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A Review on Rubber Modified Asphalt Concrete Mix (RUMAC)

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Abstract—The use of crumb rubber in road engineering as a reinforcement to the bituminous concrete acts as one of the main revalorization technique for this waste. This has not only prevented us from stockpiling of vast masses of wastes but has also abetted us in improving a lot of properties in the bituminous mixes. The main purpose of this study is to analyse the possible permanent deformation improvements, fatigue cracking improvements, stability improvements in the bituminous concrete mix by reinforcing it with the crumb rubber aggregates. For this purpose, various studies were analysed and the suggestions from the various researchers were presented. From the analysis of the different studies of the researchers it can easily be concluded that the introduction of the crumb rubber in the form of aggregates in the bituminous concrete mixes has improved numerous properties of the blended mixes within the proportional limits. The tests used to evaluate the behaviour of bituminous mix was Marshal Stability test, Indirect tensile strength test and the permanent deformation test. The results from various studies shows that the addition of the crumb rubber retards the appearance of the cracks, ruts and improves the stability of the pavements at permissible proportions.

Keywords—Fatigue cracking, crumb rubber, bituminous mix, rubber aggregates.

I. INTRODUCTION

In today's world, automobile industry is the only cradle of producing waste tyres in India and all over the world. In view of the present scenario of the waste tyres, it has evolved a new trending and hot matter of controversy over using and recycling the used tyres. This seems now an obligatory, bearing in mind the current and emerging masses of waste tyres in the world. From the environmental perspective, the stockpile and masses of tyres put a serious threat to the green environment and also results in the serious hazards to the human life, because they are having the potential of making the irreversible damage to the environment and to the human life. The stock pile tyres, provide a favourable environment to a lot of harm making insects like mosquitos to exist and reproduce exponentially, which are responsible for a lot of life threatening disease like dengue, malaria etc. The researchers and the scientists have confronted a question of seeking the solution to the problem of stock piling of these waste tyres, and finally found the way out, in exploring many civil related investigations and studies. The two famous and frequently used civil engineering materials, concrete and asphalt, fascinated several of the scientists and researchers towards the idea of utilising the tyre rubber or crumb rubber with these materials. When the crumb rubber or waste tyre rubber, was used resourcefully with these two materials an intense and significant change was observed in the mechanical properties of these materials.

A. Crumb Rubber

It is reclaimed or recycled rubber products assimilated from the used tyres of the vehicles. It is in reality the basic name for the styrene – butadiene and light weight. It is available to us in various forms like shredded tyres, in granular form and in powder form also. Its use is not only limited to pavement engineering but has made its impact in various engineering and construction techniques. The utilization of crumb rubber not only paves a way to tackle the environmental pollution problem but has lot of inherent properties which can be used by absorbing it in other materials. In the process of recycling the tyre, the steel and tire cords are expelled and diverse sizes of the rubber are obtained. The size of the rubber utilized in the examinations goes through the 4.75 mm sieve and held on 600 micron sieve and in some cases it goes higher than 4.75mm and lower than 90 micron. Based on the gradation of the crumb rubber the process of mixing of crumb rubber also differs. Most probably for the crumb rubber particles in size greater than 200 micron and sometimes greater than 90 micron are processed by dry process of mixing. The crumb rubber particles in size lesser than 90 micron are usually incorporated by the wet process of mixing. Both the processes differ in the method of mixing of crumb rubber with the bitumen. Here, for this study the dry process of mixing was analysed.

Fig 1 Crumb Rubber.

B. Production of Crumb Rubber Modified Mixes

There are actually two primary approaches for using them in the asphalt pavements like:

1. Bitumen modification: Wet Process
2. Using the ground rubber as part of the asphalt mixture with partial bitumen modification – Dry Process

In the first process of modification, the modified bitumen is produced and in the second process, the modified bituminous mixture by crumb rubber is produced.

