EFFECT OF RECLAIMED ASPHALT PAVEMENT (RAP) AND USED FOUNDRY SAND IN DENSE BITUMINOUS MACADAM (DBM-II) MIX

A Thesis Submitted in Fulfilment of the Requirement for the Award of the Degree of

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IN

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Submitted by

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DECLARATION

I hereby declare that this thesis entitled **"Effect of Reclaimed Asphalt Pavement(RAP) and Used Foundry Sand in Dense Bituminous Macadam (DBM-II) Mix"** is an reliable record of my study carried out as requirements for the award of degree of **Master of Engineering in Infrastructure Engineering** in the Civil Engineering Department, Thapar Institute of Engineering and Technology , Patiala under the supervision of **Dr. Tanuj Chopra, Assistant Professor and Dr. Aditya Parihar, Assistant Professor,** Department of Civil Engineering, Thapar Institute of Engineering and Technology , Patiala an authentic record of my own work carried out during 28 July 2018 to 11 July 2019 . This matter exemplify in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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This statement is to certify that the student concerned is correct and true to the prime of my knowledge and opinion.

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ABSTRACT

In the past 20 years, Reclaimed Asphalt Pavement (RAP) is used worldwide to reduce the use of virgin aggregates in laying new pavements, this helps in reducing the bitumen content, extinction of natural recourses as well as abbreviating energy. When over laying of pavement is done the existing layer is scarped from the surface and considered as waste, thus dumped on the other site. Similar is the Used Foundry Sand which is the waste product of metal casting industries. In this study we are using Reclaimed Asphalt Pavement (RAP) with Used Foundry Sand in asphalt mix of Dense Bituminous Macadam-II with different percentage such that maximum stability and minimum use of binder content for a fair pavement.

Will the help of Marshall method of asphalt mix design and Indirect tensile strength test(IDT) it showed at which percentage RAP and used foundry sand showed maximum strength and resistance to cracking. Resilient Modulus values are finding on the basis of IDT results using IRC: 37-(2018). Through this we are able to find the Rutting and fatigue criteria of flexible pavement of Reclaimed Asphalt Pavement (RAP) with Used Foundry Sand.

With the use of IIT Pave software we designed a pavement layer with minimum thickness of bituminous layer consisting RAP and used foundry sand. It is analyzed for both critical values of strain values of rutting and fatigue life and their values are less than allowable values as per IRC: 37-2018. Cost analysis for replacement of virgin aggregates with RAP is also analyzed.

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LIST OF ABREVATIONS

AASHTO = American Association of State Highway and Transportation Officials

ASTM = American Society for Testing and Materials

ATPB = Asphalt Treated Permeable Base

BC = Bituminous Concrete

CBR= California Bearing ratio

DBM= Dense Bituminous Macadam

FDR= Full Depth Reclamation

GSB = Granular Sub Base

HIPR = Hot in Place Recycling

HMA = Hot Mix Asphalt

IDT=Indirect Tensile Strength Test

ITS= Indirect Tensile Strength

ITSR= Indirect Tensile Strength Ratio

MDD =Maximum Dry Density

MORTH= Ministry of Road Transport and Highways

NMAS= Nominal Maximum Aggregate size

OBC= Optimum Binder Content

OGFC = Open Graded Friction Course

RAP = Reclaimed Asphalt Pavement

SCBT = Semi-circular Band Fracture Test

SMA = Stone Matrix Asphalt

TSR = Tensile Strength ratio

UCS = Unconfined Compressive Strength

VA =Percent Air Voids

VFD =Void Filled with Bitumen

VMA = Voids of Mineral Aggregate

WFS= Waste Foundry Sand

WMM=   Wet Mix Macadam

LIST OF SYMBOLS

(|E*|)=Dynamic modulus

D= Diameter of specimen

G_{mb}= Bulk specific gravity

G_{sa}=Apparent specific gravity

G_{sb}=Specific gravity

G_{se}= Effective specific gravity

Mr=Resilient modulus

N_f= Fatigue life

P=Maximum load

P_s=Percentage of aggregate by total weight of mix

S_t=IDT strength

t=Specimen height

$\varepsilon_{t=}$ Tensile strain

$\varepsilon_{v=}$ Vertical strain

CHAPTER – 01

INTRODUCTION

Flexible pavements are designed in different layers, which include the bituminous layer, surface course, base layer, sub-base course and sub grade soil. The most expensive layer is the top most bituminous layer which is direct in contact with the vehicular movement. It is a normal process to built overlay when the pavement struggle serious distress; during this process generally the existing bituminous layer is removed and the milled material is thrown away. As day by day the price of bitumen is increasing and there is depletion of natural resources, which necessitates recycling and reusing bitumen and aggregates.

Recycling of the existing bituminous pavement materials helps to make new pavement material which results in good savings of the material, energy and money. There are specific asset of recycling such as when properly used leads to vast savings up of the new materials, conservation of natural resources by reducing the need of new materials, recycled materials have shown the match or even better enhance than new virgin materials in quality, it also sustain pavement geometrics as well as pavement thickness, it also help to save the amount of energy compared to the current construction approach.

There are different methods of recycling such as Hot recycling, Cold Recycling, Hot in-place recycling(HIPR),Cold recycling, Full depth reclamation(FDR). In India, Hot recycling or hot mix recycling is mostly followed. In this method of recycling, Reclaimed Asphalt Pavement (RAP) material is blend with new materials with new bitumen to make Hot Mix Asphalt (HMA).

The first RAP was first used in 1973(Hansen,et.al) with the percentage of 3 % replacement of virgin aggregates in an asphalt mix and after all the price of asphalt is increasing the higher proportion of RAP is allowed such as 20%,30% and even up to 50% in some places. Recycling of asphalt pavements can be done by milling process of the top layer bituminous layer various milling plants are being setup which work on this. As it is known that in India most commonly top layers used in the flexible pavement are Bituminous Concrete (BC) and

Dense Bituminous Macadam (DBM).

Sometimes with addition of RAP add other filler material with it in the hot mix like used foundry sand or other fillers can be used. Used foundry sand help to stabilize the RAP hot mix to enhance its property more compared to other fillers like lime or fly ash which is not easily available.

1.1Reclaimed Asphalt Pavement (RAP)

Reclaimed Asphalt Pavement (RAP) ingredients are abolished aggregates or salvage pavement ingredients having bitumen-coated aggregates. These materials are obtained when bitumen pavements are overlayed or rehabilitation of the pavement. When crumbled and screening are done RAP consists of great quality, fine category covered with aged bitumen. The major advantage of using RAP is this help to reduce the use of new virgin aggregates and new bitumen which one of the most important material in the flexible pavement construction.

But before getting into the properties or characteristics of the RAP it should be understood what a hot mix is. Bitumen mix consist of evenly combined aggregates mixed thoroughly and filmed with the asphalt or bitumen binder , so to arid the aggregates and achieve sufficient amount of adaptability with the bitumen binder for convenient blending and feasibility both aggregates and bitumen are heated together before mixing them that's why it is termed as Hot Mix .

There are different types of hot mix it depends on traffic , climate , locally available materials and the area in reach of the pavement design then accordingly the mix is selected and different mix design criteria is followed. Some of the types of hot mix are following:-

- Dense-graded asphalt mixes
- Open-graded asphalt mixes
- Gap-graded or Stone Matrix Asphalt(SMA)

1.2 Dense –graded asphalt mixes:

Dense –graded asphalt mix is one of the well classified suitable for all layers of pavement if properly designed and build leads to formation of impermeable pavement ,generally assigned by its nominal maximal size of the aggregates also could be classified on basis of fine graded or coarse graded depending upon the dominance of the aggregate size in the mix .It also works good for design , resistance ,equalizing and patch works , the methods of designing dense-graded mixes are Superpave, Hveem and Marshall mix . Marshall mix design is most commonly method used in India.

In India two types of dense graded bituminous mixes are used with two gradations.

1.3 Dense Bituminous Macadam (DBM):

At the current date, the dense bituminous macadam (DBM) is stated for usage as a base course and binder course. There are two gradations of DBM which are generally used. In grading 1 the nominal maximum aggregate size (NMAS) is 37.5 mm and grading 2 the nominal maximum aggregate size(NMAS) is 26.5 mm, according to MORT&H the stated proportion of fine aggregates in both the grading are between 28% -42%. Due to large size of aggregate in grading 1 it becomes extremely permeable so it is better to lay this type of gradings before rainy seasons as if the water will go through the layer and damage the other GSB or WMM layer. Thus grading 2 is mostly considered base course for the both lifts. The minimum bitumen content in this gradation varies between 4-4.5%.

1.4 Bituminous concrete (BC)

At present two grading of bituminous concrete (BC) are used in India. Grading 1 nominal maximum aggregate size (NMAS) is 19 mm and grading 2 nominal maximum aggregate sizes (NMAS) is 13 mm as per MORT&H. Grading 1 here is suitable for binder course where as grading 2 is suitable for wearing course. The minimum bitumen content varies from 5.2%-5.4% according to the grading.

1.5 Open-graded asphalt mixes:

An Open-graded mix is drafted to have huge volume of air voids generally 18%-22% such that the water will drain down via pavement layer. This type of mix consists of two types: open-garded friction course (OGFC) and asphalt treated permeable base (ATPB). OGFC is type of skid resistance pavement where as ATPB is kind of porous permeable pavement layer.

1.6 Gap-graded or Stone Matrix Asphalt (SMA):

Gap-graded or SMA is a type in which large coarse aggregates ranging in between 70%-80% with about 6% of bitumen content and more quantity of filler not more than 10% by the weight. This type of mix when laid in the pavement layer opposes in the rutting and increases the durability of the pavement layer. There is also an important thing which is it reduce the tire noise due to the presence of large coarse aggregates in the mix.

1.7 Advantages and Disadvantages of Reclaimed asphalt pavement (RAP):

There are some advantages and disadvantages of Reclaimed asphalt Pavement (RAP) which is shown in table 1.1.

***Table 1.1*: Advantages and Disadvantages of RAP**

Advantages	**Disadvantages**
• It helps to save lot of construction material. • Abbreviating energy, materials and Transportation cost. • Bitumen can be recycled many times. • Recycled adaptations similar as the virgin mix. • Saves a lot of money. • Helps in reduction of emission of	• If quality not controlled leads to poor performance. • Maintenance of the pavement is difficult. • Discoloration of the asphalt pavement occurs as sunlight falls due to passage of time.

green house gases. • It also leads to the conservation of natural resources. • Usage of optimum amount of bitumen	

As discussed above about the pros and cons of RAP, so with addition of used foundry sand with RAP and virgin aggregates in the hot mix to improve the properties for that it is necessary to know about the properties and characteristics of used foundry sand.

1.8 Used foundry sand (UFS):

Used Foundry sand is homogeneous sized, immense quality silica content which is the outgrowth of the ferrous and non-ferrous in metal casting industries. This is used in mould casting after casting this foundry sand is waste so considered as a discarded material from the industry. Day by day the demand of foundry sand is increasing but there are very limited sources so you have to reuse the discarded foundry sand in various things like pavement construction, building construction, embankments and development fills. This sand is finer than normal sand.

The restoration of the used foundry sand in the construction industry would help cost-effective, environmental amicable, less weight and high strength can be achieved. As the manufacturing of the foundry per year is about 6-10 million tons (Dushyant R.Bhimani et.al) so wastage is too high also.There are basically two types of foundry sand:

1.8.1 Green sand:

Green sand is the most commonly used in metal casting of moulds , consists of more than 85% of silica content , 0-12% of clay, not more than 10% of carbonaceous supplements and about 2-4% of water. It’s colour is black or grey due to the presence of carbon ,has high resistance to high temperatures due to silica presence and bonding is good due to presence of clay particles.

1.8.2 Chemically bonded sand:

Chemically bonded sand consists of more than 95% of silica content and 3-5 % of chemical binder. In this, silica and binder are mixed such that a reaction take place which cures and bake the mass. Commonly used binder system is oxidizable phenolic urethanes, epoxy-resin ($C_{21}H_{25}ClO_{5}$), furfuryl alcohol (C5H6O2) and sodium silicates.

Use of foundry sand in asphalt mix is very reasonable and helps in sustainable development of the environment without any harm. UFS is very easy to find in any country and cost of using it in asphalt or construction work helps to reduce the construction cost with better strength of the material or mix made used for construction.

1.9 Objectives of the study carried:

The main Focus of the study was to replace the virgin aggregates with RAP and used foundry sand (UFS) in Dense Bituminous Macadam (DBM) Grade -II.

- To determine the Marshall stability at an optimum bitumen content.
- Study the effect of Indirect Tensile Strength (ITS) and Resilient Modulus on the pavement consisting of RAP and used foundry sand.
- Different proportions of RAP and used foundry sand (UFS) how that hot mix behaves when tests are conducted.
- Different properties or characteristics of RAP and used foundry sand which help in the use of making hot mix asphalt.
- Possible up to which percentage the use of virgin aggregates can be reduced such that higher strength and stability can be achieved.

1.10 Outline of Thesis

The thesis has been sub-divided into six chapters:

1. Ist chapter is about the generic introduction of Reclaimed asphalt pavement (RAP) and used foundry sand with their analysis.
2. 2nd chapter consists of the literature review in research work held with the use of Reclaimed

asphalt pavement (RAP) and used foundry sand for developing the strength of the hot mix.

3. 3rd chapter approach with the experimental work where all details of test procedures or operation are explained.
4. 4th chapter approach with the results of experiments and analysis are made of the data based on experimental method are discussed.
5. 5th chapter comprise of the analysis and designing of pavement section using RAP and used foundry sand.
6. 6th chapter comprise of outcome of the dissertation done.

CHAPTER- 02
LITERATURE REVIEW

2.1 Literature Review on Reclaimed Asphalt Pavement (RAP*)* *:*

As discussed below is the literature of Reclaimed asphalt pavement (RAP) till now for asphalt mixes.

Widyatmoko, I (2006), conducted mechanized-empirical design mixture of hot mix asphalt in pavement recycling. The laboratory test processed which contains RAP smooth stiffness and then working on mixes without RAP content. Mixtures involving RAP showed less defiance in permanent deformation as compared to the mixes without RAP. And also Fatigue resistance of the RAP was in permissible limits than the mixture without RAP.

Aravind.K and Animesh Das (2007), concluded on the design of pavement of RAP with central hot mix plant. Two different RAP samples were being processed in the laboratory, the first one include the extraction of aged binder using Centrifuge Bitumen Extractor(CBE), then the new binder was predetermined and added with the old binder such that uniform viscosity was achieved then that binder was mixed with old and virgin aggregates in the newly prepared hot mix. The second one include collection of broken RAP scrap using hammer ,while detaching the RAP it should not be crushed , then the broken RAP was added with new virgin aggregates in hot mix . Marshall test and fatigue test was being conducted in the laboratory , the marshall test with bitumen content starting from 4.5%,5.0%,5.5%,6.0% and 6.5% with average of three samples each conducted and results were compared with the virgin Semi Dense bituminous Concrete (SDBC) as per MORT&H. Here in this study the number of parameters was not in range and a common area of contentment is not accomplished. Thus leading to non establishment of Optimum binder content. Table 2.1, 2.2 and figure 2.1 shown below shows the results carried in the study.

***Table 2.1:* Description of Marshall Parameters for SDBC (virgin hot mix) as per MORT&H (*K.Aravind, 2007*)**

Parameters	Permissible limit
Air voids(VA)%	3-5
Voids in mineral aggregates (VMA)%	≥14
Voids filled with bitumen(VFB)%	65-78
Marshall stability (kN)	≥8.2
Marshall flow(mm)	2-4

***Table 2.2:* Typical Marshall test results of a mix. (3 samples average)(*K.Aravind, 2007*)**

Bitumen content (%)	**Air voids(VA) (%)**	***VMA (%)***	***VFB (%)***	***Stability (kN)***	***Flow(mm)***
4.5	5.04	17.8	71.6	7.0	1.80
5.0	3.59	16.7	78.5	10.7	2.20
5.5	3.43	16.7	79.5	8.8	2.20
6.0	2.43	15.8	84..6	7.6	2.30
6.5	2.43	14.9	83.7	7.0	2.35

The fatigue test concluded from figure 2.1 the fatigue behaviors of the hot mix made of RAP of different mixes made for that fatigue testing machine was used, the results show that at minor strain levels fatigue performance was better than the normal virgin SDBC mix.

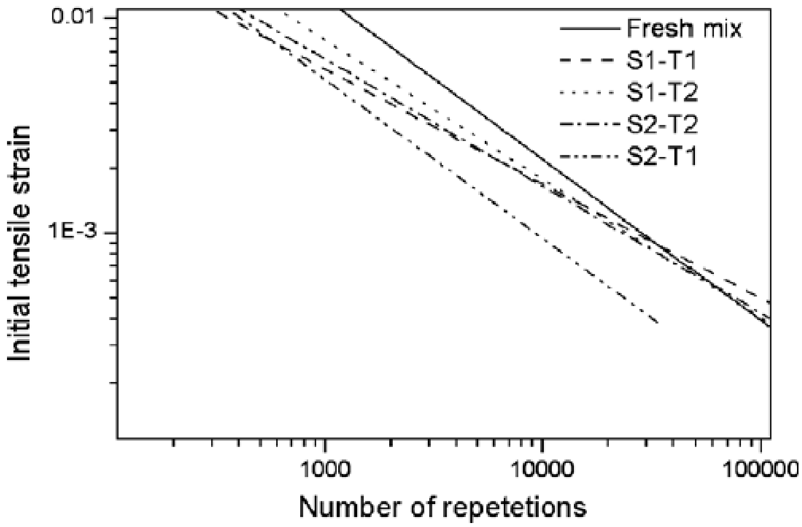

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***Figure 2.1*: Fatigue performance of different mixes carried out in study (*K.Aravind, 2007*)**

Gonzalo valdes et.al (2011), conducted a study on the recycled asphalt mixture with higher percentage of RAP. Two mixture of semi-dense containing maximum size of aggregates 12 mm and 20 mm with ratio of 40% and 60% RAP in the mix. Firstly the outcome of RAP vulnerability on recycled mix was determined, then their automated properties were studied by determining the stiffness modulus and indirect tensile strength (ITS) also cracking and fatigue nature was analyzed. The following results were being concluded:

1. The specimen of RAP showed high stiffness modulus and higher indirect tensile strength (ITS) as compared to the conventional mixtures having 60/70 Penetration grade of bitumen.
2. As the content of RAP was increasing stiffness was also increasing which was concluded from dynamic modulus test and stiffness modulus test.
3. It was possible to use the RAP up to 60% in hot mix so that better stability and stiff mix can be obtained.
4. Marshall Stability for 40% and 60% RAP was between 15.6- 21.6(kN) which was good thing for any mix design and also air voids (%) was also between 3.4-4.4% which were in permissible limits.

5. ITS value for different RAP content 40% was 3.51Mpa and 60% was 3.52 Mpa and after 6 months field cores the value reduced to 2.53Mpa for 40%, 2.91 Mpa for 60%.Also when cored after 12 months ITS value reduced to 2.86 % and 2.83 % for 40-60% RAP content.

Dr R.Sathikumar (2011), conducted a study on the technology of Reclaimed asphalt pavement (RAP) for viable pavement. The prime objective of study was sustainable technology of RAP and design mix for hot recycled mixture. The laboratory test concluded that value of Marshall stability and resilient modulus were higher than the conventional virgin aggregates and also the cost analysis in construction with RAP and virgin mix was done, RAP construction was found more economical.

Miro Rodrigo et.al (2011), provides assessment of high modulus mix of bitumen with below penetration bitumen grade with change in percentage of RAP in the asphalt mix. Total mix having different RAP percentage 0%,15%,30 and 50% were evaluated, there characteristics for different binder content was tested including stiffness modulus , toughness, moisture sensitivity, resistance to rutting and fatigue resistance. Following figures were some graphs which show the results of the study for various parameters:

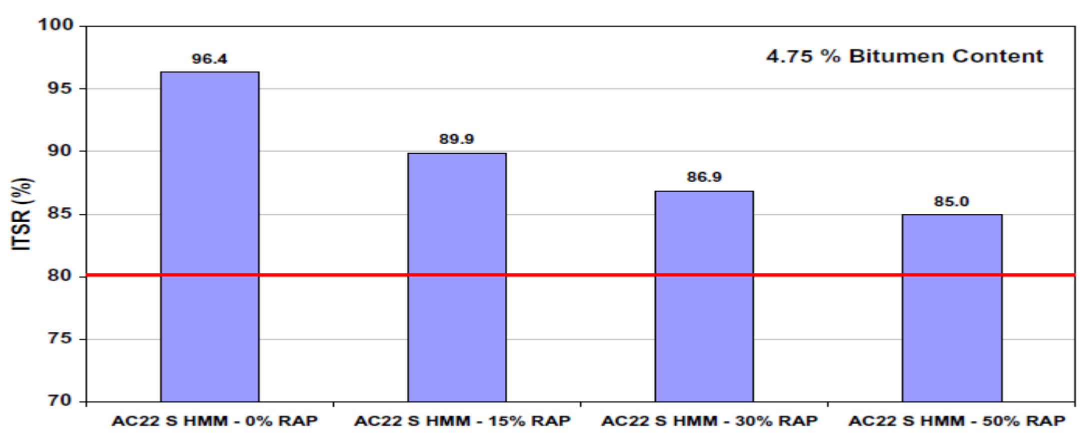


Figure2.2: **ITSR results conducted at immersion period of 72 hr at 15°c.**

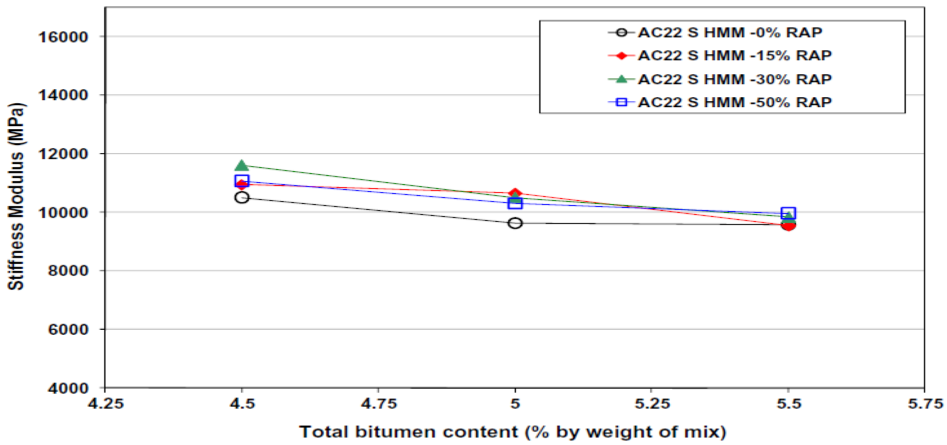


Figure 2.3: **Stiffness modulus at 20°c depending upon the binder content.**

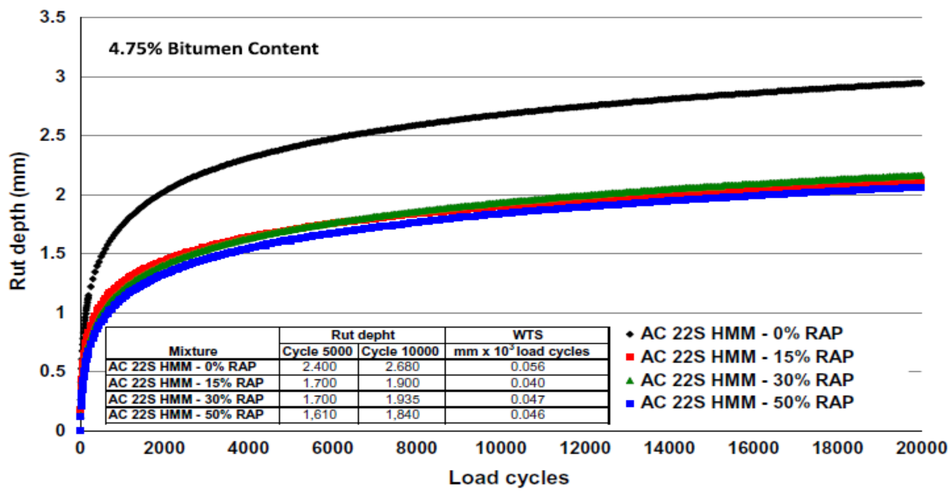


Figure 2.4: **Load cycles versus Rut depth of Wheel tracking test at 60°c.**

From figures **2.2, 2.3** and **2.4** showed that use of RAP content up to 30% was applicable as the ITRS (%) was decreasing when RAP was used at percentage of 50%, stiffness modulus derived through the design mix has not more effect on the new bitumen used so RAP mix bitumen can be used .Defiance to rutting was also significant as all RAP mix have very similar rutting levels and lower then the higher modulus mix without RAP.

Shirodkar Prashant et.al (2011), the study conducted to resolve the degree of partial blending in large mixes with RAP. When the RAP samples was mixed with new or virgin aggregates and fresh binder, limited blending of RAP binder appear in the hot mix asphalt. The author provided the systematic methodology approach for resolving the degree of in partial merging of Reclaimed Asphalt pavement (RAP) binder in RAP mix. Degree of limited blending was found for the percentage 25% RAP by the aggregates weights with PG70-28and 35% RAP by the aggregates weight for PG58-28 respectively. Figure 2.5 and 2.6 shows the systematic methodology approach as given in the study.

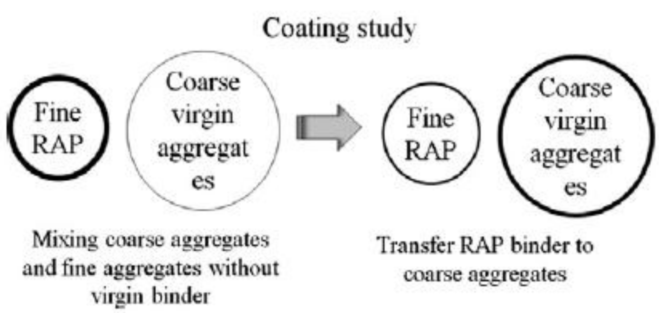


Figure2.5: **Organized depiction of coating study conducted (*Shirodkar Prashant, 2011)***

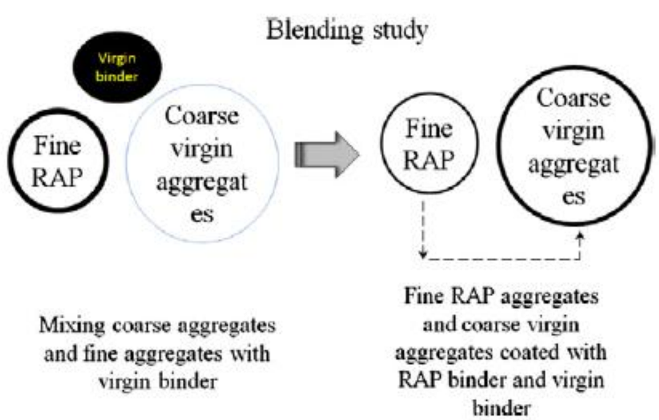


Figure2.6: **Organized depiction of blending study conducted (*Shirodkar Prashant, 2011)***

Following were some points which were the findings based on the study done:

1. Degree of limited blending for 25% RAP was 70% and 35% RAP was 96%.
2. Degree of limited blending by Blending study was much higher than the study conducted based on coating method.
3. Degree of limited blending was self-reliant of the testing temperature of binder.

