5%, 5.0%, and 5.5% the HMA samples were prepared. Then its stability and flow test was performed using Marshal Stability test machine. And the bulk density and theoretical specific gravity was determined that are used for volumetric properties analysis. The volumetric properties like stability, flow, air voids etc. are tabulated as;

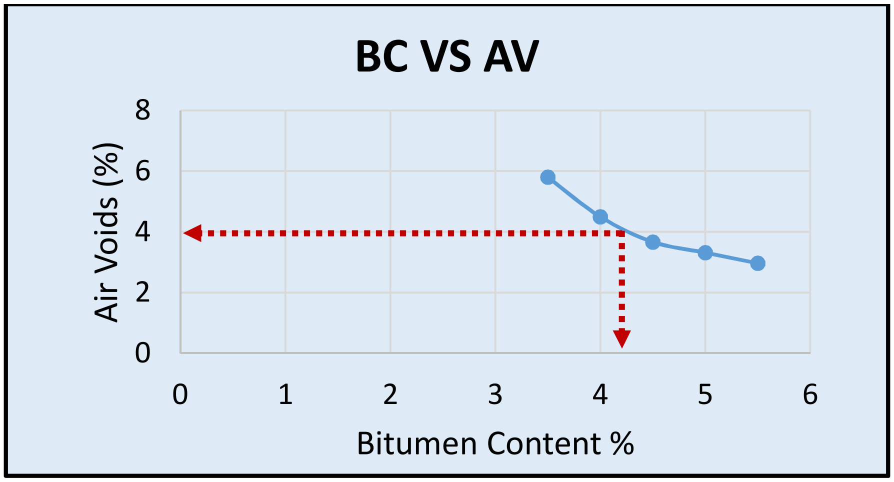
Table 3. 5: Volumetric Analysis for OBC determination

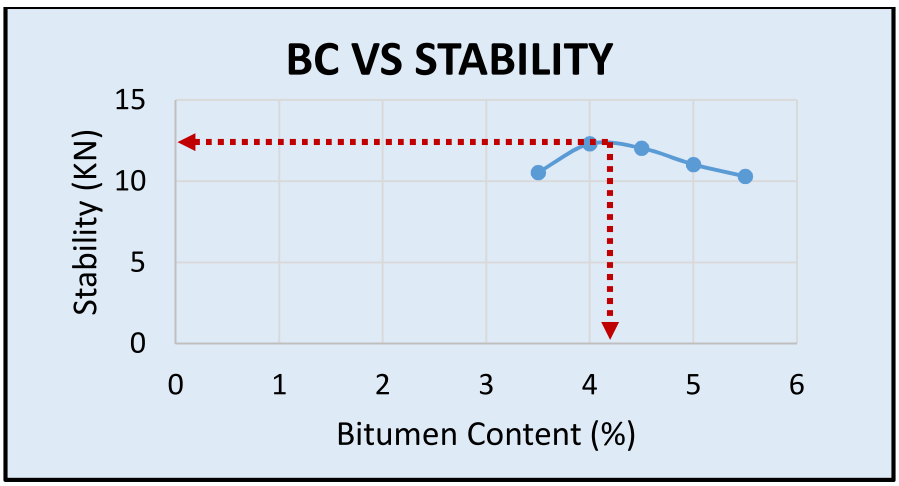
BC (%)	Stability (KN)	Flow (mm)	Gmb	Gmm	AV (%)	VMA (%)	VFA (%)	Aggregate (%)
3.5	10.529	2.326	2.339	2.483	5.79943	13.84981	58.12624	96.5
4	12.304	2.481	2.358	2.469	4.49574	13.6	66.94303	96
4.5	12.036	3.174	2.365	2.455	3.66598	13.79485	73.42495	95.5
5	11.036	3.598	2.361	2.442	3.31695	14.39122	76.95155	95
5.5	10.304	4.27	2.358	2.43	2.96296	14.95	80.18085	94.5

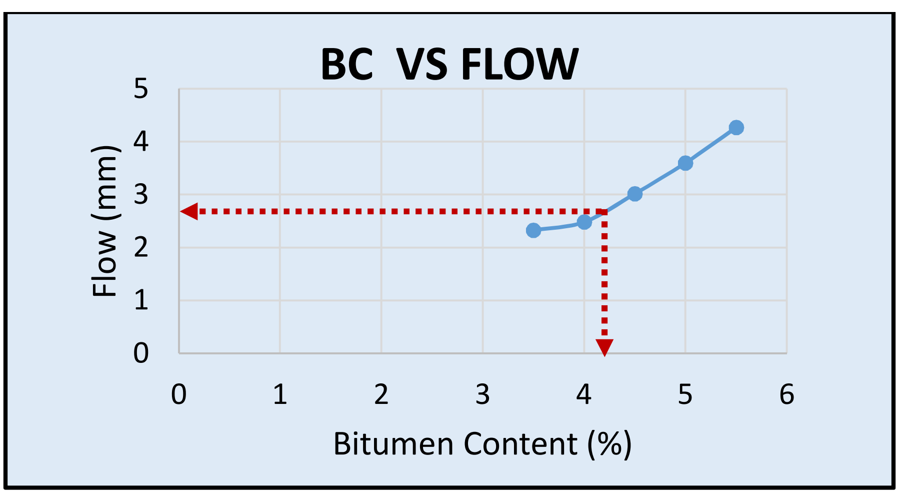
Do determine the optimum bitumen content for virgin HMA, in accordance to MS-2 manual the graphs between bitumen content and volumetric properties were drawn which is shown in figure 3.15 and Job Mix Formula of this selected mix are given in table 3.6.

