Design of Job Mix Formula (JMF) for Recycled Asphalt Pavement (RAP)

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Abstract

In hot climatic regions such as Pakistan, asphalt pavements often experience premature deterioration due to extreme heat, causing issues like cracking and rutting that significantly shorten their functional lifespan. roads don't last long. Therefore, the need for asphalt rehabilitation prior to its use is almost necessary. This research article presents a laboratory study of asphalt Rehabilitation. Rehabilitated asphalt samples have been produced by mixing a 60/70 penetration grade unmodified (base) asphalt with used material content. The results indicated rehabilitation improved conventional. Although, the usage of rehabilitated asphalt road will decrease the cost of the binder use. Therefore, the usage of rehabilitated asphalt road is more economical, because it gives better results of stability and flow values as well. The Optimum Bitumen Content appeared to be 1.35 % whereas Stability values came to be 1441.843, 1480.292 ,1587.95 ,1238.063 ,1134.25 of various Bitumen Contents.

Keywords: JMF (Job Mix Formula), RAP (Recycled Asphalt Pavement), Hot Mix Asphalt, Bitumen, Marshall Stability Test, Bulk Specific Gravity, VMA, Gmb.

1. Introduction

Transportation is the backbone of a country's economics. Throughout the whole year, enormous financial funds are being spent on maintenance and rehabilitation of previously constructed roads and for new roads projects. In Pakistan, every year in yearly budget, billions of rupees are allocated only to serve this purpose [1]. A country's prosperity and progress are significantly impacted by its pavement. And with increase in its importance, its usage is enhancing day by day. As a result, pavements are disintegrating, and their deteriorations process initiate with the passage of time. So, there occurs need for their maintenance and rehabilitation. There are many distresses and factors due to which failure of pavement occurs.

The main factor which is responsible for deterioration of pavement is phenomenon of Fatigue. Cracking due to repeated loading is regarded as major form of pavement distress in flexible roads, along with issues like rutting and cracking under low temperatures [2,3]. The repeated stress from traffic loads is the main contributor to fatigue cracking, often diminishing the service life of flexible roadways. The resistance of flexible pavements to fatigue is closely linked to the cracking tolerance of hot mix asphalt (HMA) mixtures [4]. Fatigue failure under repeated vehicle loads leads to a web of interconnected cracks in the HMA surface or base layer. In thin pavements where tensile stresses are highest, cracking typically initiates at the base of the HMA layer and extends upward to the surface, forming one or more longitudinal fractures [5]. This is called "conventional" or "bottom-

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up" fatigue cracking. Thick sidewalk cracks almost certainly start at the top. With ongoing stress, these longitudinal cracks merge, forming block-like fragments with sharp edges, often resembling a crocodile's skin pattern. Fatigue cracks can cause a variety of problems, including roughness, pitting, and moisture penetration across cracks, and structural failure [6].

Lack of subbase (Often from poor drainage or melting snow, lowers the stiffness of subbase), Wearing of lower HMA layer (the worn section adds little strength to pavement), That is, HMA can be caused by effective reduction in thickness), Excessive traffic loads (like applying greater or heavier loads than originally specified), Inadequate structural design philosophy, and cracking due to fatigue (like inadequate materials compaction) [7,8]. Thousands of kilometers of sidewalks have been degraded by the above stresses, resulting in very poor functional and structural performance, which must be maintained and rehabilitated to restore their structural integrity and functional performance [9]. This causes enormous costs as well as a huge consumption of valuable natural components including mineral aggregates alongside binders, followed by other materials used in road construction [10].

RAP is currently the most widely utilized material in the manufacturing of new asphalt mixtures. Recycling asphalt lowers the cost and need for new asphalt pavement [11]. As RAP technology advances, RAP is becoming more widely used. With respect to rutting, fraying, weathering and fatigue cracking, hot asphalt with support components has been found to be of the same quality as hot asphalt without support [12,13]. Additionally, this recycled pavement has been shown to degrade more slowly and resist water better than traditional hot-mix asphalt [14]. The main theme in context to this article was to investigate the fatigue properties of RAP binders. A sample belonging to asphalt pavement is taken from the vicinity of Khairpur on N-55highway. Binder is recovered with the help of a binder recovery plant.

