DOI: 10.53469/jpce.2025.07(10).01

Performance Evaluation of Reclaimed Asphalt Pavement in Sustainable Roadway Construction

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Abstract: ***Use of reclaimed asphalt pavements in hot mix asphalt mixtures has evolved into a regular practice in many countries around the world. Use of these materials in the past has proved to be economical and environmentally sound. Mixing RAP in virgin materials has been strongly preferred over using virgin materials alone because of the increasing costof asphalt, scarcity of good quality aggregate, scarcity of asphalt and the ever increasing need to preserve the environment. The literature survey contexts that use of reclaimed asphalt pavement is effective in improving the performance which is equal to or better than the virgin mixtures. Unfortunately, asphalt pavement recycling is yet to take off in India despite the current ambitious road building program underway. This has created a need to use RAP. This study investigates the performance and economic viability of incorporating reclaimed asphalt pavement (RAP) into stone matrix asphalt (SMA) mixtures for pavement construction. Laboratory tests assessed SMA mixes with 0%, 10%, 30%, and 50% RAP, sourced from NH-7, using VG-30 bitumen and waste engine oil as a rejuvenator. Results indicate that mixes with up to 30% RAP exhibit mechanical properties comparable to or better than virgin mixes, with enhanced tensile and fatigue strength. Economic analysis reveals cost savings of 10–51% over conventional methods, underscoring RAP's potential as a sustainable alternative. This research highlights a practical approach to recycling asphalt in India, where such practices remain underexplored despite ambitious infrastructure goals.***

Keywords: Reclaimed asphalt pavement, Stone matrix asphalt, Economic analysis, Tensile strength

List of Symbols, Acronyms and Nomenclature

NHDP: National Highway Development Program
SMA: Stone Matrix Asphalt
RAP: Reclaimed Asphalt Pavement
HMA: Hot Mix Asphalt
RTS: Retained Tensile Strength
ITS: Indirect Tensile Strength
FDR: Full Depth Reclamation
OGA: Open Grade Asphalt
VFB: Voids Filled With Bitumen
VMA: Voids In Mineral Aggregates

1. Introduction

1.1 Background

Road Transport in India accounts for 80% of passenger movement and 65% of freight movement. With 4.3 million km of roads, India has the second largest road network in the world. Only 50% of the roads are paved, even the paved length has inadequate design standards. The current state of our nation's transportation infrastructure is inadequate, and many state and city municipalities do not have the funds to rehabilitate their road networks to improve them to an acceptable level. National Highways Authority of India has prepared plans involving an outlay of Rs. 2,20,000 crores under National Highways Development Program (NHDP) and 10,000 km of expressways at a cost of Rs 1,00,000 crores are being planned in order to develop the road infrastructure and to boost the economy in India. The eleventh plan allocates Rs 2,in 78,658 crores to roads and bridge, representing 13.57 % of total outlay.

The Vision 2020 targets the development of a core network of 40000 kms to serve its industrial, agriculture and tourism industries. To meet the increasing traffic intensities and the persistent regional disparities in the accessibility to good quality roads, it has been proposed to increase the road density from the 1.09 km per sq km to 1.50 km per sq km and up gradation of existing road network to increase the share of roads with carriage width of 2 lane and above from the current 10.32% to 55%.

These mega road modernization exposes challenges of various concerns pertaining to depletion of resources like good soil and aggregates, long lead to get good quality aggregates and increase in fuel consumption etc, and also the increasing cost for the supply of bitumen, is dependent on foreign sources, and the energy requirement for processing new materials is becoming costlier every day.

Recycling of existing bituminous mixes are the only alternatives, through the reuse of aggregates and bitumen. Recycling of asphalt pavements is one of the effective and proven rehabilitation processes. Estimated world production of asphalt in 2007 is about 1.6 trillion metric tons of asphalt was produced worldwide. Out of which Asia produced 495 million metric tons of asphalt, nearly 31 percentage of total production [The asphalt paving industry: a global perspective second edition 2008].Use of the recycled materials in the road construction has been favoured over virgin materials in the light of increasing cost of bitumen, scarcity of good quality aggregates and the priority towards preservation of the environment. Considering the material and construction cost only, it is estimated that using recycled materials, saving ranging from 14 to 34% can be achieved.

Due to heavy and continuously moving traffic we find rutting of roads and also their durability is reduced. To tackle these problems new pavement mix called the Stone Matrix Asphalt (SMA) was formulated. SMA comprises of large amount of coarse aggregates and hence there will be more stone-to-stone contact which gives a better network to carry the traffic load.

1.2 Introduction

In this project we have prepared stone matrix asphalt mixes using a certain percentage of recycled asphalt materials (10%, 30%, 50% RAP), and made specimens. Later the specimens were tested for marshal stability, for the mix which showed highest stability Indirect Tensile Strength was performed and at the end of the project economic analysis was done to determine the cost saved.

2. Literature Reviews

Recycling of asphalt pavements is a technology developed to rehabilitate and/or replace pavement structures suffering from permanent deformation and evident structural damage [1]. In this context, according to [2], the reclaimed asphalt pavement (RAP) is one of the most reclaimed materials in the world. The first data documented on the use of RAP for the construction of new roads date back to 1915 [3]. However, the actual development and rise of RAP usage occurred in the 1970's during the oil crisis, when the cost of the asphalt binder (or asphalt) as well as the aggregate shortages where high near the construction sites [4]. Later, in 1997, with the Kyoto Protocol adaptation by parties and implementation in 2005, recycling received major attention and broader application in the road construction industry [5].

Several authors state that diverse methods for recycling of asphalt pavements are suitable including: hot recycling in plant, hot-recycling "in situ", cold-recycling "in situ", and others [6, 1, and 7]. Nevertheless, hot recycling is one of the most widely techniques used nowadays, where virgin materials and RAP are combined indifferent proportions and sizes [8]. Research from Europe and the United States shows that over 80% of the reclaimed material is reused in road construction, but regulations are still strict allowing inclusion of RAP in proportions ranging between 5 and 50% for production of new hot mix asphalt (HMA) mixtures [9].

Studies performed to determine the response of HMA mixtures with RAP replacements between 0 and 40%and fabricated with different asphalts, have shown the low moisture damage susceptibility of the new HMA mixtures (i.e., based on retained tensile strength (RTS) values above 95%; Superpave criteria-ASTM D4867).

Similarly, it was found that the resilient modulus values increase regardless of the tests temperature (-18, 0, 25, and 32 °C), type of asphalt (PG-46-40, PG-52-34, and PG-58-28), andaddition of RAP (15, 30, and 40%) [10].

According to [2], the incorporation of 40% RAP in HMA mixtures created no modification on the mixture properties. Conversely, when values higher than 40% were included, the mixture properties changed drastically.

In general, when higher percentages of RAP were used, evident reductions on the relative energy loss—computed based on the load-displacement curve determined for the indirect tensile test—were reported with possible appearance of premature distresses. The latter can be related to possible moisture damage that may affect the mechanical response (i.e., permanent deformation- and fatigue-response) and mixture performance.

Recent researches [1, 8, 11, 12], have established that RAP replacement at proportions above 50% are feasible to produce new HMA mixtures, obtaining satisfactory results in the mechanical properties. Similar fatigue curves were determined for HMA mixtures fabricated with low penetration asphalt (13/22) and HMA mixtures with60% RAP replacement. Likewise, the susceptibility to moisture damage was low (RTS values close to 95%). In addition, the HMA mixtures with RAP replacement increased in 50% the indirect tensile strength (ITS) as compared to that of the HMA mixtures fabricated with virgin materials. The energy dissipated during the ITS testalso increased by 100% in the HMA mixtures with RAP replacement.

Olard et al. (2008) [13] assessed HMA mixtures with high recycling rates (i.e., >50% RAP replacement) for warm- and HMA-mixture production and stated that RAP foster positive environmental impacts, including that it:(*i*) can be done in an asphalt plant or in-place, (*ii*) reuses existing materials thus eliminating disposal problems (saving or diminishing land requirements in populated countries), (*iii*) saves costly materials and in some countries rare, hard to find good aggregates, (*iv*) can correct both asphalt content and aggregate gradation of an existing HMA mixture, and (*v*) produces a stable pavement structure at a lower cost than that associated with conventional methods.

Based on the positive experiences and outcomes from global use of HMA mixtures with RAPinclusion, it can be inferred that relevant results could be obtained from application of this technology in developing countries such as India. Similarly, the same concerns rose by the Kyoto protocol and other global policies with regard to air pollution must be taken into account to minimize risks on human health and ensure environmental quality.