I.Wet process

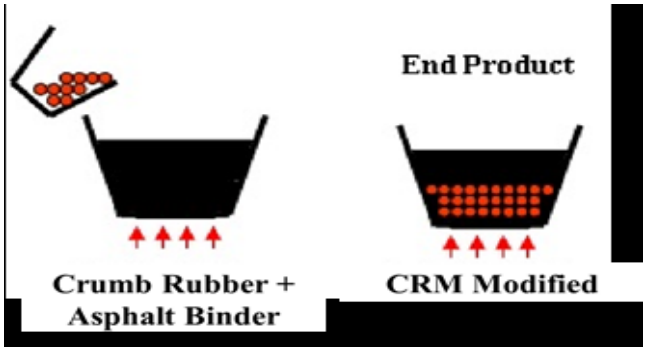

Figure 2: wet process

In this process the rubberised bitumen is produced by directly mixing the scrap tyre rubber with the bitumen binder in high temperature (1700C – 2260C). Unlike the other polymers, the waste tyre rubber doesn't becomes an integral part of the bitumen binder. During the heating of the bitumen binder, the crumb rubber softens a bit and also swells a bit because of the surface absorption of the crumb rubber particles. Due to the swelling phenomenon of the rubber particles, the volume increases incrementally. There is also an increment in the viscosity of the mix, which helps to provide resistance to the permanent deformation called as rutting. The presence of the softer rubber particles also improves the flexible nature of the mix and helps it to provide more resistance towards the cracking. Regarding the bitumen binder content used in the study, the viscosity of the blended mix is more to that of the conventional one, so takes more bitumen content as compare to that of the bitumen content used in the normal mixes.

The first method on record for the wet process goes long back to 1823 when it was developed by Hancock. Later on the principle of manufacturing process were developed by the Cassel in 1844. The first application of the rubberised asphalt comes forward in1960 by the construction of the Street in Cannes. McDonald was the first who developed an industrial technology for the production of the rubber modified bitumen (McDonald 1981)

I. *Dry Process*

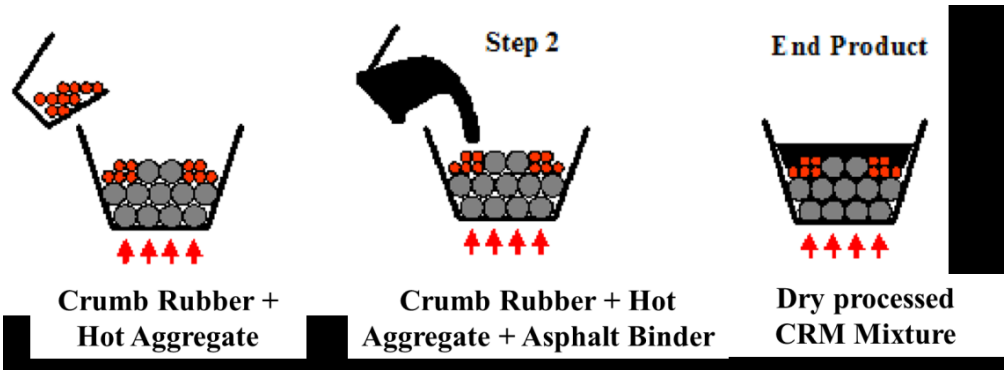

Figure 3: Dry Process

The dry method of mixing the bitumen with the crumb rubber was developed in Sweden in 1960. In this process, the crumb rubber does not modifies the bitumen wholly, but plays the role of an aggregate in the mix and only partially modifies the bitumen. Contrast to the wet process, this is much simpler because we does not needs anymore the cooking and digestion process. The crumb rubber particles are first mixed with the conventional aggregates or mineral fillers before the bitumen binder is added to it. The grain size varying from 2mm – 6mm is being used mostly in this process. The temperature at which the aggregates and the crumb rubber aggregates are mixed is likely to be 160-180 0C and after that the bitumen binder is added to the mix. For this process, the cryogenic rubber is mostly used because of its larger size. The dry process depends more on the gradation of the crumb rubber as compared to that of the wet process.

