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## Utilization of Bitumen, Aggregate and Wax with Rubber Tyre in a Flexible Pavement

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# Utilization of Bitumen, Aggregate and Wax with Rubber Tyre in a Flexible Pavement

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**Abstract.** With continuous wear and tear actions of rubber tyre on roads, a pile of waste rubber gets accumulated every year and it is posing severe threats to the environment. Due to high temperature in the summers, the road tends to become brittle, which may cause separation of binder in the bituminous road causing heavy cracks, so usage of wax tends to reduce the formation of cracks and improve the flexibility of road. This study aims to examine the effects on properties of the bitumen-aggregate mixture when the aggregates are partially replaced by similar sizes of waste rubber tyre particles and bitumen in the mix are partially replaced by a crumb waste rubber tyre, with partial addition of wax content in the bituminous samples. For this purpose of testing the suitability of using rubber waste in road pavement, Marshall Stability test is conducted on several bituminous mixtures. Varying percentages of rubber tyre, such as 0%, 5%, 10% and 15%, are used with different percentages of bitumen content (4.0, 4.2, 4.4, and 4.6), and varying percentages of paraffin wax (0-5%) is also added in the specimen with rubber and bitumen. This is utilized in obtaining the optimum content of bitumen required for best suitability of flexible pavement as well as to assess the durability and strength of a pavement. This study is performed on various mixtures, for the values of bulk density, air voids, stability value and flow value. The studies show that bitumen content corresponding to the maximum stability value and maximum bulk specific gravity in bituminous mixture, indicating the optimum bitumen percentage that can be replaced with crumb rubber tyre. This paper discusses the partial replacement of both aggregate and bitumen in the bituminous mixture, containing some percentages of paraffin, which can help in improving the serviceability level and assists in enhancing the flexibility and cohesion of road to resist heavy loadings of vehicle.

## 1. Introduction

India is a fast-growing country, and with development, waste generation also goes hand in hand. The waste under consideration in this study is 'Rubber Tyre Waste'. As per reports, tyre production in the financial year 2019 in India stood around 192 million units. Since vehicles are running on roads as a medium to transportation for humans and goods, the tyres go through wear and tear and after that discarded and dumped into landfills and waste tyre stockpiles [2, 8]. These waste rubber tyres impose a more significant threat to our environment. Wastage of land in storing and disposing of these waste



tyres serves as nests of rodents, and other bacterial forms, and last but not the least: the fire break out in these dump yards [3].

Such fires are very hard to control and releases many pollutants and hazardous gases in the atmosphere, which cause environmental degradation and posing life threats to humans [3, 9]. So, the necessity is to utilize this waste by minimizing or by neutralizing their hazardous impacts.

Highway pavement being a subject of tremendous research attracts researchers to utilize this waste in pavement construction in an economical and an environment-friendly way [1, 8, 9]. Various researchers have conducted studies based on partially replacing the bitumen of asphalt mix with crumbled waste rubber tyre, also known as "Rubber Aggregates" [1, 3, 6, 8, 11]. To efficiently use rubber waste in road construction, crumb rubber is utilized by mixing it with bitumen to form a Crumbed-Rubber Modified Bitumen (CRMB) binder, which can be used as spray seal during pavement construction [1, 11]. Reference [8], conducted laboratory test to examine the performance of bituminous mixture, where crumb rubber of various ratios, 5%, 10% and 15%, have been replaced with aggregates of specific sizes in an asphalt mixture. This gave increased stability of the mix and improved adhesion with the aggregates, which was a similar result to reference [11]. Reference [5], conducted tests with crumb rubber and concluded the improvement in rutting resistance of CRMB according to various recover and stress creep test. In order to identify optimum amount of bitumen percentage for replacement with rubber aggregates, Marshall Stability test, penetration test and ductility test is being performed on the bituminous mixture mould [8, 11]. In reference [8], rubber tyre was being used in various percentages, i.e., 2%-10% by weight, in the powdered form to replace bitumen content in the bituminous mixture [11]. After performing various tests, it was observed that for optimum replacement of crumb tyre with bitumen, crumb rubber tyre percentage came out to be 6%, which helps in increasing the durability and serviceability of road pavement [1, 8, 11]. In reference [19], an experimental test is performed to obtain the wax content required in a bituminous mixture, so as to improve the strength and flexibility of bituminous road, where 25 gm of bitumen is being used and distillation process has occurred on the sample for obtaining wax content. Reference [20], performed various analysis on bitumen samples containing wax content, where the author various types of analysis such as separation of wax, performed crystallography and did chemical characterization on the sample, so as to obtain the content of wax and analyse its properties, and found that wax can act negatively when mixed with bitumen causing brittleness, hardness and poor ductility. Reference [21], inspect total of 18 bituminous samples, of varying grade i.e., 50/70, 160/220, with the usage of wax in the mixture, and performed differential scanning calorimetry, representing that bitumen containing lower amount of wax have better resistance to cracking, as compared to bituminous mixture with higher wax content. Reference [18], asserted that the previous literature on "Partial replacement of waste materials in bitumen pavement: Dense bituminous macadam" represents determination of optimum bitumen content with addition of waste plastic and tyre rubber, while this paper depicts the bitumen required for construction of flexible pavement, with the help of waste rubber and wax. Some data has been carried forward from the previous work, while new results were obtained in this paper [18].