2.1 Benefits of Asphalt Recycling

The bituminous pavement rehabilitation alternatives are mainly overlaying, recycling and reconstruction. In the recycling process the material from deteriorated pavement, known as recycled asphalt pavement (RAP), is partially or fully reused in fresh construction.

It is important to recognize that asphalt recycling is a powerful method to rehabilitate pavements. When properly carried out, it has substantial long term economic benefits.

1) Reuse and conservation of non-renewable natural resources.
2) Preservation of the environment and reduction in land filling.
3) Energy conservation.
4) Reduction in user delays during construction.
5) Improved pavement smoothness.
6) Cost saving over traditional rehabilitation methods.
7) Improved pavement physical properties by modification of existing aggregate gradation, and asphalt binder properties.

8) Conserves aggregate and asphalt, which are very important in areas where aggregate and asphalt are in short of supply or where haul distances to remote locations are excessivelylong.
9) With proper design and construction control of recycled hot mix, the performance of the recycled pavement is equal to traditional method.

2.2 Motivation of Present Study

In India, about 15,000 tonnes of aggregates are required per kilometre of highway. A standard project of National Highway Development Project (NHDP) of 60 km road improvement requires 20 lakh ton of material. In India, mostly the old pavement materials aredumped into landfills. Landfills have been identified as the largest source of methane caused by humans. The material costs constitute about 40% of total construction cost of the project. The construction cost is growing exponentially mainly due to increase in the cost of materials. Recycling of existing bituminous mixes results in substantial savings through the reuse of aggregates and bitumen. Use of the recycled materials in the road construction has been favoured over virgin materials in the light of increasing cost of bitumen, scarcity of good quality aggregates and the priority towards preservation of the environment. This study makes an attempt at presenting a comprehensive view of one of such technology called recycled asphalt pavements. It's high time that the recycling process need to be implemented owing to their major advantages over overlaying process. These are today's burning issues and have become the purpose of the study.

2.3 Objective

1) To determine the basic engineering properties of the Virgin bitumen and Virginaggregate.
2) To determine the basic engineering properties of Reclaimed Aggregate and binder after extraction and Recovery.
3) To carry out the blending of RAP and Virgin aggregates for 10%, 30%, 50% RAP content as per MORTH V revision, satisfying SMA gradation.
4) To carry out the mix design for 10%, 30%, 50% reclaimed mixes with virgin mixes
5) To study the influence of reclaimed materials on the stability, tensile strength, andfatigue life of SMA mix through laboratory experiments.
6) To workout the economics of recycling of bituminous pavement materials.

2.4 Methodology

The methodology for this study involved the following major tasks: Literature Review, experimental design and materials selection, laboratory testing program, laboratory test result analysis, Marshall Mix design are carried out for virgin and RAP mixtures as per asphalt institute (MS-II) concept and MoRT&H. Comparison and evaluation of the Marshall properties, indirect tensile strength, fatigue life and economic analysis for Virgin asphalt mixtures and various RAP combined with virgin aggregate mixtures i.e., 20, 30, and 50%finally conclusions and recommendations for future work are present.

3. Theory and Concepts

3.1 General 7

This chapter describes the theory and concepts behind the present study which includes the concepts of recycled asphalt pavements technology, laboratory principles.

3.2 Methods of Recycling Pavements:

The common types of recycling operations include Warm mix recycling, Hot In-place Recycling (HIR), Cold In-place Recycling (CIR), and Full Depth Reclamation (FDR). Among this, hot mix recycling is very commonly used for producing Hot Mix Asphalt (HMA). Hot in- place and Cold in-place recycling are commonly used for preventive maintenance operations, whereas full depth reclamation is generally used for rehabilitation work. Based on the process adopted in recycling of bituminous mixes, the methods can be classified as central plant recycling and in-situ recycling.

3.2.1 Hot in Place Recycling:

Hot in place recycling has been described as an in situ method that rehabilitates deteriorated asphalt pavements and thereby minimizes the use of new materials. Basically this process consists of four steps: (1) Softening of the asphalt pavement surface with heat (2) Scarification and/or mechanical removal of the surface material (3) Mixing of the material with recycling agent, asphalt binder, or new mix and (4) Lay down and paving of the reclaimed mix on the pavement surface. The primary purpose of hot in -place recycling is to correct surface distresses.

Figure 2.1: Hot in place recycling

3.2.2 Cold Recycling

They can be divided into two main parts-cold in-place recycling and cold milling. Cold milling is used for obtaining materials for hot mix recycling.

1) Cold Milling: It is a method of automatically controlling the removal of pavement to a desired depth using specially designed equipment and restoration of the surface to a specified grade and slope, devoid of bumps, ruts and/or other imperfection.
2) The modern cold milling equipment has tungsten carbide teeth fixed on drums, with adjustable cutting width for a variety of pavements and excellent maneuverability for different milling situations.
3) Cold In-place Recycling (CIR): It is defined as a rehabilitation technique in which the existing pavement materials are reused insitu. The materials are mixed together without the application of heat. The reclaimed asphalt pavement material is obtained by milling or crushing the existing pavement. Fresh aggregate or recycling agent or both are added to the RAP material, which is subsequently laid and compacted. Cold in place recycling can restore the original profile of old pavements, eliminate existing wheel ruts, restore the crown and cross slopes and eliminate pot-holes and rough areas.

Figure 2.2: After being processed, the material is deposited onto the roadway in a windrow

3.2.3 Full Depth Reclamation (FDR):

It has been defined as a recycling method where all of the asphalt pavement section and the pre-determined amount of underlying materials are treated to produce a stabilized base course. Different varieties of additives, such as asphalt emulsions and chemical agents such as lime are added to obtain an improved base. The main five steps in this process are pulverization, addition of additive, shaping the mixed material, compaction and the application of a surface or a wearing course. This method is normally performed to a depth of 100 to 300 mm. The major advantages and benefits of full depth reclamation are as follows:

1) The structure of the pavement can be improved significantly without changing the geometry of the

pavement and shoulder reconstruction.

2) It can restore old pavement to the desired profile, eliminate wheel ruts, restore crown and slope, and eliminate pot holes, irregularities and rough areas.

Figure 2.3: Rejuvenating existing pavement structure by stabilizing for FDR

3.2.4 Hot Mix Recycling:

It is a method in which RAP is combined with new aggregates and an asphalt cement or recycling agent to produce HMA. The RAP can be obtained by milling with a rotary drum cold milling machine. RAP from different sources containing different asphalt contents and aggregates with different gradations should be stockpiled separately. The RAP cannot be processed in standard drum mix plant since excessive blue smoke is produced when the RAP comes in contact with the burner flame. Majority of the smoke problem is caused by the light oils in soft grades of asphalt binder used to rejuvenate the aged asphalt in the RAP. The smoke problem could be solved by various processes such as lowering the HMA plant's production rate, decreasing the moisture content of the RAP, lowering the discharge temperature of the reclaimed mix, introducing additional combustion air, and decreasing the percentage of RAP. Hot mix recycling plant is shown in Figure-2.1.

Figure 2.4: Asphalt batch plant with RAP in feed for hot recycling

3.3 Blending Of Recycled Asphalt Pavements:

Although several research studies have reported the use of RAP and its performance in new asphalt mixtures, none have emphasized the study on how much old asphalt is actually blended with new mixtures during the mixing process. The studies conducted on a blended mixture consisting of 20% RAP revealed that only a portion of the aged asphalt participated in the remixing process while the other portions formed a stiff coating around the RAP aggregates and RAP behaved as a ―composite black rock. Despite similarities between producing virgin asphalt mixtures and RAP asphalt mixtures there are challenges for maximizing RAP usage. Generally the guidelines are based on the assumption that complete blending occurs between virgin and new mixtures, but later it was understood that the amount of blending that occurs was somewhere between complete blending and no blending; however there is no actual methods available to accurately determine the amount of blending that occurs.

3.4 Gradation of Recycled Asphalt Pavements:

Designing mixes containing RAP requires special attention to ensure minimum Voids in Mineral Aggregates is met and the aggregate gradation is not significantly altered by the addition of fines associated with RAP materials. RAP is somewhat finer than virgin aggregate, therefore it is recommended that RAP used in recycled asphalt should be as coarse as possible and the fines (< 0.075mm) should be minimized. RAP crushing during production is recommended to minimize the fracture of coarse aggregate and excess fines generation as high fines content leads to rutting due to low stability. The RAP should be free of foreign materials such as broken concrete or other contaminants.