II.OBJECTIVES OF THE STUDY

The aim of the study is to analyse the impact of the crumb rubber on the stability and the behaviour of the paving bituminous concrete layer. The main objectives of this study are as follows:-

a. To understand the effects of crumb rubber and its gradation on the stability of bituminous concrete layer.
b. To summarize the tests and the possible improvements in the inherent properties of the bituminous concrete layer.
c. To ascertain the optimum content of crumb rubber which can be used with virgin aggregates to form an asphalt concrete mix.

III.PAST STUDIES

Gito Sugiyanto (2017) [1] studies the Characterization of the bituminous concrete formed from Sparred Tire Rubber. This paper displays an investigation on the utilisation of scrapped tyre rubber as partial replacement of the fine aggregate in the creation of Bitumen Concrete (BC) blend. The investigation was performed at three different stages on the Bituminous concrete blend with Zero (0) percentage, half, and 100% of the waste scrap tyre rubber substitution of aggregates at part No. 50 (0.279 mm). Laboratory tests were conducted on six the outcomes demonstrated that the ideal bitumen content for AC Standard blend is 6.78%, while BC Scrapped-tire half blend is 7.10% and BC Scrapped-tire 100 % blend is 6.22%. In view of the Marshall attributes, waste tyre rubber could be an elective material to partially replace fine aggregates in BC blends for surface layer. The utilization of rejected tyre rubber, in bitumen concrete blends can enhance the resistance to deformations from because of grooves and give better resistance to higher temperatures and loads.

Shinde. S. S. et al. (2016) [2] examined the Effect of Crumb Rubber in Bitumen Using Marshal Stability Test. From the test results of the plain bitumen and the crumb rubber modified bitumen, it was made clear that their was an increase in the penetration point and the softening point. After careful testing in the research laboratory, it was found that 4.5% of crumb rubber to be used for modification purpose is found to be optimum or suitable. The marshal stability at the optimum crumb rubber percentage was found to be 1717.04 kg, which is obviously higher to that of the conventional mixes.

Table 1 Marshal Test results

S.NO.	Crumb Rubber	Bitumen %	Density	Corrected stability (kg)	Flow (mm)
1	0	5.5	2.47	1123.60	4.6
2	10	5	2.49	1405.13	4.1
3	15	4.5	2.54	1717.04	3.9
4	20	4	2.53	1181.51	2.6

Athira R Prasad and Dr Sowmya N J (2015) [3] studied the Bituminous Modification with Waste Plastic and Crumb Rubber. In the study, the waste material like plastic waste and rubber waste as crumb rubber was used to replace the conventional materials like bitumen to get an improvement in the properties of the blended mixes. The study also reveals the comparison between the use of plastic waste and crumb rubber (3%, 4.5%, 6%, 7.5%, 9% by weight of the bitumen) in bituminous concrete mixes, and the results were analysed so as to get the better material to be used in the mixes. In addition, in the study the Query dust was utilised in place of the filler with a specific gravity of 2.44. The Marshal Stability test was used to detect the stability values of modifiers.

Table 2 Marshal test results

Bitumen %	Stability KN	Flow Values (mm)
3%	20.66	2.23
4.5%	21.53	2.5
6%	22.18	3.0
7.5%	21.65	4.8
9%	18.23	4.17

