Comparison Study on Behaviour of Coarse Aggregate Using Coating of Bitumen and CRMB (Crumb Rubber Modified Bitumen)

Abstract

Waste tyre disposal is a major problem owing to the millions of tonnes of waste tyres disposed around the world every year. Studies have shown that crumb rubber extracted from these tyres can increase the strength, durability, safety, and efficacy when coated on aggregate particles used for road construction. However, none of these studies have provided conclusive evidence. This study aimed to investigate the toughness and hardness of coarse aggregate particles coated with different concentrations of crumb rubber. Coarse aggregate particles without any coating, coated with bitumen, and coated with bitumen and different concentrations of crumb rubber (4%, 3.5%, 3%, 2%, and 1%) were tested for toughness using the aggregate impact value test and hardness using the Los Angeles abrasion test. Our findings showed that both the impact value and abrasion value for the uncoated particles were highest and it became significantly lower with the addition of bitumen and crumb rubber coating. A crumb rubber percentage of 3.5% and 2% proved to be the most suitable for achieving optimum values of toughness and hardness of the samples. This study proved that addition of bitumen and crumb rubber coating improves the toughness and hardness of the aggregate samples, and may lead to greater safety and durability when used for road construction purposes.

1. Introduction

In India, more than 15 million waste tyres are produced every year. According to the Environmental Protection Agency (EPA), out of the 242 million waste tyres generated in 1990, 78% were stockpiled, landfilled, or illegally dumped. While some states incinerate waste tyres as a one-time option, the tyres often return to the surface in many cases. Tyres that have been used to fill landfills have also gotten more expensive as landfill space has decreased. Mosquitoes thrive in the ponds of water that remain after whole waste tyres are crushed. Aside from being annoying, mosquitoes have been shown to spread a number of serious illnesses (Sharma and Singh, 2018). Tyre fires pollute the air with large amounts of carbon smoke, hydrocarbons, and residue, making them highly dangerous. These flames are almost impossible to extinguish once they have started. Currently, energy generation, cement kiln operation, electricity to operate pulp and paper mills, and tyre recycling at facilities are the most common approaches to utilize waste tyres (Deshmukh and Kshirsagar, 2017).

Around 1 to 1.8 billion waste tyres are disposed each year across the world. This equals to around 2 - 3% of all trash gathered by municipalities. This is a growing problem owing to the increasing population especially in large developing nations where the use of vehicles is higher. As vehicles are used for long-distance travels, a higher number of tyres need to be replaced contributing to the problem of waste tyre disposal. As tyres are built to provide safety and durability, they are difficult to recycle, and they are often dumped in landfills, which leads to pollution and health hazards. Such waste tyres attract disease-causing insects and rodents and release harmful chemicals in their decomposition process. Tyres are also highly flammable and can easily catch fire, contributing to air pollution and posing a risk to human and animal life. Intentional burning of tyres causes the release of mutagenic and carcinogenic chemicals into the atmosphere, so they can only be disposed in this way using advanced systems for air emission control. This process is expensive and is not affordable for developing nations nor is it profitable for developed nations.

Several efforts have been initiated to recycle waste tyres and, currently, around 13% of waste tyres are recycled annually. Some of the ways in which waste tyres are recycled include using them for constructing rubberized surfaces for playgrounds and sports fields, construction, and land management. As waste tyres are made of tough materials to enable them to withstand wear and tear, they can also be used as a replacement for concrete. However, all these uses are not enough to consume all the waste tyres that are generated globally, and the tyres need to be used for a much larger project, such as construction of roads. New developments have made the use of ground tyres as a component of asphalt mix mainstream and several advantages have been identified in using waste tyres for road construction such as better grip, lesser noise, low maintenance, and higher durability.