Recycled asphalt (RAP) can be considered the world leader in recycled materials due to its wide range of applications and economics [15]. This article concentrated the behaviour of recycled asphalt binders under fatigue stress. RAP has been effectively used into pavements for many years and offers significant natural resource savings [16]. About 90 million tonnes of recycled asphalt pavement are utilised each year, surpassing recycled paper output by a factor of two, glass, aluminium, and plastic together [17]. Even when they have come to the end of their practical service life, the elements of hot mix asphalt (HMA) asphalt roads still retain significant worth [18]. Recycled asphalt pavement is a plentiful source of pre-processed building materials for roads. The recovery of the asphalt binder is the main source of cost savings. In addition to saving money, using RAP is an environmentally friendly way to recycle [19].

These factors must be followed while reusing reclaimed asphalt pavement.

- Recycling and reuse can be advantageous for the environment, the economy, and engineering.
- Choosing materials should give priority to recycled materials.
- The engineering and environmental stability should be reviewed before deciding whether to use recycled materials.
- The selection procedure ought to be followed by an evaluation of the financial advantages.
- The use of recycled materials should not be restricted by technical requirements, which should be deleted from specifications [20,21,22].

2. Materials and Methods

Given its frequent usage in the region of Sindh Pakistan, 60/70 penetration-grade bitumen was chosen for this investigation. The tests on both Bitumen & Modified Asphalt were conducted. Bitumen was examined using several procedures, such as penetration, softening point, ductility, flash and fire point, and specific gravity assessments. After modification of asphalt mix tests which were conducted on specimens are Marshall stability & flow test. Extraction test of Bitumen calculated the bitumen content presented in asphalt mix collected from the field. and we came to know that about 3.25 % of bitumen is present in asphalt sample. Furthermore, for optimum bitumen content, samples were made with 0.5, 1, 1.5, 2 and 2.5% bitumen content (each bitumen content contains 3 samples for accurate results). Mix the aggregates with the same proportion as for aggregate gradation and dry at 175-190°C. Keep asphalt temperature b/w 121-125^{0}C. The mixing process for both was carried out at 150–160°C. Fill the sample in the mold (Measuring 63.5 mm high and 101.6 mm across in diameter.) and beat with a compactor (weight 4.50 kg, diameter 100 mm and height 45 cm) 75 strokes on both sides of the form. Leave the sample to dry for 24 hours. Find unit weight, flow and stability.

2.1 **Importance of Asphalt Properties**

The asphalt repairing materials used and their inherent qualities constantly have a beneficial impact on durability and prolonged the excellent appearance of asphalts. An asphalt structure's top layers are crucial in protecting the structure from damage and reducing load and stress. They are created as needed and are regarded as design layers of materials of generally high quality. Stone totals and bituminous folio are the essential fixes in bituminous asphalts and are hence desired to be of high quality, making their determination a considerable task that is frequently attempted to be ignored. Making useful layer blends requires the black-suitability tops and glue qualities as well as right proportioning with stone totals. You can make asphaltic black-top by refining crude oil. The most expensive and necessary component of the bituminous blend. When working to improve the exhibition qualities of bituminous blends, it is very important to consider the properties of bituminous coverings and the black-top component in a mix. For BOT type projects, the development region is interested in involving the correct kind of black-top to obtain strong asphalts with a life duration of 10-15 years.