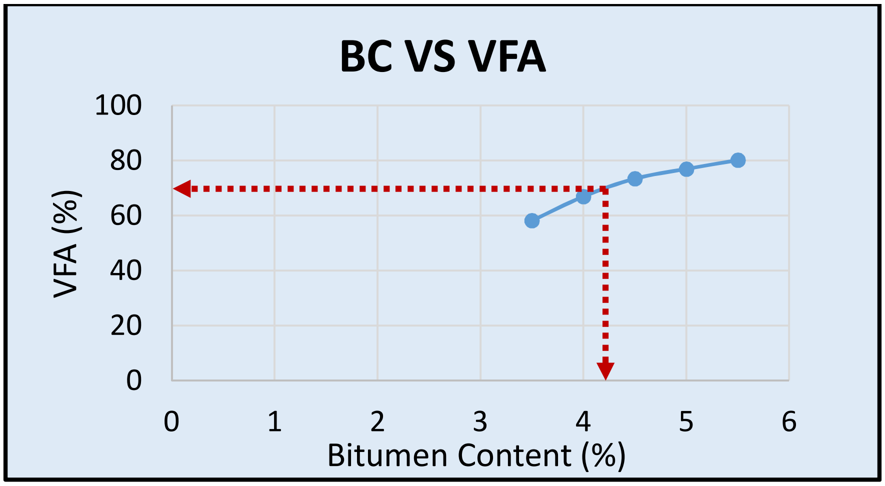
Table 3. 6: Volumetric Properties of HMA at OBC

Parameters	Measured value	Criteria	Remarks
OBC	4.33 %	NA	----
VMA	13.71 %	13 (min)	pass
VFA	70 %	65-75	pass
Stability	12.14 KN	8.006 (min)	pass
Flow	2.89 mm	2.0-3.5	pass


