USE OF RECYCLED AGGREGATES FOR LOW COST PAVEMENTS

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With specialization in

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By

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PHAGWARA

CERTIFICATE

This is to Certify that the Project report entitled "**USE OF RECYCLED AGGREGATES FOR LOW COST PAVEMENTS ",** Submitted by "**Nitin Bhardwaj"** in partial fulfilment of the requirement for the award of Masters Degree in Traffic and Transportation Engineering at Lovely Professional University, Phagwara, Punjab is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this project report has not been submitted to any other University/Institute for the award of any Degree.

Date: 29-04-2015

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Nitin Bhardwaj

ABSTRACT

The need for sustainable asphalt highway design and construction is becoming a priority within the asphalt transportation industry. This trend is necessitated by the high diminishing rate of construction materials, pressing demand on existing landfill sites, rising dumping fees, and reduced emissions into the environment. Recycled Concrete Aggregates (RCA) as sustainable aggregates in Hot Mix Asphalt (HMA) is therefore investigated in this research project. The objective of this study is to characterize the mechanical properties of asphalt mixtures with recycled concrete aggregates for low volume roads (herein, the equivalent standard axle load number is low). In this study, the RCA is substituted for virgin aggregates (VA) in a light traffic volume DGBM (control mix) at the rate of 25, 50 and 75. Voids and micro fractures existing in recycled aggregates leads to large water absorption and crush value and low density and strength. Recycled aggregates are capable of serving as a useful replacement in dense graded bituminous macadam roadways where traffic loads are minimal the results show that we can use 50 to 60 percent recycled aggregates. It is believed that a higher substitution of recycled aggregates beyond 75% will lead to a failure of the specification criterion.

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LIST OF ABBREVIATIONS

HMA	Hot Mix Asphalt
DBM	Dense Bituminous Macadam
RCA	Recycled Coarse Aggregates
MORT&H	Ministry of Road Transport & Highways
OBC	Optimum Binder Content
VA	Air Void
VMA	Void in Mineral Aggregates
VFA	Void Filled with Bitumen
TSR	Tensile Strength Ratio

LIST OF SYMBOLS

G_{sb} Bulk specific gravity of aggregates

G_{se} Effective specific gravity of aggregates

M_b Mass of bitumen used in mix

G_b Specific gravity of bitumen

G_a Apparent specific gravity

G_{mm} Theoretical maximum specific gravity of mix

G_{mb} Bulk specific gravity of the mix

CHAPTER 1

INTRODUCTION

1.1 General:

With the emphasis on sustainable development there is growing pressure to investigate the viability of reuse of all categories of waste materials such as construction and demolition materials. They are obtained with the demolition of buildings and structures. The urgency of using recycling construction and demolition material has increased because of scarcity of natural aggregates and other environmental concerns. There is very wide scope to recover them and reuse as construction material.

The transportation infrastructure system is one of the main investments every modern society must make for their economic and social development. In India special steps has been taken to improve the road and highway systems. Two ambitious projects have been initiated with the development of National Highway Development project and the rural development program, popularly known as Pardhan Mantri Gram Sadak Yojana. These programs are likely to continue for a long time period as the targets would keep on changing with the achievement of all set targets. Therefore there will be huge requirement of pavement construction materials. It is well known that naturally occurring aggregates used for road construction are depleting rapidly. They are obtained from natural rocks and possess certain engineering properties. Most of the time these materials are not available locally in sufficient quantities and are to be brought from far off places which increases the transport cost .it increases the project cost substantially. During the last few years research has been conducted on various aspects of low volume roads resulting in innovative and unconventional approaches of road construction.

1.2 Construction and Demolition Waste in India:

According to the estimation of (CPCB) the Central Pollution Control Board of India the approximate solid waste generated is in the range of 48 million tons per annum. In which the waste generated from construction industry is more than 25%. Therefore there is great need for proper management of such a high quantity of waste. According to (Gaikwad and Kumar,

2004) the quantity of waste will reach at least 65 million tons per annum. Worldwide there is use of 10 billion tons of natural rock and sand by concrete industry and production of waste materials is more than 10 billion tons per year (Mehta, 2002). Table No. 1 showing different values of constituents in million kgs per year and Figure no.1 showing various constitutes of waste according to (TIFAC ,Department of science and technology ,GOVT. OF INDIA). Construction and demolition waste produced by The European Union approximately 200 – 300 million tons per year that is approximately equal to 0.5 – 1 per capita per year (Zega C J and Maio, 2011). Construction and demolition is mainly main source of aggregates because 74% of concrete is made from aggregates if this can be reused or recycled then there will be reduction in transportation cost and landfills also.`

Table No. -1 Constituent in million kgs given by TIFAC

Constituent	Million Kgs per year
Soil gravel and sand	4200 to 5140
Bricks and masonry	3600 to 4400
Concrete	2400 to 3670
Metals	600 to 730
Bitumen	250 to 300
Wood	250 to 300
Others	100 to 150

There is approximate 12 to 14.7 million tons waste from construction industry out of which there is 7 to 8 million tons are concrete and brick waste. Figure No. 1 shows the various constitutes of waste and out of which 25 % is concrete.

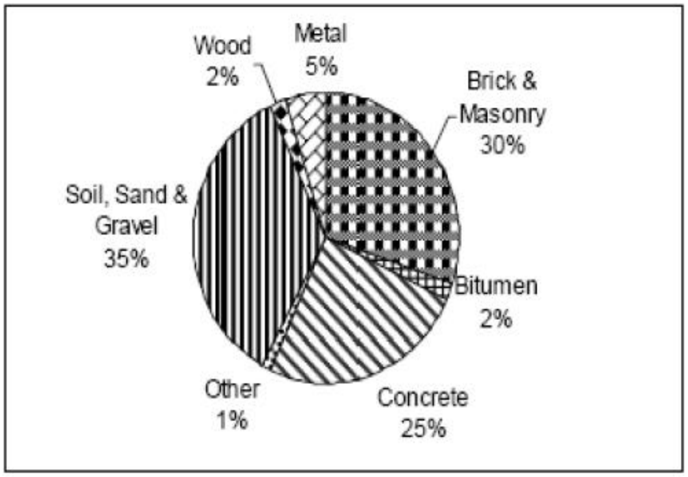

Figure No. 1 Various constitutes of waste

1.3 <u>Need of the Study</u>:

Due to fast growth in infrastructural development and increasing demand for housing there is shortage in the construction materials and also increase in cost of the materials. Generally materials which are produced by demolished structures are thrown away as a land fill. There is shortage in dumping place in city areas. Therefore it is essential to reuse and recycle the demolished materials to save environment, cost and energy. It is well known that naturally occurring aggregates used for road construction are depleting rapidly. Therefore there is need to find substitutes for it. Recycled aggregates can be used in place of normal aggregates in construction of low volume roads. For economical environmental reasons, and due to the increased amount of recycled aggregates at the present time as a result of advances in crushing technologies, there has been a growing global interest in maximizing the use of recycled aggregates in construction. Till today the research of recycled aggregates are mostly carried out in countries like Europe, Japan and United States etc. In India its research is at very initial stage. So there is wide scope of using recycled aggregates in construction of roads. The research work is mainly done on the use of recycled concrete in concrete structures or rigid pavements but very less work is done on its use in bituminous pavements.

1.4 Objectives of the Study:

- To Study the physical and mechanical performance of recycled aggregate used in bituminous mixes in place of natural aggregate.
- To utilize the recycled aggregate as a partial or full replacement of virgin aggregates in bituminous mixes.

1.5 Organization of Thesis:

The thesis consists of five chapters as described below.

- In chapter no.1 general idea about the total waste generated in India and worldwide and what is the need of recycling of materials and what are objectives of the study.
- In chapter no.2 the review of previous work, properties of the recycled coarse aggregates (RCA) and production of RCA are described.
- In chapter no.3 research methodology, materials which are to be used and tested to be performed are described
- Analysis of results and discussion on experimental investigations discussed in chapter no. 4.
- Conclusion and future scope of the work is in chapter No. 5.