3.5 Mix Design:

The basic objective of the recycled mix design is to know the best constituent proportions between the RAP, virgin binder and new aggregates. The total binder content of the recycled mix was found out by some preliminary estimation and iterative mix design process done. The average asphalt binder content of the RAP and the gradation of the old aggregates present in RAP were found out. The constituent proportions calculated from the equations were numerically identical to that of calculated as per Asphalt Institute. In the study, the proportion between the aged and virgin binder, percentage of binder present in RAP and the percentage of total binder demand of the recycled mix were known. From this percentage of virgin bitumen and RAP to be added to obtain the recycled mix was estimated.

3.6 Characteristics of Rap Material:

The important characteristic of RAP material that would greatly influence the properties and performance of the reclaimed mix is the stiffness of its binder. The recovered RAP binder is more viscous and has lower penetration values than virgin binders due to ageing. The effects of ageing are caused by chemical changes within the binder. Asphalt bituminous binder exhibits two stages of ageing namely, short term and long term.

3.7 Stone Matrix Asphalt

Stone mastic asphalt (SMA), also called stone-matrix asphalt, was developed in Europe (Germany) in the 1960s. It provides a rut resistant, durable surfacing material, suitable for heavily trafficked roads. SMA has found use in EU, Australia, the United States, and Canadaas a durable asphalt surfacing option for residential streets and highways. SMA has a high coarse aggregate content that interlocks to form a skeleton that resists permanent deformation. The stone skeleton is filled with a mastic of bitumen and filler to which fibres are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement. Typical SMA composition consists of 70−80% coarseaggregate, 8−12% filler, 6.0−7.0% binder, and 0.3 per cent fibre.

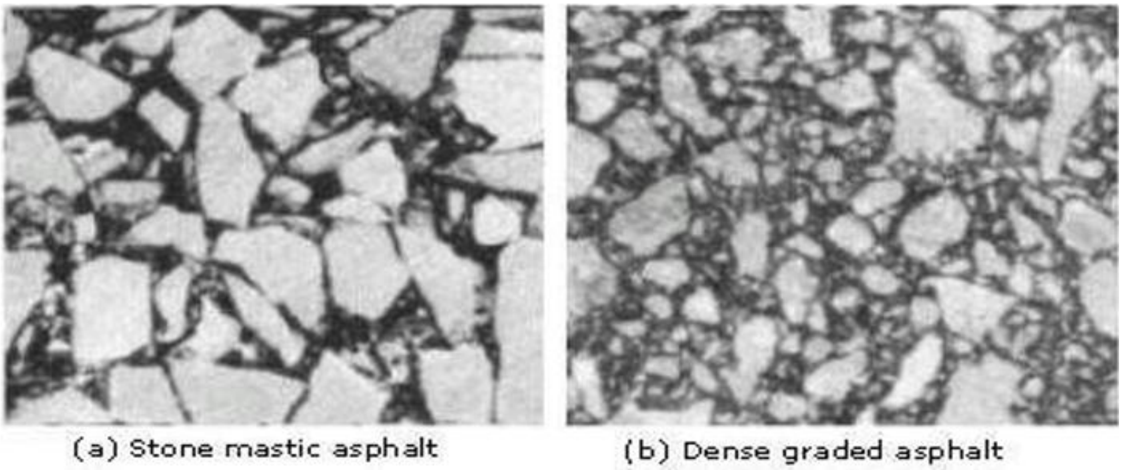

Figure 2.5: Stone Matrix Asphalt and Dense Graded Asphalt

3.8 Advantages of Stone Matrix Asphalt

1) SMA provides a durable and rut resistant wearing course.
2) The surface texture characteristics of SMA are similar to Open Graded Asphalt (OGA) so that the noise generated by traffic is lower than that on DGA but equal to orslightly higher than OGA.
3) SMA can be produced and compacted with the same plant and equipment available for normal hot mix, using the above mentioned procedure modifications.
4) SMA may be used at intersections and other high traffic stress situations where OGA is unsuitable.
5) SMA surfacing may provide reduced reflection cracking

from underlying cracked pavements due to the flexible mastic.

4. Methodology of Mix Design

4.1 Marshall Method of Mix Design and indirect tensile strength tests:

In this stage, the bitumen and aggregate quantities to fulfill the gradation and volumetric requirements of reclaimed mix will be determined for SMA. The mix design was carried out in two phases. The first phase concentrates on the mix design of virgin materials as per mid gradation method by Marshall Mix design method. In the later phase, the virgin materials were blended with RAP of different proportions to meet the graduation requirement of the mix SMA.

The step by step procedure has been carried out as indicated in the design procedure and the steps involved are

- Individual gradation of aggregate
- RAP replacement
- Specimen preparation
- Specimen testing

4.1.1 Individual Gradation of Aggregates

Table 3.1: In our project we are preparing specimens for binder course

Composition of Stone Matrix Asphalt		
SMA Designation	**13 mm SMA**	**19 mm SMA**
Course where used	Wearing Course	Binder (Intermediate) Course
Nominal Aggregate Size	13 mm	19 mm
Nominal Layer Thickness	40–50 mm	45–75 mm
IS Sieve (mm)	**Cumulative % by weight of total aggregate passing**	**Cumulative % by weight of total aggregate passing**
26.5	—	100
19	100	90–100
13.2	90–100	45–70
9.5	50–75	25–60
4.75	20–28	20–28
2.36	16–24	16–24
1.18	13–21	13–21
0.6	12–18	12–18
0.3	10–20	10–20
0.075	8–12	8–12

Table 3.2: Weight of virgin aggregates for 100% virgin specimen

IS Sieve (mm)	Cumulative %by weight of total aggregate passing	Passing at midpoint gradation	Total virginaggregate %	Total weight of aggregates in gm
26.5-19	100	100	0	0
19-13.2	90-100	95	5	60
13.2-9.5	45-70	57.5	37.5	450
9.5-4.75	25-60	42.5	15	180
4.75-2.36	20-28	24	18.5	222
2.36-1.18	16-24	20	4	48
1.18-0.6	13-21	17	3	36
0.6-0.3	12-18	15	3	36
0.3-0.075	10-20	15	3	36
0.075	8-12	10	4	48

4.1.2 RAP Replacement

Table 3.3: For RAP replacement

10% RAP		30% RAP		50% RAP	
Wt of virgin aggregates in gms	Wt of RAP aggregates in gms	Wt of virgin aggregates in gms	Wt of RAP aggregates in gms	Wt of virgin aggregates in gms	Wt of RAP aggregates in gms
0	0	0	0	0	0
56.4	3.6	42	18	49.2	10.8
411.6	38.4	258	192	334.8	115.2
163.2	16.8	96	84	129.6	50.4
190.8	31.2	66	156	128.4	93.6
39.6	8.4	6	42	22.8	25.2
33.4	2.4	24	12	28.8	7.2
33	2.4	24	12	28.8	7.2
31.2	4.8	12	24	21.6	14.4
45.5	2.4	36	12	40.8	7.2

4.1.3 Specimen Preparation

Stone matrix asphalt mix samples were prepared by using 50 blows of Marshall hammer on each face at different percentages of binder content varying from 5 to 6.5 progressing in 0.5% increment. Three specimens were cast for each binder content they are then tested for Marshall properties such as density, stability, flow, air voids, voids filled with bitumen (VFB), voids in mineral aggregate (VMA).

Approximately 1200gm of aggregates and filler is heated to a temperature of 175-190ºC. Bitumen is heated to a temperature of 121-125ºC with the first trial percentage of bitumen (say 5.5 or 6% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154-160ºC. The mix is placed in a preheated moulid and compacted by a rammer with 50 blows on either side at temperature of 138ºC to 149ºC. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by +0:5% and repeat the above procedure. Number of trials is predetermined. The prepared mould is loaded in the Marshall test setup as shown in the figure.

While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall Flow value of the specimen.