In this case study there were some limitations such as:

1. The mechanism needs at least three more extractions and rehabilitation of the binder in RAP which include before blending the mix and after blending the mix.
2. To reduce the melting during segregation, the samples were large enough that when they get heated can be segregated with lessen temperature.

Veeraragavan (Indian Road Congress 2012), carried the test on RAP in bituminous mixes. The main objective of the study was to evaluate the bitumen and aggregate requirement to achieve the gradation and quantity or mix recycled for a highway project. The other was to perform different mix design with RAP and compare their properties with virgin aggregates. Also the study showed the mechanical effect, tensile strength, performance and durability of RAP in asphalt mix.

Following things are concluded from the study*:*

1. Use of RAP in bitumen mixes lead to reduction of about 78% in the Optimum bitumen content (OBC) with air voids of 4% in the mix design.
2. Use of RAP leads in higher indirect tensile strength offers greater resistance to fatigue cracking same as the virgin aggregates mix.
3. Also provide higher rutting resistance as compared to the virgin aggregates mix.

Reyes-Ortiz et.al (2012), concluded the load evaluation of RAP with replacement in virgin mixes of hot mix asphalt. The test focused on the limited and total replacement of RAP in dense-graded hot mix asphalt (HMA) which lead to greater indirect tensile strength (ITS) and resilient modulus for both dry and wet with 100% replacement of RAP. RAP was replaced in four types: which were 100% RAP, 15% replacement, 20% replacement, and 35% replacement of RAP. At different bitumen content 2%, 3%, 4%and 5% marshall test were conducted and OBC was nearly 3% for all the mixes.

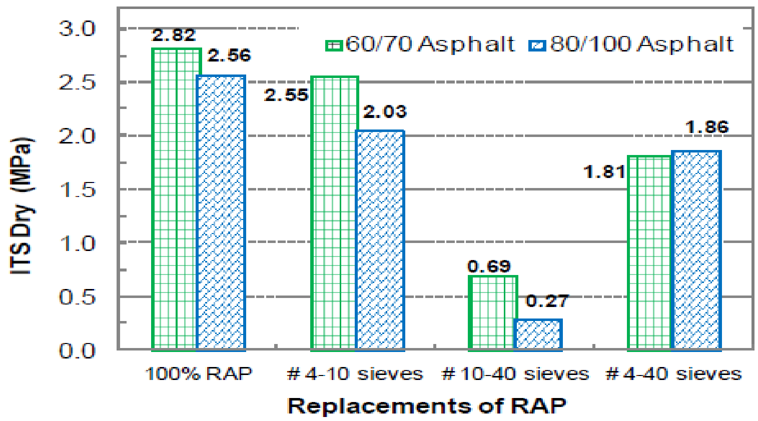


Figure2.7: **Outcome of ITS in dry condition (*Reyes Ortiz, 2012)***

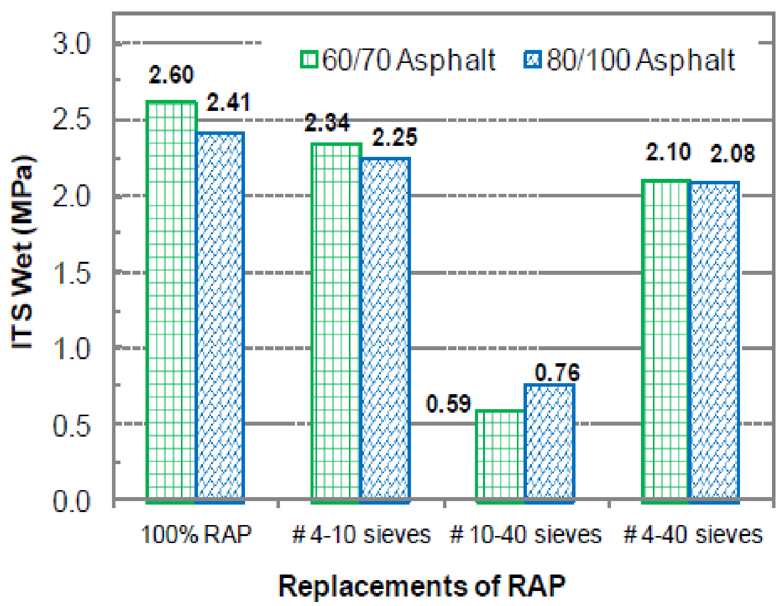


Figure 2.8: **Outcome of ITS in wet condition *(Reyes Ortiz, 2012)***

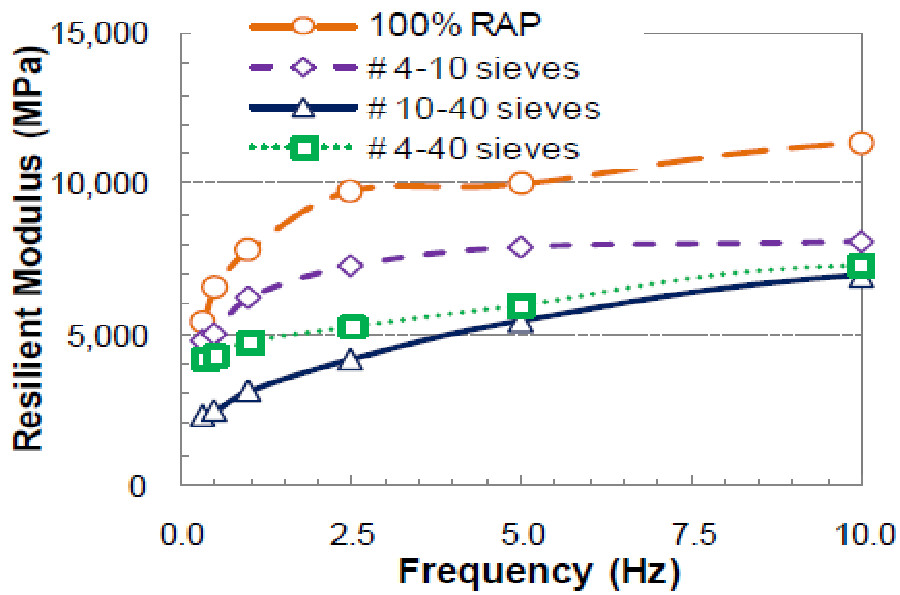


Figure 2.9: **Resilient modulus with dry condition (*Reyes Ortiz, 2012)***

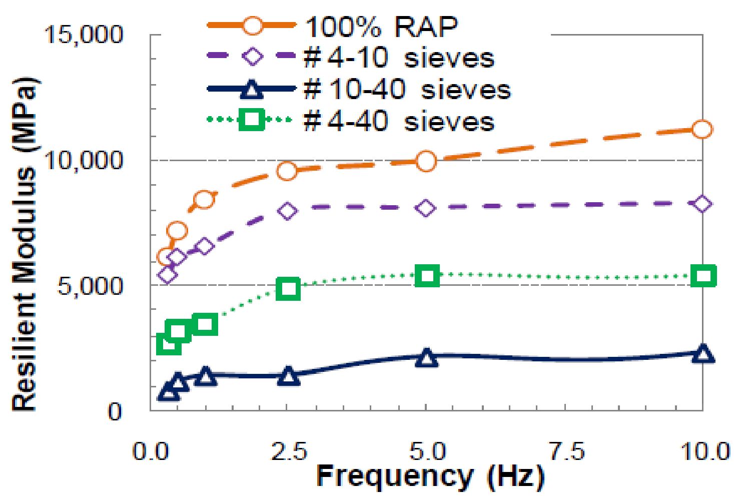


Figure 2.10: **Resilient modulus in moist or wet condition (*Reyes Ortiz, 2012)***

From above figures **2.7,2.8, 2.9** and **2.10** conclusion was made that in both ITS and resilient modulus values are higher for 100% replacement of RAP compared to other mixes with other proportion of RAP content. Highest values of IT'S in both wet and dry was with 80/100 asphalt.

C.Udayshanka and M.Varuna (2013), conducted study on dense bituminous macadam-II (DBM-II) with RAP content of 20% and 30% the samples of RAP was taken from NH-

48(Devahalli to Hassan) site. The laboratory test concluded that use of RAP in virgin mix lead to an increment in marshal stability when tested and also the cost savings were nearly 19% for 20% RAP and 30% for 30% RAP when used in pavement as compared to virgin mixes. Optimum bitumen content (OBC) for 20% RAP was found 4.37% and for 30% RAP 4.1% compared with virgin DBM-II OBC which was 4.63%. Figure 2.10 shows the marshall stability for different mixes of RAP with virgin mix , stability was found more than 23.09 KN for 20% RAP and 25.43 KN for 30% RAP where as for virgin DBM-II mix stability was near about 21.76 KN which was less than the RAP mixes. Figure 2.11 and table 2.3 shown below tells about the marshall stability and economic analysis of RAP.

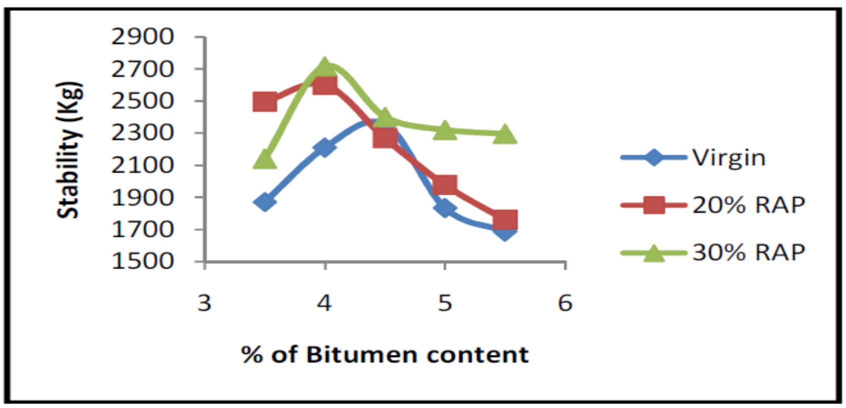


Figure2.11: **Variability of Marshall Stability (kg) with different bitumen content (*C.Udayshankar, 2013)***

Table2.3: **Economic analysis virgin mix with different RAP mixes (*C.Udayshankar, 2013)***

Mix	*Total quantity(cum)*	*Amount(Rs)*
Virgin	733	57,43,788
20% RAP	586	46,24,621
30% RAP	513	40,52,593

SpurtiO.Tambake, Dheeraj.N.Kumar, Manjunath.K.R (2014), conducted various laboratory experiments on hot mix asphalt using RAP for Bituminous concrete (BC) mix. The purpose of the study was to know the effect of RAP with fresh virgin aggregates with different proportions of 20%, 30% and 40% of Bituminous concrete (BC). Firstly the RAP was graded according with the Bituminous concrete (BC) specifications as per MORT&H and then the optimum binder content was found which was about 5.42% for fresh mix without RAP . Marshall test was conducted to find out the OBC, flow value, air voids, bulk Density, VMA, VFB, and Marshall stability as shown in table 2.4.

Table 2.4: **Marshall Properties of the research work carried (*SpurtiO.Tambake, 2014)***

Properties	Fresh mix(without RAP)	20% RAP	30% RAP	40%	Specifications as per MORT&H
OBC (%)	5.42	5.3	5.09	4.99	--
Stability (kN)	16.8	14.6	12.9	10.3	Min.9 KN
Flow(mm)	3.82	3.82	3.4	2.85	2-4
Air voids (%)	3.4	3.08	3.82	3.8	3-6
Bulk Density(kg/m³)	2281.42	2305.71	2278.72	2288.62	--
VMA (%)	15.55	15.12	15.2	15.1	12.5
VFB (%)	74.43	78.9	74.6	74	65-75

Sunil S, K.M .Malleshand T.Chhandrasekaraiah (2014), conducted study on RAP with different percentages of 10%, 20%.30% and 40% on Bituminous mixes (BC). RAP was collected from TUMKUR to CHITRADURGA-(NH4); the laboratory test includes the extraction of bitumen to know the bitumen content in the RAP mix. Different properties of RAP in studied like marshall mix design, static indirect tensile test, repeated indirect tensile fatigue test was carried .From the results it was concluded that RAP performed well in all cases such as marshall mix design , ITS and fatigue life as compared to virgin asphalt mix of BC. Bitumen grade used was VG-30 in all conventional as well as RAP mixes.

Followings are some results which are outcomes of the study conducted:

1. OBC was 5.1% for all the RAP mixes.
2. Stability of Marshall Test range from 14.75-14.40 kN.

3. Flow value was in range from 2.4-3.3 mm for all RAP mixes respectively.
4. Air voids was in range from 4.5-4.65(%) for all RAP mixes respectively.
5. VMA was in range from 16.9-17.46(%) for all the RAP mixes respectively.
6. VFB was in range from 72-74.03(%) for all the RAP mixes respectively.
7. TSR% was in range from 94.66-91.75 for all different RAP mixes.
8. Fatigue life cycle test at 0.6, 0.7 and 0.87 stress ratios was conducted and the results showed that RAP with high content performed well compared to virgin mix.

Sireesh Saride and Deepti Avirneni (2014) ,conducted a study on use of Fly ash taken from Neyvelilignites Corporation (India) with RAP mixes as a stabilizer in flexible pavement. Various test such as UCS, resilient modulus and CBR tests were performed to know the performance and strength of the RAP mix with the use of fly ash. The warp up of study was that when 20% RAP was used with virgin aggregates and about 40% of fly ash was added to the mix by the total volume of mix follow the minimum value of UCS and resilient modulus as per the IRC codes.

Following was some test results which shows the behavior of fly ash with the RAP and virgin aggregates when mixed together:

1. OMC value increases with the increase in the fly ash content in RAP mix due to the reason that micro particles in fly as take more precise surface area and which leads in more absorption of water.
2. And also when the RAP content was further increased due to coating of asphalt in RAP water absorption decreased.
3. Maximum Dry Density (MDD) decreased with increment in fly ash content because of less specific gravity of fly ash.
4. Resilient modulus (M_R) also increases with the addition of fly ash with RAP content in hot mix. It was due to the fineness ratio of the fly ash particles which lead to increase in the elastic characteristics.
5. California bearing ratio (CBR) value was found 83% for 100% RAP mix with 10% fly ash. CBR value increased with the increment in fly ash dosage. At low content of fly ash CBR value was less due to high voids in sample which leads to lower resistance of the penetration

in the sample.

6. Unconfined compressive strength (UCS) value for 80% RAP, 20% virgin aggregates and 40% fly ash in hot mix was around 1.72MPa which was considered as optimum value.
7. From the results it was concluded that when increment of fly ash was in mix results in higher stiffness and good strength but up to some limit, as more high content wants more water for compaction.

Ahmad M.Abu Abdo(2016), conducted a study on the use of reclaimed asphalt pavement(RAP) material in new flexible pavements, the author conducted experiments on Kadra-shawka road at Ras Al Khaimah(UAE).The laboratory tests like CBR, permanent deformation, fatigue cracking and thermal cracking's were conducted with different proportions of RAP content i.e.0% ,10% ,20% ,30% and up to 100% in some cases. Following were the result which tells the performance of RAP mix in hot asphalt:

1. CBR value decreased with the increase in RAP content i.e. 90% for 0% RAP and 15% for 100% RAP.
2. Rutting depth for 0% RAP was 8mm whereas for 100% RAP value was 2.3 mm.
3. Fatigue cycle test showed that stress level (%) zero percentage of RAP was higher than the RAP up to 40% used.
4. Semi-circular bend fracture (SCBT) test results showed that fracture energy for 0% RAP was way higher than the RAP content as increased up to 55%.

T.Anil Pradyumna and Dr.P.k.Jain (2016), studied the use of stabilized RAP in hot mix recycling agents in asphalt road construction.RAP sample was collected from a site in Delhi and binder content was found nearly 3.65% using Auto-Ignition Method(ASTM D6307) penetration value was 39(0.1 mm units) and 62°c was softening point. Design mix was prepared using 40% RAP with virgin aggregates of bituminous concrete (BC) with nominal maximum size of 26.5 mm as per MORT&H (2001).VG-30 was grade of binder used in the marshall mix, RAP stability was 18.75KN where as for virgin mix its stability was 13.50 kN. Flow value of RAP was also higher (3.30 mm), air voids (%) and VFB (%) was also in permissible limits. Moisture susceptibility was more than the conventional virgin mix and also values of resilient modulus for RAP mixes was more than the conventional virgin mix at different temperature 25°c, 35°c and 45°c degrees of temperature. The conclusion made from the study was that for RAP in larger portion in hot mix it was required to use recycling agent.

Kar, S.S et.al (2018), conducted a study on the properties of foamed bituminous mix with the use of RAP. Initially in the study carried the properties of virgin bitumen were determined to use less amount of water content and temperature, then with different RAP content(i.e. 0%,50% & 80%) foamed bituminous mix was made. 50% RAP content showed best results for resilient modulus and resistance to water damage test. And also 80% RAP showed good strength and resistance to water damage test within limits. So it was concluded from the study that it was really possible to design RAP mix with high content in foamed bituminous mix such that it satisfy the volumetric and performance criteria. OBC for 0% RAP is 4.8%, 50%RAP is 5.0% and 80% RAP mix is 6.2%.

M d Rashadul Islam et.al (2013), studies the relation between the Dynamic modulus and ITS of asphalt mix with the use of RAP. This study established the relation between dynamic modulus (|E*|) and ITS in hot bituminous mix .there were two types of mixes made super pave(SP)-SP-III having 15% RAP and SP-III having 35% RAP, samples having cylindrical shape with diameter of 10 cm and 15 mm Thickness of sample .As per AASHTO TP 62-07 dynamic modulus value is found at 21°c with various variation in the frequencies , after the dynamic test samples are cut in round pieces with 38-50 mm Thickness . The round samples were tested for ITS at the rate 50mm per 60 seconds as per AASHTO T28 code. Some values shown tabulated in the below table 2.5 which shows the variation of dynamic modulus and ITS Ratio for different mixes made.

Table 2.5: **Dynamic modulus and ITS ratio for different SP-III mixes (*M d Rashadul Islam, 2013)***

RAP content(%)-(sample no)		**Frequency(Hz)**		**Average of (|E*|) & ITS**	
15(1A)	35(1A)	0.1	0.1	18	14
15(1B)	35(1B)	0.5	0.5	31	20

15(2A)	35(2A)	1	1	34	24
15(2B)	35(2B)	5	5	52	33
15(3A)	35(3A)	10	10	59	38
15(3B)	35(3B)	25	25	65	41

2.2 literature review of Used Foundry Sand:

Dushyant R.Bhimani et.al (2013), conducted a study on the use of foundry sand in a viable way and use fiscally concrete .The study was done on the applications of foundry sand that was scientific, sound and economically good for viable development firstly the foundry sand was taken from GIDC, Vallabh Vidyanagar (India) then characterized the properties of them. Both physical and chemical composition are determined which conclude that it can be used in hot mix asphalt, with Portland cement, soil reinforcement and other construction works. The case study concluded that 30% foundry sand can be used in $1m^3$ of M 20 grade of mix of concrete for a cost effective and sustainable evolution of concrete.

Dr. Suji D et.al (2016), they conducted a study of replacement of waste foundry sand about 35% with quarry dust was used in hot mix. The study showed that whenever there was increase in bitumen content by 5% replacement for foundry sand was up to 25%. Waste foundry sand was successful in bituminous concrete mix design with a perfect mix design. The study concluded the use of foundry in industry but no environmental impact was studied so this was the limitation of this study.

Department of the Environment, Transport and the Regions Research Contract MP0623 Digest no. 067 (2:6/99) Symonds, they conducted a study which carried the use of green sand in hot mix as this decreases the bleeding in asphalt mix when layed in bases. When the green sand was used up to 5 % in hot mix asphalt it helped in controlling the asphalt bleeding up to 40%, thus green sand can be used in hot mix asphalt to reduce the asphalt bleeding during summers.

Pendhari Ankush R. et.al (2017), conducted a study with use of waste foundry sand in replace of normal sand in cement mixes. Waste foundry sand can be easily used in replacement as fine aggregate in cement mix, restoration of fine aggregates in place of foundry sand leads in less decrement when foundry sand was up to 30% and also gives higher strength after 28 days of curing the sample made. Flexural strength also decreased when foundry sand was used more than 30% after 28 days. And also used of foundry sand was very cost effective and it was also environmental friendly.

Saif ali et.al (2017), conducted study on various research papers on the use of waste foundry sand. The use of 20-30% foundry sand with replacement of fine particles gives better results in all most all practical purposes. By increasing content of foundry sand the compressive strength also increases, which was good for the working quality of concrete and other construction materials. When more than 30% foundry was used there was decrement in the compressive strength also. Disposal issue of waste foundry sand can be reduced by using this in construction work. Only limitation was that the buildings which are earthquake resistance cannot be made with use of used foundry sand.

AKTAS and ASLAN (2017), conducted a study on the use of Waste foundry sand in hot mix with 5% WFS and their properties are evaluated. Various test to determine properties like Marshall Stability, flow, bulk specific gravity, VMA, VFB were determined. Waste foundry sand used in the study has very homogenous distribution 80% was of size between 2mm-0.075 mm. It consisted of mostly silica content 80% is dioxide of sodium and rest was burnt carbon. Marshall Stability increased with the addition of WFS for an OBC of 4.9%, the all properties were within limits as per Turkish standards.

Abdulsattar, et.al (2018), conducted study on effect of WFS on ITS in bituminous mixes. The laboratory test with four different content of foundry sand as fine aggregate in hot mix are made i.e. 5%, 15%, 20% and 25%. Total 35 samples were made and to know the marshall stability and flow value of hot mix. The TSR values were very higher than the normal conventional mix so conclusion was made that increment in WFS leads to increase in ITS value.

CHAPTER-03

EXPERIMENTAL PROGRAMME

3.1 Materials Used:

A concise explanation of the materials and methods used in this study of investigation is provided in this section. Different sized aggregates were collected from Patiala. . RAP was collected from Patiala –Nabha road through a local contractor. The aggregates used in the marshall mix design of DBM–II have different sizes, which were 26.5 mm, 19 mm, 13.2 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm,0.3 mm , 0.15 mm and 0.075 mm. Aggregates size, shape, angularity and surface texture plays an important role in the marshall mix design. Table 3.1 shown below shows the various specifications for physical properties of coarse aggregates for DBM-II

Table 3.1: **Physical properties of coarse aggregates for DBM**

S.No.	Properties	Tests	Description	Relevant IS Codes
1.	Grain Size, Analysis and particle shape	Dust	Max 5% passing through 0.075 mm sieve	IS:2386 Part I
		Combined Flakiness and Elongation index	Max 35 %	IS:2386 Part I
2.	Strength	Los Angeles abrasion value	Max 35%	IS:2386 Part IV
		Aggregate impact value	Max 27%	
3.	Durability and other parameter	Soundness	Max 12%	IS:2386 Part V
		Water absorption	Max 2%	IS:2386 Part III
		Coating and stripping of bitumen aggregate mix	Min 95%	IS:6241
4.	Water sensitivity	Tensile strength	Min. 80%	AASHTO 283

3.2 Properties of aggregates:

As discussed above in table 3.1 the aggregate shape, angularity and surface texture of fine graded is important because this has more influence on the physical nature of dense graded mixes as compared to the coarse graded aggregates. Good Angularity and rugged texture is required such that it helps in prevention of permanent Rutting and fatigue cracking, also leads to skid resistance on the top surface. Cubical particles are adopted then the flat and elongated aggregates.

3.2.1 Porosity or water absorption:

Porosity or water absorption is one of the basic properties of aggregates, which should be not more than 2%. Generally it is supposed that high absorption rate leads to poor quality in mix design but for all cases it is not true up to 7% max porosity is allowed in various places. All tests are performed as per ASTM C 127 and 128 codes.

3.2.2 Cleanliness and Deleterious property:

Cleanliness is troubled with coatings of aggregates or extra material passing 0.075 mm sieve, Whereas deleterious property include the individual characteristic of the such as weak, sensitive or defective.

3.2.3 Toughness and abrasion resistance:

Aggregates show offer good Toughness and abrasion resistance to overcome the breakdown of the aggregates during construction and after paving under service of traffic. If the aggregates breakdown they will pop out from the pavement and cause fractured road surface. So aggregate impact value is max up to 27% and Los abrasion value is max up to 35%.

3.2.4 Durability and soundness:

Durability is discussed above that it should be durable enough to with stand the traffic efficiently without any weathering. If the aggregates are unsound the problem of pot holes, pop out and loosing of aggregate will happen.

3.2.5 Specific gravity:

This property of aggregates is used in forming weight-volume modifications for knowing the voids parameters in asphalt mix design. Specific gravity is defined as the ratio of weight of unit volume of the sample to weight of equal volume of water at 23°C.

Specific gravity= Weight in gms/volume in ml.

There are three types of specific gravity which are Bulk, Apparent and effective specific gravity.

3.2.5.1 Bulk specific gravity (G_{sb}):

This specific gravity included both volume of permeable voids and impermeable voids. It is ratio of mass of oven dried sample to the volume of aggregates plus the surface voids.

3.2.5.2 Apparent Specific gravity (G_{sa}):

This is only the volume of the aggregate particles and is the ratio of mass of oven dried aggregates to the total volume of aggregates.

3.2.5.3 Effective specific gravity (G_{se}):

This includes surface voids plus volume of water-permeable voids which are not filled by bitumen and also absorbed bitumen binder in the sample. It is the ratio of mass of dry aggregates to effective volume.