CHAPTER 2

LITERATURE REIVIEW

2.1 General:

Aljassar et al., 2005 had studied asphalt mixture prepared by recycled coarse aggregates and found its performance in terms of volume, residual Marshall Stability and rutting resistance well satisfied the related technique requirements of Kuwait.

Wong YD et al., 2007 The applicability of substituting common virgin aggregates with waste concrete aggregates (RCA) has been shown to be promising in Singapore. The noticeable finding in this research, which used the Marshall Mix design method, was the fact that it is possible to use recycled concrete materials in HMA.

Saed A et al., 2008 The use of recycled coarse aggregates in hot mix asphalt is being considered in a project being undertaken by the Federal Highway Administration Technical Advisory Group on Pavements. This project follows an earlier one-National Co-operative Highway Research Project (NCHRP) Project 598 which investigated the performance-related behavior of RCA for use in unbound pavement layers. NCHRP Report 598 gave the guidelines on some, if not all, of the natural and physical properties that need attention if RCA is to be used in miscellaneous transportation infrastructural projects.

Zhu et al., 2010 substituted RCA of Wenchuan earthquake for limestone in asphalt mixture AC-25 at different proportion. It is found that requirements of high and low temperature performance, and water stability in specification were satisfied.

Perez et al., 2012 Asphalt mixture containing RCA was studied in Spain and the results indicated that it satisfied the requirement of technique specification for low-class highway pavement, and had good permanent deformation resistance. But it was found to have poor durability due to water sensitivity of RCA. Hu Liqun prepared cement stabilized base course by substituting waste clay brick for natural aggregate at different proportion, a substitution proportion of no more than 70% and 90% was suggested for the use of coarse and fine waste brick aggregate in the mixture.

Gul et al., 2014 had tested the resistance of asphalt mixtures using RCA by repeated creep tests. It is found that the permanent deformation resistance of the coarse mixtures while increasing the RCA content, but leading opposite effect on the fine graded mixtures

2.2 Properties of Recycled Aggregates:

Raw materials for production of the natural aggregates and recycled concrete aggregate contribute to some differences and variations of aggregate properties. Recycled concrete aggregate consists of natural aggregate coated with cement paste residue, pieces of natural aggregate, or just cement paste and some impurities. Relative amounts of these components, as well as grading, affect aggregate properties and classify the aggregate as suitable for production of better mix.

2.2.1 Physical Properties: The various physical properties of recycled aggregate are presented below.

- **Shape and Surface Texture:** In particular, the shape of the coarse aggregate is an important characteristic that can affect the mechanical properties of concrete. The shape and surface texture of the coarse aggregate influence the strength of concrete by providing an adequate surface area for bonding with the paste or creating unfavorable high internal stresses. The surface texture of aggregate contributes significantly to the development of a physical bond between aggregate and cement paste. Tasong et al. (1998) identified that the rough surface texture of the aggregate as contributing to a better bonding between aggregate and cement paste in concrete.
- **Bulk Density:** The bulk density or unit weight of an aggregate gives valuable information regarding the shape and grading of the aggregates. For a given specific gravity the angular aggregates shows a lower bulk density. Bulk density of aggregates is of interest when dealt with light weight aggregates and heavy weight aggregates. In general, the saturated surface density of recycled aggregates is lower than that of natural aggregates, due to the low density of the mortar that is adhered to the original aggregate. It depends on the strength of original concrete and size of original aggregates. Gonzalez et al. (2008) concluded that recycled aggregate concrete shows less dense than conventional concrete.

- **Specific Gravity:** Hansen et al. (1983) investigated that the specific gravity decreases from 4.5 to7.6% when compared with specific gravity of natural aggregate. Topcu et al. (2004) investigated that the specific gravity of Waste Concrete Aggregates (WCA) was lower than normal crushed aggregates. The reason for this was thought to be the fact that there was a certain proportion of mortar over these aggregates. Prasad et al. (2007) noted that the specific gravity of demolished concrete aggregates is lower than that of natural aggregate. The average specific gravity of aggregate usually varies from 2.6 to 2.8.
- **Water Absorption:** It is demonstrated by Ravindraraja (2000) that the average value of water absorption in recycled aggregate was 6.35%, where as in natural aggregate it was 0.9%. The absorption capacity of recycled aggregates depends on the quality and quantity of attached mortar. There was dependence between density and water absorption capacity. Recycle aggregates with adhered motor have lower density and higher water absorption capacity. Topcu et al. (2004) investigated that the water absorption ratio was found to be much higher compared with that of normal crushed aggregates. This was attributable to mortar over these aggregates.

2.2.2 Mechanical Properties: - The various mechanical properties of recycled aggregates are as follows.

- **Abrasion Value:** Los - Angeles abrasion value changes depends on the strength of the original concrete, the amount of adhered mortar and the original aggregate quality. Hansen et al. (1983) found that the Los - Angeles abrasion loss value is 22.4% for aggregates sized 16 to 32mm and 41.4% for aggregates sized 4-8mm.
- **Impact Value:** Aggregate impact value also depends upon the way in which recycled aggregates produced and strength of original concrete. The mortar which is still left on the surface of aggregates also influences the impact value. Aggregate impact value of recycled aggregates is generally higher than the virgin aggregates.

2.3 Recycled Aggregate Production: The recycled coarse aggregates classified for this study was crushed by two different systems. One was an industrial crushing operation that incorporated a primary jaw crusher and a secondary cone crusher. The second type of crusher was a small laboratory jaw crusher.

2.3.1 Industrial Crushing System: In the industrial crushing process, concrete pieces near about of 12 to 16 inches are fed into the primary jaw crusher. The jaw crusher jaws are distanced to regulate the maximum aggregate size produced. The jaw crusher produces good recycled aggregate size and an expected gradation for concrete production. The cone crusher is used as secondary crusher to further remove the mortar from the natural aggregates. The additional removal of mortar from the aggregates produces less angular or shaped pieces and aggregate with lower absorption capacity. This suggests that the mortar content on the recycled aggregates determines the overall qualities of that aggregate. While higher cost is incurred, the additional crushing removes attached mortar and thus produces a higher quality of recycled aggregate. The cone crusher must be used as a secondary crusher because it cannot hold materials greater than 200 mm. A cone crusher squeezes material between an eccentrically gyrating spindle and a bowl below. As the pieces are broken they fall to the lower, more closely spaced part of the crusher and are further crushed until small enough to fall through the bottom opening.

Figure No. 2.1 Industrial crushing system

2.3.2 Laboratory Crushing System: The smaller laboratory crusher is commonly used in the study of recycle coarse aggregates as large quantities of materials are needed to be properly crushed and collected by an industrial crushing system. The laboratory crusher is a jaw crusher and uses the same mechanism as the jaw crusher but can crush smaller quantities of material and fit in a laboratory. Due to the closeness of the jaws and smaller quantity of material, the crusher tends to break both the mortar and aggregate. This produces more angular pieces with a higher percent of attached mortar.

Figure No. 2.2 Laboratory crushing system

2.3.3 Aggregate-Mortar Separation: The aggregate matrix bond is still important with recycle coarse aggregates as it is with natural aggregates. The strength of the bond is determined by the aggregate surface. The recycle coarse aggregates properties are determined by the attached mortar content and the natural aggregate, which affects the aggregate-mortar separation and new recycle coarse aggregates shape. An aggregate with a rough surface, such as crushed aggregate, will have a stronger bond with the mortar than a sawn or smooth-surface aggregate. The crushed rock has higher bond strength and for that reason is less likely to initiate cracking at the interface. The crushed rock tends to be weaker and is for that reason more likely to fracture through the aggregate rather than at the interface if the matrix is sufficiently strong. Recycle coarse aggregates production generally uses concrete in a structure at the end of its valuable life. Good mortar-aggregate separation is needed because the removal of this mortar improves the concrete properties and therefore should be considered when determining the cost of additional processing and aggregate choice.