F. Onyango (2015) [4] studies the effect of effects of the wastes to be used in the asphalt concrete like tyre rubber waste and plastic waste. From the studies, it is confirmed that pavements of asphalt concrete tend to have short life period, and are deteriorating mostly due to temperature variations, traffic heaping and ageing. The modification of bitumen by various materials provides a tool to produce an improved bituminous mix with enhanced properties of viscoelasticity, which makes the blended mix capable of staying without deterioration on a wider range of temperature variations and loading circumstances. In this study, 60/70 PG bitumen binder was altered by the addition of 2 to 10 percent of the plastic waste by weight of bitumen binder, ensuing the wet process. The mineral aggregates were also altered in the range of 1 to 5 percent by the volume of the mineral aggregates, by the material of crumb rubber ensuing the dry process of mixing. The properties of the LDPE bituminous binder were also assessed and in addition to that, the laboratory outcomes showed a surge in the properties like viscosity, softening point and the binder stiffness. The modified bitumen blend was then used in making bitumen mixtures by Marshall Mix design procedure. The Marshall Stability outcomes for blends blended with 2 percent of waste tyre crumb rubber and 4 percent of LDPE were found 30% advanced than the orthodox bitumen concrete mixture.

Table 3 crumb rubber size used in the study

Sieve size	%passing	%retained
4.75mm	100.0	0
2.00mm	57.5	42.5
1.18mm	48.0	52.0
0.60mm	0.5	99.5

G.H. Shafabakhsh et al. (2014) [5] explores the rutting performance by a case study of the modified hot mix asphalt with the waste rubber powder. The study has put some great suggestions in front of us like, using the crumb rubber not only helps us to decompose the waste but also helps to show an increase in the service life of the pavements and also reduces construction costs. In the study, the wheel track test has been used to associate the performance of rubberised asphalt pavement and the conventional asphalt pavements. The study also reveals that there was a substantial decrease in the degree of rutting depth in rubberised asphalt pavements to that of conventional ones. The size of the crumb rubber which was employed in the study was from 0.075mm – 2mm. The dry process was employed for the mixing of samples for Marshall Stability test.

Nuha SalimMashaan et al. (2014) [6] presented the overview of the utilising Crumb Rubber in Reinforcement of bituminous blended Pavement. The study reveals that an effort to decrease the amount of waste tyre rubber in the environment has gain a good interest as a modification material in the asphalt pavements. The utilization of crumb rubber in the support of bitumen asphalt concrete is reflected as a smart way out for economic improvement by recycling waste materials, and it is trusted that crumb rubber modifier (CRM) an elective polymer material in enhancing the properties of hot mix asphalt. This paper will like to present the review of incorporating the crumb rubber I the hot mix asphalt, and will likewise present a review on the impacts of CRM on the firmness, rutting, and resistance to fatigue of road asphalt construction. Here the review was presented for the crumb rubber of different sizes likewise 6mm, 4.75mm, 2.86mm, 1mm and also when the crumb rubber was used in the form of powder. The study reveals that their was a promising improvement in some of the properties of the bituminous asphalt concrete mix, when the crumb rubber was put in it. The polymer has played a vital role in improvising the resistance of the asphalt pavements regarding rutting and cracking.

Tomas U. Ganiron Jr (2014) [7] conducted experimental research on waste rubber as asphalt cement modifier for road pavements use of asphalt cement. The investigation was prepared for utilizing the waste tyre as a bitumen modifier for road development to comprehend the current issue on waste allocation. In it's entirely, the Marshal Stability test and Immersion tests were carried out on the specimens to decide the impact of waste tyre as a bitumen asphalt modifier in Marshall Stability and flow values, thickness and voids contents, and impact of water and compressive quality of compacted bituminous materials of highways. Perceptions from the tests performed were led in the research facility where exact information were assembled and totally accomplished. Some exciting bits of knowledge of the investigation

are: (a) scrap waste tyre is a partial substitution by 2% to the whole weight of aggregate held in sieve No. 4, has a normal or typical performance; (b) the utilization of scrap waste tyre would end in the decrease of waste or squander; (c) Marshall specimen made at right temperature and at standard conditions, gave adequate compressive quality and reduce its flow under a specific load.