Several studies have been conducted to test the properties of waste tyre crumb rubber and its suitability for construction of pavements. Mashaan et al. (2012) proved that adding crumb rubber to asphalt improved resistance to rutting and produced a sample with higher durability. Thus, roads made of this material would be smoother and safer for users. An earlier study by the same group showed that addition of crumb rubber to bitumen lowered the penetration value thereby making the sample harder, and increased the viscosity and softening point of the bitumen

(Mashaan et al., 2011). Justo and Veeraragavan (2002) showed that bitumen modified with 12% crumb rubber was more resistant to permanent deformation at increased temperatures. Huang et al. (2004) showed that rubberized concrete had much higher strength and toughness when compared to normal concrete.

Magar (2014) varied the sizes of crumb rubber particles and tested the performance of bitumen modified with different crumb rubber samples. This study found that the softening points and penetration values of bitumen modified with crumb rubber was improved as compared to unmodified bitumen. The study also reported that the size of crumb rubber particles that gave the best results was 0.3 to 0.15 mm. Xiao et al. (2009) found that varying the sizes of the crumb rubber particles used had no effect on indirect tensile strength and rutting resistance values of various samples; however, increase in size of crumb rubber particles decreased the resilient modulus values and increased the fatigue life of the various samples.

Rokade (2012) added varying percentages of crumb rubber to 5% bitumen and measured the Marshal Stability Value. He found that the value increased with an increase in crumb rubber percentage upto 12%, following which it decreased. Therefore, using 15% crumb rubber gave the best results for enhanced strength characteristics of modified bitumen. Becker et al. (2001) demonstrated that adding higher quantity of crumb rubber to bitumen increased viscosity, resilience, and softening point, and decreased penetration of the sample. However, Mavroulidou et al. (2010) reported that use of crumb rubber from 0% to 10% gave good results for density, workability, and cube compressive strength; however, use of higher concentrations of crumb rubber in modified bitumen can give negative results.

Hanumanth Rao et al. (2019) compared properties of unmodified bitumen and bitumen modified with different percentages of crumb rubber (5%, 10%, 15%, and 20%) and showed that addition of crumb rubber increased elasticity, softening point, and stability, and decreased penetration values. Suganpriya et al. (2016) tested the addition of different percentages of crumb rubber to modify bitumen and reported that adding crumb rubber beyond 12% caused the segregation of the crumb rubber particles. Use of 12% crumb rubber in the sample lowered the penetration value by 14.56% and ductility by 24.49%, and increased the softening point, fire point, flash, and viscosity considerably. Similarly, Haldar et al. (2022) reported that addition of 12% crumb rubber to bitumen increased the softening point, lowered the ductile value and lowered the penetration value of modified bitumen. Thus, this study proved that crumb rubber could be used to partially replace bitumen for road construction as both have almost the same properties, and it would ultimately lower construction costs and provide a means to recycle waste tyres. Zolfaghari et al. (2014) added varying percentages of crumb rubber from 5% to 25% in increments of 5% and studied the properties of the modified bitumen samples. They found that addition of 15% crumb rubber gave the best values for unit weight and Marshall Stability index. Bressi et al. (2019) reported that mostly 15% to 20% crumb rubber is used for most applications, and higher than 20% of crumb rubber is usually not considered safe for road construction purposes.

As is evident from the current literature, several studies have shown that crumb rubber in varying sizes and concentrations can be successfully used to modify bitumen for construction of flexible pavements. However, most studies have used concentrations of crumb rubber varying by 5% and they show inconsistency in results with some studies reporting that crumb rubber should not be used at a concentration of more than 12%, while others stating that 15% crumb rubber was the best concentration, and yet other studies stating that crumb rubber could be used up to a concentration of 20%. Also, none of the studies have tested the properties of crumb rubber varying by a percentage value of 1%. This project aims to study and compare the properties of crumb rubber at percentages between 2% and 4% and identify differences in the toughness and hardness of the resulting samples.

The central aim of this project was to assess the properties and performance of conventional coarse aggregates and modifier-treated aggregates with bitumen and various concentrations of crumb rubber using experimental analysis. This project tested the toughness and hardness of coarse aggregate samples by determining the impact value and abrasion value of the samples by varying the composition and concentration of coating among the samples. It also checked the percentage of optimum crumb rubber modified bitumen that could be used to reduce the amount of bitumen for construction and to recycle the crumb rubber.