2.3.4 Sieving: After the crushing of concrete it is sieved to remove finer particles and grade the final product. Sieving equipment is already part of an industrial crushing system so no additional costs are incurred. The fine aggregate resulting from concrete crushing and recycle coarse aggregates production must be removed from the coarse aggregate pieces. The fine aggregate portion of crushed concrete is generally taken as particles passing the 4 no. sieve. Coarse aggregates are most resourcefully sorted with inclined, low frequency vibrating screens. Material that is smaller than 2 mm is removed because most of the loss in strength comes from these particles.

2.3.5 Washing the Recycled Coarse Aggregates: There is not consent on the necessity of washing coarse aggregates prior to using them in concrete. Fine particles increase cohesion between cement and fine aggregate particles which influences the ability of the cement paste to cling to it and the aggregates. A lately published paper on the treatment of recycled concrete aggregates indicates that for RCA to be used in concrete the RCA must be washed to lower the fine particle content. One another study accomplished that washing RCA increased the strength and permeability, whereas having no effect on the drying shrinkage.

2.3.6 Presoaking the Recycled Coarse Aggregates: The coarse Recycled aggregates should be integrated into concrete in a saturated surface dry state in order to moderate the irregular water demand created by the residual mortar attached to aggregates. Presoaking to the point of saturation is the best method because it ensures consistent moisture content and makes the high absorption capacity unrelated. The suggested length of presoaking time varies between researchers.

CHAPTER 3

EXPERIMENTAL SETUP

3.1 Introduction: This chapter deals with the experimental work carried out in present investigation. This chapter has two parts. In the first part the experiments done on materials which are used (virgin aggregates, recycled aggregates, bitumen) and second part deals with the tests that are carried out on bituminous mixes.

3.2 Material Used: For preparing a Marshall specimen the material used are coarse aggregates, fine aggregates, filler and binder. Recycled coarse aggregates are used in place of virgin aggregates.

- **Aggregates:** Use aggregates for preparation of bituminous mixes (DGBM) as per MORT&H guidelines as given in Table No. 2

Table No. 3.1 Composition of dense graded bituminous macadam pavement layers (MORT&H)

Nominal Aggregate Size	**25mm**
Layer Thickness	**50-75mm**
IS Sieve (mm)	**Cumulative % by weight of total aggregate passing**
37.5	100
26.5	90-100
19	71-95
13.2	56-80
4.75	38-54
2.36	28-42
0.3	7-21
0.075	2-8
Bitumen content % by mass of total mix	Min 4.5

- **<u>Recycled and Virgin Coarse Aggregates</u>**: Recycled aggregates up to 4.75 sieve size are produced by recycling the concrete waste and produced in the different sizes 20mm, 10mm and 6mm. Virgin aggregates collected from the local source consisted of stone chips. Figure No. 3.1 showing recycled coarse aggregates which are used.

Figure No.3.1 Recycled coarse aggregates

The physical properties of aggregates for DGBM mix as per MORT&H shown in Table No.3.2

Table No. 3.2 Physical requirements for coarse aggregate for dense graded bituminous macadam (MORT&H)

Property	**Test Method**	**MORT&H Specifications**
Aggregate Impact Value (%)	IS 2386 (P IV)	Max 27
Aggregate Crushing Value (%)	IS 2386 (P IV)	Max 30
Water Absorption (%)	IS 2386 (P III)	Max 2
Flakiness Index and Elongation Index combined (%)	IS 2386 (P I)	Max 30

- **Fine Aggregates**: Aggregates passing through 4.75mm IS sieve and retained on 0.075mm IS sieve consisting of stone crusher dusts were collected from local crusher. Specific gravity of fine aggregates found 2.6.
- **Fillers**: Aggregates which passes from 0.075mm IS sieve are known as filler. Here cement is used as filler. Specific gravity of cement is found
- **Binder**: VG-30 Bitumen is used for the preparation of the mix whose specific gravity is found 1.03. It is most suitable for Indian roads. The Standard properties of the bitumen according to IS 73 – 2006 as summarized in the Table No. 3.3

Table No. 3.3 Properties of VG-30 Bitumen as per IS 73 - 2006

Property	**Test Method**	**Specifications as per IS 73-2006**
Penetration at 25 ^{0}C	IS 1203 - 1978	50-70
Ductility at 25 ^{0}C(cm)	IS 1208 - 1978	40
Specific Gravity	IS 1202 - 1978	1.03
Softening Point , ^{0}C min	IS 1205 - 1978	47

3.3 Research Methodology:

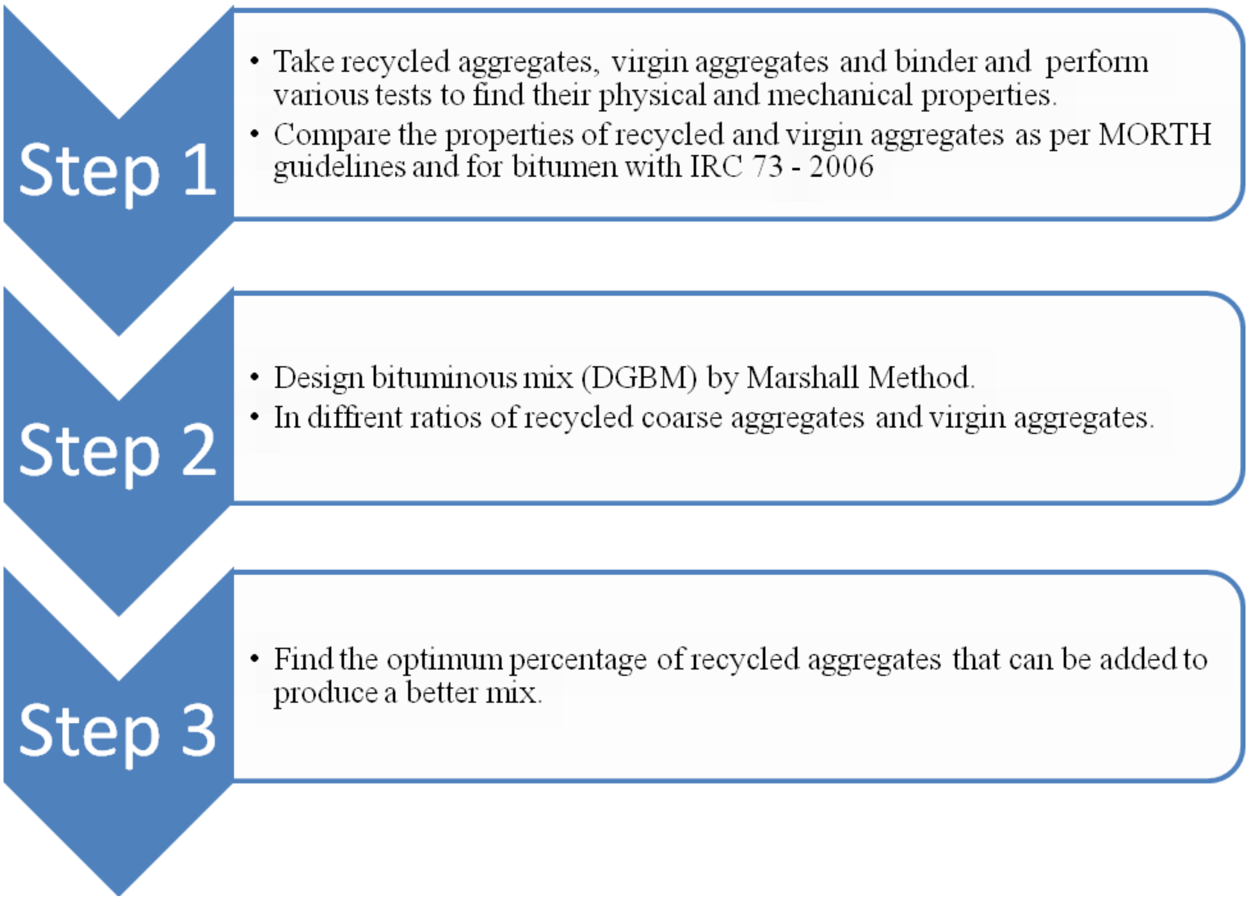

Figure No. 3.2 Research Methodology

3.4 Tests on Material Used: To find the various types of properties of the material used standard tests were conducted. The tests on the various materials are summarized as below.