Victor f. Vázquez et al. (2014) [8] investigated a road track with the crumb rubber present in it and also on the track without any modification. The whole study aims to find out the way of reducing the noise pollution. The study reveals the results of the gap graded characterisation mix. In the study, crumb rubber was used in the form of powder and was mixed bitumen by the wet process. The main theme of the research was to get the results regarding the noise pollution and its absorbance by the modified bitumen for which the laboratory as well as the field tests were carried out. In addition to that, the absorption and dynamic stiffness tests were also conducted to investigate the noise absorption mechanism in the pavement. Finally, the results suggest a good amount of noise reduction in the pavements containing crumb rubber as a modifier. Moreover, will help to decrease the amount the waste tyre rubber in the environment.

Altan Cetin (2013) [9] studied the effect on the performance of the porous asphalt mixture by varying the crumb rubber size and concentration in it, and concluded that the reusing of waste tires in the asphalt concrete pavements looks to be a vital substitute considering a large scale market for the waste tyre. In the study, the optimum bitumen content was first abstracted and later on, the other tests were performed. Throughout the study, the dry process of mixing was chosen for the sampling and the crumb rubber was mixed in different sizes and rubber content was taken in three different percentages also, 10%, 15% and 20% by the weight of bitumen. The various tests were performed on the modified mixes like permeability test, indirect tensile strength test, abrasion test, moisture susceptibility and resilient modulus tests were also carried out on the specimens. The tests results clearly showed that increase in the Cantabro abrasion loss and showed increase in case of filling of voids or reducing the voids and coefficient of permeability. In general, it was conclude that while increasing the size of particles in the mix and their content, the overall reduction was observed in the performance features of the porous asphalt pavements.

Figure 4 crumb rubber

Asim H. Ali et al. (2013) [10] studied the Performance of stone mastic asphalt pavement by utilising crumb rubber as modifier in it in Malaysia, in which a particular grade of crumb rubber was used to partially replace the fine aggregates at the grade of 40 which is 0.45mm. In the study the penetration grade of 80/100 bitumen was used and was modifies alter on at five different percentages, namely 0%, 6%, 12%, 16% and 20%, respectively by weight of the bitumen in sample. The optimum content of the crumb rubber was found to be 12% with respect of the weight of the bitumen. At this percentage of modification, the stability was found to be maximum. The resilient Modulus of SMA was also found to be higher for the modified bitumen samples, as compared to the samples, which were made conventional. For the whole process of mixing the dry process was chosen, in which the crumb rubber was directly added to the aggregates after heating them for 2 hours.

Fernando Moreno-Navarro, Et Al. (2013) [11] studied the behaviour of hot mix asphalts cracking or fatigue behaviour. From the study it was conclude that utilization of crumb rubber in the bituminous modification mixes is as revolutionary step in the decomposition of this waste. The primary aim of the examination comprises of analysing the expected fatigue cracking advancements in the performance of bituminous blends incorporating crumb rubber in contrast with bituminous blends fabricated with regular bitumen and also to the bitumen adjusted with SBS polymers. The test employed to assess their conduct was the UGR-FACT with an extra framework for taking photographs, which permits governing the propagation of the splits at each minute. The outcomes demonstrate that the adding of crumb rubber in the mix delays the appearance of breaks; in any case, when it starts, the damage spread is quicker. Hence, the fatigue cracking behaviour of blends with crumb rubber appears to be impressively elongated than the fatigue cracking behaviour of those with customary bitumen. Besides, in the blends with crumb rubber included by the dry mixing procedure, splits are more slender and less branched than in alternates.