2.2 **Asphalt binders in road paving**

Asphalt Demand and Its Usage. Black-top interest is typically around 4MMT (million metric tons) every year in India, and it is estimated that black-top activities alone account for about 45% of the total cost of street development. Recently, black-top, a decreasing product formed during the refinement process of gasoline, will typically become scarce as demand rises. This has happened at a time when the gap in the organic sector is rapidly growing. The issue with the black-top stockpiles is not improving because only countable raw petroleum treatment facilities. create black-top and only a small amount (between 1-4%) of unrefined petroleum is used for black-top. Due to the street development industry's expansion, neighborhood demand for black top has outgrown the available supply. As a result, the final points of many street projects are adversely affected, which necessitates lengthy work spreading out or concessions. Over time, the asphalt binder industry has also experienced sharp price increases. According to estimates, demand in black top will increase by 2-3% annually through 2009. Accelerating interest in blacktop, although reflecting improvements in GDP growth, will result in increased foundational consumption in non-industrialized nations. One of the largest and fastest growing black-top business areas is addressed by India. The nation is experiencing the most phenomenal growth in street work of any country, which will increase interest in black-top used in emulsions, and other clearing applications. Additionally, the nation is continuing to experience quick industrialization and solid growth in the building development markets (interface medicines). Black top will continue to be mostly used for clearing materials, which accounted for 85% of interest in 2009. In new clearing grade items, black top will continue to have the strongest development potential.

2.3 Laboratory tests and specifications

Tests Conducted	Standards	Limits
Penetration	(AASHTO T-49, ASTM D-5)	60-70
Ductility	(AASHTO T-51, ASTM D-113)	100 cm (minima)
Softening Point	(AASHTO T-53, ASTM D-36)	49-56°C
Specific Gravity	(AASHTO T-288, ASTM D-70)	1.01-1.06
Flash and Fire Point 1) Flash Point 2) Fire Point	(AASHTO T-48, ASTM D-92)	225°C min.

2.4 **Mix design**

Binder and aggregate are mixed in exactly the right amounts to create asphalt mixture. The relative amounts of these components define the asphalt mixture's physical characteristics and its functional behavior in the constructed pavement over a 28-day period. The mix design approach is used to determine the appropriate ratios of aggregate and binder in the asphalt mixture.

2.5 Mix characteristics and behavior

When an asphalt mixture sample is created in the lab, it is examined to ascertain its likely behavior in a road structure. The analysis is focused on five aspects of the asphalt mixture and how such aspects are expected to impact the behavior of the asphalt mixture. The following are the five traits:

1) Mix Density
2) Voids presented with air
3) VMA
4) VFA
5) Binder Content

2.6 Fuel extraction test

Asphalt content was determined following the procedures outlined in ASTM 2172.

2.7 Specific gravity test

The described procedure is used to calculate the Marshall void properties and compaction density of bituminous test samples. The calculations and test may be used to determine whether different asphalt aggregate blends are appropriate for the Marshall Mix design process. For both laboratory-prepared samples and asphalt concrete cores, the procedure is suitable for quality monitoring, acceptance testing, and research analysis.

2.8 Marshall test

To use the Marshall method to make the asphalt concrete mix.

Requirement of Marshall Test

Compaction, number of strikes from the ends of sample	75
Stability	340(minutes)
Flow, 0.25 mm	8 to 14
% Air voids in mixture	5 – 9
Binder-filled air voids (%)	50 – 70
Percent voids present	12 in

2.9 Stability test

The specimen is immersed in water at 60 °C for 30 minutes prior to conducting the stability test. Loading is applied through the Marshall device at a uniform deformation speed of 5 millimeters per minute until the specimen breaks. Marshall Stability is deemed to exist when the specimen fails at the maximum total KN. The stability value so obtained is volume-corrected. The Flow Value is the entire under greatest load, the amount of deformation, expressed in 0.25 mm units. It shouldn't take longer than 30 seconds to complete the test after removing the sample from the bath.

3. Results

The outcomes of the bitumen aggregates and the asphalt testing are summarized below.

3.1. bitumen testing: the tests on bitumen are performed in order to get acquainted with the properties of the bitumen so that accordingly the OBC can be determined for particular gradation of aggregates.

3.1.2 Aggregate testing: in the pavement designing the testing of aggregates is very important as the gradation of the aggregates crucially play with the OMC optimum bitumen content, thus knowing aggregate properties and its gradation is primary in such kind of researches.