3.4.1 Sieve Analysis: The required sieves were placed in the order of decreasing size from top to bottom. Sizes are 37.5mm, 26.5mm, 19mm 13.2mm, 9.5mm and 4.75mm for coarse aggregates. The sieves were shaked up and down mechanically with a rate of 100 strokes per minutes. Force through the aggregate more than 19mm size by hand. Sieve was ended when no more than 1 percent of aggregate by weight passed from the sieve layer. The mass of the aggregate in each sieve was determined by weighting and curve is drawn by plotting these values.

3.4.2 Aggregates Crushing Value Test: Aggregates used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak the stability of pavement structure is likely to be adversely affected. The strength of coarse aggregates is assessed by aggregates crushing value test. Dry aggregates passing 12.5mm sieve and retained on 10mm sieve are filled in three layers with tamping in cylindrical vessel having internal diameter 115mm and height 180mm. Tamping is done by tamping road of diameter 16mm and length 450 to 600mm. a crushing load of 40 tonnes is applied at a rate of 4 tonnes/minute and crushed aggregates sieved through 2.36mm sieve. Aggregates crushing value = W2/W1 X 100 Where W2 is crushed material passing through 2.36 mm and W1 is sample material. The crushing value for surface course should not be exceeded 30%.

Figure No. 3.3 Crushing value testing machine

3.4.3 Aggregate Impact Value Test: The aggregates impact test is used to carry out to evaluate the resistance to impact of aggregates. Aggregates should have size between 12.5mm and 10mm are taken and filled in 3 layers with tamping of 25 strokes with tamping road. Metal hammer of weight 13.5 to 14kg is dropped with a free fall of 380mm and the test specimen is subjected to 15 numbers of blows. Aggregate Impact Value= W2/W1 X 100. Where W2 is the crushed aggregates passing through 2.36 IS sieve and W1 is the total weight of the sample. For dense graded bituminous macadam impact value should not be more than 27 %.

Figure No. 3.4 Impact testing Machine

<u>3.4.4 Specific Gravity and Water Absorption Test:</u> The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Specific gravity test helps in the identification of stone. Water absorption gives an idea of strength of the aggregate.

Figure No. 3.5 Specific gravity testing

W1 = Weight of aggregates suspended in water with the basket.

W2 = Weight of basket suspended in water.

Ws = Weight of saturated aggregates in water (W1 – W2).

W3 = Weight of saturated surface dry aggregates in air.

Weight of water equal to the volume of aggregates (W3 – Ws)

W4 = Weight of oven dried aggregates.

Specific gravity = W4/ (W3 – Ws)

The specific gravity of rocks varies from 2.6 to 2.9.The water absorption is expressed as percent water absorbed in terms of over dried weight of the aggregates.

3.4.5 Flakiness and Elongation Index Test: The particle shape of aggregates is determined by percentage of flaky and elongated particles contained in it by using flakiness gauge and elongation gauge. The flakiness index of aggregates is the percentage by weight of particles whose least dimension is less than 0.6 times of its mean dimension and elongation index of aggregates is the percentage by the weight of aggregates whose greatest dimension is greater than 1.8 times their mean sizes. Elongation index is not applicable for particle size smaller than 6.3mm. Combined Flakiness and elongation index for Bituminous and Non-Bituminous mixes = Max. 30%

3.4.6 Penetration Test for Bitumen: This test determines hardness or softness of bitumen by measuring depth in tenths of millimeter to which a standard loaded needle will penetrate vertically in five seconds. Sample is maintained at temperature of 25^0C. Penetrometer shown in Fig No. 3.6 consists of needle assembly with a total weight of 100g and device for releasing and locking in any position. There is a graduated dial to read penetration value $1/10^{th}$ of a millimeter. Bitumen grade is specified in terms of penetration values. 80-100 or 80/100 grade bitumen means penetration value of the bitumen in the range of 80-100 at standard test conditions. Range of penetration value used in pavement construction is 20- 225. Penetration value of VG 30 bitumen is lies between 50 -70.

Figure No. 3.6 Penetrometer

3.4.7 Ductility Test for Bitumen: Ductility of material is its property to elongate when subjected to tension before breaking. Ductility of bitumen is expressed as the distance in centimeters to which a standard briquette of bitumen can be stretched before the thread breaks. Test specimen after prepared by molding is kept at a constant temperature in water bath for a period of 85 to 95 minutes. Briquette is removed from the plate, side pieces detached and the sample is tested by pulling clips at the ends, placed in the Ductilometer shown in Fig No. 3.7 Two clips are pulled at the rate of 5cm/minute, until rupture. Distance in centimeters that the briquette stretches before breaking gives ductility of the material. Ductility value of bitumen varies from 5 to 100 for different bitumen grades. A minimum ductility value of 75 cm has been specified by the ISI for bitumen of grades 45 and above.

Figure No. 3.7 Ductilometer

3.4.8 Softening Point Test for Bitumen: It is measured using ring ball apparatus as Shown in Fig No. 3.8 Softening point is the temperature at which the substance attains a particular degree of softening under specified conditions of the test. Standard ring ball apparatus is used for determine the softening point. The softening point of VG - 30 is 47^0C.

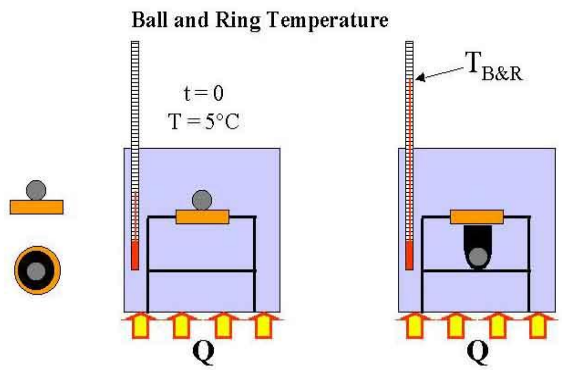

Figure No. 3.8 Ring ball apparatus

3.5 Preparation of Bituminous Mixes: The mixes are prepared as per Marshall procedure specified in ASTM D1559. The coarse aggregates, fine aggregates and filler are mixed for DGBM layer according to the gradation adopted in Table No. 3.1 Comparative study is done on DGBM by replacing the recycled coarse aggregates with virgin aggregates in different ratios. The ratio of virgin aggregates to recycled aggregates according to Table No. 3.4 here optimum binder content (OBC) is found By Marshall Test by varying the bitumen content 4 to 7% and also the optimum ratio of recycled aggregates to virgin aggregates is found.

Table No. 3.4 Ratio of Virgin aggregates to Recycled coarse aggregates

Virgin aggregates (%)	Recycled aggregates (%)
75	25
50	50
25	75

The aggregates are heated separately at a temperature up to 170^{0}C and bitumen is heated at a temperature up to 163^{0}C. Required quantity of bitumen is added and mixes them thoroughly till the color and consistency of the mixture appeared to be uniform. Mixing time should be between 2 to 5 minutes. Then mixture prepared was put into the preheated Marshall mould and samples were prepared by giving 75 blows with standard hammer (45 cm, 4.86 kg) on each side of the mould. Then specimens were kept for cooling for one day to room temperature. Then sample was extracted with the help of Marshall Extractor and sample was kept in the water bath at a constant temperature of 60^{0}C for 30 minutes. The preparation is shown in following Figures.