BC VS AV
Air Voids (%)
Bitumen Content %
0
2
4
6
8
0
1
2
3
4
5
6


BC VS STABILITY
Stability (KN)
Bitumen Content (%)
0
5
10
15
0
1
2
3
4
5
6


BC VS FLOW
Flow (mm)
Bitumen Content (%)
0
1
2
3
4
5
0
1
2
3
4
5
6



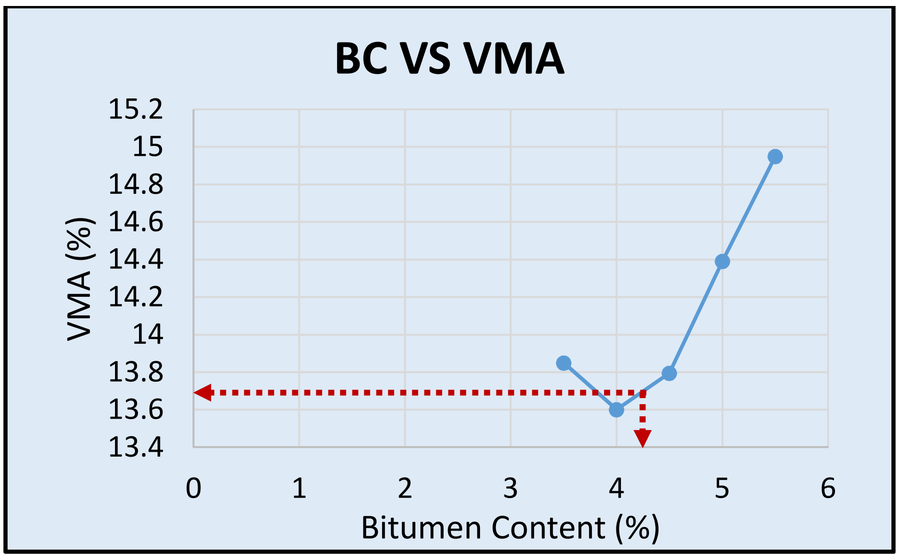


Figure 3. 16: Volumetric Properties of HMA at OBC

3.12 Preparation And Volumetric Analysis of Cloth Modified HMA Sample

As the main concern of the research was the incorporation of cloth waste so it was used through dry mixing technique in different ratios of 0.1% to 1% (by total weight of mixture) with increment of 0.25 to get the optimum ratio through which bitumen have to be modified. Due to high melting point of these fabrics, the aggregate was heated at 260 ˚C before mixing for 30 minutes, while the bitumen was separately heated at 110˚C in the oven. The shredded pieces of the cloth were added after heating of aggregates and thoroughly mixed to coat the aggregates with this melted polymer. To bring the temperature to mixing range of up to 160˚C it was cooled. And then the required weight of bitumen (reduced due to modification with cloth) according to OBC was added. Furthermore, the specimens were made according to the standard marshal sample preparation procedures. 0.75% modification was selected as optimum after testing for volumetric properties as it gives maximum modification while keeping all volumetric properties in allowable range.

Table 3. 7: Volumetric Properties of Cloth Modified HMA

S. No	**Description**	**Results**		**Criteria**
		PET Cloth Modified HMA	**AC Cloth Modified HMA**	
1	Stability (KN)	12.646	14.54	8.06
2	Flow (mm)	3.31	3.47	2 – 3.5
5	AV (%)	4.344	4.068	2 - 5
6	VMA (%)	13.943	13.87	>13
7	VFA (%)	68.842	69.668	65-70

3.13 Performance testing samples preparation

After optimum bitumen content determination, samples for three performance testing were prepared i.e. Rutting Resistance, Resilient Modulus and Moisture susceptibility.

3.13.1 Double Wheel Tracker Test

For rutting resistance or permanent deformation of HMA mixture double wheel tracker test was performed. According to AASHTO T324-14 [38], the universal double Wheel Tracker was used to determine the mixes' sensitivity to premature failure as their resistance to permanent deformation and rutting. 3 specimens of every individual ratio were prepared according to the selected gradation through gyratory compactor. The blending of bitumen and aggregates were performed according to the method discussed in above sections. Then it is kept for conditioning in oven for two hours at 135 ºC. After the conditioning the mix were poured into gyratory compactor mould having plates with filter paper on both sides and then kept in gyratory compactor to compact through gyrations of about 125. After the sample had been compacted to the desired level, the mould containing it was removed from the gyratory compactor, and the sample of dimensions measuring approximately 6" in diameter and 6" in height was then extracted using a mechanical ejector. After that samples having dimensions of diameter 6inch and thickness 2.4inch was cut down from Superpave gyratory compacted specimens through saw cutter. And then tested in wheel tracker machine by exposing it to loading of 705N (158 lbs.) with 25cycles/min through a steel wheel that was 50mm broad for as long as it took for 12.5mm of deformation.

Figure 3. 17: Rutting Samples Preparation and Testing

3.13.2 Indirect Tension Test

Indirect tension test was performed to find the resilient modulus. The ASTM D-7369-20 standard (39) was followed in the execution of this test. With a total of 9 specimens, having dimensions of the same Marshall samples were used. Using Marshall Mould, the testing samples were prepared through same method on which Marshall's specimens were prepared with modification of bitumen with shredded pieces of individual cloths. In order to get the samples to test temperature, they were kept in an air bath at 25 °C for 4 hours after being allowed to cool at room temperature for 24 hours. After that the sample was loaded into the universal testing machine (UTM-25), and the linear variable differential transducers

(LVDTS) were kept in position both horizontally and vertically by means of an alignment mechanism. 15cycles/min of loading stress was applied while the loading strips and sensors were in fixed place and the resulting response was recorded through five load pulses. From every individual mix combination three samples were evaluated, and the average finding values were reported.