## 2. Materials and Methodology

### 2.1. Preparation of Mixture

The study is conducted using conventional bitumen of 80/100 grade; fine and coarse aggregates such as gravels and crushed stones are being sieved and used in the experiment according to their respective sizes, and waste rubber tyres accumulated from dump sites are being cut into smaller pieces as per the experiment requirement. Weighted amount of Rubber aggregates (5%, 10%, 15%) are sieved as per IS 383-1970 sieve analysis method [12], where particles of sizes between 2.36mm and 75 $\mu$ m are being utilized in replacing aggregates and bitumen binder respectively. For the preparation of CRMB, bitumen is heated at 165-175°C and the aggregates are heated up to a temperature of 145-155°C

separately. After mixing bitumen and aggregate uniformly, the mixture is required to be heated at 165°C, so as to keep the viscosity of bitumen lower for proper coating of aggregates and binding both bitumen and aggregates efficiently. Blending of rubber aggregates in bitumen binder took 45 to 60 minutes at a uniform temperature of 165°C. Various laboratory tests have been performed on various samples of bitumen, aggregates and bituminous mixtures, such as Los Angeles test and Aggregate Impact Value test (IS Code was performed for determining the abrasion value and impact value of aggregates respectively as per IS 2386 (Part-IV)-1963 [13], Ductility and Penetration tests were performed on bitumen samples as per accordance with IS 1208-1978 [14] and IS 1203-1978 [15] respectively, and the Marshall stability test was performed to evaluate mix design parameters of bituminous mixture samples. To perform the performance test of bituminous samples with the usage of candle wax, a bituminous modifier, is being used in the samples. It is used to enhance the physical properties of bitumen, which improves the performance of bitumen road, by increasing the cohesion bond between aggregates and bitumen. Wax of varying percentages, i.e., 0-5% by weight of bitumen, is added to the specimens of bitumen and aggregates, in order to obtain the wax modified bitumen sample. Various kinds of commercial wax are available, such as montan wax, petroleum wax and paraffin wax, which are being added in bituminous mixtures to improve performance of pavement. The observed value from laboratory and standard values of materials are compared in the Table 1 given below.

**Table 1.** Observed values of Laboratory Tests on Bitumen and Aggregates

Tests Performed		Observed Values	General Values
Bitumen (VG-10)	Softening Point (°C)	45	40(min)
	Specific Gravity (kg/m <sup>3</sup> )	1.02	0.97-1.02
	Flashing Point (°C)	248	220-270
	Ductility Value (cm)	102	75 (min)
	Penetration Value (0.1 mm)	99	80-100
Aggregate	Abrasion Value (%)	29.84	Less than 40
	Impact Value (%)	26.31	Less than 30