3.2. Tables of various tests results

This is the section where the experimental and analysis work of bitumen, aggregates and the asphalt is concluded in tables and the figures for easy understanding, as given below;

Table bitumen properties

Tests Conducted	Standards	Results
Penetration	(AASHTO T-49, ASTM D-5)	66

Ductility	(AASHTO T-51, ASTM D-113)	140 cm
Softening Point	(AASHTO T-53, ASTM D-36)	53°C
Specific Gravity	(AASHTO T-288, ASTM D-70)	1.03
Flash and Fire Point 1) Flash Point 2) Fire Point	(AASHTO T-48, ASTM D-92)	310°C 368°C

3.2.1. aggregate blending details

The table below presents the aggregate blending details.

Blending of Aggregates									
Material	Hot Bin #1		Hot Bin #2		Hot Bin #3		Total Blend	Target Value	Specification
Use %	32		35		33		100		
Sieve	% Pass	Blend	% Pass	Blend	% Pass	Blend			
1 in	100	32	100	35	100	33	100	100	100
3/4 in	87.09	27.87	100	35	100	33	95.87	95	90-100
3/8 in	58.47	18.71	35.4	12.39	100	33	64.10	82	56-70
#4	24.89	7.96	21.91	7.67	100	33	48.63	63	35-50
#8	22.33	7.15	19.1	6.69	29.261	9.66	23.49	29	23-35
#50	6.36	2.0352	7.24	2.53	6.968	2.30	6.87	8.5	5-12
#200	1.14	0.3648	8.345	2.92075	6.323	2.09	5.37	5	2-8

3.2.2. weights of aggregates used with varying proportions of bitumen

The table below presents the weights of aggregates used with varying proportions of bitumen

Passing	Re-tained	Aggregate Weights Corresponding to Different Bitumen Percentages (grams)											
		Job Mix %	0.50 %	Job Mix %	1.00%	Job Mix %	1.50 %	Job Mix %	2.00%	Job Mix %	2.5%	Job Mix %	3.00%	Total for 18 trials
25mm	19.5mm	4.11	49.33	4.09	49.08	4.07	48.83	4.05	48.58	4.03	48.34	4.01	48.09	887.88
12.5mm	9.5mm	31.61	379.31	31.45	377.41	31.29	375.50	31.13	373.60	30.97	371.69	30.82	369.78	6827.66

9.5mm	4.75mm	15.39	184.68	15.31	183.75	15.24	182.82	15.16	181.89	15.08	180.97	15.00	180.04	3324.19
4.75mm	2.36mm	25.02	300.25	24.90	298.74	24.77	297.23	24.64	295.72	24.52	294.21	24.39	292.71	5404.50
2.36mm	300µm	16.53	198.42	16.45	197.42	16.37	196.43	16.29	195.43	16.20	194.43	16.12	193.43	3571.56
300µm	0.075µm	1.49	17.87	1.48	17.78	1.47	17.69	1.47	17.60	1.46	17.51	1.45	17.42	321.63
0.075µm	Pan	5.35	64.14	5.32	63.82	5.29	63.50	5.26	63.18	5.24	62.85	5.21	62.53	1154.58
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bitumen			6		12		18		24		30		36	108
Total			1200		1200		1200		1200		1200		1200	

3.2.3. Experimental findings

Experimental findings for identifying the ideal bitumen concentration are summarized in the table.

Sample	Height	Wt. in Air	Wt. in Water	SSD Weight	Stability	Flow
0.5% S1 S2	6.3 cm 6.5 cm	1186.2 g 1196.3 g	689.8 g 693.3 g	1189.6 g 1200.8 g	135 120	400 400
1.0% S1 S2	5.1 cm 6.0 cm	1102.1 g	644.8 g	1102.6 g	130	410
1.5% S1 S2	6.3 cm 6.3 cm	1198.9 g 1195.8 g	700.4 g 697.5 g	1200.2 g 1197.1 g	130 145	540 420
2.0% S1	6.5 cm 6.3 cm	1190.3 g 1161.7 g	682.4 g 674.5 g	1193.2 g 1163.0 g	95 105	640 590