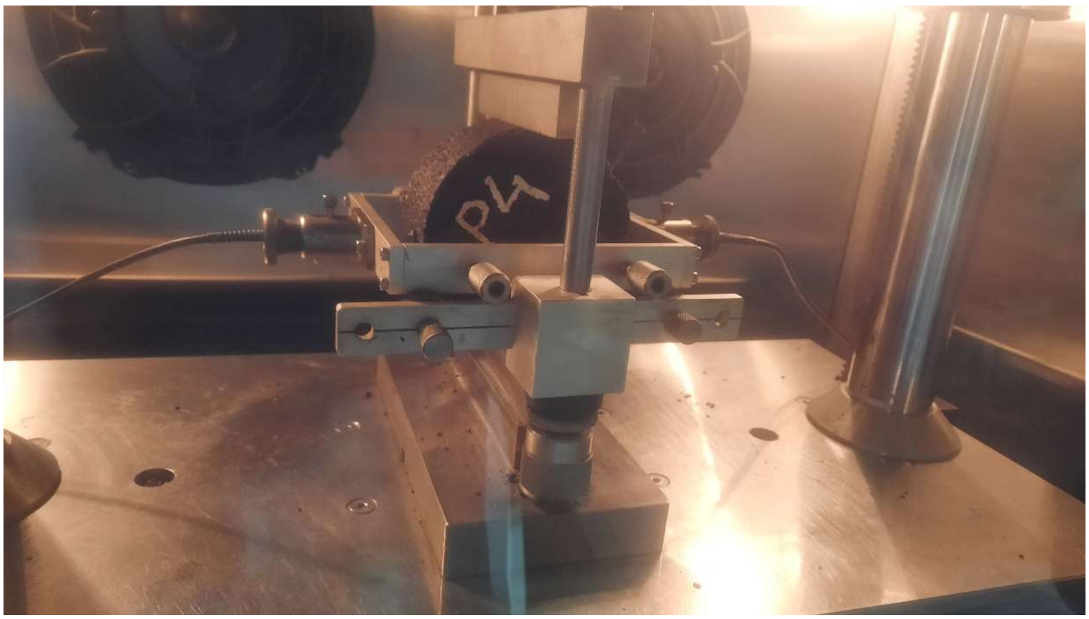


Figure 3. 18: Resilient Modulus Test Samples in UTM-25

3.13.3 TSR Test

This test was performed according to AASHTO T 283-14 standard [40]. Specimens of same size as that of Marshal was prepared through same procedure and divided into two sets for determination of dry and wet indirect tensile strength. For wet specimens conditioning was performed by keeping these samples in water bath at 60°C for 24 hours. Then it was cooled at 25°C temperature for 1hour to match the testing temperature range. In Universal testing machine (UTM-25), compressive stress in a vertical plane along the specimen's diameter was used to determine the indirect tensile strength of the mix. The sample breaks by splitting along the vertical diameter as shown in the picture because of uniform tensile stresses that are generated by the loading configuration in the direction of the applied load. After testing the wet and dry ITS values were calculated using equation.

$$\text{ITS} = \frac{2P_{\text{max}}}{\pi t d},$$

Where P_{max} = Maximum applied load,

t = Sample's thickness,

d = Sample's diameter.

And tensile strength ratio is equal to;

$$\text{TSR}(\%) = \frac{\text{ITS}_{\text{wet}}}{\text{ITS}_{\text{dry}}} \times 100.$$

Figure 3. 19: Indirect Tensile Strength Test

3.14 Summary

This chapter describe the adopted methodology and material characterization to achieve the targeted objectives. According to the performance in Pakistan's climatic conditions virgin bitumen of penetration grade 60/70 (Babae 60/70) was selected and purchased from market for this research due to its suitability for moderate to cold temperature. Virgin aggregates of limestone nature with various available sizes were collected from the Margalla Hills near Taxila, Pakistan. Conventional testing were performed before blending it. For OBC determination volumetric analysis were carried out. The pieces of waste cloth that was obtained from different garment firms of Mardan was first shredded using shredding machine. To make the mix with cloth modification the sieved aggregate was firs heated to desire temperature and then calculated amount of PET and AC cloth pieces were added in individual samples, then it is mixed thoroughly so that the polymer cloth melt down and cover the aggregate. After that the required bitumen was added and blended down for specified time to prepare the HMA mix. The sample preparation and performance tests were discussed and testing procedures were elaborated.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Introduction

In region of variable environmental temperature like Pakistan having moderate to cold environmental conditions and high loadings, the most common distresses are fatigue cracking, rutting and moisture damage etc. so this study focuses on the replacement of bitumen through cloth waste to check the resistance against main selected pavement's distresses. Using various percentages of cloth waste an optimum value was selected. On the selected optimum percentage the blending of aggregate and binder was performed using cloth waste as bitumen modifier. The performance testing were carried out on cloth modified samples. The main purpose is the modification percentage of bitumen through cloth waste that cannot adversely affect the mechanical properties of virgin HMA.

4.2 Performance Testing Results

For evaluation of Asphalt mix's performance having virgin bitumen and modified bitumen with cloth waste various performance tests were performed. The results obtained are discussed below.

4.2.1 Rutting Resistance

Wheel tracking tests were performed in dry conditions on specimens prepared for rutting. A total of nine samples were tested, three for each individual mix. Likewise the improved performance of using rubber modified asphalt in HMA studied by G.H, and M. Sadeghnejad [41], the cloth modification also enhanced the HMA mechanical properties. All the tested specimens showed excellent rutting resistance, where cloth modification further improved the rutting resistance as polyester cloth and acrylic cloth modification have shown a decline of 13.63% and 9.33% in rut depth. All of the samples passed the wheel tracking test requirements of 12.5 mm rut depth at a temperature of 45°C, which is the required testing temperature for bitumen of grades 60/70 that is utilized in this research. The number of passes was also fixed at 10,000, which is the required rutting criteria. According to study of M Shukla, D Tiwari [23] the modification of asphalt with polyester fiber results 21% reduction in rut depth. The results of the wheel tracking tests are reported in Table and graphically displayed in Figure;