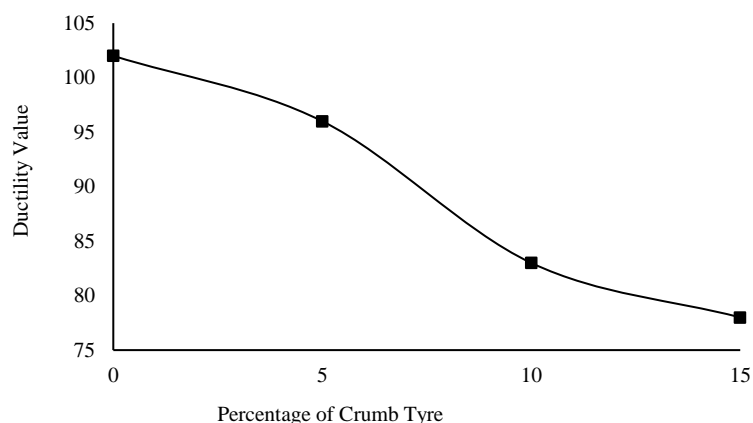
## 2.2. Marshall Stability Test

CRMB mixtures have been prepared to determine rheological and physical properties of bitumen binder with addition of rubber aggregates, by performing Marshall Stability Test [17]. For preparation of samples, a specimen of 10.1 cm diameter and 7.5 cm height is used, which is in the form of cylindrical mould. The percentage replacement of bitumen with crumb tyre and aggregate with tyre particles of same size were kept same in terms of percent replacement by weight, thereby maintaining the overall replacement in the mixture in similar context. Example, if replacement of 5% is mentioned, then 5% bitumen is replaced by crumb rubber and 5% aggregates are replaced by rubber. Marshall Specimen samples were prepared by addition of rubber aggregates and crumb rubber in varying percentages, such as 5%, 10%, 15%, with respect to weight of bitumen and aggregates, at a higher temperature of about 165°C so as to get a homogenous mixture. After applying 75 blows on samples, CRMB samples are placed into water bath apparatus for cooling purpose for about 30 minutes. Marshall Stability and Flow values are being determined using the dial gauge on the Marshall apparatus. Mix design consists of various parameters such as stability value, flow value, air void, bulk specific gravity, voids in mineral aggregates percentage and voids filled with bitumen.

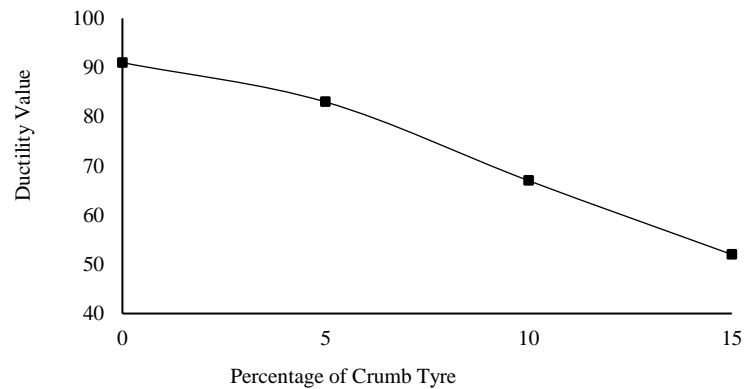
## 3. Results and Discussions

### 3.1. Ductility Test

The ductility test has been performed in accordance with IS 1208-1978 [14], the cooled down briquette specimens are stretched after keeping them in water bath of ductility machine for 90mins. Minimum suggested value for flexible pavement should be 75cm [14]. The graph in Fig. 1a shows ductility value of specimens decreases with an increase in the crumb tyre content, which corresponds to less flexibility in pavement, when no wax is added to the sample. With 15% replacement of bitumen with crumb tyre, the ductility value decreased by almost 23.53%, although it was still more than the minimum value, so it can be accepted. In fig 1b., ductility value has been noted down for bituminous mixture containing 5% wax and varying percentages of rubber aggregates. It can be seen from both the graphs fig. 1a and 1b, ductility value is less for sample containing 5% wax, i.e., 78 m, while ductility value is more for sample with 0% wax, i.e., 102 mm, which depicts that the sample containing 5% wax is more resistant to temperature changes as compared to sample with no wax. If the sample has ductility more than 100mm approximately, it is highly susceptible to temperature changes, which can lead to heavy damage of road such as flushing, cracking and bleeding of bituminous road. While, addition of wax would improve the bond between the bituminous aggregate samples and make the bituminous road more resilient towards drastic temperature changes.