3.3 Results of the physical properties of aggregates:

1. Combined flakiness and elongation of coarse aggregate :29.93%
2. Impact value of coarse aggregate :18.59%
3. Specific gravity and water absorption of 40 mm coarse aggregates:

a) Bulk specific gravity(oven dry): 2.690

b) Bulk specific gravity (SSD): 2.705

c) Apparent specific gravity :2.731

d) Water absorption (%): 0.571%

4. Specific gravity and water absorption of 20 mm coarse aggregates **:**

e) Bulk specific gravity(oven dry): 2.640

f) Bulk specific gravity (SSD): 2.657

g) Apparent specific gravity : 2.685

h) Water absorption (%): 0.630%

5. Specific gravity and water absorption of 10 mm coarse aggregates :

i) Bulk specific gravity(oven dry): 2.612

j) Bulk specific gravity (SSD): 2.632

k) Apparent specific gravity : 2.667

l) Water absorption (%): 0.787%

6. Specific gravity and water absorption of stone dust fine aggregates:

m) Bulk specific gravity(oven dry): 2.568

n) Bulk specific gravity (SSD): 2.600

o) Apparent specific gravity : 2.654

p) Water absorption (%): 1.27%

7. Bulk specific gravity (oven dried) of filler : 2.125

3.4 Bitumen and its properties:

Bitumen is one of the most important and expensive material in design of flexible pavement. Almost all the paving bitumen used in India is achieved by processing of crude petroleum oils. Bitumen are classified on the basis of its viscosity (VG). As per IS: 73-2013, it clearly mentions that specifications of paving bitumen as per the viscosity gradations at 60°C of bitumen. Commonly for DBM-II, VG-30 or VG-40 grade bitumen is used. The basic requirement of paving bitumen is that it should be homogenous and not form foam when heated up to 175°c.

Figure3.1 **Bitumen VG-30 used in the study.**

There are various physical test for the paving of bitumen as per IS: 73 -2013

3.4.1 Consistency tests

Consistency defines the extent of fluidity of bitumen at any specific temperature.

As bitumen is thermoplastic in nature its consistency varies with increase in temperature. Following are some test which tells the consistency of bitumen:

a. Absolute viscosity :

Viscosity is the resistance offered by fluid flow. Viscosity gradation of paving bitumen is done by Cannon- manning's vacuum viscometer, ASTM D 2171 and IS: 1206(part-II) explains the procedure of the test. The temperature of viscometer should be 60 °C while performing this test.

b. Kinematic viscosity :

As per ASTM D 2170 and IS: 1206(part-III) are the codes which are used to find the kinematic viscosity at 135°C with the Zeitfuchs cross-Arm Viscometer. At 135°C bitumen is adequately fluid such that is can flow in the capillary tube without gravitational forces, thus no need to provide vacuum in this test. The reason behind the choosing the 135°C temperature is because it is generally at mixing and paving of the bituminous pavement.

c. Penetration :

This test is one of the factual and generally done in measuring the consistency of the bitumen. This test is performed at a temperature of 25°C. As per ASTM D 5 and IS:1203 test is done with the help of a penetration needle weighing 100 gm , the bitumen sample is heated then allowed to cool until 25°C is achieved . After that needle is allowed to penetrate for 5 seconds, then the depth of penetration is measured in units of 0.1 mm.

d. Softening point :

This is also a factual test generally used to measure consistency of bitumen. As per ASTM D 36 and IS: 1205 it's define the temperature at which bitumen cannot resist the weight of steel balls and starts falling. That temperature is used to find the change of phase of bitumen from semi solid to liquid phase.

3.4.2 Specific gravity:

Specific gravity of bitumen changes with the increase in temperature. Specific gravity of bitumen is measured by Pycnometer method as per ASTM D70 and IS: 1202. The test results include both the temperature of bitumen and water used. Generally specific gravity of bitumen at a temperature of 25°C is used in asphalt mix design.

Table 3.2: **Physical properties of bitumen (VG-30) used in the experimental work**

Property	**Value Obtained**	**Test Method**
Kinematic Viscosity (135˚C) ,poises(cP)	415	ASTM D4402-15 and ASTM D2170 or IS 1206(part-III)
Absolute Viscosity (60˚C) ,poises(cP)	2558	IS :1206 (1978)
Softening Point ˚C	55	IS :1205 (1978)
Ductility (27˚C) cm	108	IS :1208 (1978)
Penetration (25˚C)	68	IS : 1203 (1978)
Specific Gravity (25˚C)	1.05	IS: 1202 (1978)

3.5 Used Foundry Sand:

Used foundry sand is firstly oven dried then the required test is performed on the sand .Used foundry sand is basically the waste from the metal or non-metal casting industries, after the casting the mould which is made of foundry sand is of no use so it is considered as the waste product in that industry. In this sand high content of silica is there approximately more than 85% rest is clay and other particles.

Used foundry sand with RAP content with partial replacements of (0%, 5%, 10%, and 15%) was used in mix design of asphalt. Waste or used foundry sand was taken from the university metal casting lab.

To find out the properties of foundry sand various test are performed but mainly grain size distribution and specific gravity by Pycnometer method was done in the thesis work. Before conducting the test, the used foundry sand was dried for around 24-48 hours at a temperature of 105°C as per ASTM D2216.

Figure 3.2: **Used foundry sand used for research work.**

3.5.1 Grain size distribution:

In this research work the grain size distribution is done by sieve analysis method. Sieve analysis is mostly done for classification of the different soils. The basic principle behind the sieve analysis is different sieves of different sizes are combined together and then the compute the percent passing through each of sieves through the shaker and then all the different size particle cumulative percentage is determined. Sieves used in the test are 4.75 mm, 2.36 mm, 1 mm, 600 microns, 425 micron, 150 micron and 75 micron. Code used for the sieve analysis is IS: 2720. If moisture content of soil is above 5% then it should be measured and tabulated. In our used foundry sand most of particle size is between 0.15mm – 0.075 mm which is 89.6% -98.8%, there were very less particle size greater than 0.6 mm. Thus from this it was concluded that this will acts as filler in our hot mix asphalt sample for the mix design and can be used.

3.5.2 Specific gravity by Pycnometer method

Specific gravity of particles passing 4.75 mm IS sieve is determined using Pycnometer. Specific gravity helps in identification and classification of soil, which further leads to get an idea that it is suitable for construction material; the soil which have more specific gravity gives more strength, hence used in road works and foundations. Figure 3.3 shows how to find the specific gravity using Pycnometer. While performing the experiment it should be noted that proper vacuum should be created before weighing. Indian Standards code used to perform test was IS: 2720-partIII.

***Table 3.3:* Specific gravity of used foundry sand.**

Sample no.	**Specific gravity(G)**
1.	2.550
2.	2.318
3.	2.487
Average	2.442

3.6 Reclaimed Asphalt Pavement (RAP):

Reclaimed Asphalt pavement (RAP) is the scraped or milled material from the existing pavement. RAP was taken from Patiala-Nabha road (Punjab, India) by the help of local contractor. First of all the RAP was milled from the surface which was no longer in use and considered as the waste material. So in this research work used foundry sand can be used this RAP with used foundry sand for DBM-II (as per MORT&H) to form a stable and durable asphalt mix with optimum use of bitumen content. Before making the Marshall mix design it is important to find the properties of RAP such as the bitumen content in RAP, aggregate impact value and specific gravity.

3.6.1 Bitumen extraction:

Bitumen extraction in this research work was carried by centrifugal extractor to determine the bitumen content in RAP. Before conduction the test the RAP was taken 500 gm and benzene or petroleum is required to conduct the test. Filter paper was required such to measure the weight of fine particles in the RAP. The RAP 500 gm sample was placed in the centrifugal extractor and benzene was poured then the filter paper was applied on that and it should be closed tightly such that bitumen does not bleed. Centrifugal extraction for each sample was done at least 15-25 minutes such that all bitumen was separated from the RAP sample. Then the weight of sample plus weight of filter paper was taken to find out the bitumen content. The average bitumen content in RAP sample was 4.0%. Below figure 3.4 shows the test conducted during the study of bitumen content in RAP.

Figure 3.3: Bitumen extraction using centrifugal extractor.

3.6.2 Aggregate impact value:

Aggregate impact value test helps us to know the resistance to breakdown from impact only. In this test a standard size sample ranging between 14 mm-10 mm in diameter and then subjected to a loading in form of 15 blows from a hammer having diameter of 100 mm, then that sample was allowed to pass through the 2.36 mm sieve and then the loss or cumulative percentage was calculated to determine the aggregate impact value of RAP. Code used is IS: 2386(Part IV) guidelines were followed while performing experiment. Weight of hammer was around 14 kg and dimensions of cup were 50 mm height and 102 mm was diameter of cup in which RAP sample was placed.

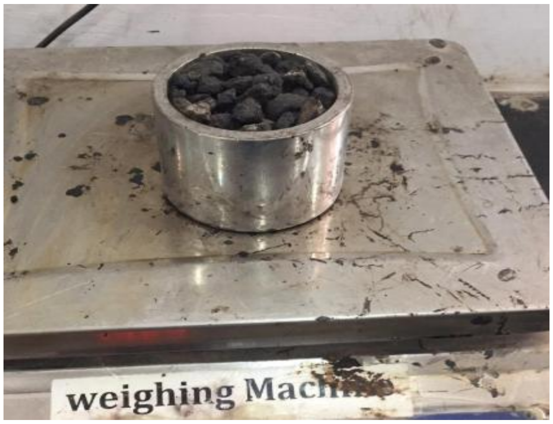


Figure 3.4: **Aggregate impact value (AIV %) test on RAP**

Table 3.4: Properties of RAP aggregates

S.No	Description	Values
1.	Specific gravity	2.68
2.	Aggregate Impact value (AIV),%	14.01
3.	Combined EI+FI,%	26

3.7 Marshall test for DBM-II:

Marshall Mix design is worldwide adopted for determining the stability and flow characteristics of bituminous mixes. Marshall mix design allow to find the optimum binder content(OBC) of bitumen used in paving mix at different bitumen contents and also allow to study various properties like Marshall stability, flow value, unit weight and voids in the mixture. Entire Marshall Test conducted in the study was as per ASTM D6926, ASTM D 6927 and MS-II guidelines (7^{th} edition).

1. ASTM D 6926-method for preparation of bituminous specimen using Marshall apparatus.
2. ASTM D 6927- method to find Marshall Stability and flow of paving bitumen mixes.

3.7.1 Job mix formula:

1. The procedure starts with the preparation of marshal samples as per ASTM D 6926 and MS-II (7th edition) using 75 blows each face of specimen.
2. A series of Marshall Specimen were prepared for a range of different bitumen content so that the test data curves show a well defined optimum value of each property. The range of bitumen content by weight of aggregates for test data is taken as 4.5%, 4.75%, 5.0%, 5.25%, 5.5%, 5.75%and 6.0% with an increment of 0.25%.
3. Combined aggregates and bitumen are heated at 160°Cand 175°C respectively and individual batches were mixed at 165°c in laboratory at controlled temperature conditions.
4. For Marshall Specimens at each bitumen content at least three samples were prepared by compacting 75 blows on each face of the DBM-II (containing RAP + used foundry sand) in Marshall Mould between 95°c -105°c.
5. The Marshall specimen was kept overnight after casting to cool down to room temperature and extruded from moulds.
6. The Marshall specimens were also tested for compacted density, Marshall Stability and flow value.
7. The reproducibility of the properties of DBM-II mix at different bitumen content was established by laboratory trail at constant aggregate gradation and selected bitumen contents. Then all the properties of the mix were observed and calculated in summary sheets with tables and graphs.

3.7.2 Equipment:

1. A compaction hammer having a flat, circular tamping face with nominal diameter of 98.4 mm and weighing around 4.5 kg with free fall of 457 mm.
2. Compaction pedestal having a 200 x 200 x 460 mm wooden post capped having 305 x 305 x 25 mm steel plates. The wooden post must have a dry weight 670-770 kg/m^3 which rest on a solid surface area (concrete slab).
3. Oven for the heating bitumen and specimen mould including base plates at required

temperature.

4. Hot plate required for heating the compaction hammer, spoon and spatula.
5. Round metal pans having 4litres capacity was required for mixing bitumen and aggregates.
6. Thermometer for determining temperature of bitumen and aggregates. It should be armored glass type with metal stem, temperature ranging from 10°c to 235°c.
7. Compaction mould having base plate, forming mould and collar. Inside diameter of forming mould is 101.6 mm and height nearly 75 mm.
8. A weighing balance or scale that can determine the maximum weight without any error. Only this is that its sensitivity of balance or scale should be at least by one gram.
9. Large mixing spoon for placing the mixture in mould while casting.
10. Marshall stability and flow was determined by a compression testing device as per ASTM D6927,it was designed in such a way that to apply loads on test specimens by cylindrical shape segments inside radius is 51 mm at loading rate of 51mm.
11. Water bath should be at least 150 mm in depth for fully immersion of the specimens and thermo- statically controlled such that it can maintain temperature of 60°c ±1°c. The tank must have false bottom with shelf for suspending specimen at least 50 mm above the bottom of heat water bath.
12. Marshall stability and flow testing machine have rate of loading 50±5 mm per minute.

3.7.3 Preparation of Marshall Sample:

1. Take approximately 1200 gm of the ingredients to prepare a mould of Marshall Mix, with optimum bitumen content in that mix as per DBM-II specifications such that height of specimen should be at least 63.5±1.27 mm.
2. Before placing in the mould, the mixture and base plate, mould, collar was heated at a temperature of 165°c and 105°c. Face of compaction hammer should be clean such that no impurity mixes with the specimen and hammer is also heated at 105°c. Room temperature of laboratory should be 20°c-30°c.
3. Heat sufficient amount of bitumen at 120°c to prepare samples. After that mix bitumen and aggregate until all the aggregates get fully coated, mixing can be done by hand also. While mixing it should be kept on hot plate to ensure that it doesn’t get cool while mixing.
4. Check the temperature of the freshly mixed, if the temperature was higher than the

compaction temperature it was allowed to cool down but if temperature goes below the compaction temperature sample was discarded.

5. Place the paper disc in the assembled, preheat Marshall mould and pour the loose asphalt mix and also check temperature. Spade the mix with the help of spatula 15 times in the perimeter and 10 times in the interior. Then preheat the hammer to apply 75 blows on face side of the sample.
6. Remove the mould from the base plate and place on paper disc and rotate the mould 180° such that top surface was now on bottom. Place hammer on the new side of mould and apply 75 blows on that side of the sample.
7. Remove the paper filters from top and bottom of specimen and allowed to cool, then extruded from mould using hydraulic jack. Place identification marks on each specimen using grease pencil.
8. In below mentioned figures3.8, 3.9, 3.10, 3.11 and 3.12 shows the method of making Marshall Specimens.

Figure 3.5: **Prepared Marshall Specimens with different RAP contents**

Figure 3.6: **Marshall grading of aggregates.**

Figure 3.7: **Mixing of marshall sample**

Figure 3.8: **Applying 75 blows on marshall mould**

Figure 3.9: **Allow specimen to cool down for 24 hour.**

Figure 3.10: Extraction of **Marshall Specimen.**

3.7.4 Testing of Marshall Specimen:

1. Measure the heights and weight of all specimens. Height should be taken from 3 sides and average height was taken.
2. Determine the bulk specific gravity of each specimen by weighing in air. Submerge the samples in water and their SSD weight was measured both before and after submersion. As per ASTM D 6752 guidelines.
3. Heat the water bath at 60°c and place the specimen from about 30 min, position of specimen should be in staggered manner so that all samples were heated for the same duration before testing.
4. After that remove the specimens from water bath and pat with towel such that excess water was removed and quickly place the specimens in Marshall testing head.
5. Bring the loading ram in contact with testing head of marshal machine. Zero the flow gauge as well as loading-deformation recorder, and then start applying load at rate of 50 mm/min. when the load starts decreasing stop both flow meter and load.
6. Then record the stability and flow value (load in KN and flow in 0.25 mm).
7. Then repeat the test for other samples and note the readings in the Performa provided.
8. Calculate the mix volumetric with different formula as per MS-II (7^{th} edition).

Figure3.11: **Dry weight of Marshall Specimen.**

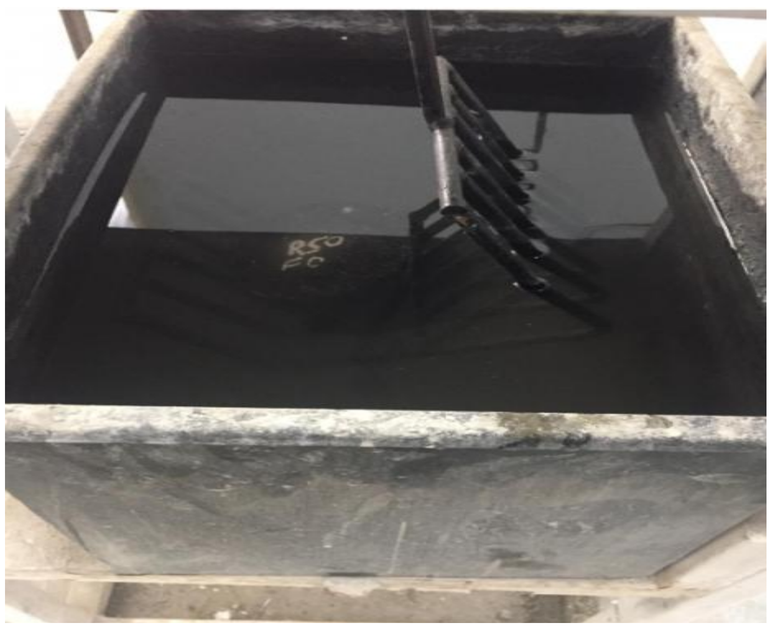


Figure3.12: **Submerged weight of specimen.**

***Figure 3*.13: Saturated Surface Dry weight of specimen(SSD).**

***Figure 3.14*: Specimens are kept in Hot water bath at 60°c.**

Figure 3.15: **Marshall Flow and Stability testing.**

3.7.5 Volumetric analysis of mix:

In the Marshall testing following are some volumetric analysis:

1. Bulk specific gravity
2. Voids in Mineral Aggregate (VMA)
3. Voids filled with Bitumen (VFB)
4. Percent Air voids (Va)

1. **Bulk specific gravity** :

Bulk specific gravity was calculated when Marshall Specimen was removed from mould and specimen was allowed to cooled down at room temperature.

Specific gravity= A/ (B-C)

A= weight of dry sample in gm

B= weight of saturated surface dry sample in gm

C= weight of sample in water in gm

2. **Voids in Mineral aggregate (VMA):**

Voids in Mineral aggregate for each Marshall specimen was calculated using bulk specific gravity (G_{sb}), the bulk specific gravity of the compacted mix (G_{mb}) and percentage of aggregate by total weight of mix (P_s).

VMA (%) =100 - [(G_{mb}* P_s ÷ G_{sb})]

3. **Voids filled with bitumen (VFB)**:

Voids filled with bitumen are voids in the mineral aggregates which are fully filled with bitumen (except the absorbed bitumen).

VFB=100(VMA- Va) ÷VMA

VMA= voids in mineral aggregate

Va= percentage of air voids in mix.

4. **Percent Air voids(Va):**

Percent air voids **(**VA) were the small air spaces between bitumen coated aggregate particles. Percent air voids can be determined by following formula:

VA=100 x [(G_{mm} **-** G_{mb}) ÷ G_{mm}]

Va = Air voids in compacted sample

G_{mm}= Maximum specific gravity of void less asphalt mix

G_{mb} = Bulk specific gravity of compacted specimen.

3.8 Indirect tensile strength test (IDT):

Tensile properties of bitumen are related to cracking .The indirect tensile strength (IDT) was used to determine the tensile properties of the bituminous mix which further leads to know the cracking effects in the asphalt mix. Higher the value of IDT higher was the resistance to cracking. IDT test was determined by loading of cylindrical specimen across its diameter plane at a specific loading rate and temperature. This test was executed as per the guidelines by ASTM D 6931-17. In this study various IDT test were conducted on various RAP plus used foundry sand Marshall Specimens. IDT was performed with loading device and loading steel strips 12.70±0.3 mm wide for specimen having diameter of 100 mm where as 19.05±0.3

mm wide for specimen of 150 mm diameter. It should be noted that length of loading strips shall exceed the specimen Thickness. Loading strips were such arranged that it should not cause frictionless surface and loose motion when subjected with samples. Water bath was required to maintain a temperature of the specimens with in ±1°c, reliable thermometers and sample measurement scale was required while performing the test. Minimum 3 samples were casted for the IDT test.

3.8.1 Procedure of performing test:

1. First step was to determine the height of the specimen.
2. Place the specimen in water bath for at least 30 minutes but not more than 120 minutes.
3. Remove the sample from water bath and with the help of towel excess water was removed, and then sample was immediately fix on the lower strip.
4. After that the upper strip was made in contact with the sample perpendicular to the specimen. It should be ensured that vertical strips were parallel to each other and placed on the centre vertical diameter plane.
5. Apply vertical compressive load on the specimens at the rate of 50±5 mm/min. After that maximum load was calculated.

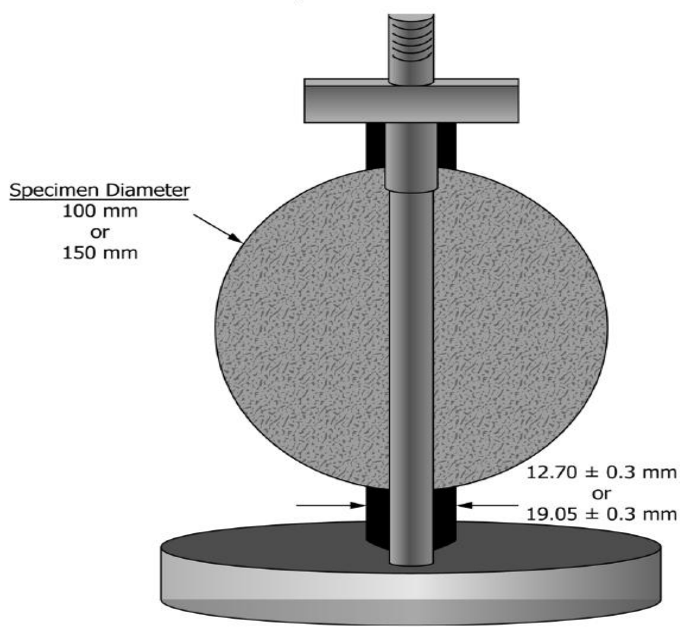


Figure 3.16: IDT test apparatus (ASTM D**6931-17**)

3.8.2 Calculation of IDT test:

Following is the formula given by ASTM D 6931-17:

S_t=2000*P/ π*t*D

Where S_t **= IDT** Strength, MPa

P= Maximum load, KN

t = specimen height before test, mm

D= diameter of the specimen, mm

3.9 Resilient Modulus (M_R) of Asphalt Mix:

Resilient Modulus is defined as the modulus of elasticity of the asphalt mix under repeated load and is the measure of circulation of different loads in pavement layers. Resilient modulus (M_R) helps in controlling fatigue cracking which is caused due to tensile stresses at the bottom of the bituminous layer and also the determine the permanent fracture through the pavement. ASTM D 7369-11 and IRC: 37-2018 is used to determine the resilient modulus using the values of indirect tensile strength test (IDT).

In IRC: 38-2018 empirical relation is given for Resilient Modulus (M_R) and indirect tensile strength test (IDT). The below is equation for DBM layer to find the resilient modulus using ITD or ITS at 35°c specimen temperature:

M_R= 11.088 x IDT-3015.80 …………………………………. [(IRC: 37-2018Equation 3.1]

Where M_R= resilient modulus at 35°c

IDT= indirect tensile strength in kPa

Poisson's ratio value of 0.35 is used to analyze bituminous layer of the pavement. DBM layer is layed in one or two layers (DBM-I or DBM-II) depending on the thickness requirement which is directly dependent on traffic volume and other parameters. Resilient modulus helps us to find how to have longer life of asphalt pavements, to avoid moisture leading distresses and to have best bottom-up fatigue resistance.

***Table 3.5*: DBM layer type with percentage of air voids (%)**

Layer type	**Air voids (%)**
Single Layer DBM(I&II)	3.5%
Double layer DBM(I&II)	3.0%

CHAPTER-04
RESULTS AND DISCUSSIONS

4.1 Introduction:

In this chapter, the results and their outcomes obtained from the experiments performed will be discussed. This chapter starts with the test performed on the Reclaimed asphalt pavement(RAP), Used Foundry Sand , Marshall testing , Indirect tensile strength test (IDT) and resilient modulus of elasticity of the asphalt mix.

4.2 Reclaimed asphalt pavement(RAP) test:

The test performed on RAP firstly was the bitumen extraction, sieve analysis and aggregate impact test, Los Angeles abrasion test during the experimental work.

a) **Bitumen extraction test results** :

Total sample taken was 500 gm.

Table4.1: **Bitumen extraction of RAP**

S. No	Content	Sample 1	Sample 2	Sample 3
1.	W1 (gm)	500	500	500
2.	W2 (gm)	475	474	476
3.	W3(gm)	10	10	10
4.	W4(gm)	15	16	14
5.	W5=(W4-W3) (gm)	5	6	4
6.	Bitumen content (%)	4.0	4.0	4.0

Where, W1= weight of mixture before test in gm.

W2= weight of mixture after test in gm.

W3= weight of filter paper used before test in gm.

W4 = weight of filter paper used after test in gm.

W5= weight of fine particles in mixture in gm.

Bitumen content (%) = W1-(W2+W5)/W1.

From the above test it was found that the average bitumen content in RAP mix was 4.0 %

b) **Sieve Analysis of RAP**:

The DBM-II has been used in the asphalt mix design so the grading of the RAP was also done as per the sieves specified by MORT&H. So below graph from figure 4.1 shows the sieve analysis of RAP as per DBM-II.

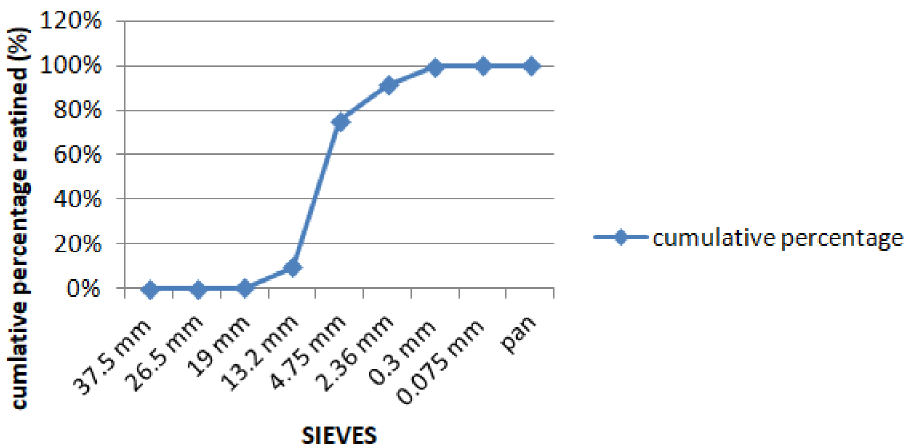


Figure 4.1: **Sieve analysis of RAP**

c) **Other properties of RAP aggregates**:

Various physical properties of RAP aggregates were to be found on basis of various tests shown in table 4.2. Properties like Aggregate impact value, Abrasion value, Flakiness & Elongation indices, Water absorption and specific gravity are important properties for Marshall Mix design.