Table 4. 1: Results obtained from DWT Test

Cycles	Virgin HMA rut depth (mm)	0.75% PET cloth modified HMA rut depth (mm)	0.75% AC cloth modified HMA rut depth (mm)
1	0	0	0
1000	3.05	2.72	2.68
2000	3.39	2.96	3.02
3000	3.71	3.39	3.49
4000	3.96	3.48	3.77
5000	4.18	3.61	3.88

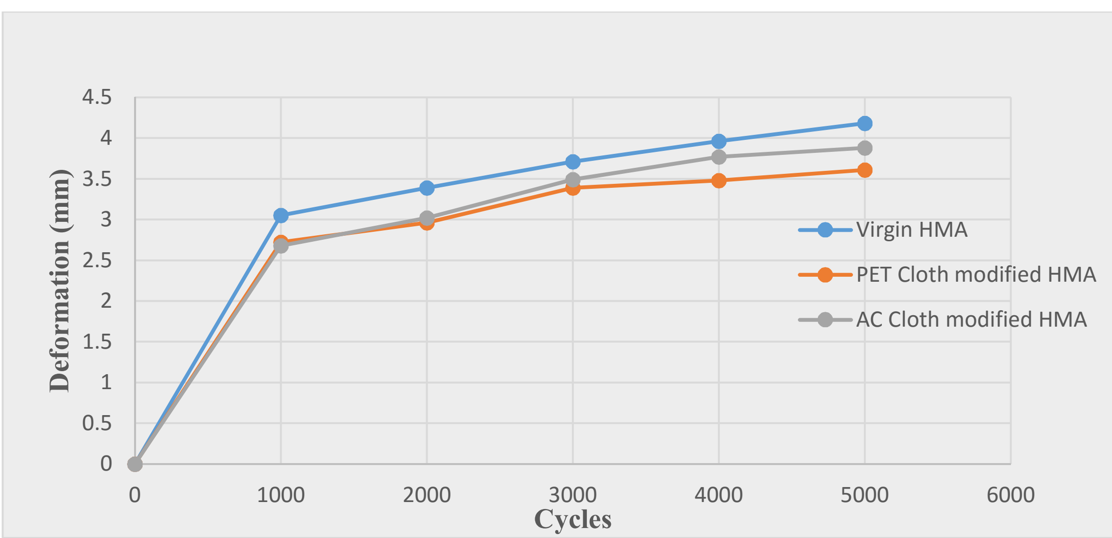


Figure 4. 1: Graphical representation of Results obtained from DWT Test

4.2.2 Resilient Modulus Test Results

The indirect tension test was performed to analyze the influence of cloth modification on the stiffness properties of HMA mixtures. Using cloth modified bitumen as binder showed a huge enhancement in the resilient modulus values. A total of nine samples three for each mix were tested under cyclic loading of standard frequency. The control mix showed the lowest value of 1230.5MPa and polyester cloth modification showed the highest value of 1757.5MPa. The increase in resilient modulus values by modification of polyester and acrylic cloth is about 42.8% and 29.37%. While using a mixture of Polypropylene and Aramid fibers Klinsky, L. M. G [12] stated a 15% increase the resilient modulus. The results of our performed tests are reported in table, from these results it is suggested that the elastic properties improves with bitumen modification by cloth waste, and the use of modified asphalt concrete results in asphalt mixtures with increased stiffness and consequently, higher load-bearing capability.

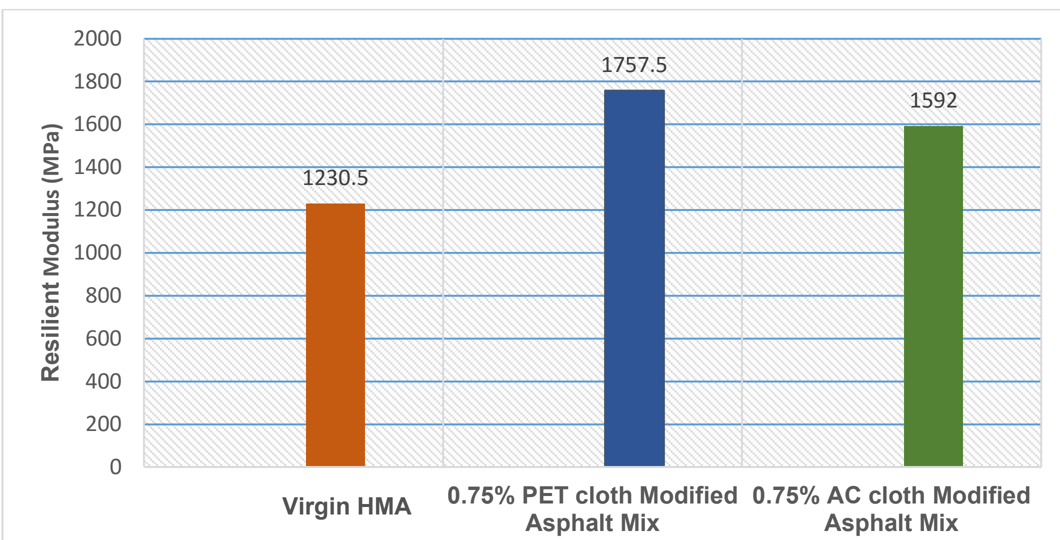


Figure 4. 2: Resilient Modulus of Modified HMA mix

Table 4. 2: Mr Values of Tested HMA

S. No	Specifications	Mean Mr (Mpa)
01	Virgin HMA	1230.5
02	0.75% PET cloth Modified Asphalt Mix	1757.5
03	0.75% AC cloth Modified Asphalt Mix	1592