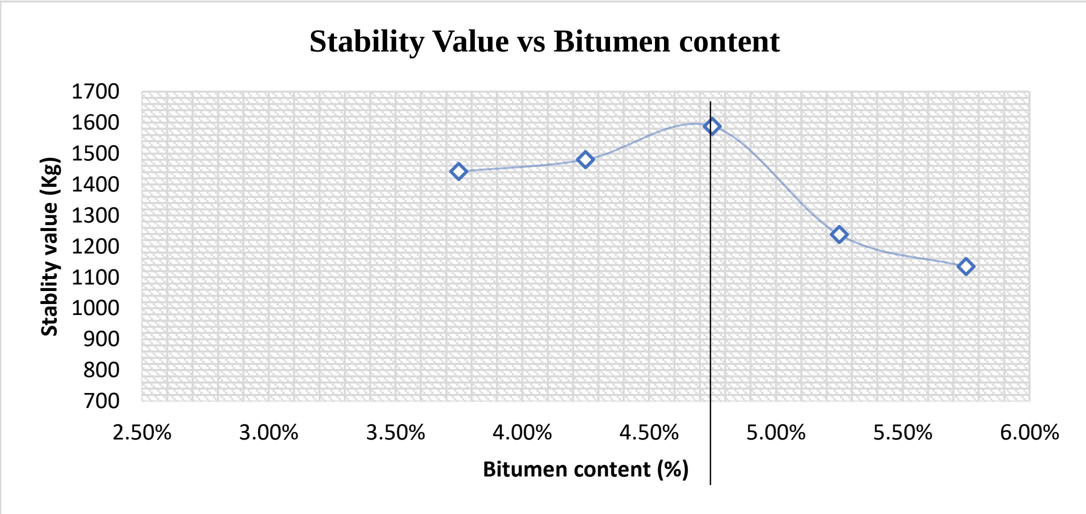
S2						
2.5% S1 S2	6.1 cm 6.3 cm	1173.1 g 1169.6 g	687.3 g 678.3 g	1173.4 g 1170.3 g	140 90	490 450

3.2.4. overall results of marshal data sheets from 0.5%to 2.5% bitumen

The following table shows overall results of marshal data sheets from 0.5%to 2.5% bitumen

S.No.	Stability Value	Flow Value	VMA	Pa (% air voids)	Gmb	VFB	Bitumen Content
1	1441.843	13.867	14.179	6.25	2.37	55.921	3.75%
2	1480.292	13.867	13.256	4.026	2.408	69.629	4.25%
3	1587.95	12.6	14.139	3.736	2.396	73.577	4.75%
4	1238.063	13.6	14.625	3.036	2.395	79.241	5.25%
5	1134.25	18.533	15.076	2.325	2.395	84.578	5.75%

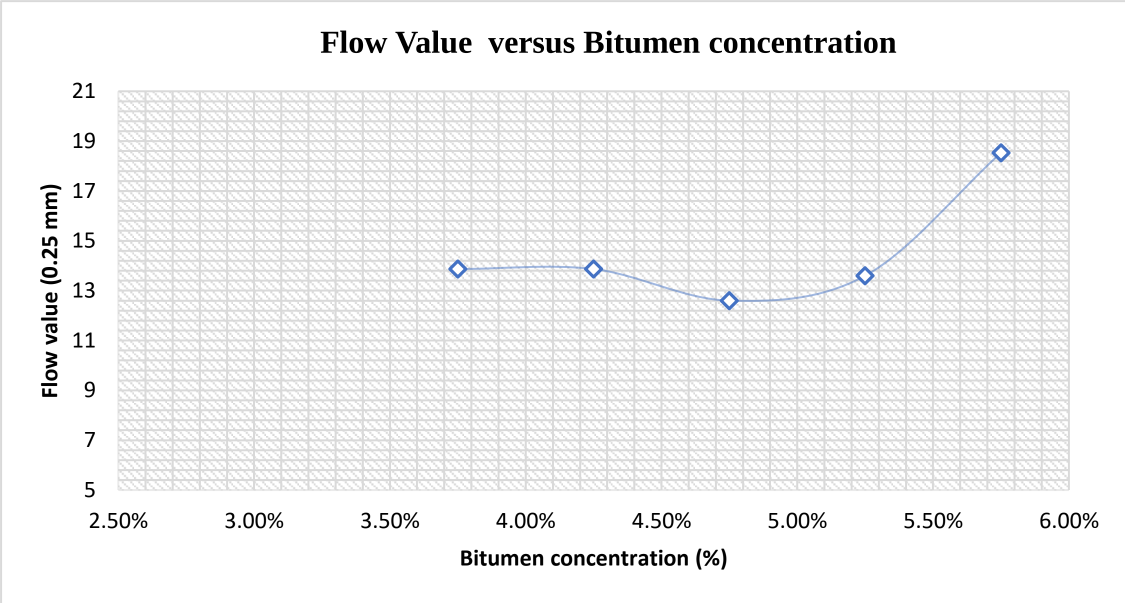
3.2.5. figure 1 Stability value vs Bitumen content