Table 4.2: **Physical properties of RAP**

Property	Results	Specifications
Aggregate impact value ,%	14.0127	Maximum 27
Abrasion value ,%	26.2	Maximum 35
Flakiness& Elongation indices,%(combined)	26	Maximum 30
Water absorption,%	1.5	Maximum 2
Specific gravity	2.68	-

4.3 Used Foundry Sand test results:

There are two main test results that are done on used foundry that is sieve analysis and specific gravity.

Table 4.3: **Results of sieve analysis of used foundry sand.**

Sieve No.	Mass of sieve (gm)	Mass of sieve + soil (gm)	Mass of soil Retained (gm)	Cumulative mass of soil retained (gm)	Cumulative percentage of soil retained (%)
4.75mm	284	284	0	0	0
2.36mm	434	436	2	2	0.4
1mm	366	368	2	4	0.8
600 micron	290	294	20	24	4.8
425 micron	372	432	60	84	16.8
150 micron	220	584	364	448	89.6
75 micron	456	502	46	494	98.8
PAN	294	302	8	500	100

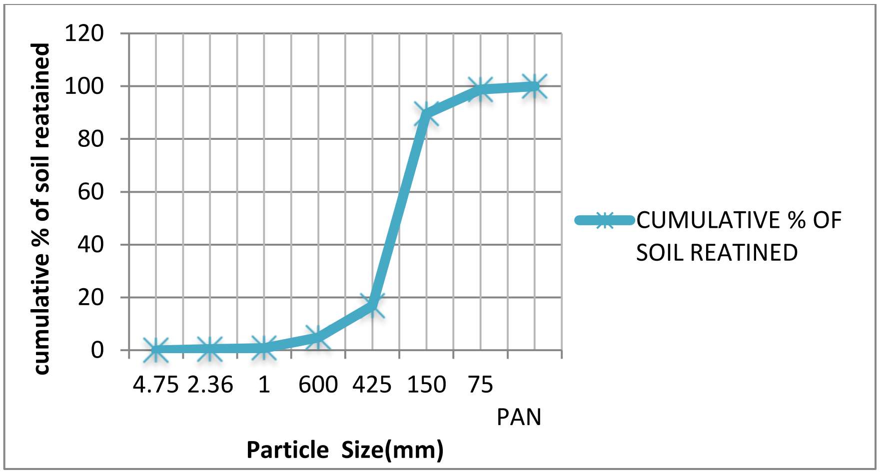


Figure 4.2: **Sieve analysis of used foundry sand**

Table 4.4**: Results of specific gravity of used foundry sand**

Contents	Sample (1) (gm)	Sample (2) (gm)	Sample (3) (gm)	Sample (4) (gm)	Average
Weight of Pycnometer(M1)	666	666	666	666	-
Weight of Pycnometer + Soil(M2)	868	870	870	870	-
Weight of Pycnometer+ Soil + Water(M3)	1648	162	1620	1618	-
Weight of Pycnometer + Water (M4)	1508	1502	1504	1496	-
G= M2-M1/(M2-M1) - (M3-M4)	3.25	2.55	2.31	2.48	**2.64**

From above tables 4.3, 4.4 and figure 4.2, it was concluded that no such heavy metals are in the used foundry sand as majority of particles are below 1 mm in particle size and specific gravity is in range, thus this can be used as a filler material in DBM-II with RAP in asphalt

4.4 Marshall Mix design:

Before going to the test results of Marshall Mix design it was required have to know the calculated gradations of aggregates which were taken as per DBM-II specified in MORT&H (5^{th} edition).

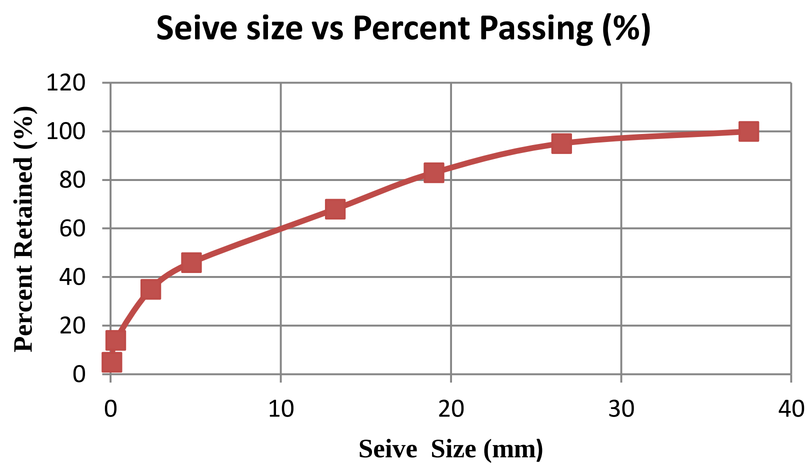


Figure 4.3: **Percent passing of virgin aggregates with different sieve sizes**

4.4.1 Optimum binder content:

To find the optimum binder content in the study of RAP and used foundry in asphalt mix. Following were results of test done on various bitumen contents with an increment of 0.25% in DBM-II (virgin mix). Bitumen used in testing is of VG-30.

Table 4.5: **Properties of the virgin DBM-II mix design.**

Properties	**VG-30 bitumen content (%)**						
	4.0	4.25	4.50	4.75	5.0	5.25	5.5
Bulk density(gm/cc)	2.360	2.371	2.68	2.366	2.364	2.362	2.360
Stability (kN)	12.78	13.52	13.73	14.50	14.23	13.03	12.68
Flow(mm)	2.4	3.7	3.9	4.0	4.4	4.8	5.1
Air voids (%)	5.68	4.58	4.12	3.3	3.0	2.44	2.0
VMA (%)	16.41	16.64	17.20	17.34	17.62	17.97	18
VFB (%)	65.38	72.31	76.11	81.26	82.34	84.64	86.4

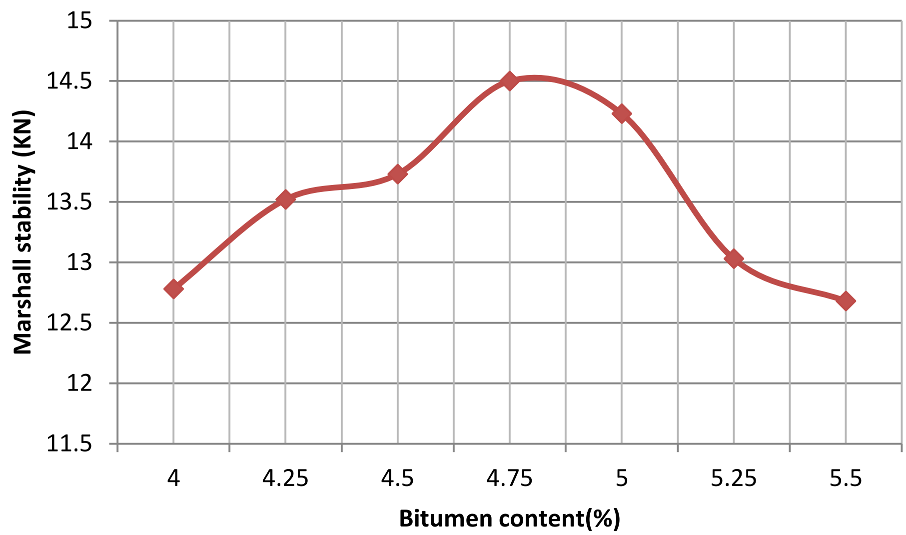


Figure 4.4: **Marshall Stability (kN) versus Bitumen content (%) for OBC.**

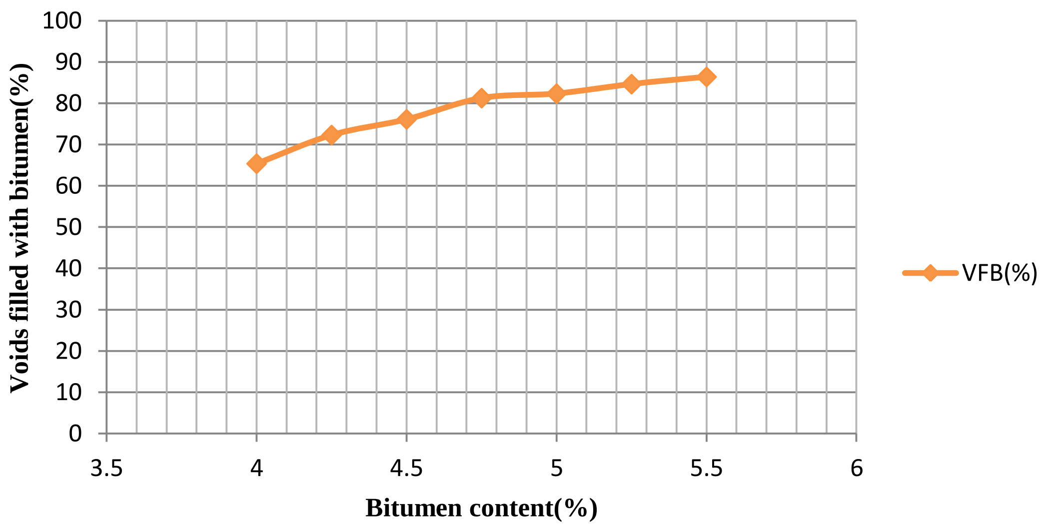


***Figure 4.5*: VFB (%) versus Bitumen content for OBC.**

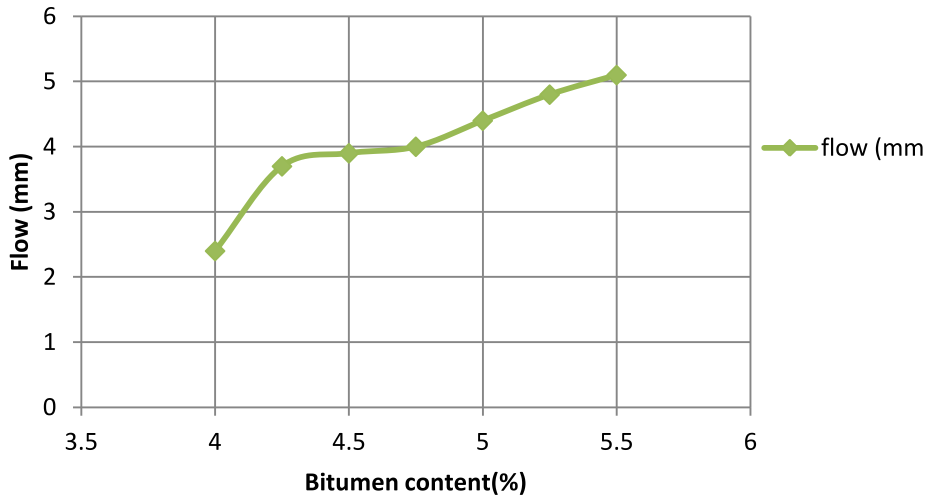


Figure 4.6: **Flow (mm) versus Bitumen content for OBC.**

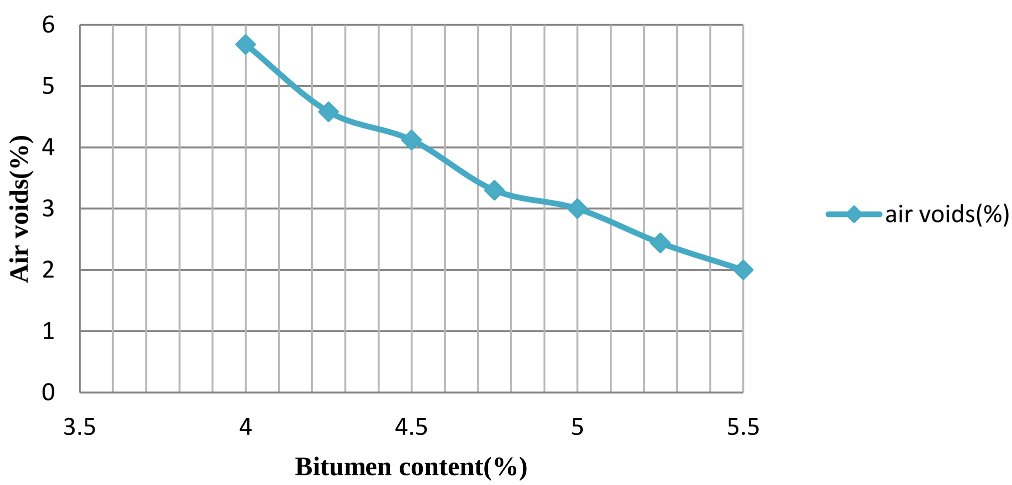


Figure 4.7: **Air voids (%) versus Bitumen content for OBC.**

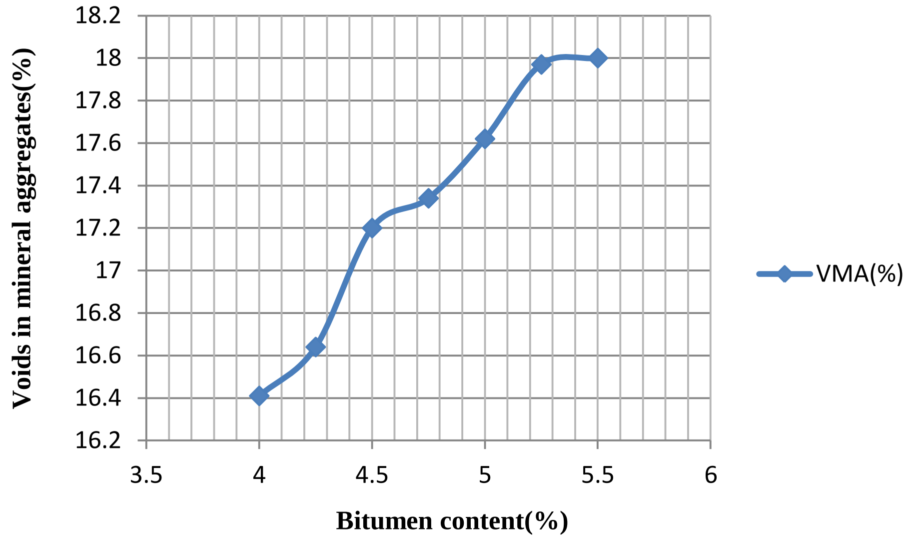


***Figure 4.8*: VMA (%) versus Bitumen content for OBC.**

Mix design results for DBM-II conventional mix at different bitumen content as shown in table 4.5and figures 4.4-4.8 is as follows:

1. From all above graphs we concluded that Optimum binder content for the taken mix design of DBM-II is 4.75%.
2. Above mix design study confirms that all measured and calculated properties of Dense Bituminous Macadam (DBM)-II (virgin mix) satisfy the design criteria of MORT&H specifications.
3. The percent of air voids decreases with increasing bitumen content, ultimately approaching a minimum void content.
4. The curve for stability value was observed that also increases with increasing bitumen content up to a maximum after which the stability decrease.
5. The flow value increases with increment in bitumen content.
6. The percent voids in mineral aggregates (VMA) generally decrease to a minimum value then increase with increase in bitumen content.
7. The percent voids filled with bitumen (VFB) increases with increase in bitumen content.

4.4.2 Approach of the mix design using RAP (%) and used foundry sand (%) for design of Marshall Mix:

The simple approach for the Marshall Mix design with RAP and used foundry sand was taken as shown below in table 4.6. When the Marshall Stability decreases and other parameters were out of range stop increasing the percentage of RAP and used foundry sand and conclude the results.

***Table 4.6*: Percentage variations of RAP (%) and Used Foundry Sand (%)**

Percentage of RAP	Percentage of Used Foundry Sand
0%	5% 10% 15%
10%	0% 5% 10% 15%
20%	0% 5% 10% 15%
30%	0% 5% 10% 15%
40%	0% 5% 10% 15%
50%	0% 5% 10% 15%
60%	0% 5%

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VMA	% VFB	Stability(kN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3)/ Gsb	{(9-8)/9}x100	Measured	Corrected (11a×5b)	
						A	B	C	D							
1.	**2.**	**3.**	**4.**	**5.a**	**5.b**	**6.**				**7**	**8.**	**9.**	**10**	**11a.**	**11.b**	**12.**
R0F5	4.75	95.25	2.439	66.3	1	1212	712	1225	513	2.362	3.15	13.76	77.1	11.77	11.77	4.3
R0F5	4.75	95.25	2.439	63.6	1.09	1164	684	1173	489	2.38	2.41	13.11	81.61	11.77	12.28	3.1
R0F5	4.75	95.25	2.439	66	1.04	1200	710	1213	503	2.385	2.21	12.92	82.87	10.97	11.4	3.3
Avg.										**2.375**	**2.59**	**13.26**	**80.53**	**11.5**	**11.44**	**3.56**
R0F10	4.75	95.25	2.439	65	1.04	1200	700	1204	504	2.38	2.41	13.11	81.61	17.53	18.23	3.1
R0F10	4.75	95.25	2.439	65.6	1.04	1212	709	1217	508	2.385	2.21	12.92	82.89	17.53	18.23	3.3
R0F10	4.75	95.25	2.439	65.4	1.04	1210	706	1214	508	2.381	2.37	13.07	81.86	16.43	17.08	3.2
Avg.										**2.382**	**2.33**	**13.03**	**82.12**		**17.84**	**3.2**
R0F15	4.75	95.25	2.439	65	1.04	1210	710	1218	508	2.381	2.37	13.07	8186	17.74	18.3	3.5
R0F15	4.75	95.25	2.439	66.3	1	1222	717	1227	510	2.396	1.79	12.52	85.7	17.5	17.5	3.6
R0F15	4.75	95.25	2.439	66	1.04	1221	714	1226	507	2.386	2.02	12.36	81.02	17.84	18.55	3.4
Avg.										**2.387**	**2.06**	**12.65**	**82.86**		**18.06**	**2.46**

Table 4.7: Corrected stability for RAP (0%) with used foundry sand (5%, 10% &15%) at OBC of 4.75%

Bulk Specific Gravity of total aggregates (Gsb) =2.609
Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696
Specific Gravity of Bitumen =1.015

Mixing temperature = 165°c
Compaction Temperature = 150°c
No. of Blows each side = 75

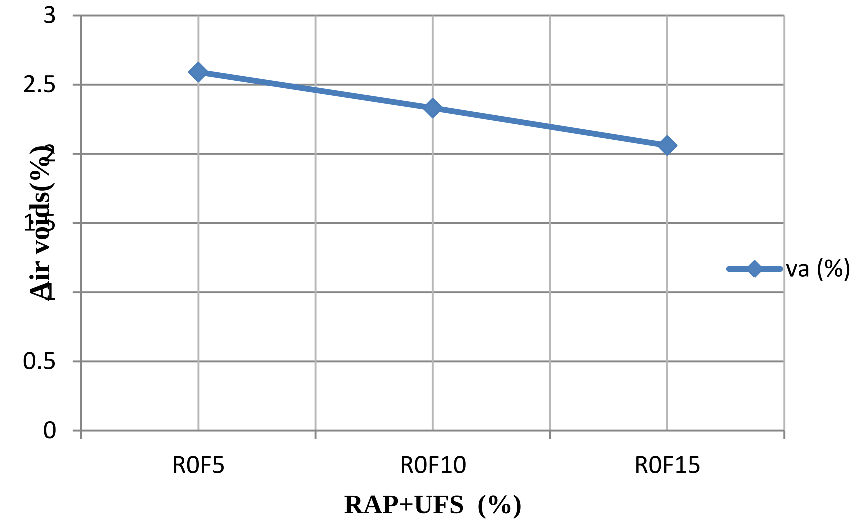


Figure 4.9: **Air voids (%) versus RAP (0%) and used foundry sand (%).**

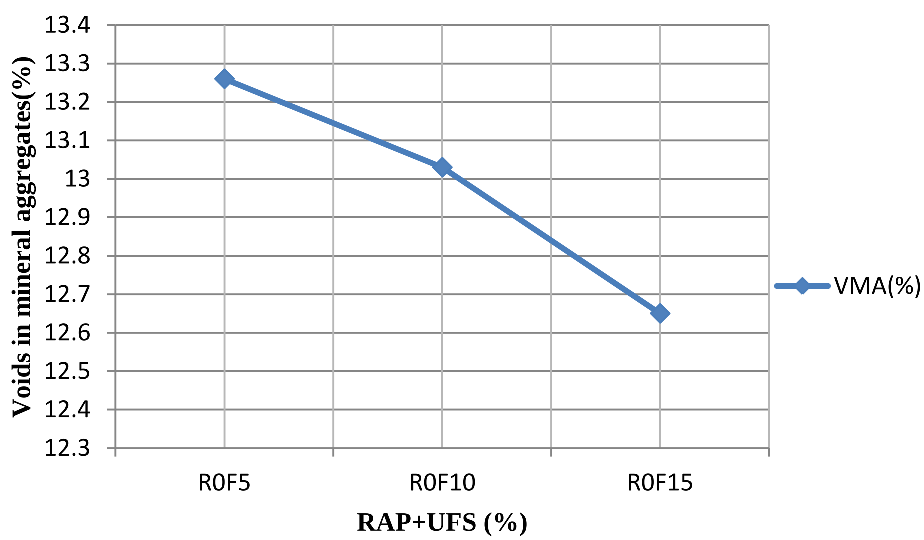


Figure 4.10: **VMA (%) versus RAP (0%) and used foundry (5%, 10%, and 15%).**

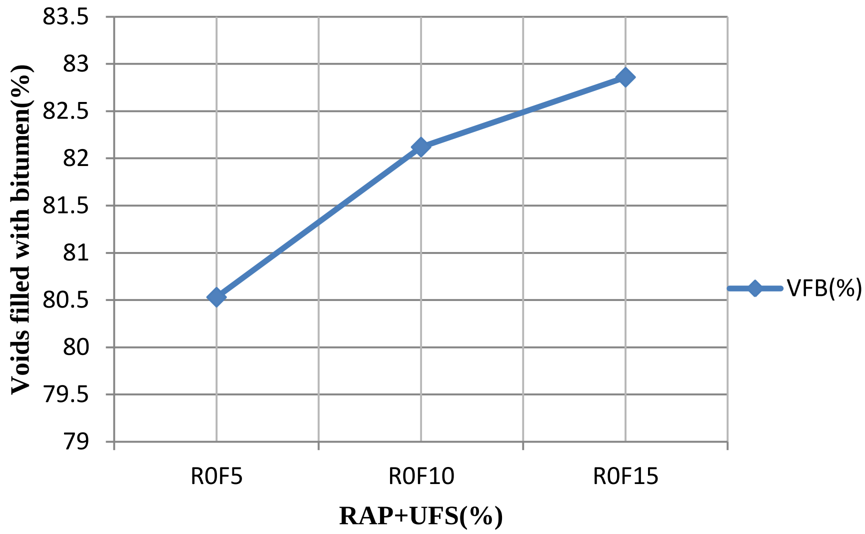


Figure 4.11: **VFB (%) versus RAP (0%) and used foundry sand (5, 10, and 15%).**

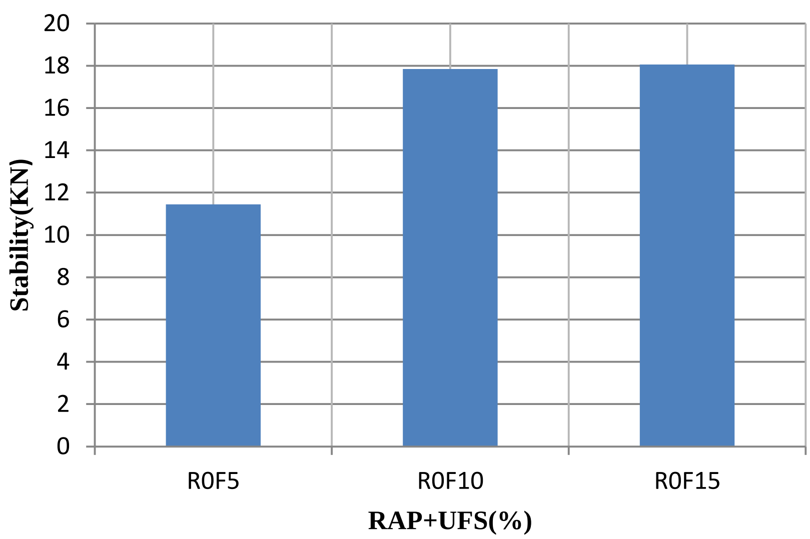


Figure 4.12: **Marshall Stability (kN) versus RAP (0%) and used foundry sand (5%, 10%, and 15%)**

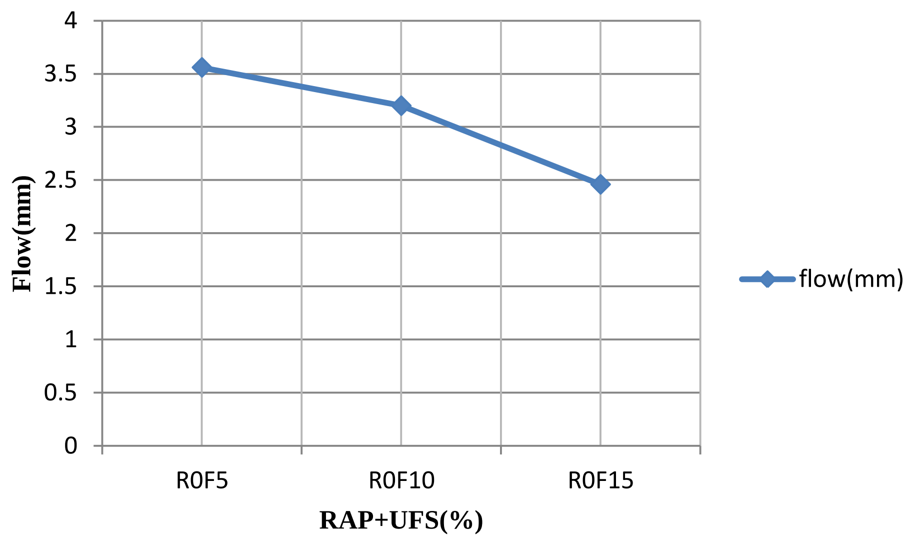


Figure 4.13: **Flow (mm) versus RAP (0%) and used foundry sand (5%, 10%, and 15%).**

Mix design results for DBM-II with RAP (0%) and used foundry sand (5-15%) as shown in table 4.7 and figures 4.9-4.13 is as follows:

1. From above results it was concluded that as the content of used foundry sand (%) increases in RAP having 0% in mix design the air voids were decreasing but they were in permissible limits as per the MORT&H.
2. VMA (%) was also decreasing as the content of used foundry was increasing and was in permissible limits.
3. VFB (%) was increasing as the content of used foundry is increasing with RAP (0%) mix.
4. Marshall Stability (kN) also increases as the content of used foundry sand increasing but only up to the R0F10 after that Marshall Stability (kN) decreasing.
5. Flow (mm) value was also decreasing with the increase in used foundry content with RAP (0%).