4.2.3 Effect on moisture susceptibility

To evaluate the prepared specimens for resistance to water damage TSR test was performed. This test accomplishes two objectives while not being a performance test. It first determines the susceptibility of an asphalt binder and aggregate mixture to moisture. Second, it evaluates how well antistripping additives work [28]**.**[35]. For assessing the TSR value a total of 18 samples were tested through indirect tensile strength test, nine of which in wet condition and the other nine in dry conditions, three for each individual mix. The results show there is no significant impact on resistance to water damage, where the resistance of polyester cloth modified HMA samples reduced by 3.6%. Agha, N [4] in his recent study of using PET bottle waste modified bitumen in varying percentages ranges from 0% to 10%, stated that the TSR ratio shows an increasing trend from 0% to 4% but after that the trend reverses and TSR ratio gradually declines up to 10%. The density of polyester fiber is greater so when melts the volume decreases a little bit and the tendency to cover the aggregates by polymer decline. While the moisture susceptibility is dependent on the volume of air voids thus it is evident that the moisture susceptibility will be increases. The results obtained from the tests are represented as.

Table 4. 3: TSR Values

S. No	Specifications	Tensile strength ratio
01	Virgin HMA	94.8
02	0.75% PET cloth Modified Asphalt Mix	91.2
03	0.75% AC cloth Modified Asphalt Mix	94.4

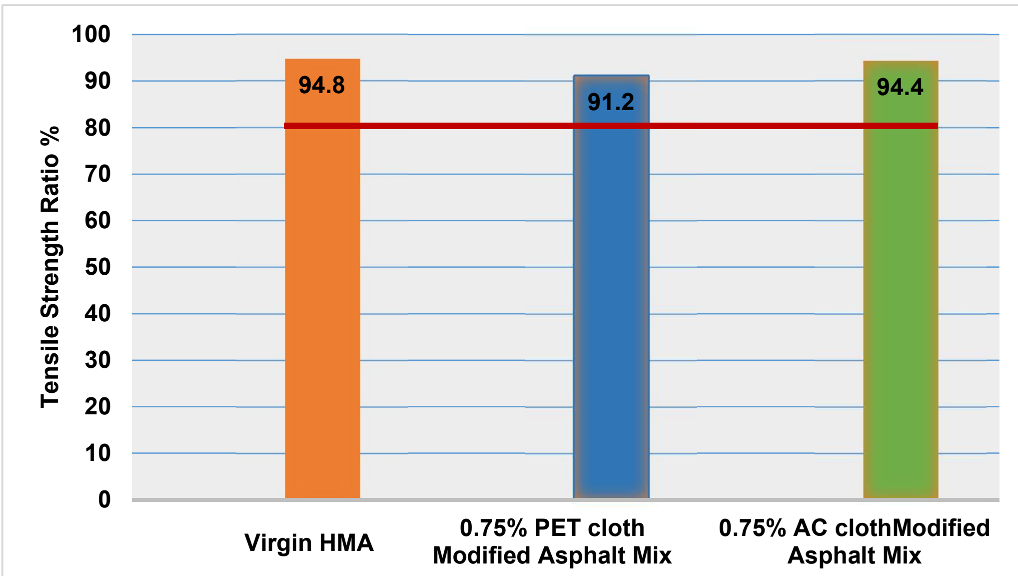


Figure 4. 3: Graphical representation of TSR Values

4.3 Environmental and Economic Impacts

Being human clothing is our one of the basic necessities. But with the civilization and economic growth the textile industry expanded, due to which the apparel sector got full bloom in preparation of multitudinous varieties of cloths from various different sources. As consequences the production of cloth and garment factory waste is on heave in all over the world. According to reports of various commissions of United Nations, every second the amount of clothing incinerated or disposed of in a landfill is equal to one garbage truck, as every year 85% of textiles are discarded in landfills [43]. On the other hand, the road construction industry faces some major challenges like detrimental effects on pavement by traffic growth, increase in binder prices [44], ban on Margallah queries of limestone due to environmental pollution, flooding due to excessive rains and exposure of pavement to moisture. To confront these major issues researchers looked forward for different solutions, as ASajjad, SMO Raza [13] from his research findings concluded that using textile industry Polyester waste in the construction of roads in sustainable form helps in the improvement of reliability and performance of traditional road construction and preventing the environment from the harmful effects of these waste. Al-Sabaeei, A., Napiah [14] from his study concluded that it is necessary to introduce waste materials modifiers for bitumen and asphalt mixture modifications so that such waste materials may be disposed of and the bitumen's performance can be improved in a sustainable way.