Figure No. 3.9 Blending of aggregates

Figure No. 3.10 Mixing of aggregates and binder

Figure No. 3.11 Provinding blows

Figure No. 3.12 Sample after compaction

3.5.1 Tests on Bituminous Mixes: Tests conducted on the bituminous mixes with different binder content and different concentration of recycled aggregates.

3.5.2 Marshall Test: Marshall Mix design is a standard laboratory method, which is approved worldwide for identifying and reporting strength and flow characteristics of asphalt pavements. In India, it is a very popular method of characterization of asphalt mixtures. This test has also used by many researchers to test the asphalt mixture. This test method has been widely accepted because of its simplicity and low cost. Given that some of the advantages of Marshall method was decided to use this method to determine the optimal Binder Content (OBC) mixing and also the study of various characteristics such as Marshall Stability, flow value, unit weight, air voids etc. Figure No. 3.13 and Figure No. 3.14 showing Marshall Sample and Marshall Apparatus with loaded specimen respectively.

Figure No. 3.13 Marshall samples

Figure No. 3.14 Stability and flow testing

Marshall Properties such as flow value, stability, air voids and weight are studied to obtain OBC and optimum ratio of recycled aggregates to virgin aggregates. Unit weight and air voids were calculated by using procedure which is reported by Das and Chakroborty.

3.5.3 Parameters Used for Volumetric Analysis in Marshal Method: The all Marshall properties were calculated as per formulae and definitions which are used for calculation are explained below

Bulk specific gravity of combined aggregates (G_{Sb})

G_{Sb} = 100 / (W1/G1 + W2/G2 + W3/G3 + W4/G4)

Where W1, W2, W3 and W4 are percentage by weight of aggregates and G1, G2, G3 and G4 are their specific gravities.

Effective specific gravity of aggregates (G_{se})

$G_{se} = 100 - P_b / (100/G_{mm} – P_b/G_{b)}$

Where P_b is percentage of bitumen content

G_{mm} = Maximum specific gravity of the loose mix

G_b = Specific gravity of the bitumen

Theoretical maximum specific gravity (G_{mm})

$G_{mm} = M_{mix}$ / Volume of (Mix – Air void)

Bulk specific gravity of the specimen ($G_{mb)}$

G_{mb} = A / (B-C)

Where A = Mass of the dry specimen in air

B = Mass of the saturated surface dry specimen in air

C = Mass of specimen in water

Air voids (VA)

VA = $(1- G_{mb} / G_{mm})$ X 100

Voids in mineral aggregates (VMA)

$VMA = 100 - (G_{mb} \times P_s / G_{sb})$

Where P_s = percentage of aggregates present by total mass of the mix

Voids filled with bitumen (VFB)

VFB = (VMA – VA / VMA) X 100

Or (VMA – VTM / VMA) X 100

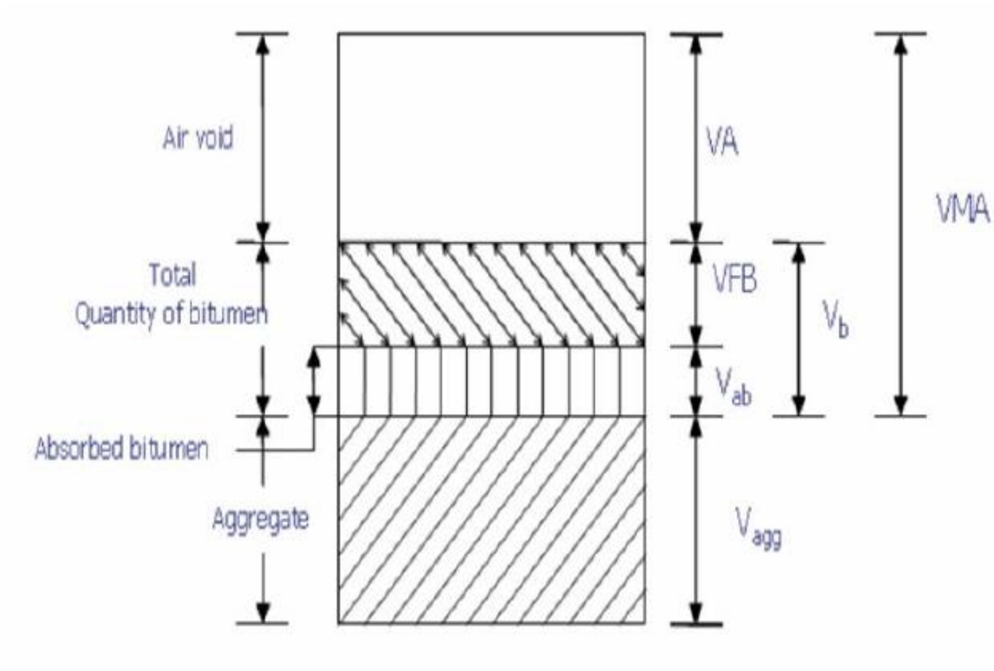

Figure No. 3.15 Phase diagram of bituminous mix

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction: This chapter deals with result and observation of tests carried out in previous chapter. In the first section of this chapter the properties of materials which are used are defined, in second section Marshall properties are calculated and plotted, in third section calculation of optimum binder content of DGBM and in the fourth section calculation of optimum binder content and optimum ratio of recycled to virgin coarse aggregate.

4.2 Properties of Materials Used: The aggregate impact value and crushing value of recycled aggregates is less and water absorption is high this is due to mortar attached on the surface of aggregates. The properties computed are tabulated in Table No. 4.1

Table No. 4.1 Results of physical properties of aggregates

Property	**Test Method**	**Virgin Aggregates**	**Recycled Aggregates**	**MORT&H Specifications**
Aggregate Impact Value (%)	IS 2386 (P IV)	11	21	Max 27
Aggregate Crushing Value (%)	IS 2386 (P IV)	21	28.33	Max 30
Water Absorption (%)	IS 2386 (P III)	1.45	3.25	Max 2
Flakiness Index and Elongation Index combined (%)	IS 2386 (P I)	22.5	27.33	Max 30

Table No. 4.2 Specific gravities of the aggregates

Description of materials	**Specific gravity**
Virgin coarse aggregates	2.64
Recycled coarse aggregates	2.53
Fine aggregates	2.6
Bitumen VG-30	1.03

Table No. 4.3 Results of properties of binder

Property	**Test Method**	**Value**	**Specifications as per IS 73-2006**
Penetration at 25 ^{0}C	IS 1203 - 1978	65	50-70
Ductility at 25 ^{0}C(cm)	IS 1208 - 1978	42	40
Specific Gravity	IS 1202 - 1978	1.034	1.03
Softening Point , ^{0}C min	IS 1205 - 1978	48.5	47

4.3 Aggregate Gradation and Blending of Aggregates: Aggregates grading and blending is shown in Table No. 4.4 and Table No. 4.5 respectively and Figure No. 4.1 shows blending of aggregates.