Niraj D. Baraiya (2013) [12] presents the review on the construction of the road of bitumen by utilising the crumb rubber in it. The study presents that the use of four wheelers, bike vehicles and so on, is expanding systematically. Subsequently measure of waste tyres is also additionally growing. Squander tyres in India are sorted as strong or dangerous waste. It is

assessed that 60 percent of wasted tyres are arranged through obscure ways in the urban and country zones. This prompts different natural issues, which incorporate air pollution related with open burning of tyres (particulates, odour, visual effects, and other destructive contaminants, for example, hydrocarbons, dioxin and oxides of nitrogen) and aesthetic contamination. In this way, it is significant to utilise the squanders adequately with particular development in each field. The waste tyres can be utilized as well sized partial replacement to the aggregates in the different bituminous blends in the event that it is cut in the shape of aggregates and can be entitled as rubber aggregate. This not just limits the contamination happened because of waste tyres yet additionally limits the utilization of conventional or natural aggregates which is accessible in modest amount.

Junan Shen et al. (2007) [13] investigates the impact on the high temperature properties of the crumb rubber modified binders by varying the surface area and the gradation of the modifier. The tests like complex modulus, the phase angle and the high temperature grade of the crumb rubber modified binder was examined. The surface area of the particles of crumb rubber was measured with the help of BET (Branuaer, Emmett and Teller) tester. The average particle size of crumb rubber blended mixes was calculated based on the gradations and the particle size index was taken. The Dynamic Shear Rheometer (DSR) was employed to calculate the properties of crumb rubber modified bitumen regarding high temperatures. A total of 108 crumb rubber modified bitumen blends were prepared, by using the altered combinations of the variables. The outcomes of the study are like: (1) the surface area of the ambient crumb rubber modifier was found to be double as compared to that of cryogenic one, which lead to the greater value for (G) and phase angle of crumb rubber. (2) The phase angle and G were also affected by both the average dimensions of the particles and the surface area, however among the two surface area was found to be much dominating.

Silvrano A. Dantas Neto et al. (2006) [14] studied the Influence of Crumb Rubber Gradation on Asphalt-Rubber Properties. The study reveals that the gradation of crumb rubber is unique of the factors which have a critical effect on asphalt rubber properties. Therefore, this work ponders the impact of gradation of crumb rubber on the asphalt rubber properties conversed by penetration, rotational viscosity (using Brookfield viscometer), softening point and the resilience. Test samples were produced with a 50/70 penetration grade straight asphalt and the pounding/grinding process, which fundamentally comprises in a tearing and pulverizing the old tires at encompassing temperature. The absorption time was an hour and the processing temperature was 170 ºC. The outcomes demonstrate that the rotational viscosity and the resilience are the properties most influenced by the gradation of rubber. It was likewise seen that the increase of the crumb rubber specific surface (fine crumb rubber) produces an asphalt rubber with lower resilience and higher viscosity. The utilization of coarse scrap tyre rubber affects for the most part the resilience.

S. K. Palit et al. (2004) [15] studied the Laboratory Evaluation of Crumb Rubber Modified Asphalt Mixes. In this study, the crumb rubber which is being employed for the laboratory tests was obtained from truck and bus tires and the bitumen which was used here was penetration grade 80/100. A lot of properties of the modified bitumen like temperature susceptibility, moisture susceptibility, rutting behaviour, fatigue and oxidative aging were evaluated. Three aggregate gradations : (1) superpave (2) MORTH specified gradation for bituminous asphalt concrete (3) one gap graded, were employed for the investigation. The size of the crumb rubber, which was used in the study, is 0.6mm and the filler used here is cement passing 0.075 mm sieve. The results from the tests revealed that the crumb rubber modified mixes were better in performance rather than that of the conventional mixes, when rutting or permanent deformation and fatigue were considered. The study also suggests the lower temperature susceptibility and greater resistance to the moisture damage compared to that of the normal mixes. Among all the gradations, which were used here, the superpave gave all the way better performances as compared to that of the other gradations that were being employed here.