To study the economic impact of using Cloth modified HMA mix in pavement construction, cost analysis was performed, to assess the reduction in cost while using modifier. A road section of one kilometer having standard width of 3.6 meter, high volume and high speed [45] with wearing course of asphalt concrete having thickness of 50mm was assumed. Since the properties and compacting efforts of the lower layers, base and subbase, and the preparation method of the subgrade is similar for both mixtures, so it will not be considered only the cost of the HMA surface course was taken into account in this comparison. Moreover, only material costs associated with the initial stages of road building were considered in this cost analysis. Savings (%) shall notably increase when cost analysis of full life-cycle is conducted having both monetary and non-monetary costs.

4.3.1 Calculations of Material Cost

According to Marshall Mix Design, for virgin HMA asphalt has a density of 2360 kg/m^3. Using the Composite Schedule of Rates (CSR) – 2022 of NHA for Rawalpindi District [46], the cost was estimated. After estimation there is a huge difference in construction cost of virgin HMA and Cloth modified Asphalt mix per kilometer of the assumed road section. This difference is shown in table.

Table 4.4: Materials Cost Calculations

Description of Items	**Calculations**	**Results**
HMA mix volume	100 x 3.6 x .050	180 m^3
Density of mix	…..	2360kg/m^3
Total weight of mixture for 1km road section	180 x 2360	424800kg = 424.8 tons
Selected OBC	-----	4.33
Required Weight of binder	424.8 x .0433	18.393 tons
Price of 1 ton bitumen		102208 Rs
Price of Bitumen	18.393 x 102208	1879997 Rs
Considering 0.75 % modification of bitumen by cloth waste		
Selected percentage of cloth modifier	-----	0.75% (By total mix weight)
Total weight of the cloth modifier	0.0075 x 424.8	3.186 tons
Required weight of bitumen after addition of cloth modifier	18.393 – 3.186	15.207 tons

Cost of binder modified with cloth	15.207 x 102208	1554277 Rs
Cost Reduction	1879997 - 1554277	325720

After comparing the cost of construction of virgin HMA and waste materials per kilometer per lane (3.6 m) for a road section with a thickness of 5 cm, the drawn figure demonstrates that, in addition to other benefits like improved properties and environmental benefits, waste material will result in cost savings during construction. By adding 0.75% of waste cloth to the mix, we can reduce the cost of asphalt binder by up to 17.3%. If we can somewhat compromise the physical properties of the Asphalt mixture, we may utilize as much as one percent of cloth, but we'll keep our research to 0.75% here.