Table No. 4.4 Gradation of recycled and virgin aggregates

Sieve size	**Size of virgin aggregates (individual gradation)**				**Size of recycled aggregates (individual gradation)**			
	20 mm	10 mm	6 mm	sand	20 mm	10 mm	6 mm	Sand
37.5	100	100	100	100	100	100	100	100
19	38	100	100	100	42	100	100	100
13.2	12	88	100	100	14	86	100	100
9.5	5	30	100	100	6	34	100	100
4.75	0.8	10	40	100	1.2	8	42	100
2.36	0.2	3	25	80	0.4	3.2	28	80
0.3	0.03	0.7	10	38	0.04	0.05	2.2	38
0.075	-	-	0.3	12	-	-	0.03	12

Table No. 4.5 Blending of aggregates

Sieve size mm	**Blending of aggregates**				**Combined gradation**	**Specified Limits as per MORT&H**
	20 mm	**10 mm**	**6 mm**	**sand**		
	20 %	25 %	30 %	25 %	100 %	100
37.5	20	25	30	25	100	100
19	7.6	25	30	25	87.6	71 - 95
13.2	2.4	22	30	25	79.4	56 - 80
9.5	1	7.5	30	25	63.5	40 - 65
4.75	0.16	2.5	12	25	39.66	38 - 54
2.36	0.04	0.75	7.5	20	28.29	28 - 42
0.3	0.006	0.175	3	9.5	12.681	7 - 21
0.075	-	-	0.09	3	3.09	2 - 8

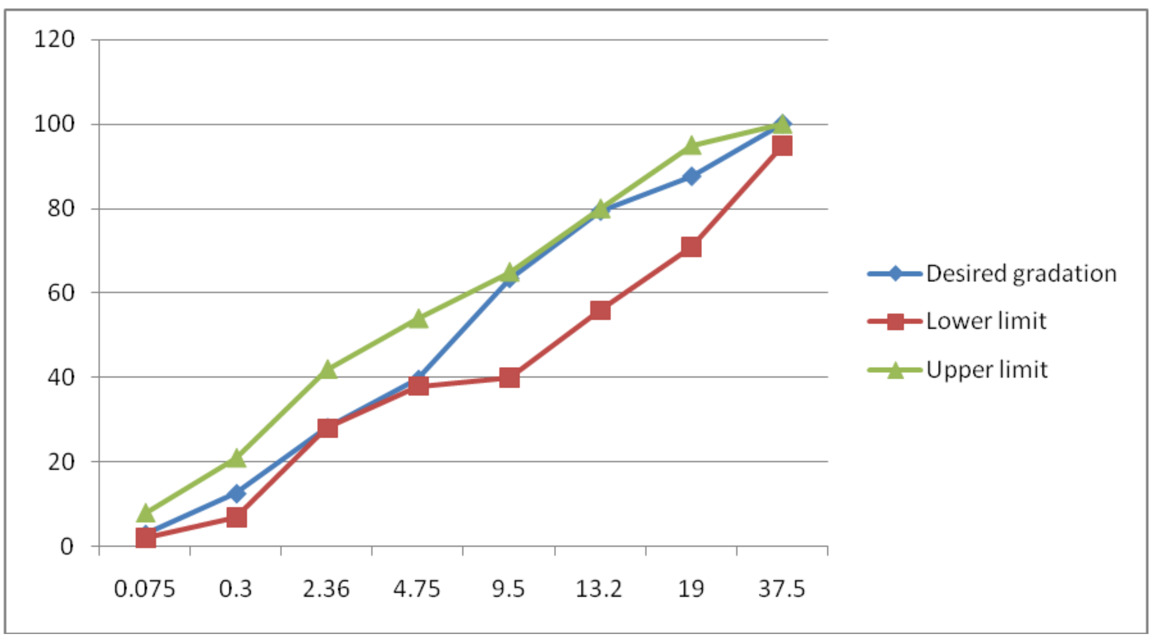

Figure No. 4.1 Blending of aggregates

4.4 Effect of Recycled Aggregates on Marshall Properties of DGBM Mix: Here result in variations of Marshall Properties with different binder content and RCA are taken by percentage 25%, 50% and 75% for DBM.

4.4.1 Weight of Samples and Specific Gravities: When the sample is prepared its dry weight and weight in water is taken. By using these values bulk volume of sample is calculated and after that G_{mb} is calculated by formula given in chapter 3. The values that are obtained are shown in Table No.6.

Table No. 4.6 Weight and specific gravities of the mixes

No. of samples	Type of mix	% of bitumen	Weight			G_{mb}	Average G_{mb}
			In air	In water	SSD		
2	75% VA + 25 % RA	4.5	1195	682	1200	2.306	2.302
			1218	679	1209	2.298	
2	75% VA + 25 % RA	5	1213	682	1205	2.319	2.321
			1220	687	1212	2.323	
2	75% VA + 25 % RA	5.5	1198	678	1195	2.312	2.31
			1218	682	1209	2.308	
2	75% VA + 25 % RA	6	1205	680	1195	2.339	2.343
			1207	683	1197	2.348	
2	50 % VA + 50% RA	4.5	1210	673	1205	2.273	2.275
			1208	674	1204	2.277	
2	50 % VA + 50% RA	5	1204	683	1195	2.294	2.289
			1210	684	1200	2.283	
2	50 % VA + 50% RA	5.5	1210	672	1203	2.281	2.280
			1203	669	1197	2.279	

2	50 % VA + 50% RA	6	1195	682	1200	2.308	2.300
			1217	678	1209	2.292	
2	25% VA + 75% RA	4.5	1212	770	1203	2.241	2.240
			1198	662	1192	2.240	
2	25% VA + 75% RA	5	1212.2	664	1204	2.221	2.218
			1204	669	1207	2.214	
2	25% VA + 75% RA	5.5	1214	672	1207	2.249	2.232
			1212	662.2	1205	2.216	
2	25% VA + 75% RA	6	1208	671	1201	2.262	2.245
			1210	662	1203	2.23	

4.4.2 Marshall Test Values: For every sample the Marshall Test data that is stability and flow value is recorded and tabulated. The stability is in kN and flow value is in mm.

Table No. 4.7 Marshall Test values

No. of samples	Type of mix	% of bitumen	Stablity value (kN)	Average Stability	Flow value (mm)	Average flow
2	75% VA + 25 % RA	4.5	10.40	10.60	2.2	2.3
			10.80		2.4	
2	75% VA + 25 % RA	5	11.85	11.51	2.66	2.56
			11.20		2.46	
2	75% VA + 25 % RA	5.5	10.20	10.95	2.96	3.04
			11.10		3.12	
2	75% VA + 25 % RA	6	9.90	9.78	3.68	3.62
			9.65		3.56	

2	50 % VA + 50% RA	4.5	10.10	10.20	2.53	2.63
			10.30		2.73	
2	50 % VA + 50% RA	5	11.05	10.575	2.80	2.88
			10.10		2.96	
2	50 % VA + 50% RA	5.5	10.60	10.75	3.34	3.3
			10.90		3.26	
2	50 % VA + 50% RA	6	9.30	9.40	3.76	3.61
			9.50		3.46	
2	25% VA + 75% RA	4.5	8.60	8.35	2.54	2.61
			8.10		2.68	
2	25% VA + 75% RA	5	9.10	8.85	2.96	3.04
			8.60		3.12	
2	25% VA + 75% RA	5.5	8.90	9.10	3.34	3.285
			9.30		3.23	
2	25% VA + 75% RA	6	8.75	7.99	3.65	3.80
			7.90		3.96	

4.4.3 Calculations and Results: The values of G_{sb}, G_{mm}, G_{mb}, VA, VFB, VMA are calculated. For all these calculations formulae given in chapter three are used.