**Fig. 1a.** Graph of bitumen test for Ductility Value (0% Wax)

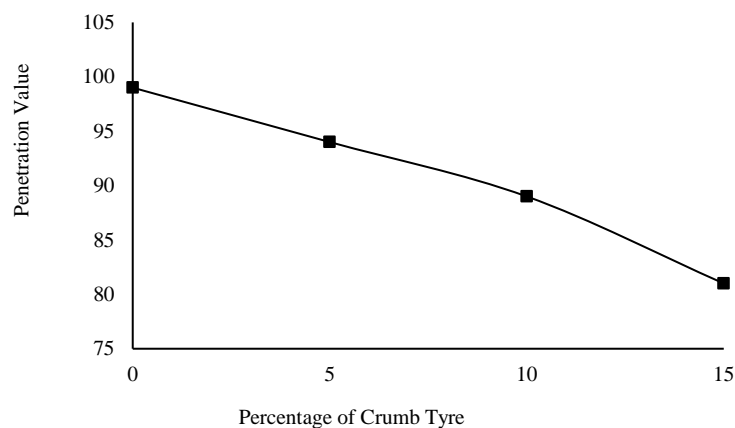


**Fig. 1b.** Graph of bitumen test for Ductility Value (5% Wax)

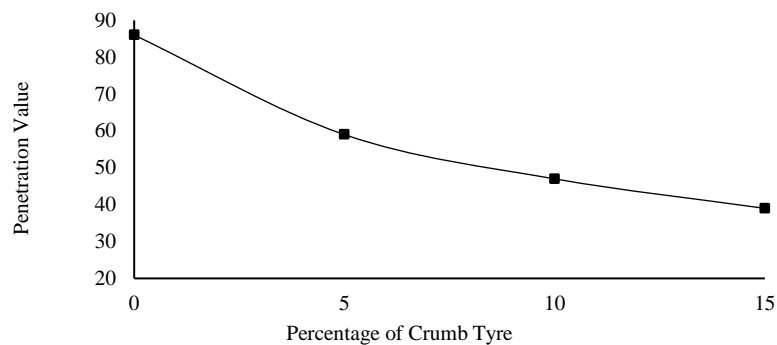
### 3.2 Penetration Test

The Penetration test is used to examine the consistency of the bituminous sample, through measurement of depth of standard needle penetrating inside the sample. This test is performed in compliance with IS Code 1203-1978 [15]. The penetration result illustrated in Fig 1c depicts the penetration value decreases with the increase in rubber content, when 0% wax is present in the sample. As the rubber aggregates increases in CRMB sample, the penetration value reduces by 18.2%, indicating that the stiffness of the sample increases. This change of behaviour of bituminous sample helps in making the binder resistant to high temperature change and makes it less vulnerable to cracking and rutting.

In fig. 1d, penetration value has been noted, where 5% wax has been added to the sample containing mixture of bitumen and rubber aggregates. We can observe that when we have added 5% of wax in bituminous sample, the penetration value has decreased from 98 mm to 86 mm for 0% addition of rubber aggregates in both the figures 1c and 1d, indicating that binding property of bitumen with aggregates has improved and resistance to heavy cracking of road has enhanced. Also, with an increase in rubber content and addition of 5% wax in fig. 1d, penetration value has been constantly decreased, showing that stability and durability of road has improved.



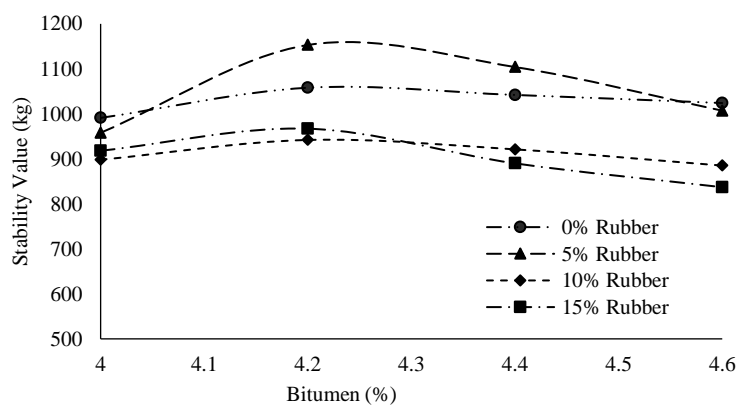
**Fig. 1c.** Graphs of bitumen test for Penetration Value (0% Wax)