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VMA	% VFB	Stability(kN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3)/ Gsb	{(9-8)/9}x100	Measured	Corrected (11a×5b)	
						A	B	C	D							
1.	**2.**	**3.**	**4.**	**5.a**	**5.b**	**6.**				**7**	**8.**	**9.**	**10**	**11a.**	**11.b**	**12.**
R10F0	4.75	95.25	2.409	67.6	0.96	1203	688	1214	526	2.287	5.06	16.5	69.33	17.79	17.07	3.1
R10F0	4.75	95.25	2.409	67	1	1203	694	1211	517	2.326	3.56	15.08	76.39	18.38	18.38	3
R10F0	4.75	95.25	2.409	67.5	1	1202	693	1210	517	2.324	3.52	15.15	76.76	18.03	18.03	3.2
Avg.											**4.04**	**15.57**	**74.16**		**17.82**	**3.1**
R10F5	4.75	95.252	2.409	66.3	0.96	1228	712	1236	524	2.343	2.73	14.46	81.12	19.25	18.48	2.8
R10F5	4.75	95.25	2.409	66.3	1	1217	709	1223	514	2.367	2.73	13.58	79.89	16.04	19.04	3
R10F5	4.75	95.25	2.409	66	1	1202	692	1210	518	2.32	3.69	15.3	75.88	18.78	18.78	3.1
Avg.											**3.05**	**14.44**	**78.96**		**18.76**	**2.96**
R10F10	4.75	95.25	2.409	66	1	1229	714	1235	521	2.358	2.16	13.91	84.47	18.83	18.83	3.1
R10F10	4.75	95.25	2.409	66.3	1	1224	717	1230	519	2.358	2.16	13.91	84.47	19.25	19.25	3
R10F10	4.75	95.25	2.409	66.2	1	1226	712	1229	517	2.371	1.577	13.43	88.25	17.34	17.34	2.92
Avg.											**1.96**	**13.75**	**85.73**		**18.47**	**3**
R10F15	4.75	95.25	2.409	64.3	1	1225	720	1229	509	2.406	0.12	12.17	98.98	18.93	18.93	3
R10F15	4.75	95.25	2.409	64.6	1	1229	718	1231	513	2.395	0.58	12.56	95.38	18.67	18.67	2.8
R10F15	4.75	95.25	2.409	64.2	1	1227	712	1230	518	2.368	1.7	13.54	87.44	17.5	17.5	2.7
Avg.											**0.8**	**12.42**	**92.93**		**18.36**	**2.83**

***Table 4.8*: Corrected stability for RAP (10%) with used foundry sand (0%, 5%, 10% &15%) at OBC of 4.75%**

Bulk Specific Gravity of total aggregates (Gsb) =2.609 Mixing temperature = 165°c

Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696 Compaction Temperature = 150°c

Specific Gravity of Bitumen =1.015 No. of Blows each side = 75

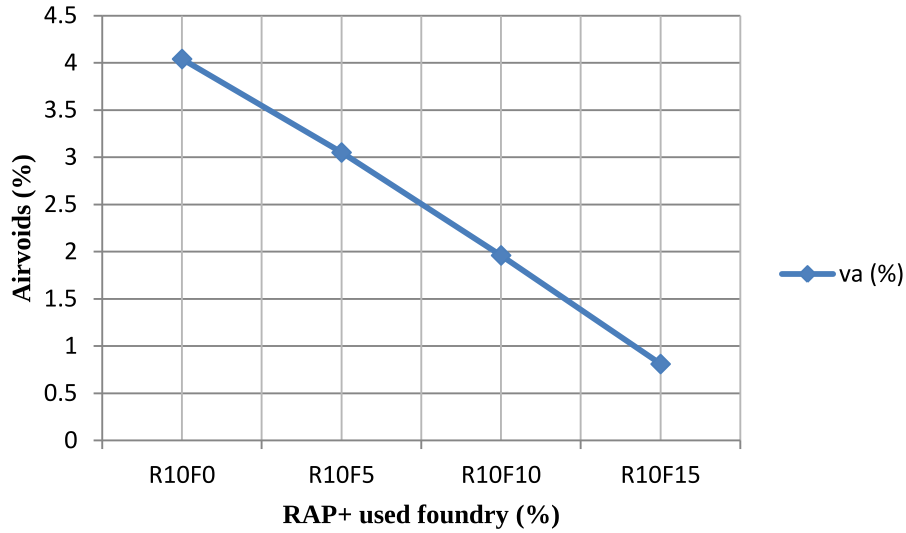


Figure 4.14: **Air Voids (%) versus RAP (10%) and used foundry sand (0%, 5%, 10%, and 15%).**

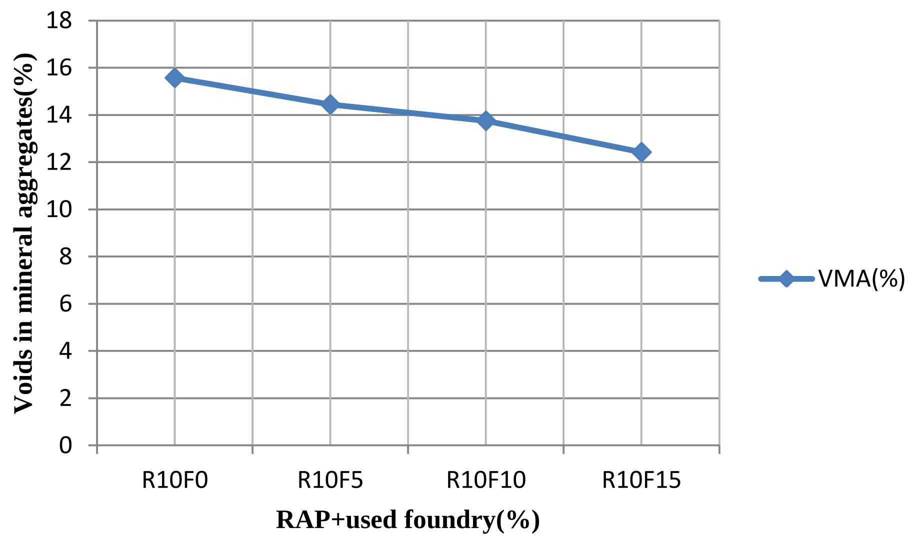


Figure 4.15: **VMA (%) versus RAP (10%) and used foundry sand (0%, 5%, 10%, and 15%).**

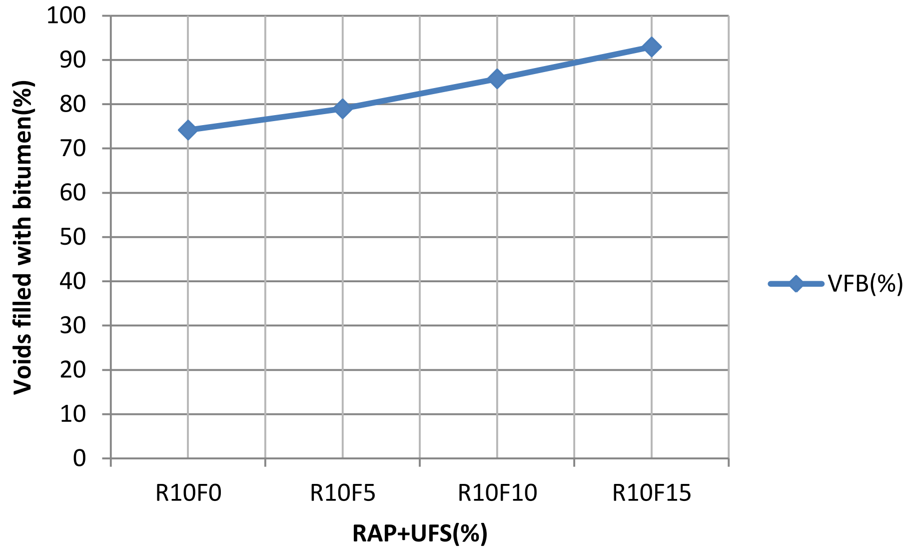


Figure 4.16: **VFB (%) versus RAP (10%) and used foundry sand (0%, 5%, 10%, and 15%).**

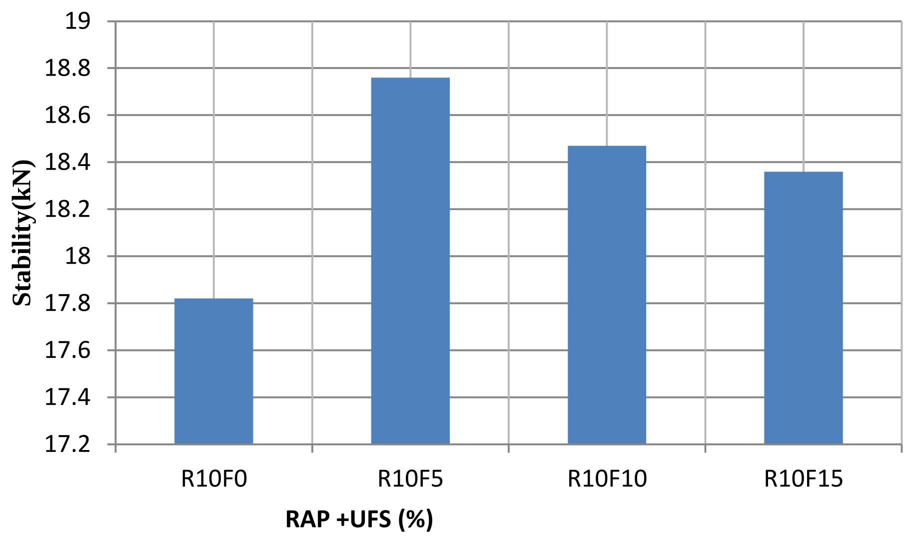


Figure 4.17: **Marshall Stability (kN) versus RAP (10%) and used foundry sand (0%, 5%, 10%, and 15%).**

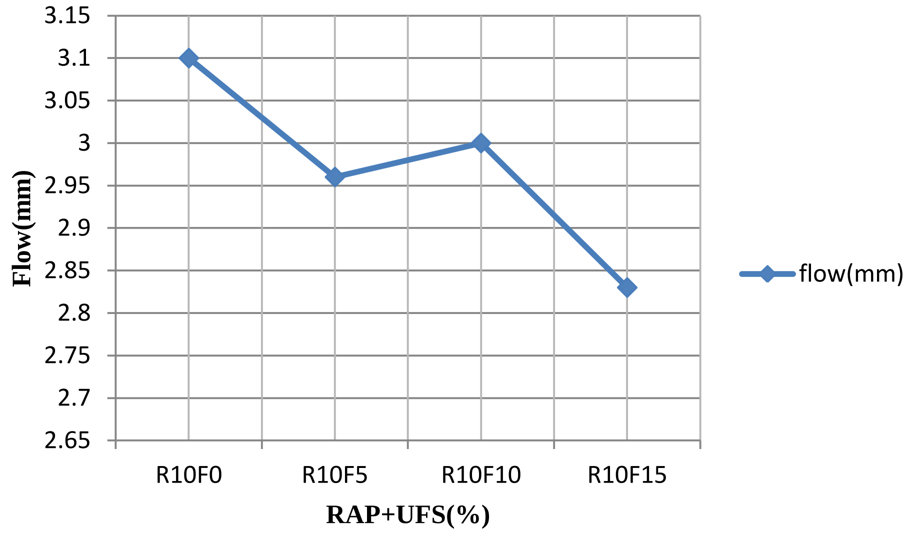


Figure 4.18: **Flow (mm) versus RAP (0%) and used foundry sand (0%, 5%, 10%, and 15%).**

Mix design results for DBM-II with RAP (10%) and used foundry sand (5-15%) as shown in table 4.8 and figures 4.14-4.18 is as follows:

1. From the above graph 4.14, it was concluded that air voids were decreasing with the addition of used foundry sand in RAP (10%) mix. Air voids up to R10F10 was in permissible limits but for R10F15 air voids were not in required limits.
2. VMA % was also decreasing with increase in content of used foundry sand, and all the values except R10F0 was in permissible limits.
3. VFB% is also increasing with the increase in content of used foundry sand in mix. VFB (0%) for R10F15 was very high which was not in permissible limits.
4. Marshall stability (kN) increased with increment in used foundry sand but up to on R10F5, then after for R10F10 and R10F15 stability was less.
5. Flow (mm) value was also decreasing with the increase in content of used foundry sand. All the values were within permissible limits.

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VMA	% VFB	Stability(kN)		Flow (mm)
						In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3)/ Gsb	{(9-8)/9}x100			
				Measured (mm)	Stability Correlation Ratio	A	B	C	D					Measured	Corrected (11a×5b)	
1.	**2.**	**3.**	**4.**	**5.a**	**5.b**	**6.**				**7**	**8.**	**9.**	**10**	**11a.**	**11.b**	**12.**
R20F0	4.75	95.25	2.413	66	1.09	1128	656	1140	484	2.33	3.43	14.93	77.02	17.32	18.87	3.6
R20F0	4.75	95.25	2.413	66	1.09	1127	654	1138	484	2.328	3.52	15	76.53	18.21	19.84	3.3
R20F0	4.75	95.25	2.413	67	1.09	1130	659	1142	483	2.339	3.06	14.6	79.04	17	18.53	3.1
Avg.											**3.33**	**14.84**	**77.53**		**19.08**	**3.33**
R20F5	4.75	95.252	2.413	67.3	1	12.4	702	1216	514	2.342	2.94	14.49	79.71	18.03	18.03	4
R20 F5	4.75	95.25	2.413	64.6	1.09	1178	687	1181	494	2.384	1.2	12.96	90.74	17.31	18.86	4.2
R20 F5	4.75	95.25	2.413	65.3	1	1200	700	1218	518	2.316	4.01	15.44	74	18.4	18.9	4
Avg.											**2.71**	**14.29**	**81.48**		**18.59**	**4.06**
R20F10	4.75	95.25	2.413	64.6	1.04	1207	704	1210	506	2.385	1.36	12.11	89.62	19.2	19.96	3.02
R20F10	4.75	95.25	2.413	65	1	1238	725	1241	516	2.339	0.58	12.41	15.32	19.3	19.3	3
R20F10	4.75	95.25	2.413	66	1	1230	715	1233	518	2.374	1.61	13.32	87.91	220	20	2.8
Avg.											**1.18**	**12.94**	**90.95**		**19.75**	**2.94**
R20F15	4.75	95.25	2.413	64.3	1.04	1214	712	1216	504	2.408	0.2	12.08	98.34	17	17.68	2
R20F15	4.75	95.25	2.413	65.3	1.04	1221	716	1224	508	2.403	0.41	12.27	96.65	18	18.72	2.2
R20F15	4.75	95.25	2.413	64	1.04	1212	710	1216	506	2.395	0.74	12.56	94.1	17.3	17.992	2.1
Avg.											**0.45**	**12.3**	**96.36**		**18.13**	**2.1**

***Table 4.9*: Corrected stability for RAP (20%) with used foundry sand (0%, 5%, 10% &15%) at OBC of 4.75%**

Bulk Specific Gravity of total aggregates (Gsb) =2.609 | Mixing temperature = 165°c

Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696 | Compaction Temperature = 150°c

Specific Gravity of Bitumen =1.015 | No. of Blows each side = 75

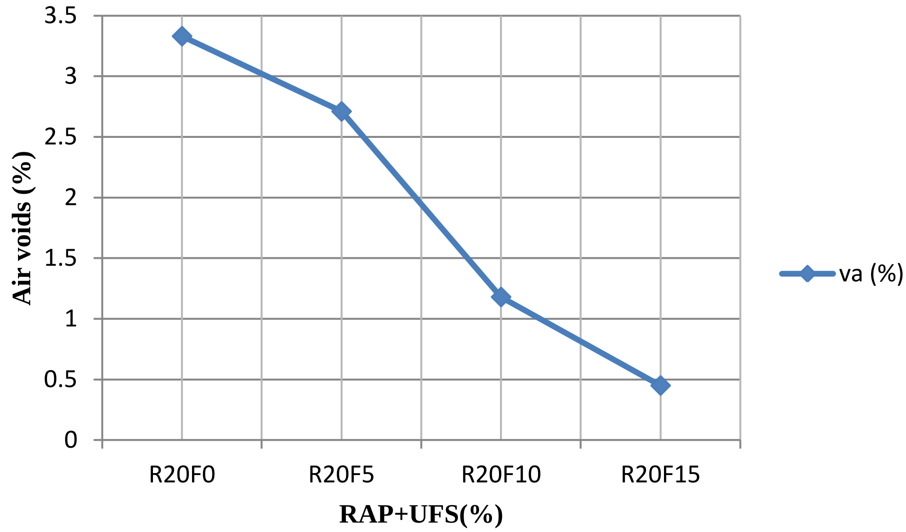


Figure 4.19: **Air voids (%) versus RAP (20%) and used foundry sand (0%5%, 10%, and 15%).**

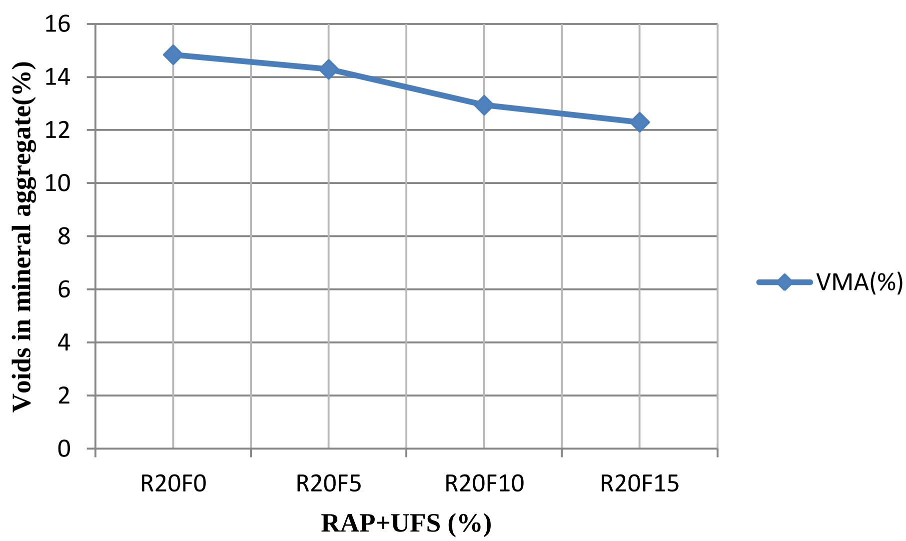


Figure **4.20: VMA (%) versus RAP (20%) and used foundry sand (0%, 5%, 10%, and 15%).**

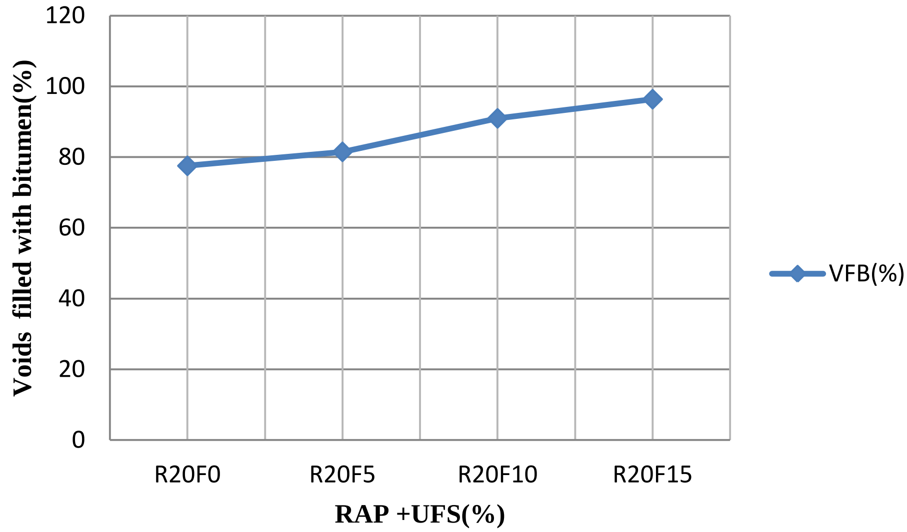


Figure 4.21: **VFB (%) versus RAP (20%) and used foundry sand (0%, 5%, 10%, and 15%).**

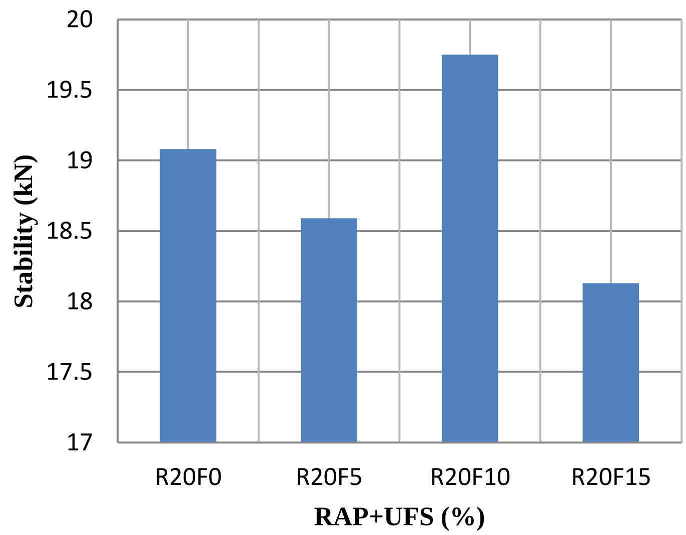


Figure 4.22: **Marshall Stability (kN) versus RAP (20%) and used foundry sand (0%, 5%, 10%, and 15%).**

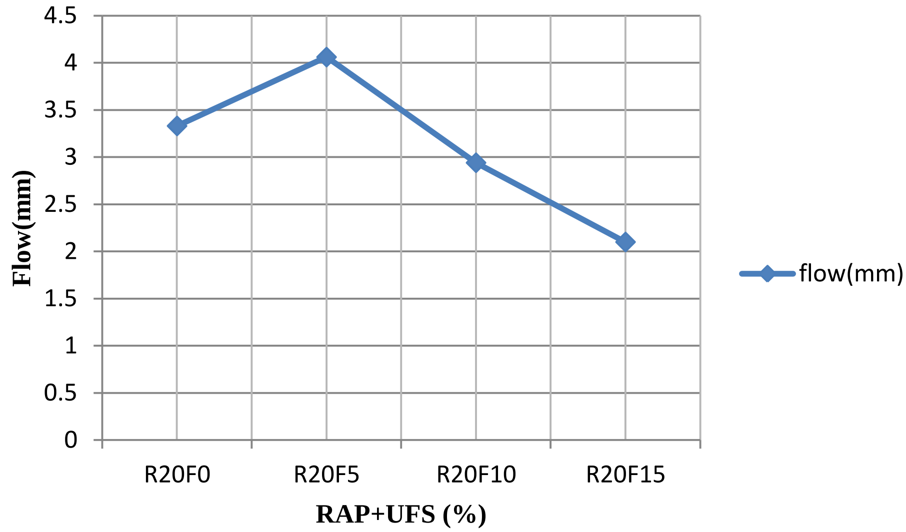


Figure 4.23: **Flow (mm) versus RAP (20%) and used foundry sand (0%, 5%, 10%, and 15%).**

Mix design results for DBM-II with RAP (20%) and used foundry sand (0-15%) as shown in table 4.9 and figures 4.19-4.23 is as follows:

1. Air voids (%) were decreasing with the increase in used foundry sand (%) up to R20F5 air voids (%) were in range but after that they start decreasing up to 0.5% which was not in limits.

2. VMA (%) also decreased with the increase in used foundry content with RAP (20%).

3. VFB (%) starts increasing with increase in used foundry sand with RAP (20%) in the mix.

4. Marshall Stability increased up to R20F10 then it decreases when more used foundry up to 15% was added.

5. Flow (mm) value also decreased with the increase in used foundry content with RAP (20%).At all different percentage flow values were within permissible limits.