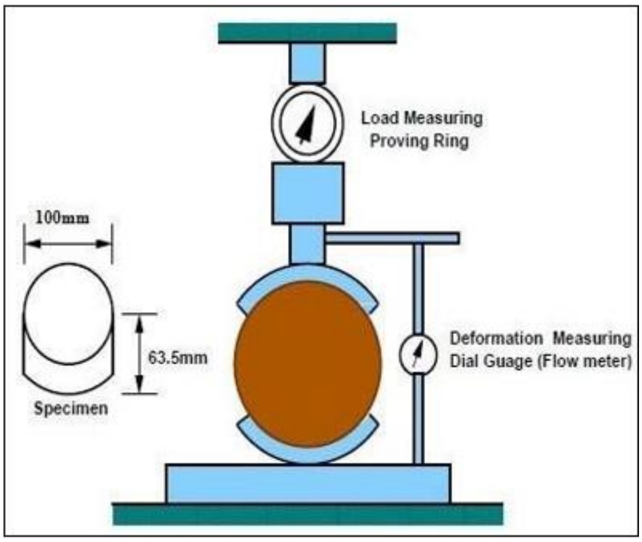

Figure 3.1: Marshall stability Apparatus

4.2 Preparation of Graphical Plots:

I determined the average values of these properties for each mix. with different bitumen content and the following graphical plots are prepared:

a) Binder content versus corrected bulk density.
b) Binder content versus air voids(VV)
c) Binder content versus voids filled with bitumen (VFB).
d) Binder content versus stability
e) Binder content versus flow

4.2.1 Relation between Bulk Density and Binder Content:

Relation between bulk density and binder content for virgin bitumen (VG-30) is as shown in the graph. The variation of Bulk density with increase in the binder content is as shown in the Figure. As the binder content increases density also increases up to a certain binder content and reaches a maximum point then it decreases on further increase in the binder content.

4.2.2 Relation between Air Voids and Binder Content:

Relation between air voids and binder content for virgin bitumen (VG-30) is as shown in the graph. The graph of Air Voids in the Aggregate and the binder content is as shown in the figure. With the increase in bitumen content, VV of Marshall sample decreases, as bitumen replaces the air voids present in the mix.

4.2.3 Relation between VFB and Binder Content:

Relation between voids filled with bitumen and binder content for virgin bitumen (VG-30) isas shown in the figure. The graph of Voids Filled with Bitumen and the binder content is as shown in the figure. With the increase in bitumen content, VV of Marshall sample decreases, as bitumen replaces the air voids present in the mix and subsequently VFB increases with the increase in the bitumen content.

4.2.4 Relation between Stability and Binder Content:

Relation between stability and binder content for virgin bitumen (VG-30) is as shown in the figure. The variation of the stability with the binder content is as shown in the figure. Stability value increases with the increase in the bitumen content, as the aggregate-bitumen bond gradually gets stronger. But with further increase in the bitumen content, the applied load is transmitted as hydrostatic pressure, keeping the friction across the contact points of aggregates immobilized. This makes the mix weak against plastic deformation and the stability falls.

4.2.5 Relation between Flow and Binder Content:

Relation between flow and binder content for virgin bitumen (VG-30) is as shown in the figure. The variation of the flow with the binder content is as shown in the figure.

The flow value increases with the increase in bitumen content. The increase is slow initially,but later the rate increases with the increase in bitumen content.

4.3 Selection of OBC

The optimum binder content has been taken as the average of the median of air voids (4%),peak of bulk density and peak of stability.

4.4 Selection of optimum RAP percentage:

Optimum percentage of RAP was found out after performing marshal stability test. It was found that 30% RAP and 70% virgin mix was the best mix.

4.5 Indirect Tensile Strength Test:

Indirect tensile strength test was performed on 100% virgin mix and 30% RAP, 70% virginaggregate mix.

The Indirect Tensile Test is performed by loading a cylindrical specimen with a single or repeated compressive load, which acts parallel to and along the vertical diametric plane. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametric plane, which ultimately causes the specimen to fail by splitting along the vertical diameter. The Indirect Tensile Test is one of the most popular tests used for hot bituminous mixture characterization in evaluating pavement structures. Figure-3.2 shows the schematic representation of indirect tensile strengthtest assembly.

Test Procedure for Conducting Indirect Tensile Strength Test:

1) The test specimens are prepared at the optimum bitumen content using Marshall Method mix design for appropriate mix as per MoRT&H specifications.
2) The height of the specimens is noted down. Each set of specimens was tested at test temperature of 250C to determine their indirect tensile strength.
3) The load at failure was recorded and the indirect tensile strength was computed using therelation given below.
4) Indirect tensile stress: σ x = (2 x P) / (π x D x t)

Where: σ x = Horizontal stress (N/mm2), P= Failure load (N), D= Diameter of the specimen (mm), t=Height of the specimen (mm).

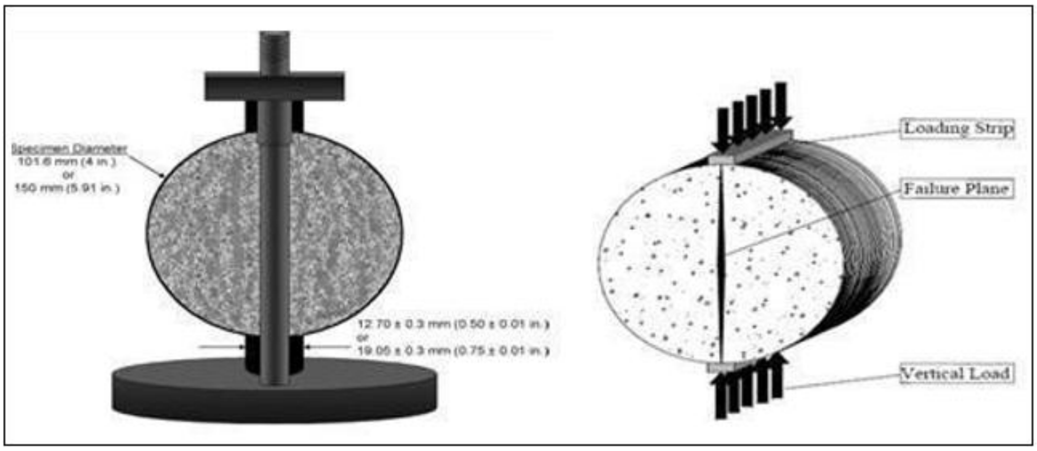

Figure 3.2: Schematic representation of indirect tensile strength test

5. Results

Table 3.4: Tests on virgin bitumen

Properties	Obtained value	PermissibleLimit	Specification
Penetration at25°c,5sec	65	60-70	IS -1203:1978
Softening point(R&B),°C	53	45-55	IS -1205:1978
Flash point, °C	235	175 min.	IS -1448:1969
Specific gravity	1.01	0.99 min.	IS -1202:1978

Table 3.5: Tests on virgin aggregates

S. No	Properties	Conventional aggregate	Requirements as per table500-14MORT&H(IV) specifications
1	Aggregate impact value (%)	17.6	Max 27%
2	Aggregate crushing value (%)	24.9	Max 30%
3	Water absorption of aggregates (%)	0.55	Max 2%
4	Specific gravity of aggregate	2.5	2.5-3
5	Flakiness and elongation index (combined index)	28.7	Max 30%

Test on virgin bitumen and virgin aggregates, confirm their suitability for use.

Table 3.6: Bitumen extraction and grading

Sl. no	Weight of RAP in kg	Bitumen obtained in g	Percentage bitumen
1	1	39.7	3.97
2	1.5	55.2	3.68

Hence, the total quantity of bitumen in the RAP used is 3.825%

Table 3.7: Tests on RAP bitumen

Sl.no	properties	Rap binder	Permissible Limit
1	Penetration value of bitumen @25 0C	45	60-70
2	Softening point 0C	48	45-55

From the above table, we can conclude that the recycled binder has lost its properties due to aging and hence has to be rejuvenated.

Table 3.8: Tests on RAP aggregates

S. No	Properties	Conventional aggregate	Requirements as per table 500-14MORT&H(IV) specifications
1	Aggregate impact value (%)	19	Max 27%
2	Water absorption of aggregates (%)	0.3	Max 2%
3	Specific gravity of aggregate	2.4	2.5-3
4	Flakiness and elongation index (combined index)	25	Max 30%

The RAP aggregates hence confirm to the MORTH requirements.

Table 3.9: Determination of rejuvenating oil content

Sl. No.	Percentage rejuvenating oil	Penetration value
1	0	43
2	0.05	64
3	0.1	83

The virgin binder used is of grade 60/70 and hence the penetration value has to be between 60 and 70. Thus, the optimum percentage of rejuvenating oil would be 0.05%.