By Jong R. Kim (2001) [16] studied the Characteristics of Crumb Rubber Modified (CRM) Asphalt Concrete. The mix design of CRM asphalt concrete with the Marshall method to assess low temperature practices and temperature susceptibilities of CRM asphalt concrete are presented. The mix configuration was performed utilizing one asphalt cement (120/150 penetration grade). Also five aggregate gradations with three rubber contents were used (0, 3, and 5% by weight of aggregates). All blends fulfilled the Marshall mix criteria. For the laboratory examinations the three different grades of crumb rubber were selected and were used with at three different percentages of bitumen (0, 3, and 5%). Also for the study, the treated and untreated samples of crumb rubber were also used. The study however reveals that the use of CRM did not altogether influence the general temperature susceptibility of the blends. It did, in any case, considerably diminish the mixture modulus at any given temperature. The reduction in modulus was emphasized as the content of crumb rubber was increased. The potential for thermal cracking diminished with the amount of crumb rubber. This exhibited a CRM asphalt mixture could relieve stress develop by its capacity to strain.

IV.ADVANTAGES OF USING CRUMB RUBBER

i. *Environmental*: the waste tyre rubber provides us the source for the rubber granules which are used in the asphalt concrete. It is estimated that the rubber granules are produced at such a quantity that it can be used sufficiently to modify the 4000 km pavement of two lane.
ii. *De-icing:* it has been reported that the rubber asphalt pavements keep themselves de-iced. The patent holder for this claims that the de-icing of the pavements occurs due to the compression of the protruding rubber aggregates which

deform under vehicle loads. The deformation in the pavements causes cracks in the ice accumulated layer and breaks it down into pieces which are later on cleared from the road by the help of the wind of the running vehicles.

iii. *Noise Reduction*: it has been reported that the rubberised asphalt pavements reduce the noise pollution up to 10 dB as compared to that of the normal level of noise in the normal pavements.

iv. *Skid Resistance*: it is also claimed that the surface texture of the rubberised asphalt pavements containing rubber aggregates give pavement the improved skid resistance under all weather conditions like dry, wet and icy conditions. The results have shown that there is a decrease of almost 25% in stopping distance of vehicles under wet conditions.

v. *Hydroplaning and Water Spray*: the presence of rubber aggregates in the surface makes the surface texture with good surface drainage, which ultimately eliminates the hydroplaning and diminishes the water spray.

vi. *Sanding and Salting*: with the improvements in the skid resistance of the pavements the need of sanding and salting during winters is totally reduced, which in turn helps us to minimize the maintenance costs and also prevent the vehicles from the corrosive damage.

V.HAZARDS OF TYRE WASTE.

i. The amount of production of the waste tyres in our country is so large that it has become impossible to totally decompose them or landfill them due to unavailability of such lands.
ii. The waste tyres produce carbon and its products when it is burnt down.
iii. Potentially harmful substances were found exposed to highly acidic solutions.
iv. Apart from these harmful emission of substances there is also a threat of fires in rubber and once it is started it is hard to stop.
v. The stockpiles of tyres has proven to be ideal breeding ground for mosquitoes when a little water is pooled or retained in them.

VI.CONCLUSIONS

In present study, numerous past works were fully analysed and following conclusions were drawn on the basis of same:

1. The utilisation of Crumb Rubber in Bituminous Concrete pavements enhances the resistance against cracking and it reduces the stiffness of aged binder.
2. With the inclusion of crumb rubber, the moisture susceptibility and rutting résistance of mixtures gets improved.
3. Up to 8% of crumb rubber has shown good results when used in the bituminous concrete pavements.
4. The replacement of the aggregates in the asphalt concrete by the crumb rubber has resulted in the saving of the natural aggregates, which is reducing day by day in the world, because of its alarming use in the construction works.
5. There is initially a huge increase in the marshal stability of the blended mix as compared to that of the normal mix, and has shown a promising improvement in other parameters of marshal test.
6. The blended mix has also improved the Indirect Tensile Strength of the mix, which is nowadays a great concern regarding the issue of fatigue in pavements.
7. The rutting strength of the blended pavement has also shown a great improvement, by decreasing the rutting depth in the blended mix as compared to that of the normal mix.

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