**Fig. 1d.** Graphs of bitumen test for Penetration Value (5% Wax)

### 3.3 Stability Value

Stability value is an indicator of strength and toughness of the material, where stability provides resistance to deformation under repeated loading of vehicles. When a deformation load at the rate of 50.8 mm/min is applied on a specimen at a temperature of 60°C, the stability provides resistance to heavy loads and the material is less susceptible to rutting. As per data shown in Fig 2a, the stability value initially increases with an increase in Bitumen content, but then the stability value decreases sharply. When there is an addition of rubber aggregates in CRMB mixture, the interlocking bond between aggregates and bitumen binder improves, which causes an increase in stability values. Also, addition of wax content in CRMB mix can enhance the resistance against high temperature variation and prevent rutting and cracks. However, due to non-uniform behaviour of bitumen, the rubber particles get distorted and dispersed inside the mixture, causing poor bonds of rubber aggregates with bitumen binder and reduces the stability value of bituminous mixture. As per the graph illustrated, the maximum stability value occurs at 4.23% of bitumen content, when 5% rubber tyre is added into CRMB mixture, where 5% wax is also present in all samples.

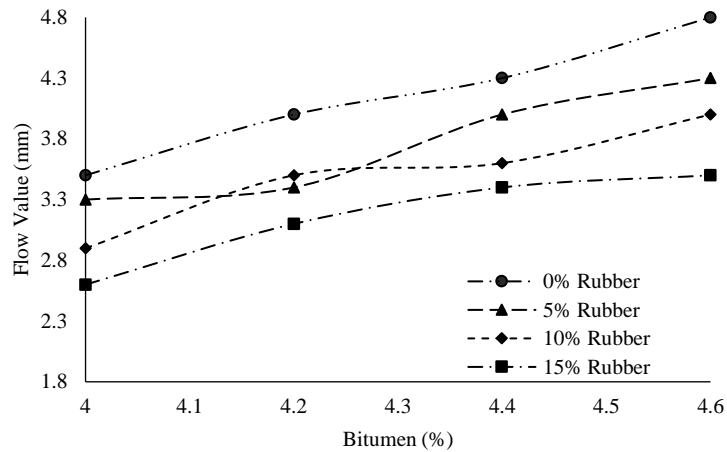


**Fig. 2a.** Behaviour of the bitumen mix in terms of Stability Value

### 3.4 Flow Value

Flow value is an indicator of plasticity indicator of a material, which is measured by variation in dimension of specimen when a uniform loading is applied on it. As per fig. 2b, it is observed that the flow value constantly increases with an increase in bitumen content because addition of bitumen content and wax content (5% wax) enhances flexibility of the material. Thus, the material has less resistance to deformation caused by heavy loading and more susceptible to rutting. Also, it is observed that flow value decreases when rubber aggregates are increased, as rubber aggregates fills up the voids

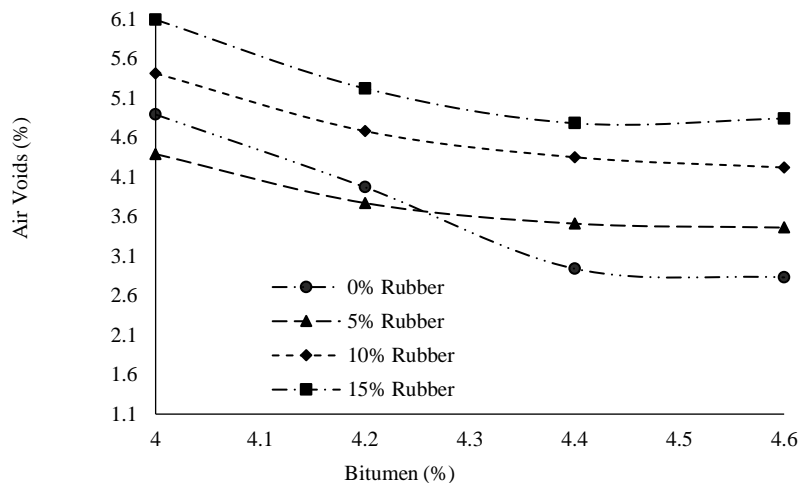
in bitumen mixture, which reduces flexibility of material and improves resistance of material towards deformation.