From the above interpreted graph results we can analyze that the bitumen content starting from 3.75 % from 5.75 % shows how the stability value varies. The peak stability value 1587.95 comes under 4.75 % bitumen concentration.

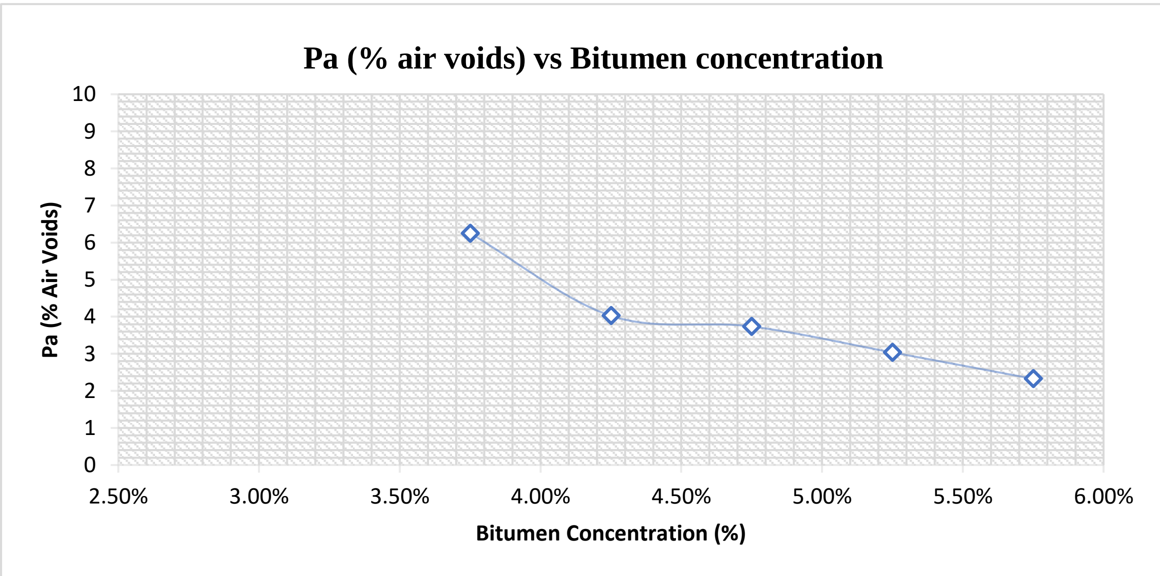
3.2.6. figure 2 Flow value vs. Bitumen concentration