Table 3.10: Marshal Test results for virgin specimens

Bitumen %	Wt.in air (g)	Wt.in water (g)	Bulk density (g/cc)	Theore tical density (g/cc)	Vv%	Vb%	VMA %	VFB	Stability (kN)	Flow
5	1260	720	2.333	2.461	5.184	11.905	17.089	69.665	30.799	3.35
5	1265	720	2.321	2.461	5.681	11.842	17.523	67.580	29.054	3.28
5	1265	715	2.300	2.461	6.538	11.735	18.273	64.218	29.015	4.2
5.5	1255	722	2.355	2.443	3.635	13.215	16.849	78.428	33.010	4.52
5.5	1265	725	2.343	2.443	4.126	13.147	17.273	76.114	31.799	4.3
5.5	1272	728	2.338	2.443	4.304	13.123	17.427	75.301	32.520	4.7
6	1255	725	2.368	2.426	2.407	14.497	16.904	85.763	35.000	5.4
6	1260	729	2.373	2.426	2.202	14.528	16.730	86.836	38.200	5.1
6	1260	730	2.377	2.426	2.018	14.555	16.573	87.825	37.700	5.2
6.5	1269	732	2.363	2.410	1.929	15.674	17.603	89.040	31.360	7.8
6.5	1275	735	2.361	2.410	2.013	15.660	17.674	88.609	33.390	7.2
6.5	1282	735	2.344	2.410	2.736	15.545	18.281	85.034	29.370	7.6

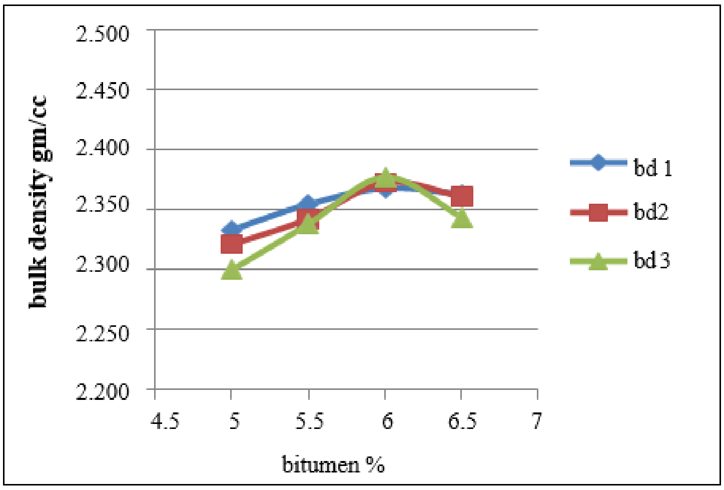

Figure 3.3: Bulk density v/s Binder content

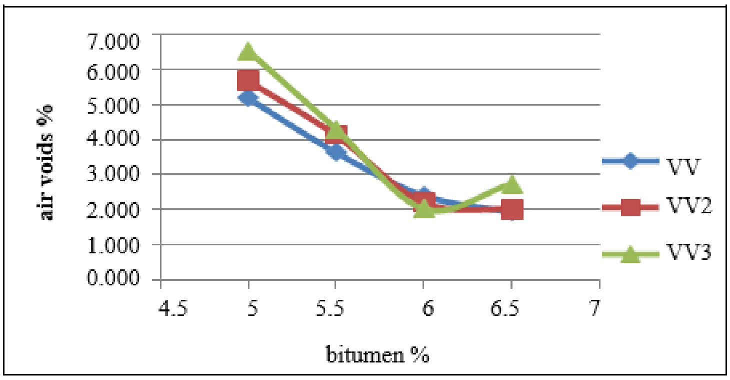

Figure 3.4: Percentage Air voids v/s Binder content

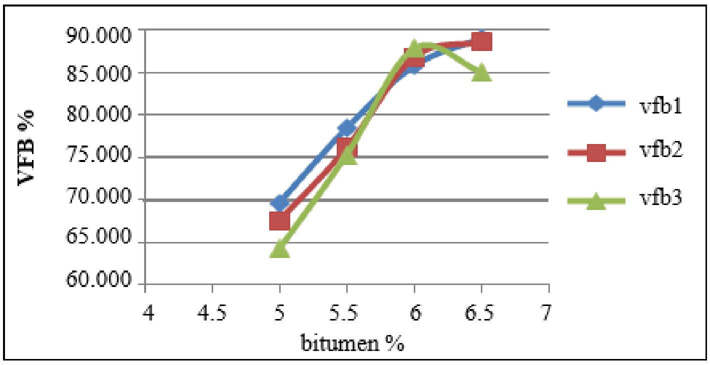

Figure 3.5: Percentage VFB v/s Binder content

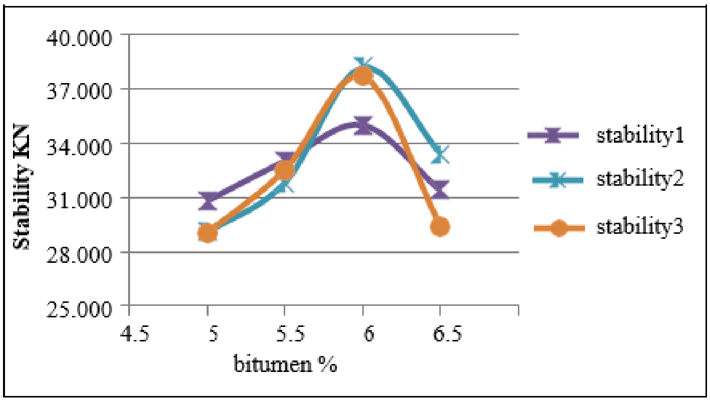

Figure 3.6: Stability v/s Binder content

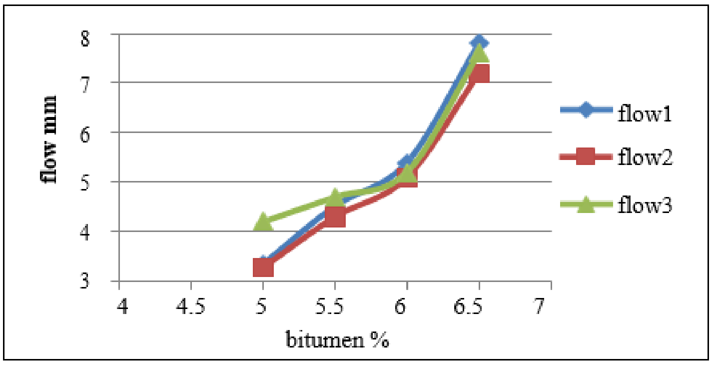

Figure 3.7: Flow v/s Binder Content

Table 3.11: Marshall test results for 10% rap

Bitumen %	Wt.in air (g)	Wt.in water (g)	Bulk density (g/cc)	Theoretical density (g/cc)	Vv %	Vb%	VM A%	VFB %	Stability (kN)	Flow
5	**1253**	701	2.270	2.2.445	5171.16	11.24	18.40	61.08	11.023	5.1
5	1260	708	2.283	2.511	9.10	11.30	20.40	55.40	11.582	5.3
5	1240	701	2.301	2.511	8.38	11.39	19.77	57.60	12.389	5.6
5.5	1243	707	2.319	2.493	6.96	12.63	19.59	64.45	12.975	5.8

5.5	1248	710	2.320	2.493	6.94	12.63	19.57	64.55	13.715	5.7
5.5	1248	710	2.320	2.493	6.94	12.63	19.57	64.55	14.380	6.5
6	1250	715	2.336	2.475	5.58	13.88	19.46	71.31	14.727	6.8
6	1255	715	2.324	2.475	6.08	13.81	19.89	69.41	15.552	6.9
6	1252	712	2.319	2.475	6.31	13.77	20.08	68.59	14.922	7.0
6.5	1252	715	2.310	2.457	5.11	15	20.11	74.60	13.756	7.3
6.5	1264	719	2.319	2.457	5.61	**14.93**	20.53	72.69	12.999	7.5
6.5	1261	714	2.305	2.457	6.18	**14.84**	21.01	70.61	11.795	7.5