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VMA	% VFB	Stability(kN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3)/Gsb	{(9-8)/9}x100	Measured	Corrected (11a×5b)	
						A	B	C	D							
1.	2.	3.	4.	5.a	5.b	6.				7	8.	9.	10	11a.	11.b	12.
R30F0	4.75	95.25	2.438	69	1	1221	712	1233	521	2.343	3.89	14.46	73.09	20.43	20.43	4.1
R30F0	4.75	95.25	2.438	68	0.96	1220	710	1234	524	2.328	4.511	15	69.93	21	20.16	3.9
R30F0	4.75	95.25	2.438	68.5	0.96	1218	713	1238	525	2.32	4.84	15.3	68.36	20.18	19.37	3.7
Avg.											**4.41**	**14.92**	**70.46**		**19.98**	**3.9**
R30F5	4.75	95.252	2.438	65.6	1	1206	692	1213	516	2.337	4.14	14.68	71.79	222.03	22.03	3.9
R30F5	4.75	95.25	2.438	65	1	1204	695	1216	521	2.31	5.25	15.66	66.47	21.33	21.33	3.7
R30F5	4.75	95.25	2.438	65.9	1	1200	692	1214	522	2.298	5.74	16.1	64.34	23	23	3.2
Avg.											**5.04**	**15.48**	**67.53**		**22.12**	**3.6**
R30F10	475	95.25	2.438	64.3	1.04	1207	708	1210	502	2.404	1.37	12.23	88.63	20.4	21.21	3.3
R30F10	4.75	95.25	2.438	64	1.04	1206	706	1212	506	2.383	2.25	13.00	82.69	19.93	20.72	3.2
R30F10	4.75	95.25	2.438	64.9	1	1200	703	1213	510	2.352	3.65	14.13	74.16	21.3	21.3	3
Avg.											**2.43**	**13.12**	**81.82**		**21.07**	**3.16**
R30F15	4.75	95.25	2.438	65.6	1.04	1212	710	1214	504	2.404	1.39	12.23	88.63	20.01	20.81	2.9
R30F15	4.75	95.25	2.438	66	1	1213	708	1217	509	2.383	2.25	13	82.69	19	19	2.7
R30F15	4.75	95.25	2.438	66.2	1.04	1200	707	1203	496	2.419	0.77	11.68	93.4	18.97	19.72	2.4
Avg.											**1.47**	**12.33**	**88.24**	**19.32**	**19.84**	**2.6**

***Table 4.10*: Corrected stability for RAP (30%) with used foundry sand (0%, 5%, 10% &15%) at OBC of 4.75%**

Bulk Specific Gravity of total aggregates (Gsb) =2.609

Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696

Specific Gravity of Bitumen =1.015

Mixing temperature = 165°c

Compaction Temperature = 150°c

No. of Blows each side = 75

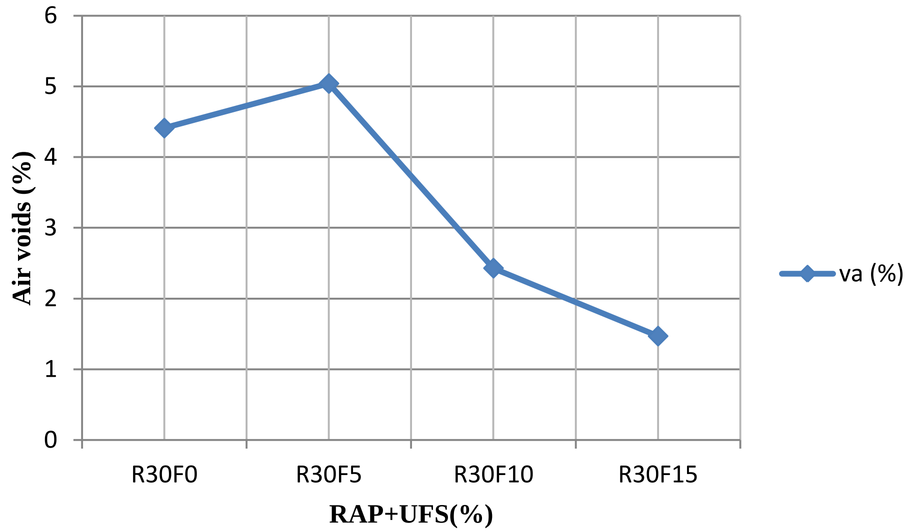


Figure 4.24: **Air voids (%) versus RAP (30%) and used foundry sand (0%, 5%, 10%, and 15%).**

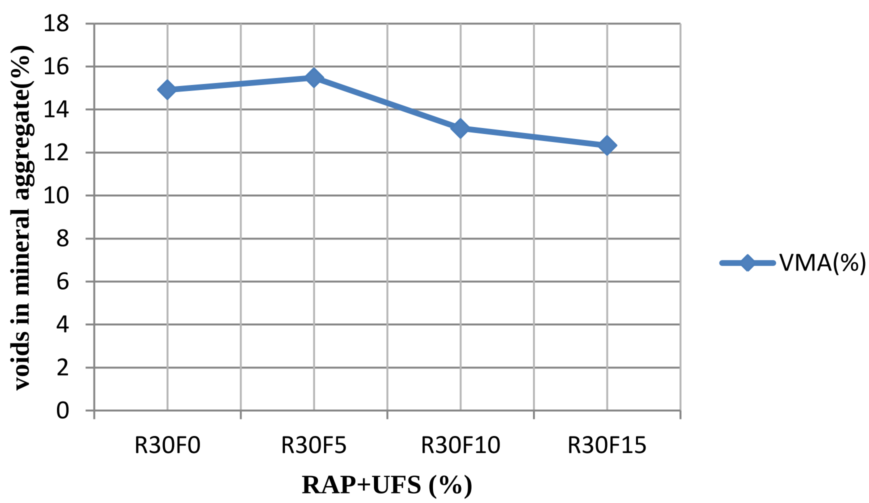


Figure 4.25: **VMA (%) versus RAP (30%) and used foundry sand (0%, 5%, 10%, and 15%).**

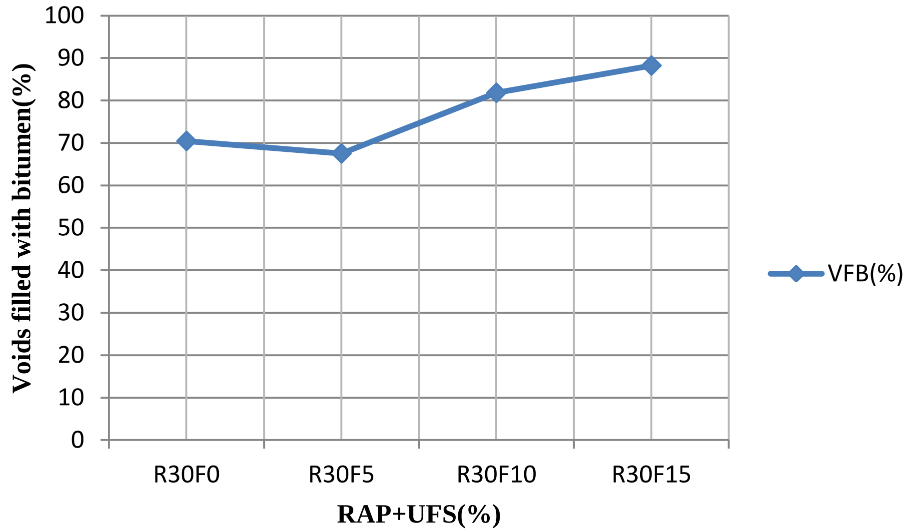


Figure 4.26: **VFB (%) versus RAP (30%) and used foundry sand (0%, 5%, 10%, and 15%).**

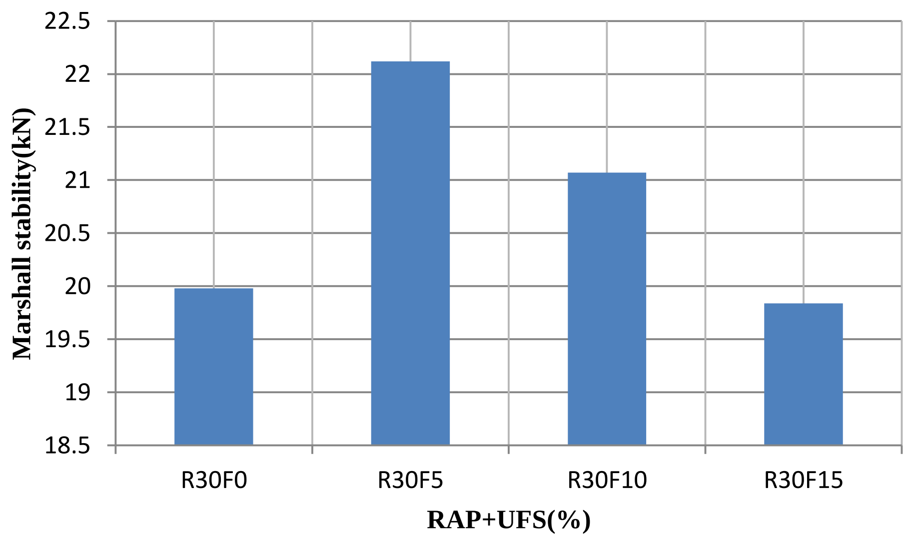


Figure 4.27: **Marshall stability (kN) versus RAP (30%) and used foundry sand (0%, 5%, 10%, and 15%).**

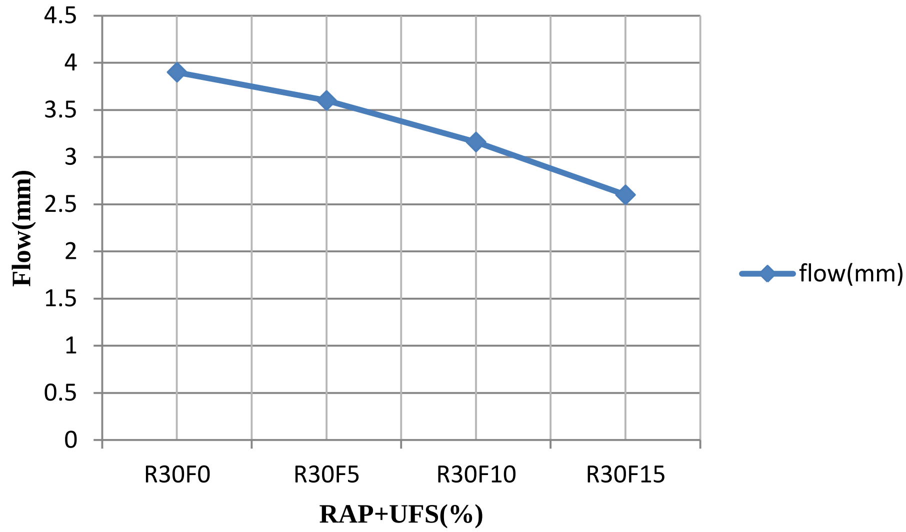


Figure 4.28: **Flow *(mm)* versus RAP (30%) and used foundry sand (0%, 5%, 10%, and 15%).**

Mix design results for DBM-II with RAP (30%) and used foundry sand (0-15%) as shown in table 4.10 and figures 4.24-4.28 is as follows:

1. Air voids (%) decreased with increase in used foundry sand content with RAP (30%). All the values up to R30F10 are within permissible limits.
2. VMA (%) also decreased with the increment in used foundry content.
3. VFB (%) also increased with increase in used foundry content.
4. Marshall stability (kN) also increase with increase in used foundry content with RAP (30%) Up to a certain content as after R30F10 stability decreased.
5. Flow (mm) value decreased with the increase in used foundry content but all the values were within permissible limits.

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VM A	% VFB	Stability(kN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3) /Gsb	{(9-8)/9}x100	Measured	Corrected (11a×5b)	
						A	B	C	D							
1.	2.	3.	4.	5.a	5.b	6.				7	8.	9.	10	11a.	11.b	12.
R40F0	4.75	95.25	2.44	68.6	1	1200	690	1208	518	2.316	5.08	15.44	67.09	23	23	4.2
R40F0	4.75	95.25	2.44	68	1	1200	688	1210	522	2.298	5.81	163.1	63.91	22.92	22.92	4
R40F0	4.75	95.25	2.44	68.2	1	1202	692	1209	517	2.324	4.75	15.15	68.64	21.07	21.07	3.7
Avg.											**5.21**	**15.56**	**76.54**		**22.33**	**3.96**
R40F5	4.75	95.25	2.44	68.3	1	1206	698	1209	511	2.36	3.27	13.84	76.37	23.98	23.98	2.9
R40F5	4.75	95.25	2.44	67.8	1	1204	697	1208	511	2.356	3.44	13.98	78.42	20.03	20.03	3.2
R40F5	4.75	95.25	2.44	67.2	1	1200	694	1204	510	2.352	3.6	14.13	74.52	21.8	21.8	3
Avg.											**3.43**	**13.98**	**76.43**		**21.93**	**3.03**
R40F10	4.75	95.25	2.44	66	1.04	1204	706	1205	499	2.412	1.14	11.94	90.45	20.7	21.52	2.7
R40F10	4.75	95.25	2.44	66.2	1.04	1203	705	1204	499	2.41	1.22	12.01	89.84	19	19.76	2.5
R40F10	4.75	95.25	2.44	66.8	1.04	1200	702	1203	501	2.395	1.84	12.56	85.35	18.7	19.44	2
Avg.											**1.36**	**12.17**	**88.54**		**20.24**	**2.4**
R40F15	4.75	95.25	2.44	64.6	1.04	1203	703	1205	502	2.396	1.8	12.52	85.62	20	20.8	2
R40F15	4.75	95.25	2.44	64.8	1.04	1202	701	1203	502	2.394	1.88	12.59	85.06	20.8	21.63	2.7
R40F15	4.75	95.25	2.44	64.8	1.04	1200	700	1202	502	2390	2.04	12.74	83.98	23.02	23.94	2.2
Avg.											**1.9**	**12.61**	**84.88**		**22.12**	**2.3**

***Table 4.11*: Corrected stability for RAP (40%) with used foundry sand (0%, 5%, 10% & 15%) at OBC of 4.75%**

Bulk Specific Gravity of total aggregates (Gsb) =2.609

Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696

Specific Gravity of Bitumen =1.015

Mixing temperature = 165°c

Compaction Temperature = 150°c

No. of Blows each side = 75

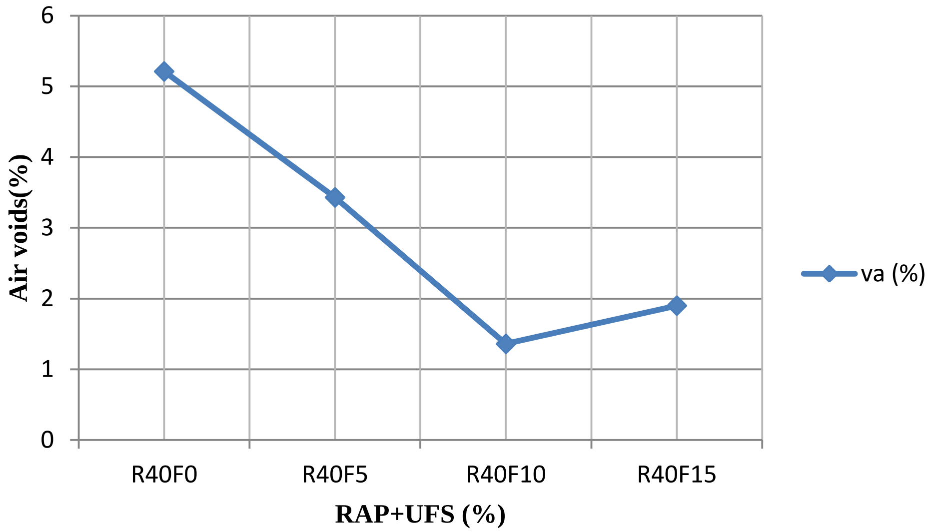


Figure 4.29: **Air Voids (%) versus RAP (40%) and used foundry sand (0%, 5%, 10%, and 15%).**

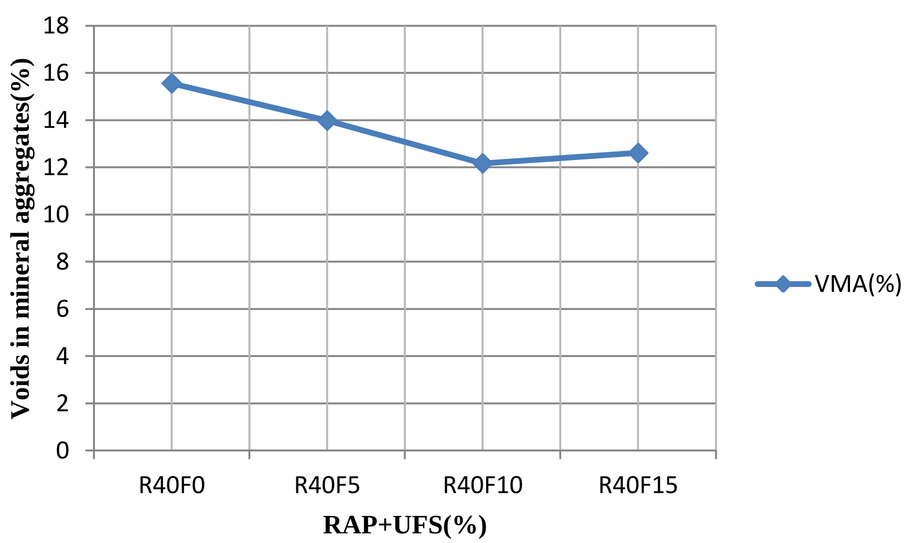


Figure 4.30: **VMA (%) versus RAP (40%) and used foundry sand (0%, 5%, 10%, and 15%).**

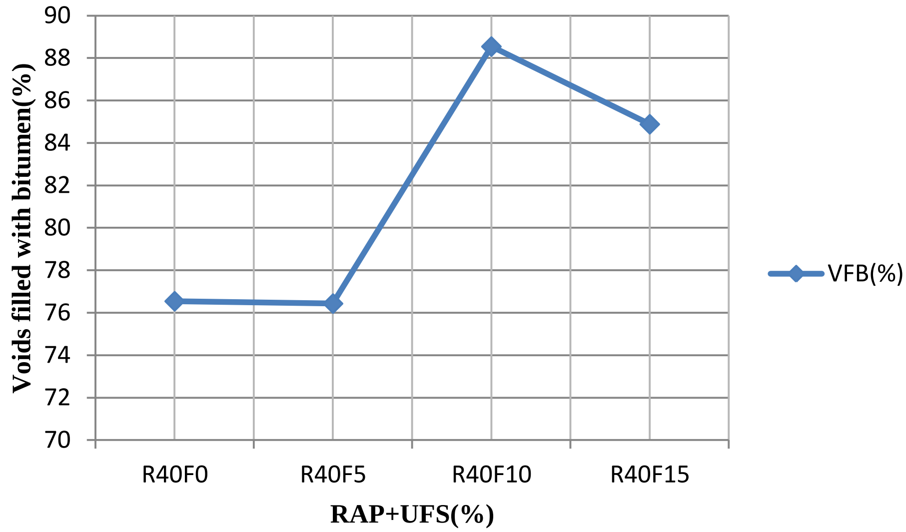


Figure 4.31: **VFB (%) versus RAP (40%) and used foundry sand (0%, 5%, 10%, and 15%).**

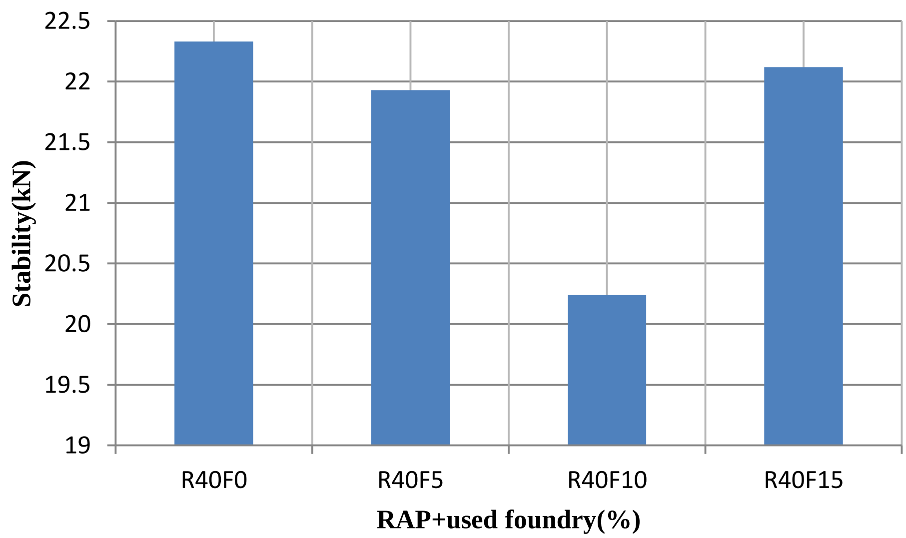


Figure 4.32: **Marshall Stability (kN) versus RAP (40%) and used foundry sand (0%, 5%, 10%, and 15%).**

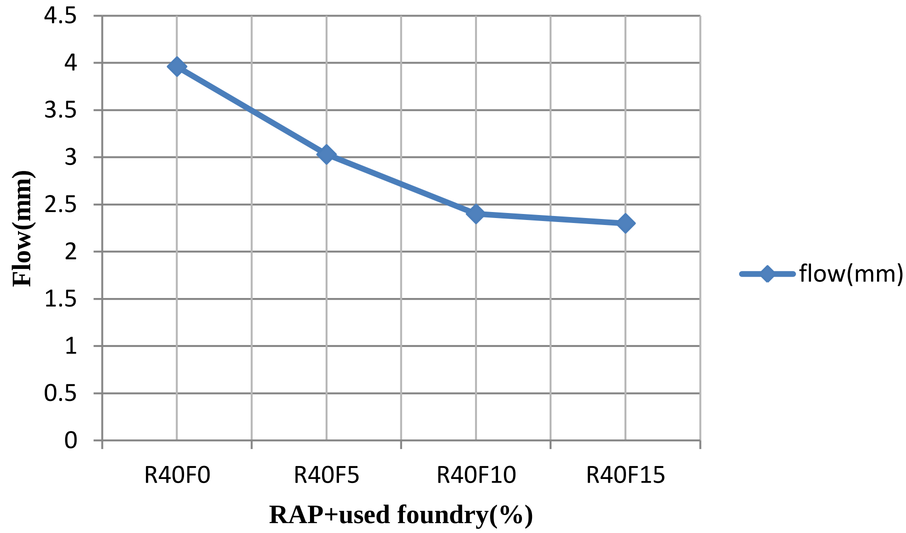


Figure 4.33: **Flow (mm) versus RAP (40%) and used foundry sand (0%, 5%, 10%, and 15%).**

Mix design results for DBM-II with RAP (40%) and used foundry sand (0-15%) as shown in table 4.11 and figures 4.29-4.33 is as follows:

1. Air voids (%) decrease with the increase in content of used foundry sand in RAP (40%) mix up to R40F10 then it was increased.
2. VMA (%) decreases with increase in used foundry sand content with RAP (40%) mix up to R40F10 then it showed an increment.
3. VFB (%) firstly decrease as content of used foundry increases up to R40F5 then it showed increment in R40F10 and again at R40F15 VFB (%) showed decrement.
4. Marshall stability(kN) increases with increase in used foundry sand(%) with RAP(40%) but at R40F10 stability shows an decrement .
5. Flow (mm) value also showed that with increase in used foundry sand (%) with RAP (40%) its value decreases gradually.

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (G_{mm})	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VMA	% VFB	Stability(kN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3)/ Gsb	{(9-8)/9}x100	Measured	Corrected (11a×5b)	
						A	B	C	D							
1.	**2.**	**3.**	**4.**	**5.a**	**5.b**	**6.**				**7**	**8.**	**9.**	**10**	**11a.**	**11.b**	**12.**
R50F0	4.75	95.25	2.445	69.6	0.96	1226	707	1231	524	2.339	4.33	14.6	70.34	23.3	2236	4.7
R50F0	4.75	95.25	2.445	69	0.96	1224	705	1232	527	2.332	5.03	15.22	66.95	22.7	21.79	4
R50F0	4.75	95.25	2.445	69.8	1.09	1200	702	1208	506	2.371	3.02	13.43	77.51	20	21.8	4.2
Avg.											**4.12**	**14.1**	**71.6**		**21.98**	**4.3**
R50F5	4.75	95.25	2.445	6.6.0	1	1225	709	1228	519	2.36	3.47	13.84	74.92	24.32	24.32	3.9
R50F5	4.75	95.25	2.445	66.2	1	1224	707	1227	520	2353	3.76	14.09	73.31	23.02	23.02	4
R50F5	4.75	95.25	2.445	66.9	1	1200	700	1209	509	2.357	3.59	13.95	74.26	23.37	23.37	3.2
Avg.											**3.6**	**13.96**	**74.16**		**23.57**	**3.7**
R50F10	4.75	95.25	2.445	63.6	1.04	1203	705	1206	501	2.401	1.79	12.34	85.49	20.22	21.02	2.9
R50F10	4.75	95.25	2.445	63	1.04	1202	704	1207	503	2.389	2.29	12.78	82.08	19.98	20.77	2.6
R50F10	4.75	95.25	2445	63.8	1.04	1200	700	1202	502	2.39	2.24	12.74	82.42	22	22.88	2
Avg.											**2.1**	**12.62**	**83.32**		**21.55**	**2.5**
R50F10	4.75	95.25	2.445	6.3.3	1.04	1216	714	1217	503	2.417	1.145	11.75	90.25	18	18.72	2.7
R50F10	4.75	95.25	2.445	63	1.04	1217	712	1219	507	2.4	1.84	12.38	85.13	18.83	19.58	2.4
R50F10	4.75	95.25	2.445	63.4	1.09	1200	710	1202	492	2.439	0.24	10.95	97.8	18.72	20.4	2.2
Avg.											**1.075**	**11.69**	**91.06**		**19.56**	**2.43**

***Table 4.12*: Corrected stability for RAP (50%) with used foundry sand (0%, 5%, 10% &15%) at OBC of 4.75%**

Bulk Specific Gravity of total aggregates (Gsb) =2.609 — Mixing temperature = 165°c

Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696 — Compaction Temperature=150°

Specific Gravity of Bitumen =1.015 — No. of Blows each side = 75

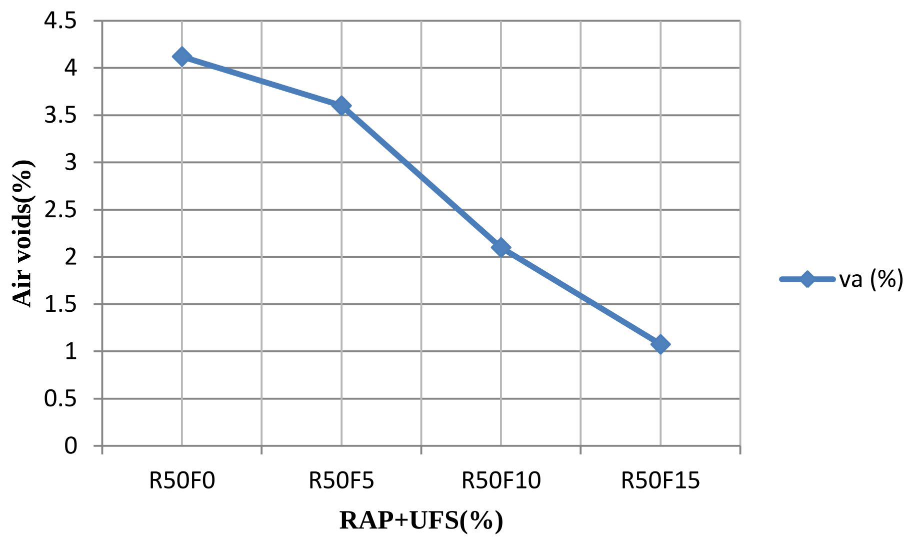


Figure 4.34: **Air voids (%) versus RAP (50%) and used foundry sand (0%, 5%, 10%, and 15%).**