3.2.6. Flow value vs. Bitumen concentration



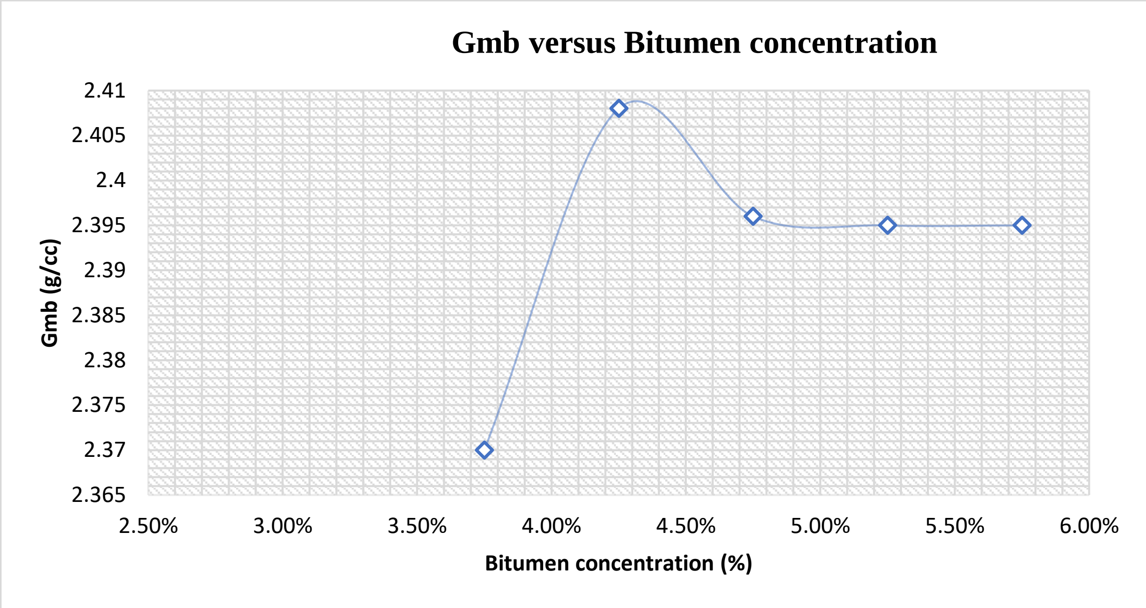
From the above interpreted graph results we can analyze that the bitumen concentration starting from 3.75 % from 5.75 % shows how the flow value varies. The peak flow value 18.533 comes under 5.75 % bitumen concentration.

3.2.7. figure 3 Pa(%) vs. Bitumen concentration



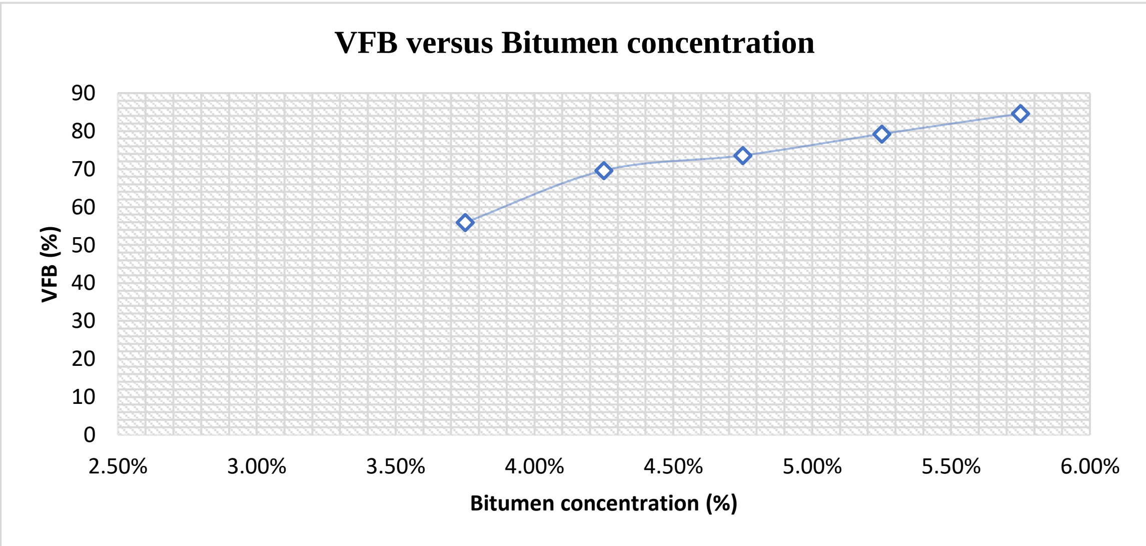
From the above interpreted graph results we can analyze that the bitumen content starting from 3.75 % from 5.75 % shows how the Pa (%) value varies. The peak Pa (%) value 6.25 comes under 3.75 % bitumen concentration.