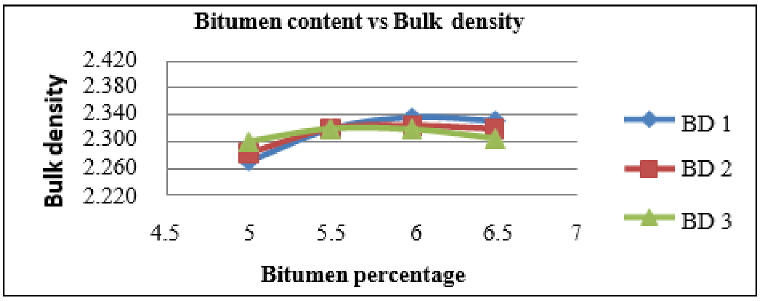

Figure 3.8: Bitumen content vs Bulk density

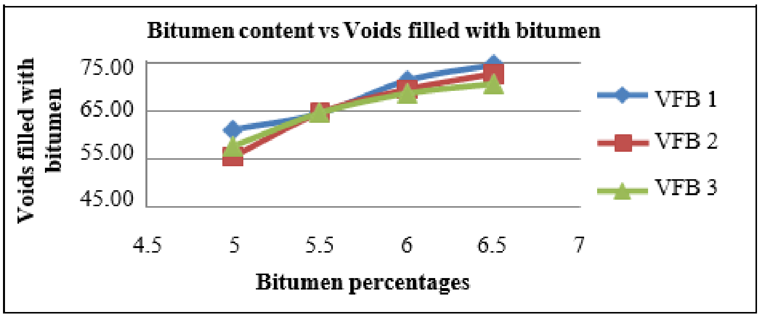

Figure 3.9: Bitumen content vs Voids filled with bitumen

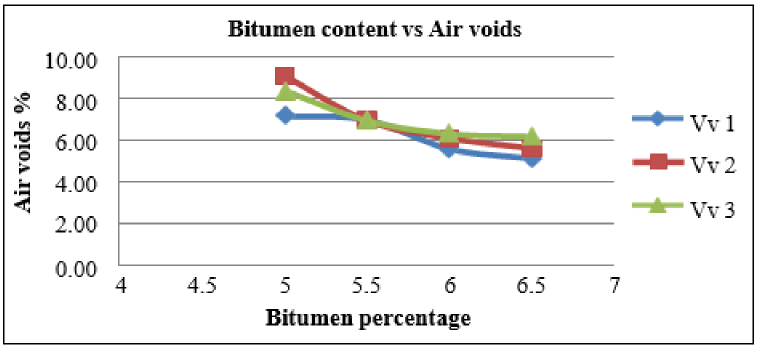

Figure 3.10: Bitumen content vs Air voids

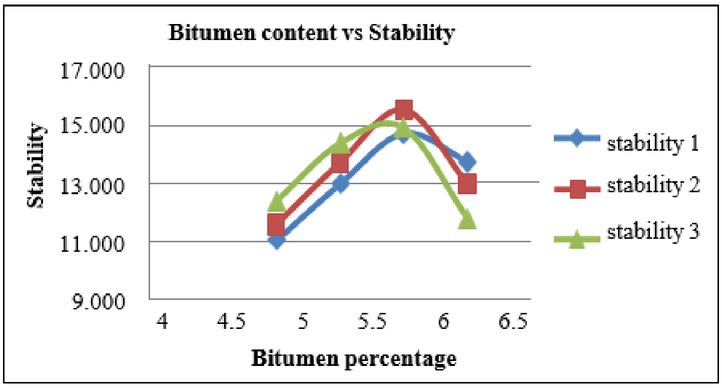

Figure 3.11: Bitumen content vs Stability

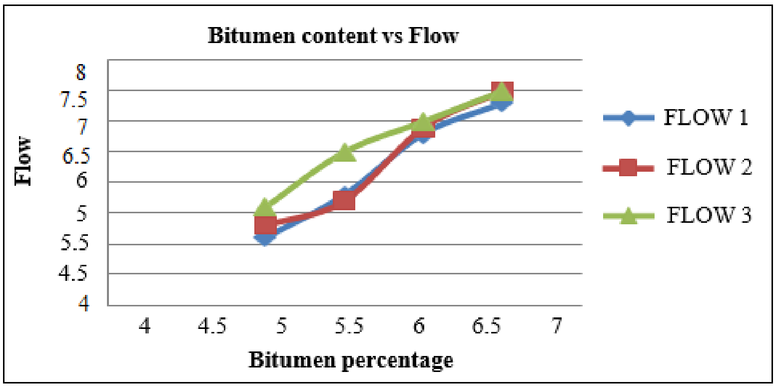

Figure 3.12: Bitumen content vs Flow

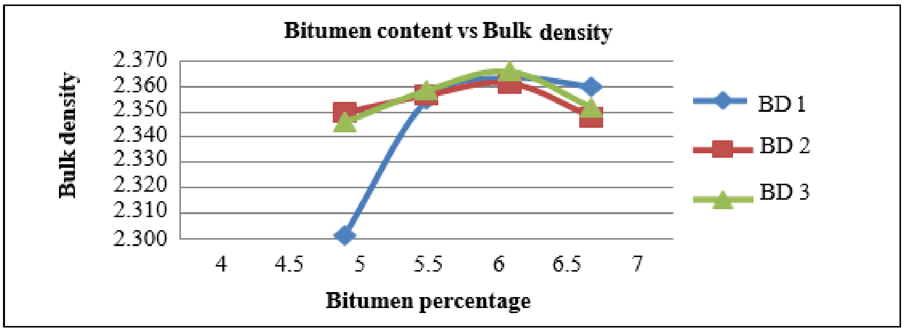

Figure 3.13: Bitumen content vs Bulk density

Table 3.12: Marshall Test results for 30% rap

Bitu men %	Wt, in air (g)	Wt. in water (g)	Bulk density	Theoretical density (g/cc)	Vv%	Vb%	VMA %	VFB %	Stability (kN)	Flow
5	1245	704	2.301	2.441	5.73	11.39	17.12	66.54	12.30	4.2
5	1243	714	2.350	2.511	6.43	11.63	18.06	64.41	13.14	4.9
5	1248	716	2.346	2.511	6.58	11.61	18.19	63.83	13.53	5.1
5.5	1248	718	2.355	2.493	5.53	12.82	18.36	69.86	13.85	5.8
5.5	1249	719	2.357	2.493	5.46	12.83	18.29	70.16	14.43	6.1
5.5	1250 hu	720	2.358	2.493	5.38	12.84	18.22	70.47	14.89	6.4
6	1255	724	2.363	2.475	4.49	14.04	18.53	75.76	16.48	6.9
6	1261	727	2.361	2.475	4.57	14.03	18.60	75.41	17.26	7
6	1254	724	2.366	2.475	4.39	14.06	18.44	76.21	17.29	7.3
6.5	1265	729	2.360	2.457	3.95	15.19	19.13	79.38	15.90	7.5
6.5	1268	728	2.348	2.457	4.43	15.11	19.54	77.33	14.82	7.8
6.5	1270	730	2.352	2.457	4.28	15.14	19.42	7795	13.98	7.5