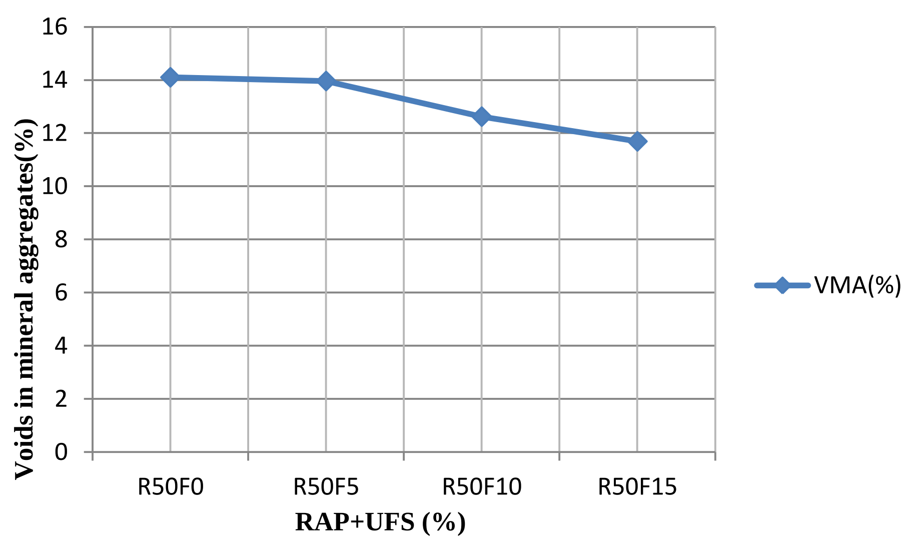


Figure 4.35: **VMA (%) versus RAP (50%) and used foundry sand (0%, 5%, 10%, and 15%).**

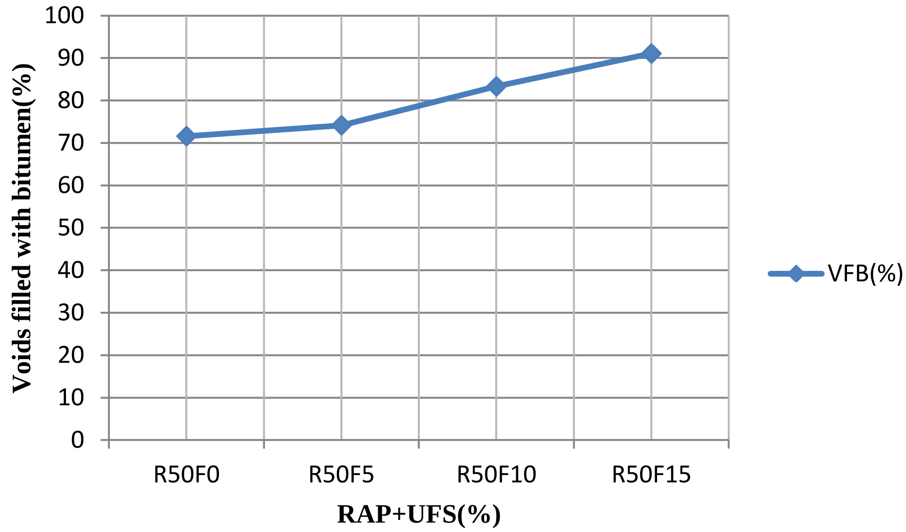


Figure 4.36: **VFB (%) versus RAP (50%) and used foundry sand (0%, 5%, 10%, and 15%).**

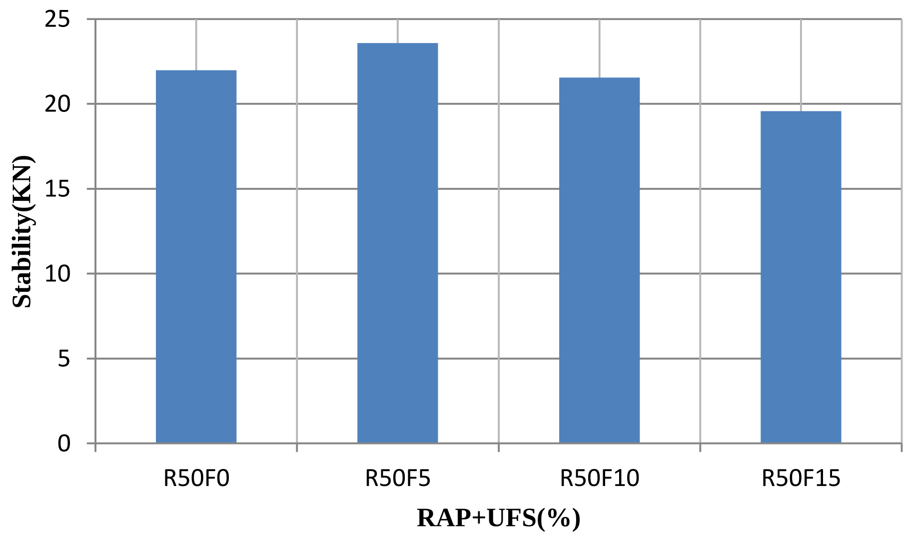


Figure 4.37: **Marshall stability (kN) versus RAP (50%) and used foundry sand (0%, 5%, 10%, and 15%).**

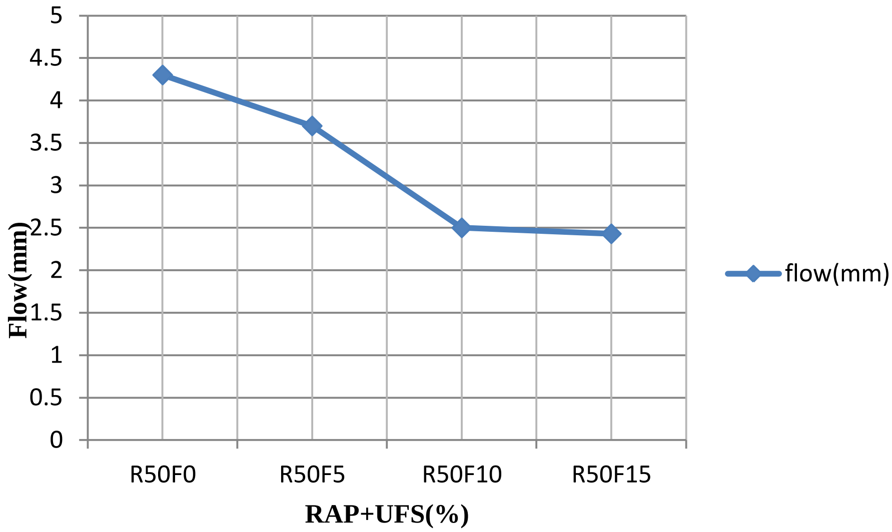


Figure 4.38: **Flow (mm) versus RAP (50%) and used foundry sand (0%, 5%, 10%, and 15%).**

Mix design results for DBM-II with RAP (50%) and used foundry sand (0-15%) as shown in table 4.12 and figures 4.34-4.38 is as follows:

1. Air voids (%) decreases with the increase in the content of used foundry sand with RAP (50%) up to R50F10 air voids are in permissible limits but for R50F15 they are below the range.
2. VMA (%) decreases with the increase in the content of used foundry sand with RAP (50%), only R50F0 showed the values which was higher than the permissible limit.
3. VFB (%) increases with the increase in used foundry sand content with RAP (50%) only R50F0 and R50F5 VFB (%) are in limits as per specifications.
4. Marshall Stability increase with increase in used foundry sand with RAP (50%) up to a certain limit then it decrease.
5. Flow (mm) value also decreased with increment in used foundry sand (%) with RAP (50%). All the values were within permissible range of 2-4 mm (as per MORT&H).

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Weight of Specimen (gm)				Bulk Sp. Gr. Of Compacted Mix= (A)/(D)	% Air Voids (Va)	% VMA	% VFB	Stability(kN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	In Air	In water	SSD in air	Vol. (C-D)		(4-7)x 100/4	100-(7x3) /Gsb	{(9-8)/9}x100	Measured	Corrected (11a×5b)	
						A	B	C	D							
1.	2.	3.	4.	5.a	5.b	6.				7	8.	9.	10	11a.	11.b	12.
R60F0	4.75	95.25	2.552	68	1	1200	700	1215	515	2.33	8.69	14.93	41.1	12	12	5
R60F0	4.75	95.25	2.552	68.4	1	1200	698	1214	516	2.325	8.89	15.11	41.16	12.33	12.33	4.9
R60F0	4.75	95.25	2.552	68.2	1	1200	702	1217	515	2.33	8.69	14.9	41.16	10.12	10.12	4.8
Avg.											**8.69**	**14.98**	**41.14**		**11.48**	**4.9**
R60F5	4.75	95.25	2.552	66	1.04	1225	709	1227	518	2364	7.95	15.93	40.1	9.86	10.25	4.2
R60F5	4.75	95.25	2.552	65.3	1	1220	702	1224	522	2.337	7.82	15.63	41.26	10	10	49
R60F5	4.75	95.25	2.552	65	1	1200	700	1205	505	2.376	8.72	14.9	42.36	9	9	3.7
Avg.											**8.17**	**15.48**	**41.24**		**9.75**	**4.2**

***Table 4.13*: Corrected stability for RAP (60%) with used foundry sand (0%, 5%, 10% &15%) at OBC of 4.75%**

Bulk Specific Gravity of total aggregates (Gsb) =2.609

Effective Specific Gravity of Total Aggregate (Gse), avg. =2.696

Specific Gravity of Bitumen =1.015

Mixing temperature = 165°c

Compaction Temperature=150°c

No. of Blows each side = 75

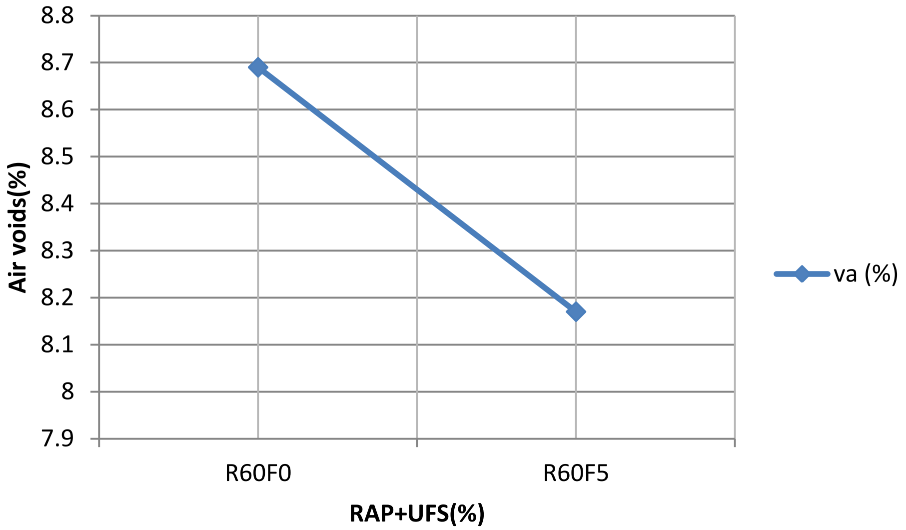


Figure 4.39: **Air voids (%) versus RAP (60%) and used foundry sand (0% & 5%).**

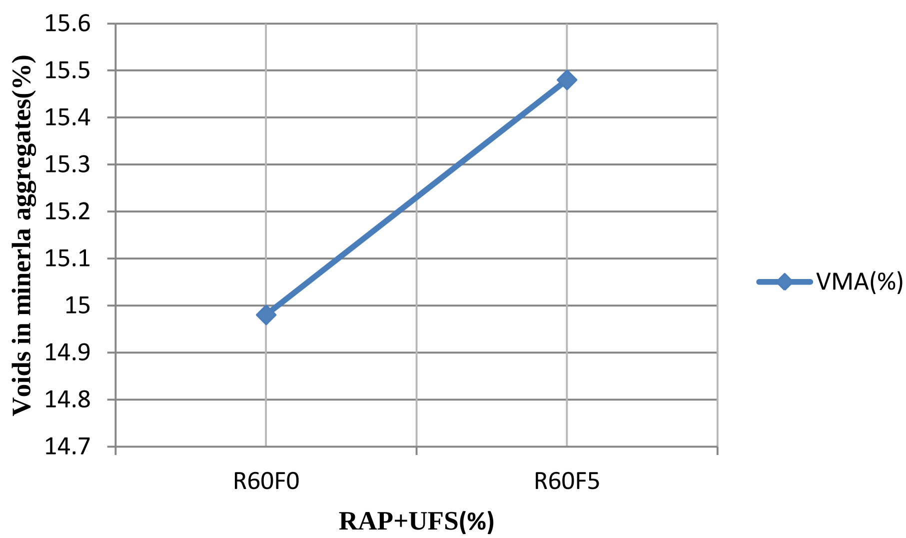


Figure 4.40: **VMA (%) versus RAP (60%) and used foundry sand (0% & 5%).**

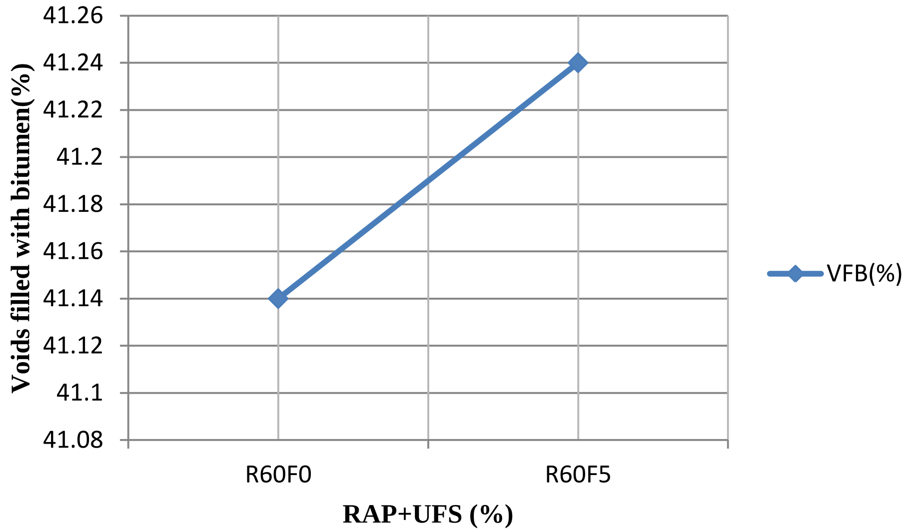


Figure 4.41: **VFB (%) versus RAP (60%) and used foundry sand (0% & 5%).**

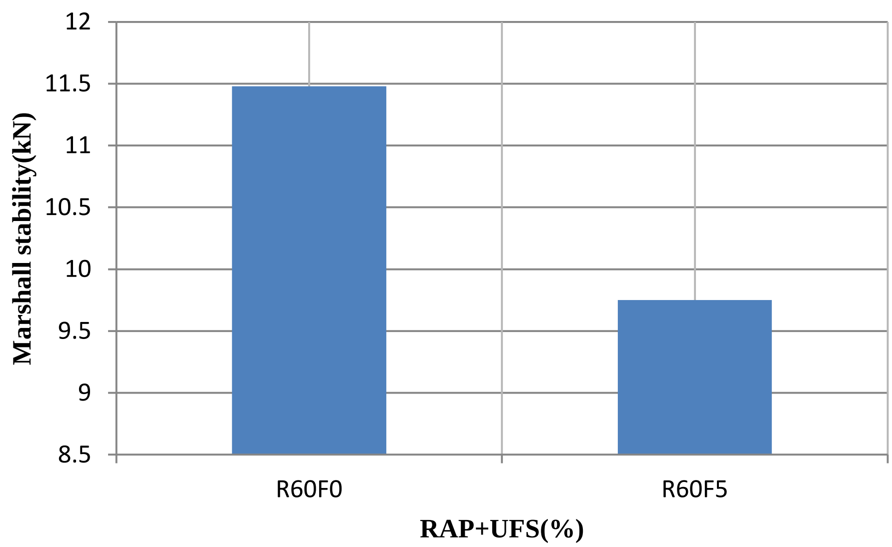


Figure 4.41: **Marshall Stability (kN) versus RAP (60%) and used foundry sand (0%& 5%).**

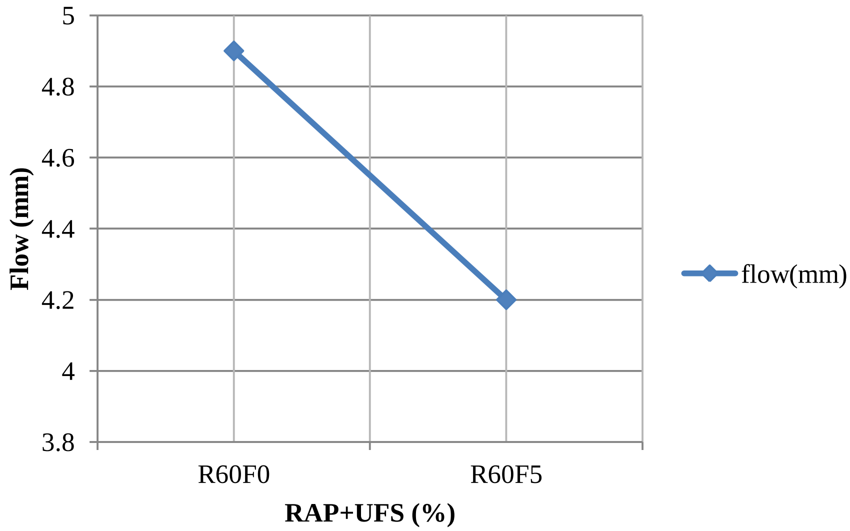


Figure 4.42: **Flow (mm) versus RAP (60%) and used foundry sand (0%& 5%).**

Mix design results for DBM-II with RAP (60%) and used foundry sand (0-5%) as shown in table 4.13 and figures 4.39-4.42 is as follows:

1. Air voids (%), VMA (%), and VFB (%) in the R60F0 and R60F5 were not at all in permissible limits.
2. Marshall stability (%) also decreases and was calculated very less as we increase used foundry sand (%) with RAP (60%) in mix.
3. Flow value also decrease as the content of used foundry (0%) with RAP (60%) in mix.

4.5 Indirect Tensile Strength Test (IDT) Results :

The optimum samples which have high Marshall stability were used in conducting the indirect tensile strength test (IDT). Similar gradations as done in marshall was done with bitumen content of 4.75% in each sample with RAP and used foundry sand in the mix. All the test were done in conditioned (25°c) placing the samples in water bath for 30 minutes but to make sure that time shall not exceeds 120 minutes as per ASTM D6931.Below are the table 4.14and figure 4.43 which shows IDT results:

Table 4.14: **IDT test results for optimum specimens**

Type of Mix	Thickness of specimen(mm)	IDT(MPa) (conditioned)
R0F0	66	0.597
R0F15	65.7	0.603
R10F5	65.3	0.656
R20F5	66.4	0.672
R30F5	65.5	0.686
R4015	64	0.693
R50F5	66.3	0.718
R60F0	68.2	0.498

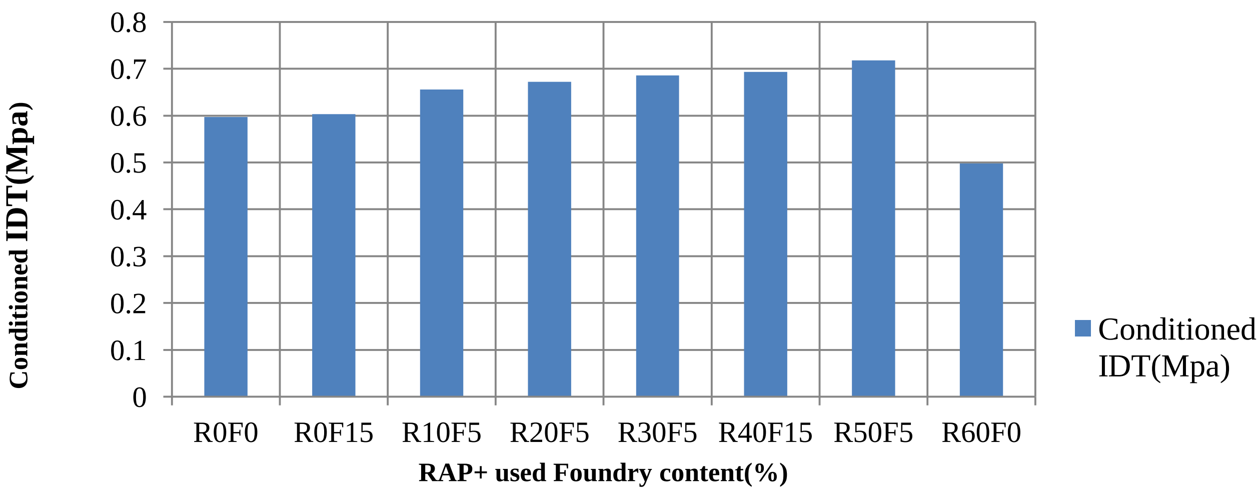


Figure 4.43: **IDT versus RAP (%) and used foundry sand (%)**

The discussion of the IDT results from the graph is mentioned below:

1. From above graph it was clear that as the content of RAP (%) was increasing up to 50%, the value of IDT was increasing but when 60% RAP is added without foundry sand IDT value decreases up to 0.5 MPa which is very less.
2. So it was concluded from here that only up to RAP (50%) with used foundry sand (5%) was maximum percentage up to which mix was within limits.
3. As the percentage of RAP was increasing in the mix shows higher stiffness due to asphalt present in the RAP with the new asphalt binder added to mix as compared to conventional mix without RAP and used foundry sand.

4.6 Resilient Modulus, (M_R) of Bituminous Mix :

Resilient modulus (M_R) was calculated using equation from the following equation:

$$M_R = 11.088 \times IDT - 3015.80$$ …………………………………….. [IRC: 37-2018]

Where M_R= resilient modulus at 35°c in MPa

IDT= indirect tensile strength in kPa

***Table 4.15*: Resilient Modulus for different types of RAP (%) and used foundry sand (%)**

Type of Mix	Resilient Modulus, M_R(MPa)
R0F0	3603.736
R0F15	3670.264
R10F5	4257.928
R20F5	4435.336
R30F5	4590.568
R40F15	4668.184
R50F5	4945.384
R60F0	2506.024

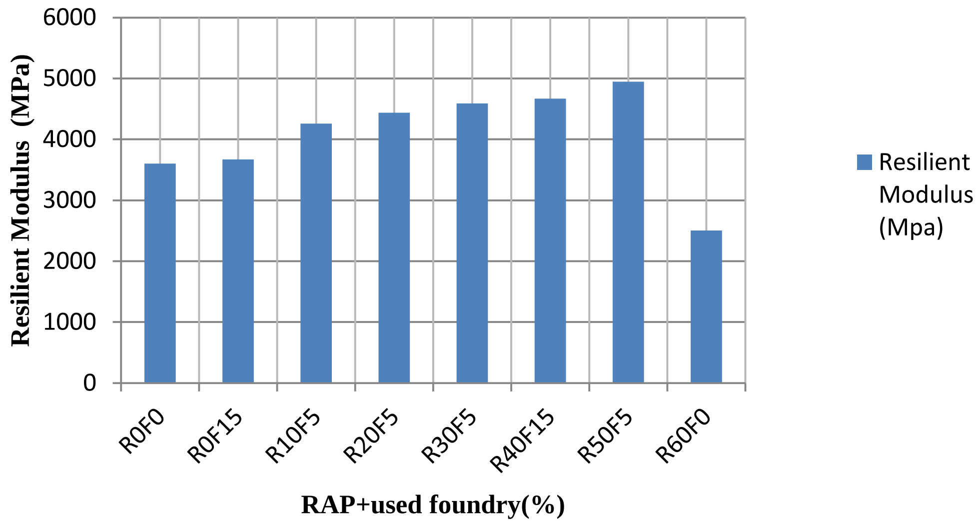


Figure 4.44: Resilient Modulus (M_R) versus RAP (%) and used foundry sand (%).

1. From figure 4.4 and table 4.14 it was concluded that Resilient Modulus was also increasing with increase in percentage of RAP with used foundry sand but only up to R50F5.
2. All the values of resilient modulus were within limits and can be used to design for flexible pavement using IITPAVE as per IRC: 37-2018.

CHAPTER- 05

ANALYSIS AND DESIGN OF PAVEMENT SECTION

5.1 PRINCIPLES OF PAVEMENT DESIGN:-

The pavement structure is a linear elastic multilayered system and in pavement analysis, when the wheel loads is applied on the top surface of the pavement structure it can produced two types of strains:

1. Tensile strain, ε_t, at the bottom of the bituminous layer
2. Vertical strain, ε_V, on the top of the sub grade layer.

These are the two parameters for the pavement design which limit cracking and rutting in the bituminous layer. When critical horizontal tensile strain (ε_t,) value is more than the allowable strain value, cracking will occur on the top surface of the bituminous layer and distresses in the pavement due to fatigue and w

hen vertical compressive strain (ε_V) is exceeds than the allowable strain value, permanent deformation (rutting) will occur on the surface in the pavement structure, due to the overloading of sub grade and the pavement may distresses due to rutting. A three layered pavement structure and their critical strain as shown in figure 5.1

5.2 Fatigue Model Criteria:-

According to the IRC: 37-2018, the equation for the fatigue model at 90% reliability is given below:

$N_f = 0.5161 * C * 10^{-04} * [1/\varepsilon_t]^{3.89} * [1/M_R]^{0.854}$ (90 percent reliability)………. (5.1)

Where N_f = fatigue life,

ε_t = Maximum Tensile strain at the bottom of the bituminous layer

M_R = resilient modulus of the bituminous layer

$C=10^M$, and $M=4.48(Vbe/Va+Vbe-0.69)$

Va= percentage of Air voids in the mix used in bottom bituminous layer.

Vbe= percentage volume of effective bitumen in the mix used in the bottom bituminous layer.