**Fig. 2b.** Behaviour of the bitumen mix in terms of Flow Value

### 3.5 Air Voids Percent, $V_A$

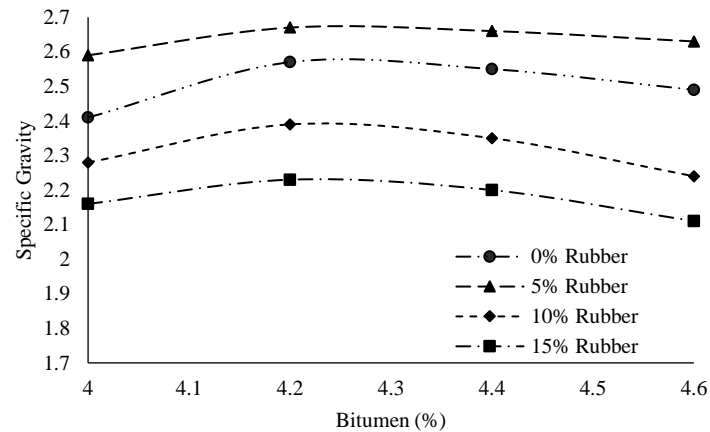
The minute air spaces occurring between the coated aggregate particles in the compacted bituminous mixtures are known as air voids. This can be decreased by increasing the binder content, increasing the compacting effort, adding fines which return to asphalt mixture and well as varying the aggregate gradation. The air void in the tested specimen can be observed in the graph represented in fig 3a. At same rubber replacement content, the air voids can be seen to decrease with the increase in the bitumen content, and due to presence of 5% wax content. According to reference [16], if the voids are less than 3% in the mixture, it can lead to rutting due to plastic flow and if it is more than 8%, then it may result in premature cracking or ravelling due to moisture and oxidation.



**Fig. 3a.** Behaviour of specimens with respect to Air Voids

### 3.6 Bulk Specific Gravity

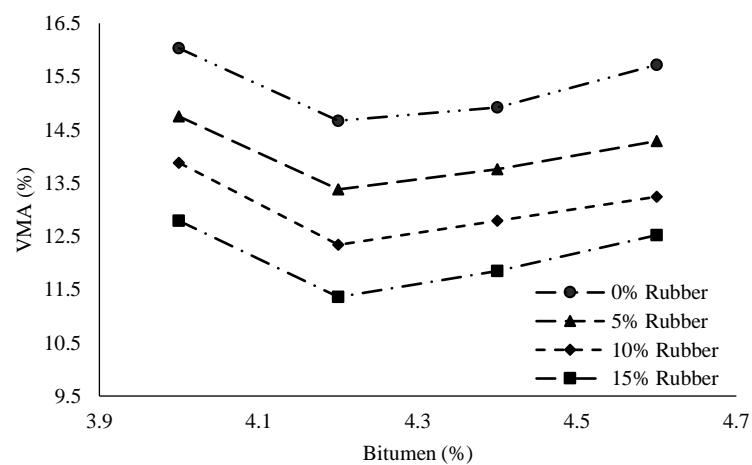
The bulk specific gravity helps in the calculations of the voids in mineral aggregate (VMA) and voids filled by bitumen (VFB). The usual range of bulk specific gravity varies from 2.2 to 2.5. This is calculated covering the specimen with wax and using the water displacement technique. The values obtained from the test are represented in the Fig. 3b. When the percentage replacement of bitumen with tyre was kept constant the bulk specific gravity of the specimens increases when the bitumen content increases from 4% to 4.2%, and tends to decrease after 4.2%.