Table No. 4.8 Calculations of VA, VMA and VFB

No. of samples	Type of mix	% bitumen	G_{sb}	G_{mm}	Avg. G_{mb}	Gse	VA (%)	VMA (%)	VFB (%)
2	75% VA + 25 % RA	4.5	2.60	2.43	2.302	2.596	5.26	15.44	65.00
2	75% VA + 25 % RA	5	2.60	2.419	2.321	2.604	4.05	15.19	73.30
2	75% VA + 25 % RA	5.5	2.60	2.398	2.31	2.599	3.66	16.04	77.28
2	75% VA + 25 % RA	6	2.60	2.372	2.343	2.587	1.63	15.29	89.01
2	50 % VA + 50% RA	4.5	2.588	2.423	2.275	2.588	6.10	16.05	61.99
2	50 % VA + 50% RA	5	2.588	2.406	2.289	2.587	4.86	15.97	69.5
2	50 % VA + 50% RA	5.5	2.588	2.378	2.280	2.574	4.16	16.78	75.20
2	50 % VA + 50% RA	6	2.588	2.344	2.300	2.556	1.87	16.46	88.6
2	25% VA + 75% RA	4.5	2.57	2.410	2.240	2.371	7.02	16.72	58.00
2	25% VA + 75% RA	5	2.57	2.375	2.218	2.361	6.61	18.01	63.29
2	25% VA + 75% RA	5.5	2.57	2.336	2.232	2.394	4.45	17.92	75.16
2	25% VA + 75% RA	6	2.57	2.294	2.245	2.42	2.13	17.88	87.4

4.5 Graphs Obtained: The graphs are plotted for the data collected above.

- **Stability vs. Bitumen Content:** Value of stability and bitumen content plotted against bitumen in x axis and stability in y axis and shown in Figure No. 4.2

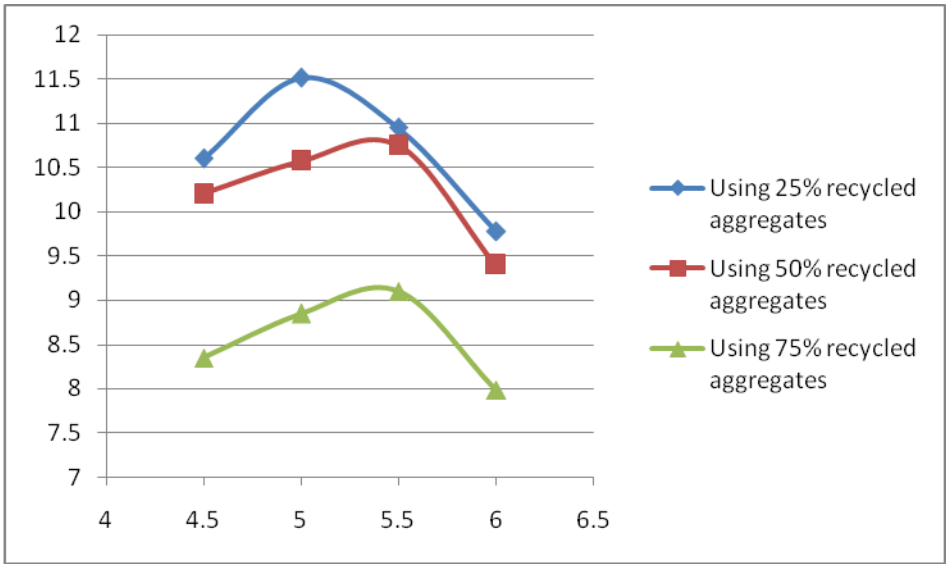

Figure No. 4.2 Stability vs. bitumen content

- **Flow Value vs. Bitumen Content:** Flow value and bitumen content plotted against bitumen in x axis and stability in y axis shown in Figure No. 4.3

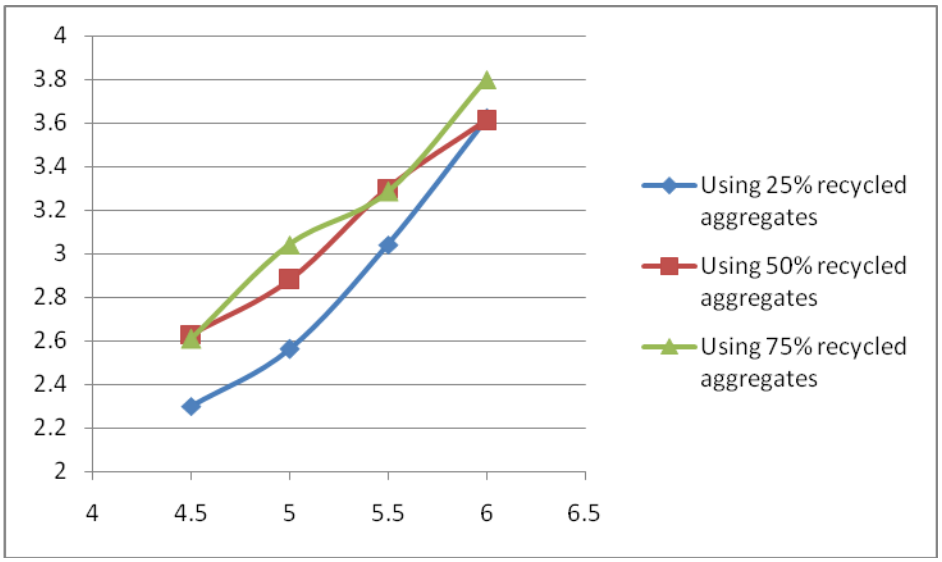

Figure No. 4.3 Flow value vs. bitumen content

- **VMA vs. Bitumen Content:** Voids in mineral aggregates (VMA) and bitumen content plotted against bitumen in x axis and stability in y axis shown in Figure No. 4.4

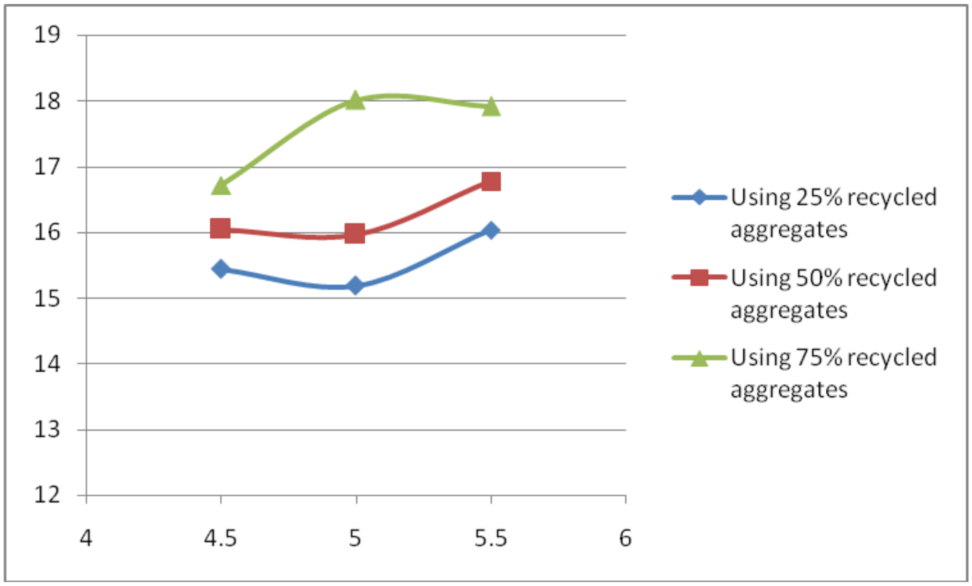

Figure No. 4.4 VMA vs. bitumen content

- **VFB vs. Bitumen Content:** Voids filled with bitumen (VFB) plotted against bitumen content, in x axis and stability in y axis shown in Figure No. 4.5