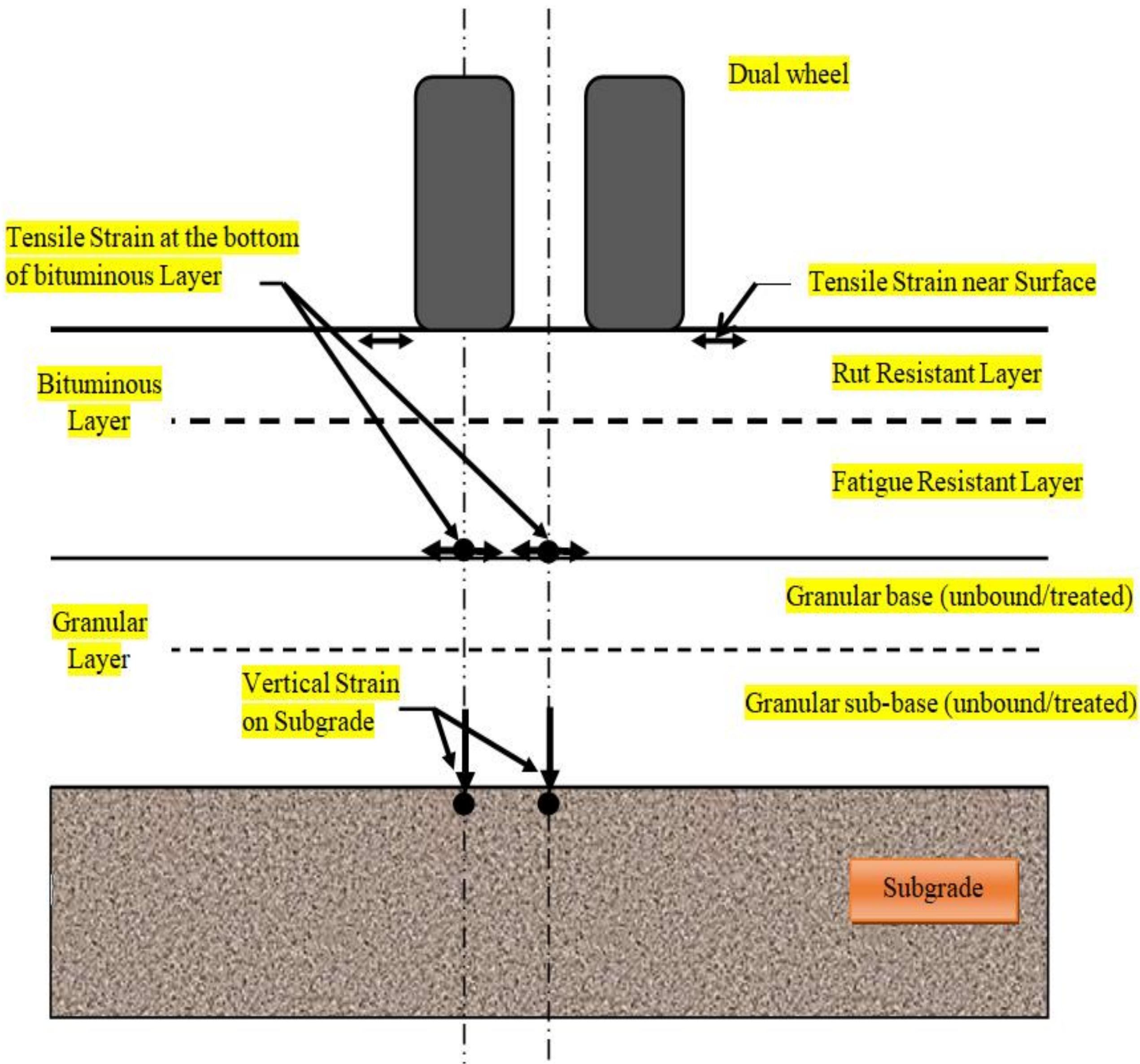


***Figure 5.1*: A pavement section with bituminous layer, granular base and GSB showing the locations of critical strains.**

To avoid frequent maintenance, a reliability level of 90 percent is recommended for highways having a design traffic exceeding 30 msa.

5.3 Rutting Model Criteria:-

The equation for rutting model at 90% reliability is given below:-

N_R= 1.41x 10^{-8}x $[1/\varepsilon_V]^{4.5337}$ (90 percent reliability)….………. (5.2)

Where, N_R = Number of cumulative standard axles

ε_V = Vertical strain in the sub grade.

Various parameters to be taken while using IITPAVE is mentioned below in table 5.1 from IRC: 37(2018).

Table 5.1: **Standard conditions for pavement analysis using IITPAVE**

Analysis Condition	
Material response model	Linear elastic model
Layer interface condition	Fully bonded (all layer)
No. of wheels	Dual wheel
Wheel loads	20 kN on each single wheel
Contact stress for critical parameter analysis	0.56 MPa for tensile strain and vertical compressive strain on sub grade
Critical mechanistic parameters	
Bituminous layer	Tensile strain at the bottom
Sub grade	Compressive strain at the top

5.4 Design of Pavement Thickness and analysis of design:

A problem is taken to design a conventional pavement with VG-30 bitumen at 35° C

Mr of bituminous layer =2000 Mpa ……………………………….. (IRC: 37-2018, Table 9.2)

CVPD=50 msa

CBR=10%

Allowable Vertical Strain=372.6 microns

Allowable Horizontal Strain=198.26 microns

Pavement Structural Design Catalogue (IRC: 37-2018, Figure 12.6)

Bituminous Course = 40 mm

Dense Bituminous Macadam = 105 mm

Granular Base = 250 mm

Granular Sub Base = 200mm

5.4.1 IITPAVE Analysis – Conventional

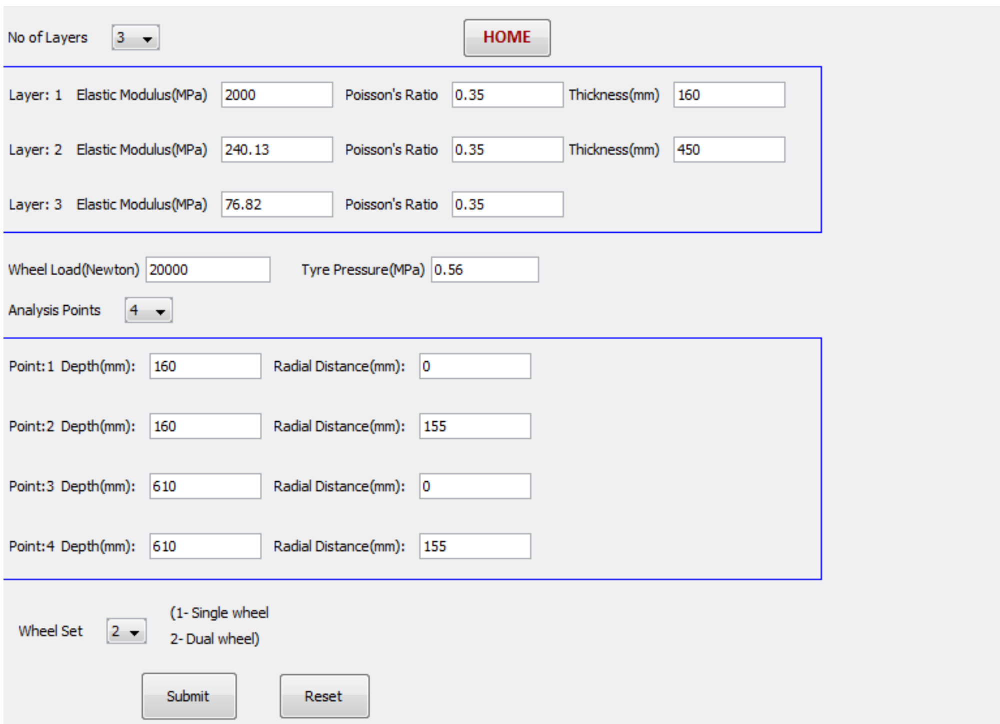
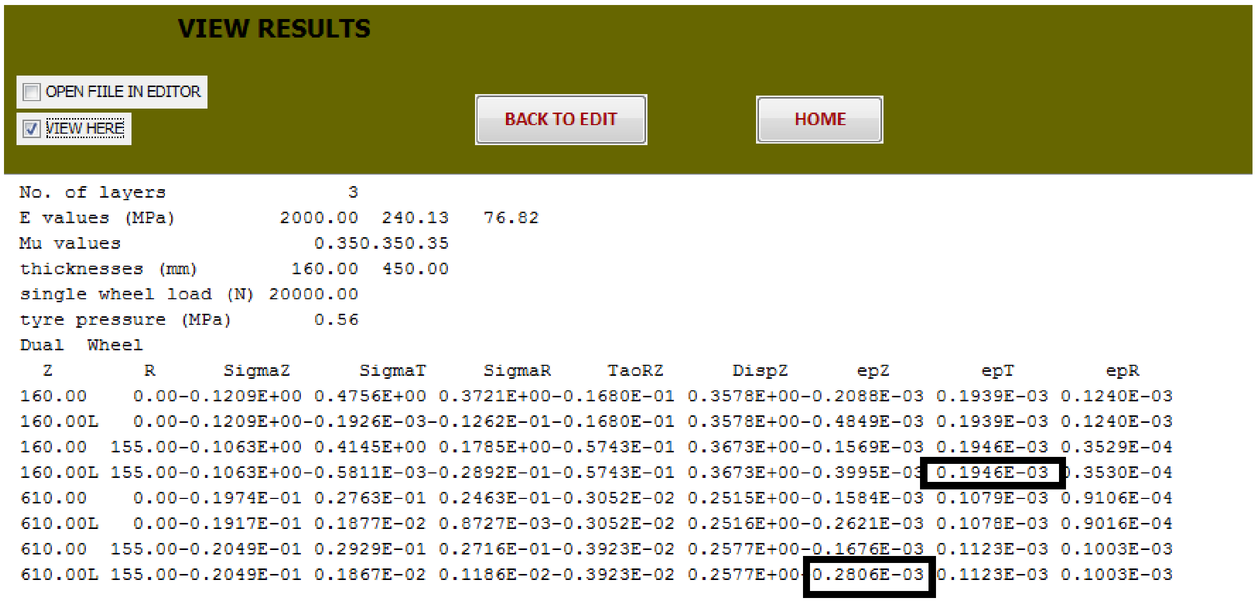


***Figure 5.2*: Input parameters for conventional pavement.**




```
No. of layers              3
E values (MPa)        2000.00  240.13   76.82
Mu values                0.350.350.35
thicknesses (mm)       160.00  450.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ        epT        epR
160.00     0.00-0.1209E+00 0.4756E+00 0.3721E+00-0.1680E-01 0.3578E+00-0.2088E-03 0.1939E-03 0.1240E-03
160.00L    0.00-0.1209E+00-0.1926E-03-0.1262E-01-0.1680E-01 0.3578E+00-0.4849E-03 0.1939E-03 0.1240E-03
160.00   155.00-0.1063E+00 0.4145E+00 0.1785E+00-0.5743E-01 0.3673E+00-0.1569E-03 0.1946E-03 0.3529E-04
160.00L  155.00-0.1063E+00-0.5811E-03-0.2892E-01-0.5743E-01 0.3673E+00-0.3995E-03 0.1946E-03 0.3530E-04
610.00     0.00-0.1974E-01 0.2763E-01 0.2463E-01-0.3052E-02 0.2515E+00-0.1584E-03 0.1079E-03 0.9106E-04
610.00L    0.00-0.1917E-01 0.1877E-02 0.8727E-03-0.3052E-02 0.2516E+00-0.2621E-03 0.1078E-03 0.9016E-04
610.00   155.00-0.2049E-01 0.2929E-01 0.2716E-01-0.3923E-02 0.2577E+00-0.1676E-03 0.1123E-03 0.1003E-03
610.00L  155.00-0.2049E-01 0.1867E-02 0.1186E-02-0.3923E-02 0.2577E+00-0.2806E-03 0.1123E-03 0.1003E-03
```

***Figure 5.3*: Calculated Vertical Strain (epZ) & Calculated Horizontal Strain (epT).**

Now design the same pavement with RAP and used foundry sand of R50F5 whose resilient modulus is known for same thickness and hit and trial method is used to optimize the thickness.

Mr=4945.384 Mpa

CVPD=50 msa

CBR=10%

Pavement Structural Design Catalogue (IRC: 37-2018, Figure 12.6)

Bituminous Course = 40 mm

Dense Bituminous Macadam = 105 mm

Granular Base = 250 mm

Granular Sub Base = 200mm

Allowable Vertical Strain=372.6 microns

Allowable Horizontal Strain=148.971 microns

5.4.2 IITPAVE Analysis –R50F5 [RAP (%) and used foundry sand (%)]

By hit and trial method for reducing the minimum thickness of bituminous layer is adopted.

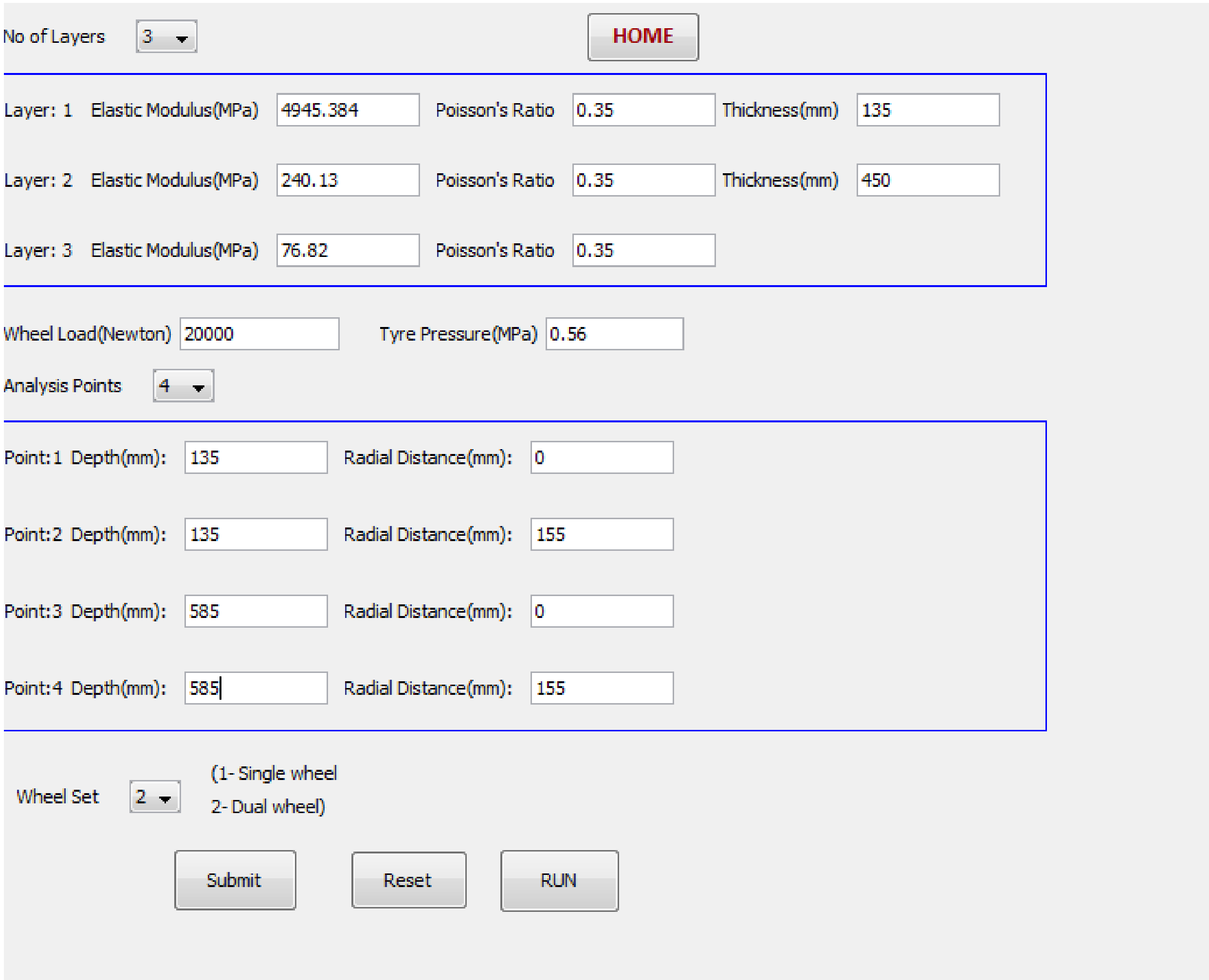
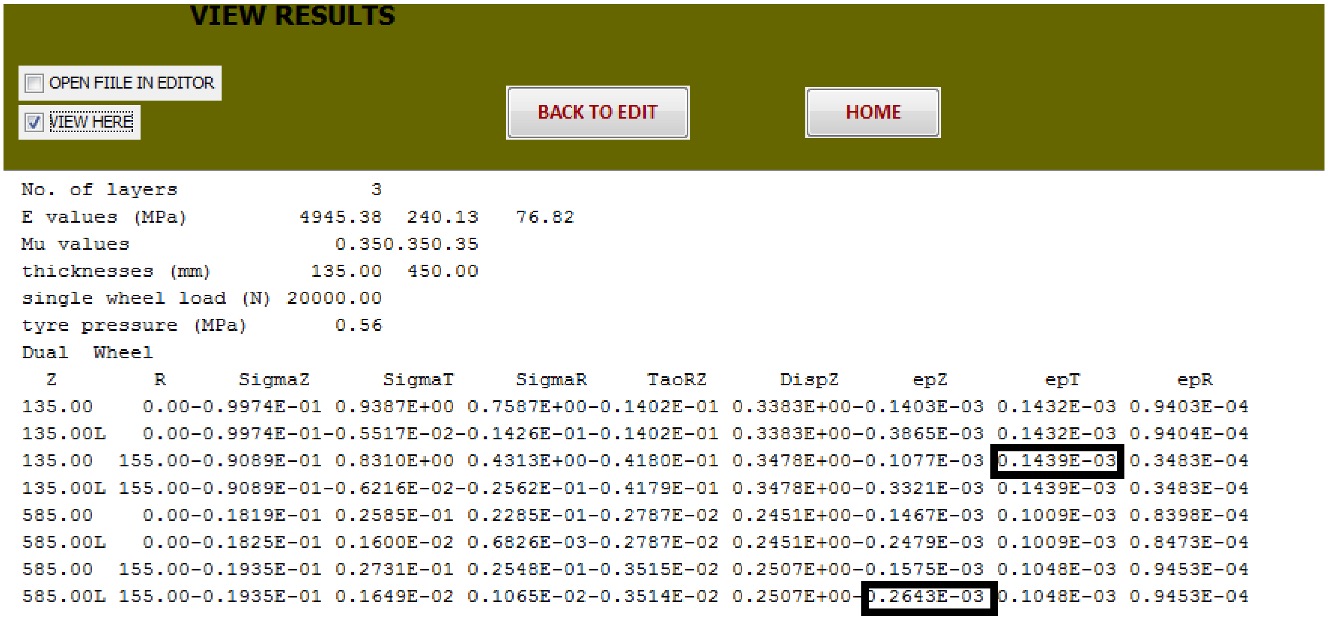


***Figure 5.4*: Input parameters for R50F5 pavement.**




```
No. of layers                3
E values (MPa)         4945.38  240.13   76.82
Mu values                 0.350.350.35
thicknesses (mm)         135.00  450.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ       epZ        epT        epR
135.00     0.00-0.9974E-01 0.9387E+00 0.7587E+00-0.1402E-01 0.3383E+00-0.1403E-03 0.1432E-03 0.9403E-04
135.00L    0.00-0.9974E-01-0.5517E-02-0.1426E-01-0.1402E-01 0.3383E+00-0.3865E-03 0.1432E-03 0.9404E-04
135.00   155.00-0.9089E-01 0.8310E+00 0.4313E+00-0.4180E-01 0.3478E+00-0.1077E-03 0.1439E-03 0.3483E-04
135.00L  155.00-0.9089E-01-0.6216E-02-0.2562E-01-0.4179E-01 0.3478E+00-0.3321E-03 0.1439E-03 0.3483E-04
585.00     0.00-0.1819E-01 0.2585E-01 0.2285E-01-0.2787E-02 0.2451E+00-0.1467E-03 0.1009E-03 0.8398E-04
585.00L    0.00-0.1825E-01 0.1600E-02 0.6826E-03-0.2787E-02 0.2451E+00-0.2479E-03 0.1009E-03 0.8473E-04
585.00   155.00-0.1935E-01 0.2731E-01 0.2548E-01-0.3515E-02 0.2507E+00-0.1575E-03 0.1048E-03 0.9453E-04
585.00L  155.00-0.1935E-01 0.1649E-02 0.1065E-02-0.3514E-02 0.2507E+00-0.2643E-03 0.1048E-03 0.9453E-04
```

***Figure 5.5*: Calculated Vertical Strain (epZ) & Calculated Horizontal Strain (epT) of R50F5 pavement.**

From the above output by IITPAVE the Thickness was reduced up to 135 mm of bituminous layer.

Thus it was concluded that to provide following thickness of each layer of pavement:

Bituminous Course = **40 mm**

Dense Bituminous Macadam = **85 mm**

Granular Base = 250 mm

Granular Sub Base = 200mm.

5.5 Comparison of Composition Thickness and Strain Values.

Now the comparison has to be made to find the difference between allowable strain of conventional pavement and actual strain we calculated from the design as shown below in table 5.2 & 5.3.

***Table 5.2*: Strain Values Comparison.**

Vertical Strain-epZ (micron)	**Horizontal Strain-epT (micron)**	**Vertical Strain-epZ (micron)**	**Horizontal Strain-epT (micron)**
Conventional (Allowable Strain)		R50F5 (Calculated Strain)	
372.6	198.26	372.6	148.971

***Table 5.3*: Composition Thickness Comparison.**

Conventional		**R50F5**	
Composition Type	***Thickness (mm)***	***Composition Type***	***Thickness (mm)***
BC	50	BC	40
DBM	110	DBM	85
GB	250	GB	250
GSB	200	GSB	200

1. From the above table 5.2 and 5.3 comparison it was concluded that if RAP (50%) with used Foundry Sand (5%) is used it would be able to reduce the Thickness of Bituminous layer up to 35 mm (reduction of BC=10mm and DBM=25 mm) in the total pavement of top layer.
2. This shows that it was a huge reduction to minimize the cost of top bituminous layer, which help us to minimize the total cost.

5. 6 Cost Analysis:

Cost analysis is done for the cost savings of virgin aggregates compared to RAP (%) mixes. Suppose to design for 1 km stretch of two lane road having width 7.0 m; Cross-sectional area of that 1 km will be 7700 Square meters.

The quantities for DBM-II layer having thickness 85 mm and 40 mm thickness for Bituminous concrete (BC). All the quantities and rates were taken as per schedule rates of J&K schedule of Rates (2012) [revised edition 2017]. Below table 5.4 shows the cost savings in DBM-II.

Table 5.4: **Cost analysis of virgin aggregates in DBM-II (85 mm)**

DBM-II Nominal size 26.5mm	**Quantity of virgin aggregates(Cum)**	**Cost of virgin aggregates (Cum) (Rs)**	**Total Cost of material (Rs)**	**Cost Savings (Rs)**
Virgin DBM-II	655	1100	Rs 720500	-
10% RAP	589.5	1100	Rs 648450	Rs 72050
20% RAP	524	1100	Rs 576400	Rs 144100
30% RAP	458.5	1100	Rs 504350	Rs 216150
40% RAP	393	1100	Rs 432300	Rs 288200
50% RAP	327.5	1100	Rs 360250	Rs 360250

Similarly cost of Bituminous Concrete (BC) for 1km having 40 mm thickness can be calculated by following as shown in table 5.5

Table 5.5**: Cost analysis of virgin aggregates in BC-II (40mm)**

BC-II Nominal Size 13.2 mm	**Quantity of virgin aggregates(Cum)**	**Cost of virgin aggregates (Cum) (Rs)**	**Total Cost of material (Rs)**	**Cost Savings (Rs)**
Virgin BC-II	424.8	1150	Rs 488520	-
10% RAP	382.32	1150	Rs 439668	Rs 48852
20% RAP	339.84	1150	Rs 390816	Rs 97704
30% RAP	297.36	1150	Rs 341964	Rs 146556
40% RAP	254.88	1150	Rs 293112	Rs 195408
50% RAP	212.4	1150	Rs 244260	Rs 244260

CHAPTER- 06
CONCLUSIONS

6.1 Conclusion:

Based on the results of the experiments the following conclusions are drawn:

1. The Reclaimed Asphalt Pavement (RAP) when used with Used Foundry sand in DBM-II of asphalt mix showed better stability and flow values. When the RAP percentage was 0% and as there was increase in the used foundry sand (%) in the asphalt mixes the Marshall Stability showed an increment from 11.44 kN -18.06 kN was observed and similarly there was decrement in the flow up to 2.46 mm.
2. As the content of RAP (%) with respect to Used Foundry Sand (%) was increasing the stability value was also increasing, when RAP was 10% and UFS was 10% it showed Marshall Stability up to 18.36 kN and flow was 2.83 mm. From this mix design we concluded that UFS can only be used up to 10% with 10% RAP.
3. When the quantity of RAP (20%) and UFS (10%) was increased it showed better results of stability and flow then the R20F15 mix. Similarly in all cases like R30F5, R40F15 and R50F5 showed better Marshall Stability results and flow value in permissible limits.
4. When the percentage of used foundry sand was 15% in the mix stability decrease when content of RAP was more, when RAP percentage was less used foundry sand can be used up to 15%,such that better stability and ,flow as well as air voids can be reduced.
5. The maximum stability by R50F5 showed stability of about 23.7 kN and flow of 3.7 mm which was within permissible limits, so up to 50% RAP and 5% used foundry sand can be used to lay the pavement successfully.
6. Indirect tensile strength (IDT) value was also increasing with increase in RAP (%) with Used Foundry Sand (%) only up to R50F5 which was 0.718 MPa.
7. Resilient Modulus was also increasing with the increase in RAP (%) with Used Foundry Sand. R50F5 showed M_R Value of 4945.384 Mpa which was very high as compared to conventional M_R Value.

8. Resilient Modulus helps to know both the fatigue criteria and rutting criteria which could be very useful in pavement evaluation. It also tells about the stiffness of the mix that means smooth stiffness more than conventional mix design.
9. Thickness of the pavement was reduced by 35mm using IITPAVE when RAP (50%) with used foundry sand (5%) was used and compared to conventional pavement.
10. Cost savings was high up to 50% as compared to virgin DBM-II and BC-II.
11. Economic and Sustainable development could be achieved which was the prime objective of our study that was to reduce the amount of virgin aggregates with recycled aggregates.
12. The use of waste or used foundry sand in asphalt mix leads to produce the greener hot mix asphalt which was very environment friendly.

6.2 Future scope and suggestions:

Trial Section with recommended Mix (R50F5) should be laid and the performance Characteristics of the section in terms of Rutting and Fatigue cracking should be analyzed for various standard axle repetitions.

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