3.2.8. figure 4 Density (Gmb) vs. Bitumen concentration



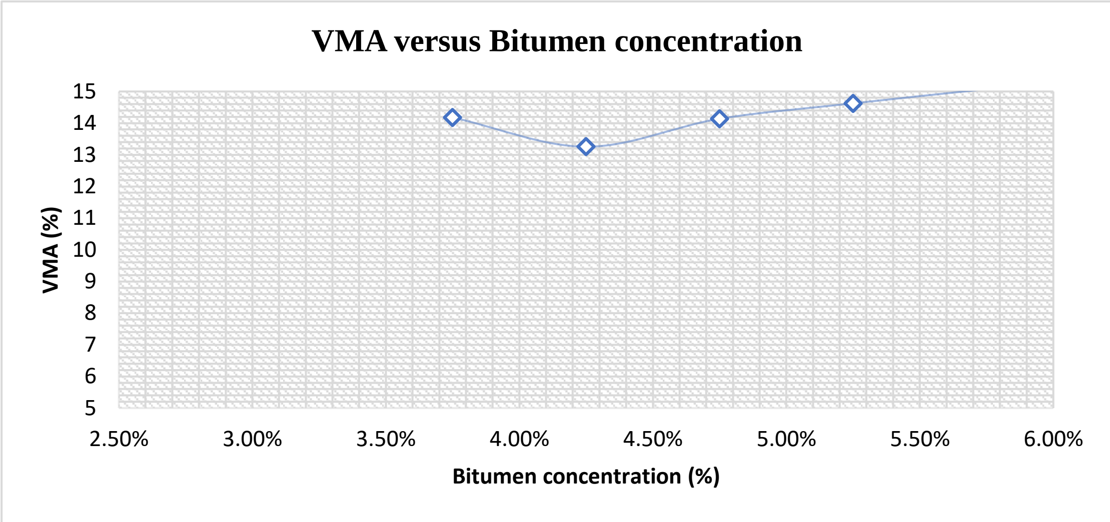
From the above interpreted graph results we can analyze that the bitumen content starting from 3.75 % from 5.75 % shows how the Density (Gmb) value varies. The peak Density (Gmb) value 2.408 comes under 4.25 % bitumen concentration.

3.2.9. figure 5 VFB versus Bitumen concentration



From the above interpreted graph results we can analyze that the bitumen content starting from 3.75 % from 5.75 % shows how the VFB value varies. The peak VFB value 84.57 comes under 5.75 % bitumen concentration.

3.2.10. figure 6 VMA versus Bitumen Concentration



From the above interpreted graph results we can analyze that the bitumen content starting from 3.75 % from 5.75 % shows how the VMA value varies. The peak VMA value 15.076 comes under 5.75 % concentration of bitumen.

4. Discussion

Ideal Concentration of Bitumen

B1 = Bitumen concentration at the highest weight density= 4.75%.

B2 = Bitumen content of no more than 4% voids of air = 4.6%

B3 = Maximum stable bitumen content = 4.5%

OBC = (B1+B2+B3)/3 = (4.75+4.6+4.5)/3

OBC = 4.6%

Actual OBC = 4.6 – 3.25 = 1.35 %

5. Conclusions

We can conclude this research that the concept of 3Rs i.e. Reduce, Reuse and Recycle is emphasized. The sample of asphalt collected from field site can be again used in the construction of roads in such a way that optimum bitumen content 1.35 % obtained from results added to the asphalt waste sample which was collected from field can be beneficial for the road construction thus reducing cost, energy and time. It is possible to do additional study by examining samples' other mechanical qualities. The bitumen grade 60/70, which is more common in hot climates, is used in this investigation. With different grades of bitumen, more research may be done.

Abbreviations

The following abbreviations are used in this manuscript:

OBC	Optimum bitumen content

RAP	Recycled Asphalt Pavement
JMF	Job Mix Formula

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