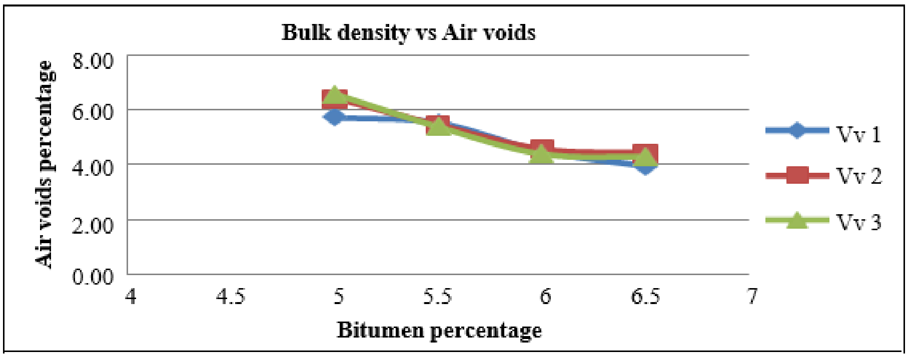

Figure 3.14: Bulk density vs Air voids

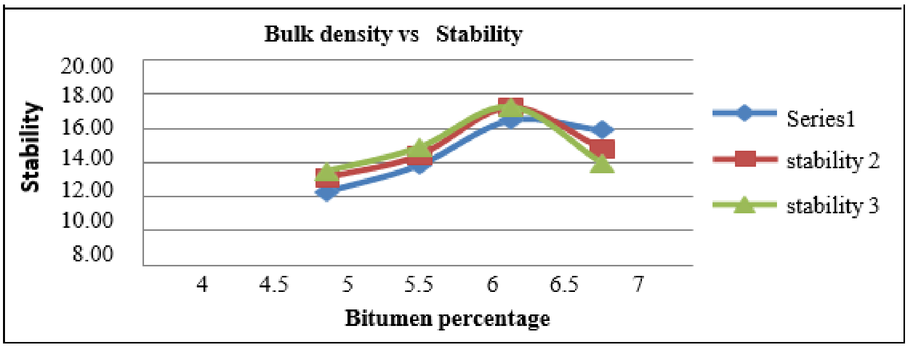

Figure 3.15: Bulk density vs Stability

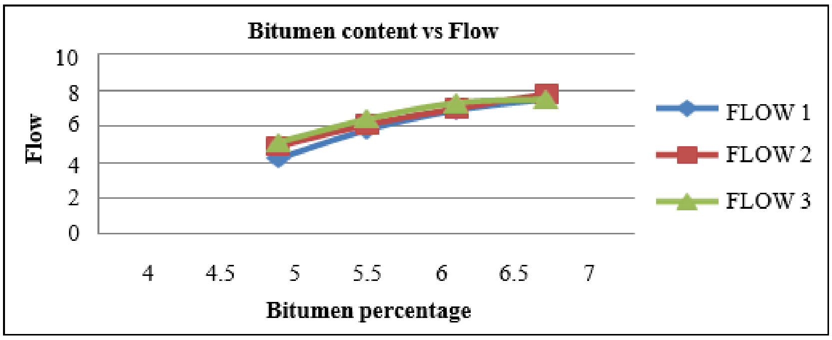

Figure 3.16: Bitumen content vs Flow

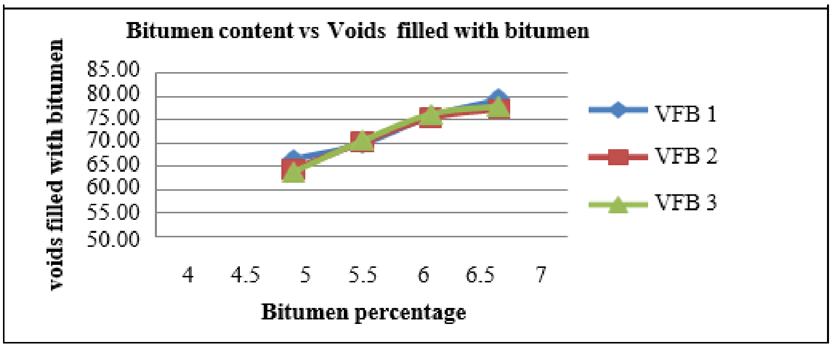

Figure 3.17: Bitumen content vs Voids filled with bitumen

Table 3.13: Marshall Test results for 50% rap

Bitumen %	Wt, in air (g)	Wt. in water (g)	Bulk density	Theoretical density (g/cc)	Vv%	Vb%	VMA %	VFB %	Stability (kN)	Flow
5	1245	706	2.31	2.445	5.53	**11.43482**	16.9624	67.41272	11	3.1
5	1247	716	2.348	2.511	6.48	11.62574	18.1046	64.21428	11.76	3.5
5	1247	718	2.357	2.511	6.13	11.66969	17.79498	65.57858	12.42	4.2
5.5	1248	720	2.364	2.493	5.18	12.87129	18.04639	71.32333	12.86	4.5
5.5	1249	721	2.366	2.493	5.1	12.8816	17.98072	71.64117	13.63	4.6
5.5	1253	724	2.369	2.493	4.98	12.89843	17.87359	72.1647	13.94	5.1
6	1255	725	2.368	2.475	4.31	14.06688	18.37831	76.54066	14.7	5.5
6	1255	726	2.372	2.475	4.13	14.09347	18.22401	77.33461	14.98	5.4
6	1258	728	2.374	2.475	4.08	14.1005	18.1832	77.5469	14.05	5.9
6.5	1260	725	2.355	2.457	4.15	15.15684	19.30344	78.51886	12.96	6.4
6.5	1262	728	2.363	2.457	3.81	15.20933	19.024	79.94813	12.65	7.5
6.5	1265	730	2.4	2.457	3.77	15.21699	18.98322	80.16022	11.98	7.8