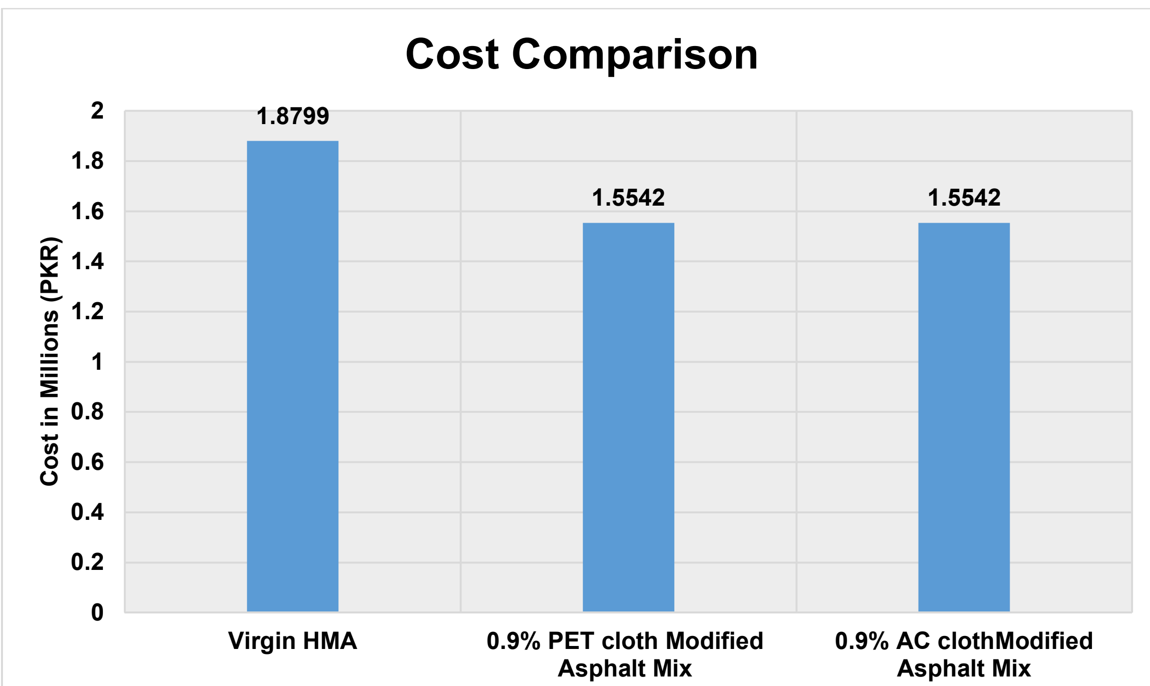


Figure 4. 4: HMA Cost Comparison

4.4 Chapter Summary

This chapter discusses an in-depth analysis of results obtained from various performance testing performed in the laboratory. The results from the UTM machine have been analyzed in relation to the improvement in resilient modulus values, and TSR values have been determined for assessing moisture susceptibility. To analyze the data from performance testing, both graphs and tables were presented. Results from Moisture Susceptibility were compared with and without the integration of waste cloth, and the results were analyzed. This comparison revealed that, under stress-controlled conditions, the incorporation of PET cloth can be associated with a slight reduction, that can be neglected and that of AC cloth is same. The findings of the Indirect tension test, the wheel tracker test, and the Moisture susceptibility test, for controlled specimens and the specimen containing cloth waste were displayed as bar charts and graphs. Then, a cost comparison is conducted for the control mix and the mix with the 0.75% cloth. The cost of virgin bitumen used for the construction of one-kilometer long section with an average thickness of 50mm was 1.879 million. The cost of 0.75% cloth modified binder for a one-kilometer long section was reduced from 1.879 million to 1.554 million, showing a 17.3% cost reduction that also ensures the safe disposal of non-biodegradable cloth waste.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In recent years, one of the most important areas of research that got fame in the field of flexible pavements has been the modification of bitumen and asphalt mixtures. This is because of two reasons; one is the day by day accretion of cloth waste due development of fashion industry and the other is shortening of road's service life due to increment in traffic volume or exposure to moisture. This study is a pioneer approach to use specific cloth waste as bitumen modifier and check its impact on rheological properties of HMA. Asphalt binder of grade 60/70 and limestone aggregate with NHA class B gradation for wearing course was selected for this research. Different mechanical properties like stability, rutting resistance, resilient modulus and moisture susceptibility of cloth modified HMA were evaluated in this research work. Consequently, the primary goal is to build environmentally sustainable pavement by incorporating a large percentage of cloth waste. Some conclusions based on the laboratory investigations can be recapitulated as;

5.2 Conclusions

After extensive laboratory research, the behavior of the HMA mixtures made with cloth-modified bitumen rather than virgin bitumen has been observed. After the analysis of performance test's results following conclusions were drawn.

- On optimum bitumen content the cloth modification showed an increase in stability and flow while a little increase in air voids percentage.
- With the addition of cloth waste HMA showed a better resistance to permanent deformation than virgin HMA. Moreover, the rutting resistance of polyester cloth

modified HMA has a highest rutting resistance. This is because of the adhesion property that increases the stiffness of the mix.

- The addition of cloth waste in HMA significantly increases the resilient modulus of the HMA. In comparison the polyester cloth modification shown the highest improvement of 42.8% corresponding to virgin HMA.
- With the incorporation of cloth waste the moisture susceptibility test showed a slight decrease in performance irrespective of the cloth type, which shows that this modified HMA is slightly less resistant to water damage.
- The increase in moisture susceptibility is due to increase in the air void percentage.
- Along the other benefits including positive environmental impacts enhancement in some mechanical properties, bitumen modification results in cost savings of about 17.3% in terms of monetary benefits.

5.3 Recommendations

This research study intends to produce modified asphalt mix by substituting some bitumen with shredded pieces of waste cloth, so assisting in environmental protection by turning non-biodegradable waste into a useful product. On the basis of results and conclusions some recommendations are as fallow:

- The performance testing of Rutting resistance, resilient modulus and moisture susceptibility were done in this study to evaluate performance. Additionally some other performance tests such the fatigue cracking, creep test, workability, dynamic

Modulus, flow number, or flow time were not conducted. It is advised to conduct different experiments on various fabric contents in HMA for the tests described above as well, to further categorize cloth behavior in HMA.

- It is suggested that in field a trial section should be constructed to test the performance of HMA with waste cloth as an alternative to asphalt binder in order to ensure that the mixture is appropriate for Pakistan's climate and traffic patterns.
- It is also recommended to determine the chemical behaviors of polymer cloth waste with asphalt binder so that if any rejuvenating agent can improve its properties and can be used in addition to cloth in HMA. In this way, more amount of polymer cloth might be utilized reducing the virgin bitumen content.

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