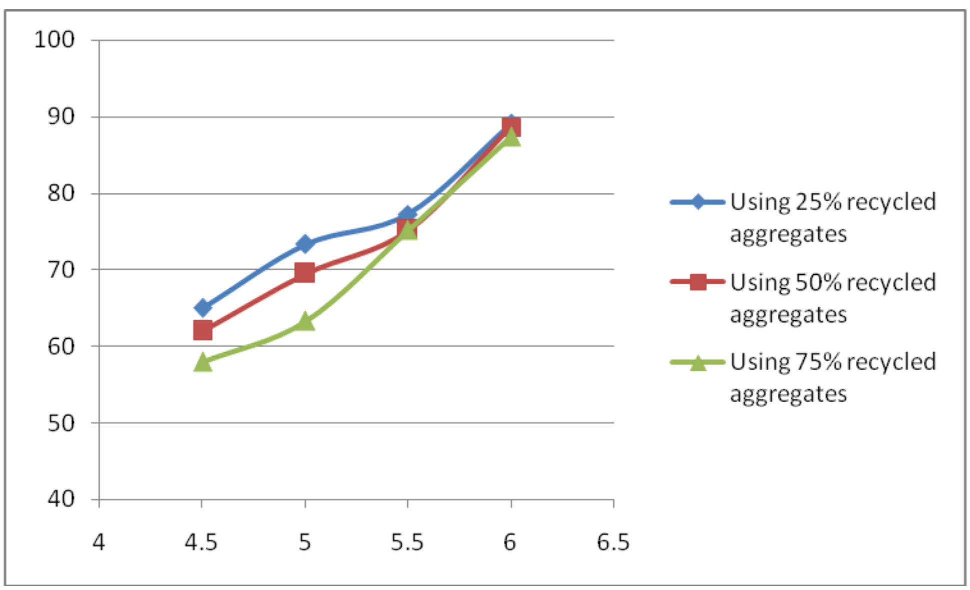

Figure No. 4.5 VFB vs. bitumen content

- **<u>4.5.5 Air Voids vs. Bitumen Content:</u>** Air voids plotted against bitumen content bitumen in x axis and air voids in y axis shown in Figure No. 4.6

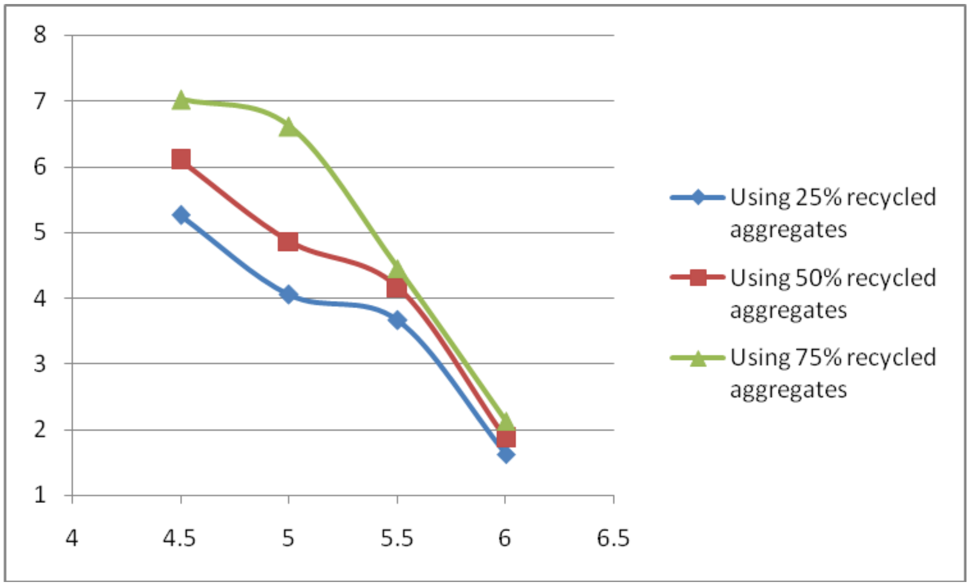

Figure No. 4.6 Air voids vs. bitumen content

<u>4.6 Determination of Mix Design Parameters:</u> From the curves, at 4 % air voids the mix properties are shown in Table No. 4.9

Table No. 4.9 Mix properties at 4 % air voids

Properties	25 % recycled aggregates	50 % recycled aggregates	75 % recycled aggregates
Bitumen content	5.5	5.5	5.5
Stability	10.95	9.60	8.40
Flow	3.04	3.3	3.28
VMA	15.20	14.76	13.21
VFB	82.14	78.76	72.30

4.7 INTERPRETATION OF RESULTS:

- **Marshall Stability:** For each of three mixes, samples were prepared at four different bitumen content 4.5%, 5%, 5.5% and 6% with two samples for each fraction. Fig No. 4.1 shows the plot of Marshall Stability against bitumen content. The stability value increases with increases in bitumen content up to a maximum value, then decreases with increase in bitumen content. It is clear from the graph as the percentage of recycled aggregates increases the stability value decreases. The stability dropped by very large value when 75 percent aggregates are replaced with virgin aggregates but up to 50 percent it gives good results.
- **Flow Value:** It is clear from the graph results that increase in bitumen content leads to linear increase in the flow values. Fig No. 4.2 shows the plot of flow against the different bitumen content. For all the three mixes at three different bitumen contents, the flow values are within the standard limits 2 – 4 mm as specified by MORTH. Replacing recycled aggregates up to 50 % gives similar flow values. In 75 % replacing the flow values are increases as compared to other values
- **Air Void Content:** The air voids are the total volume of the small pockets of air between coated particles throughout a compacted paving mixture, expressed as percentage of the bulk volume of the compacted paving mixture. Fig No.4.5 shows air voids content gradually deceases with increase in bitumen content and that is due to the increase of voids percentage filled with bitumen in asphalt mix. As the proportion of recycled aggregates increases the air voids increases because mortar is attached on the surface of aggregates, which causes roughness therefore coating is not done properly therefore air voids increases as the proportion of recycled aggregates increases. Fig No. 4.5 shows the plot between air voids and bitumen content.
- **Voids in Mineral Aggregates (VMA):** Voids in the mineral aggregates is the volume of intergranular void space between the aggregate particles of a compacted paving mixture, including the air voids and volume of asphalt not absorbed into the aggregates. Fig No. 4.3 shows the plot between VMA and different binder contents. With increase in bitumen content the voids in mineral aggregates decreases and as the recycled

aggregates increases VMA value decreases this is due to lack of coating of bitumen on the surface of recycled aggregates.

- **Optimum Bitumen Content:** The optimum bitumen content has been obtained by taking the averages of bitumen contents at which the mix has compacted density, maximum stability and 4% design air voids. It is observed from the graph that the VMA increase with increase in bitumen content. The increase in VMA as a result of increase in percentage of recycled aggregates added is attributed to the increased absorption of bitumen content by filler.
- **Voids Filled with Bitumen (VFB):** The relationship between voids filled with bitumen and bitumen content is presented in Fig No. 4.4. It is observed from the plot that VFB increase with increase in bitumen content. The value of VFB for mixes which contained more recycled aggregates (75 %) is lower than which contained lower recycled aggregates (50%, 25%), Implying that addition of recycled aggregates in higher percentage reduces the VFB values.

__CHAPTER 5__

CONCLUSION:

- Voids and micro fractures existing in recycled aggregates leads to large water absorption and crush value and low density and strength.
- Recycled aggregates are capable of serving as a useful replacement in dense graded bituminous macadam roadways where traffic loads are minimal the results show that we can use 50 to 60 percent recycled aggregates. It is believed that a higher substitution of recycled aggregates beyond 75% will lead to a failure of the specification criterion.
- The attached mortar on the recycled aggregates surface enabled these aggregates to absorb a large amount of bitumen during DBM manufacture. The laboratory results showed that the bitumen absorption increased with the recycled aggregates content. This result highlights the absorptive character of recycled aggregates.
- The attached mortar caused the recycled aggregates roughness. This roughness is the primary reason for why mixture compaction was more difficult. The air voids content increased with the recycled aggregates content for this reason.

5.1 FUTURE SCOPE

- Marshall Properties of DBM mixes prepared with recycled coarse aggregates are investigated with VG 30 penetration grade bitumen and optimum ratio of recycled coarse aggregates to virgin coarse aggregates was found, however other properties like drain down characteristics, static tensile strength creep characteristics were not studied due to lack of equipments. Therefore these properties needed to be investigated.
- Use of other fillers may result in better performance with recycled coarse aggregates. So it may also be evaluated in future.

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