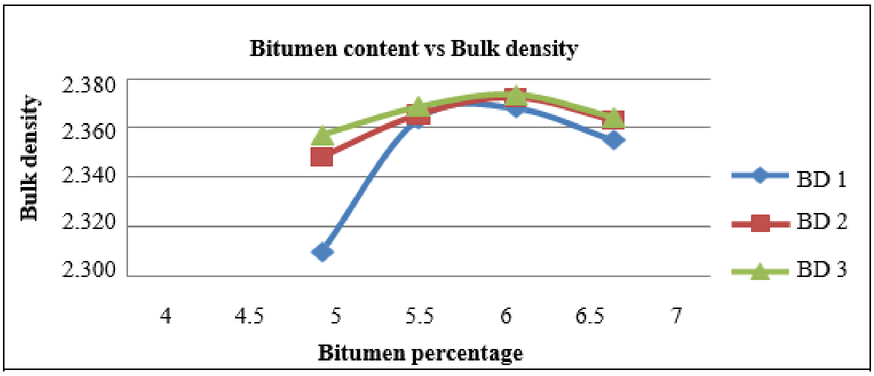

Figure 3.18: Bitumen content vs Bulk density

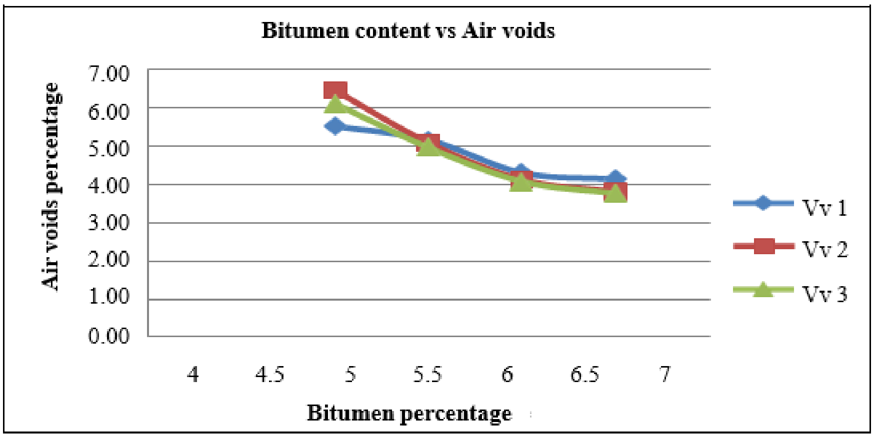

Figure 3.19: Bitumen content vs Air voids

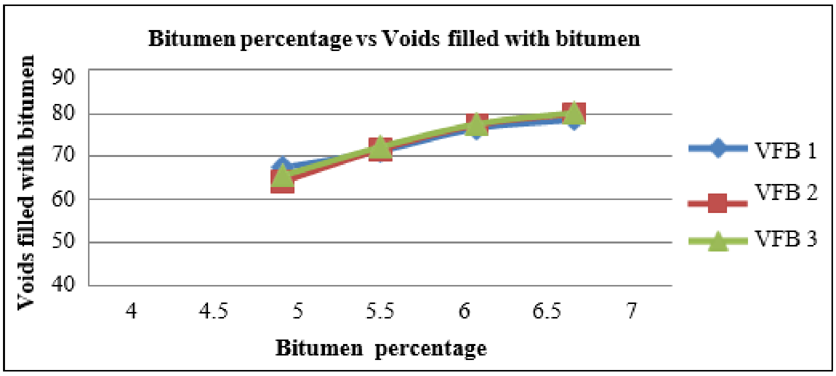

Figure 3.20: Bitumen percentage vs Voids filled with bitumen

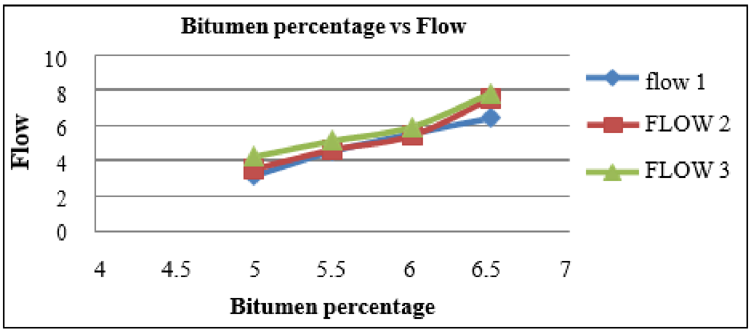

Figure 3.21: Bitumen percentage vs Flow

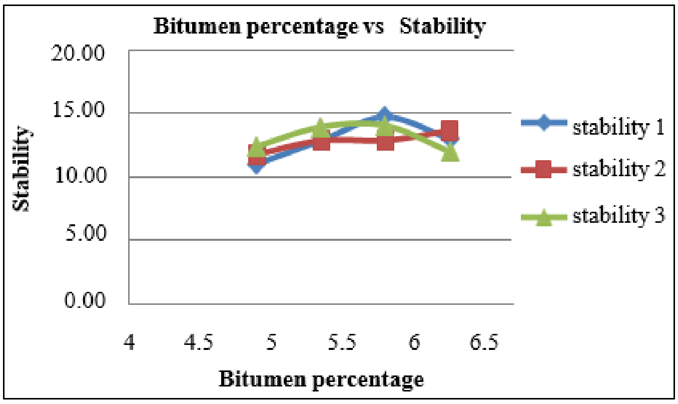

Figure 3.22: Bitumen percentage vs Stability

Table 3.14: ITS test results

TEMP	ITS CONV	ITS 30% RAP
25	0.88	0.942
30	0.809	0.9

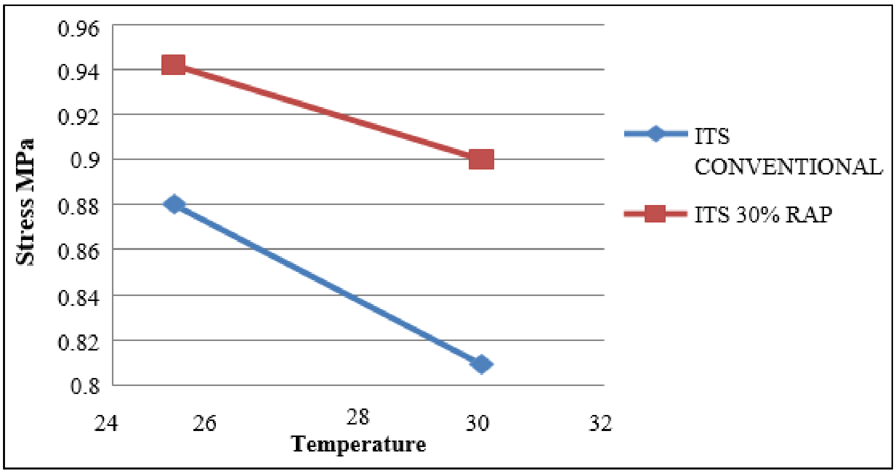

Figure 3.23: ITS graph

4.2 Economic Analysis

In the present study an attempt is made to recycle the paving mixes and work out the costinvolved for recycling.

Furtherly, A comparative assessment is made by computing the cost for the conventional aswell as RAP mixes. A typical example for one kilometer length for two lane highway is considered for cost analysis. The costs are calculated based on the schedule of rates of Govt.of Karnataka. The details of economic analysis are given below.

Table 5.1: Cost for Virgin mix

Particulars	Length (m)	Width (m)	Depth (m)	Qty. of aggregates (m^3)	Qty. of Bitumen (m^3)	Qty. of virgin materials (m^3)	Rate/m^3	Amount (Rs.)
SMA	1000	7	0.1	700	42	742	9436	7001512
Total								

Table 5.2: Cost for 10% RAP

Particulars	Length (m)	Width (m)	Depth (m)	Qty. of aggregates (m^3)	Qty. of Bitumen (m^3)	Qty. of virgin materials (m^3)	Rate/m^3	Amount (Rs.)
Milling	1000	9	0.1	-	-	990	36	35640
SMA	1000	7	0.1	700	42	668	9436	6303248
Total								6338888

Table 5.3: Cost for 30% RAP

Particulars	Length (m)	Width (m)	Depth (m)	Qty. of aggregates (m^3)	Qty. of Bitumen (m^3)	Qty. of virgin materials (m^3)	Rate/m^3	Amount (Rs.)
Milling	1000	9	0.1	-	-	990	36	35640
SMA	1000	7	0.1	700	42	520	9436	4906720
Total								4942360

Table 5.4: Cost for 50% RAP

Particulars	Length (m)	Width (m)	Depth (m)	Qty. of aggregates (m^3)	Qty. of Bitumen (m^3)	Qty. of virgin materials (m^3)	Rate/m^3	Amount (Rs.)
Milling	1000	9	0.1	-	-	990	36	35640
SMA	1000	7	0.1	700	42	371	9436	3500756
Total								3536396

After analyzing the economic analysis, the percentage of cost saving realized from the recycled mixes of 10%, 30%, and 50% in comparison with virgin mix (0% RAP) are 19%,30%,51% respectively are found to be reduction in total cost.

6. Conclusions

This research focused on assessing the impact of incorporating reclaimed asphalt pavement (RAP) into stone matrix asphalt (SMA) mixture at varying proportion of 0%, 10% ,30% and 50%. The laboratory analysis using the marshall mix deign method reveled that the mix containing 30% RAP achieved the most balanced perform in term of stability, flow, density, and air voids. Additionally, the indirect tensile strength result indicated improved tensile resistance in RAP- modified mixed, particularly at 30% suggesting enhanced cracking resistance compared to the conventional mix.

Also study demonstrates that SMA mixes with 10–30% RAP outperform virgin mixes in stability and tensile strength, while offering cost reductions of 10–51%. These findings validate RAP as a viable, sustainable option for pavement construction in India, where recycling lags despite resource scarcity. Future work could explore higher RAP percentages and field trials to confirm long-term performance, paving the way for broader adoption in infrastructure development.

On a broader scale, the use of RAP supports environmentally responsible construction practices by reducing dependence on virgin material, minimizing waste, and promoting resource efficiency. These benefits along with sustainable infrastructure goals and have the potential to influence future policies and construction standard in the roads sector.

To build on these findings, future studies could investigate field performance RAP- based pavements under real traffic condition, explore the use of different rejuvenating agent, and perform environmental impact assessment such as life-cycle or carbon footprint analyses. Such work would contribute further to validating RAP as a viable and sustainable alternative in asphalt pavement construction.

- Based on the Marshall properties, the SMA mixes prepared with RAP material of 10, 30, and 50% shows higher stability when compared with the conventional virgin mixes (0%).
- Based on the Marshall test results, the SMA mixes prepared with RAP materials of 10%, 30% shows all the Marshall properties of the mixes are well within the specifiedlimit.
- Indirect tensile strength of SMA mixes prepared with RAP materials shows highertensile strength at 25ºC when compared with SMA virgin mix.
- The saving can be realized from utilization of recycled materials as per the methodology, the reduction in the total cost is 10, 30, and 51% comparing with the virgin mixes.

7. Scope for Further Studies

- In the present study, the various tests were carried out for 0, 20, 30, and 50% RAP materials. However various other percentages can be evaluated.
- To know the realistic results and performance accurately 100% RAP materials can be evaluated.
- Various other binders can be used.
- Semi Field test track studies need to be carried out for validating the performance of the RAP mixes.

Declaration

In accordance with the requirements for the Degree of M.Tech Programme in Transportation Engineering, in Faculty of Engineering and Technology, I present this Project report on “utilization of reclaimed (RAP) in pavement construction”. I declare that the work presented in the report is my own work except as acknowledged in the text and footnotes.

Certificate

This is to certify that Mr. Arun Kumar Bhatt, Enrollment No.-MUR2300720, has submitted the project report entitled “Utilization of reclaimed (RAP) in pavement construction” in partial fulfillment for the award of the degree of Master of Technology in Transportational Engineering. The report is up to my satisfaction and as per the format prescribed for the writing of the report. His work is approved for presentation.

Acknowledgement

I am deeply indebted to **Dr. Ashok Kumar Gadiya**, Chairman, MEWAR UNIVERSITY, Chittorgarh for providing me the infrastructural facilities. My utmost gratitude to almighty God, who has been very kind to me all the time. The achievement would be worthless if it was not the timely help and guidance of well-wishers. I know acknowledge is not well enough to scale their help and wishes.

It is an immense pleasure to thank **Dr. Esar Ahmad** for his precious guidance, constant encouragement throughout the training. I also express my thanks to all the faculty members for their valuable suggestions from time to time. I would also like to thank my classmates and all that has directly and indirectly helped me during my work. I would also like to thank my parents and my family members for providing me with their blessing, immense encouragement, moral support, constant inspiration, enthusiasm and co-operation.

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