**Fig. 3b.** Behaviour of specimens with respect to Bulk Specific Gravity

### 3.7 Voids in Mineral Aggregates (VMA)

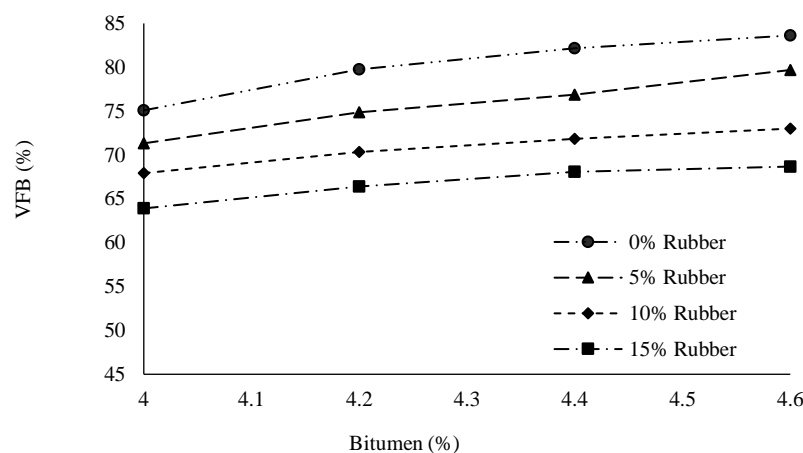
The void spaces that are present between the aggregate particles in the compacted bitumen-aggregate mixtures are termed as Void Mineral Aggregates (VMA). The higher values of VMA represent more space for binders. These spaces are generally taken by bitumen and air voids. The graph in Fig. 4a show that on the same level of replacement of bitumen with the waste rubber tyre and adding wax content, the VMA decreases when the bitumen percentage increases from 4% to 4.2% but when the bitumen percentage is increased after 4.2%, the VMA value increases slowly. Minimum value of VMA is generally desired to get durable binder film thickness.



**Fig. 4a.** Behaviour of the bitumen mix in terms of VMA%

### 3.8 Voids Filled with Bitumen (VFB)

A Void filled with bitumen is the percentage of voids present in the mixture, which is being filled up by bitumen binder. It may also be represented as volume of effective bitumen content. There is a maximum value of VFB for each aggregate and blend material, which cannot be altered although it can be altered if compaction effort is changed. The acceptable range for VFB is 65%-75%, which indicated that materials with VFB in the given limit are durable and strong enough to resist heavy deformations. The graph in Fig 4b depicts that the VFB percentage increases with an increase in bitumen content, due to the fact that more bitumen content will fill up the gaps between aggregates in the mixture, which increases the effective bitumen film thickness between coarse and fine aggregates. However, for increase in rubber content, the trend of VFB percent decreases gradually because addition of rubber aggregates increases the voids in the mixture, causing the effective bitumen thickness to reduce around the aggregates.



**Fig. 4b.** Behaviour of the bitumen mix in terms of VFB%

## 4. Conclusions

The Based upon the experimental research conducted in this paper, the addition of rubber aggregates and varying wax content in bituminous mixture helps in enhancing the physical properties of Crumb-Rubber Modified Bitumen binder (CRMB), as illustrated in the results by showing a decrease in ductility and penetration value, making the binder less susceptible to high temperature, reducing the creep effect on road and increasing resistance against rutting formation on flexible pavement. Rubber aggregates in bituminous mixture tends to increase stability up to some extent, increases the value of Voids filled with Bitumen (VFA %) and decreases Voids in mineral aggregates (VMA %), depicting various properties of Marshall mix design for obtaining the optimum bitumen content. For 5% rubber content, the bitumen content corresponding to maximum stability value and bulk specific gravity comes out to be 4.23%, which is considered the optimum bitumen content for replacing it with rubber aggregates, where 5% wax content remains constant in all the sample used in Marshall stability tests. This study indicates replacing 4.23% optimum bitumen content with the crumb rubber helps in providing higher bitumen stability value, as higher stability values provide better bond strength between rubber and bitumen binder and enhances the toughness of surface. CRMB pavement with 5% rubber contents helps in providing better stability as compared to other CRMB mixtures, improving both strength and serviceability of pavement. It is observed that an addition in wax content results in the reduction of mixing and compaction temperature, indicating that addition of wax content is beneficial in reducing the mixing and compaction temperatures. The utilization of rubber in road pavement will help in providing improved life and durability of a flexible pavement and provides least

cost recycling method of waste disposal. The utilization of rubber in road pavement will help in providing improved life and durability of a flexible pavement and provides least cost recycling method of waste disposal.

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