2. Materials and Methods

Coarse aggregates were obtained locally and they were passed through a sieve that could pass particles of 20 mm size and retain particles of 12.5 mm size, followed by a sieve that could pass particles of 12.5 mm size and retain particles of 10 mm size. Intermediate sieves were used to pass the coarse aggregate sample, following which the aggregates were collected, cleaned, and sorted. The sorted aggregates were weighed and batched according to their sizes. VG-30 grade or

60/70 grade of bitumen was used for coating the coarse aggregate sample. In order to confirm the grade of the bitumen, penetration test was carried out as per IS:1203-1978 and the results of the penetration test are given in Table 3.1.

Table 3.1: Results of Penetration Test of Bitumen for Confirmation of Grade

Readings	Observations						Avg. Penetration Value (mm)	Admissible Value (mm) as per IS:1203
	1	2	3	4	5	6		
Initial	*0*	*0*	*0*	*0*	*0*	*0*	*66.83*	*60-70*
Final	*65*	*68*	*68*	*69*	*65*	*66*		

The crumb rubber used was of 40 Mesh and 10 Mesh collected from Trirubber India Inc., located in Kalaikunda, Dewanmara Ayma, West Bengal – 721304. The physical properties of the crumb rubber sample(s) (40 Mesh and 10 Mesh) are given in Table 3.2.

Table 3.2: Physical Properties of 40 Mesh and 10 Mesh Crumb Rubber

Sl. No.	Physical Property	40 Mesh Crumb Rubber	10 Mesh Crumb Rubber
1.	*Specific gravity*	*1.02*	*1.04*
2.	*Moisture content*	*0.69%*	*0.66%*
3.	*Theoretical Weight/Density*	*720 kg/m^3*	*715 kg/m^3*

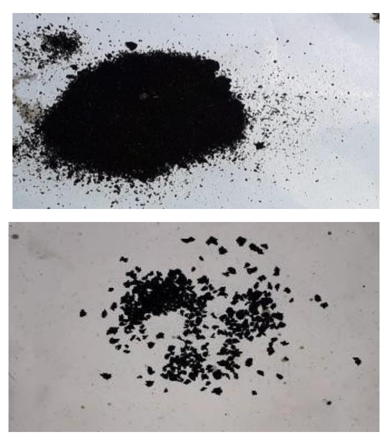

Fig 3.1: Penetration test for bitumen   Fig 3.2: Crumb rubber 40 Mesh (above) and 10 Mesh (below)

A total of 8 samples were used in this study as shown in Table 4.1.

Table 4.1: Samples Used for Analysis

S. No.	Sample	Bitumen coating for Impact Value Test	Crumb rubber coating for Impact Value Test	Bitumen coating for Los Angeles Abrasion test	Crumb rubber coating for Los Angeles Abrasion test
1.	*Coarse aggregate sample*	*No*	*No*	*No*	*No*
2.	*Bitumen-coated coarse Aggregate sample*	*40g*	*No*	*500g*	*No*
3.	*Sample coated with bitumen and 4% of 40 Mesh crumb rubber*	*40g*	*1.6g*	*500g*	*20g*
4.	*Sample coated with Bitumen and 3.5% of 40 Mesh crumb rubber*	*40g*	*1.4g*	*500g*	*17.5g*
5.	*Sample coated with bitumen and 3% of 40 Mesh crumb rubber*	*40g*	*1.2g*	*500g*	*15g*
6.	*Sample coated with bitumen and 1% of 10 Mesh crumb rubber*	*40g*	*0.4g*	*500g*	*5g*
7.	*Sample coated with bitumen and 2% of 10 Mesh crumb rubber*	*40g*	*0.8g*	*500g*	*10g*
8.	*Sample coated with bitumen and 3% of 10 Mesh crumb rubber*	*40g*	*1.2g*	*500g*	*15g*

The aggregate impact value test for toughness was carried out as per [IS: 2386 (Part IV) – 1963]. The sample was filled in the metal cup of the apparatus upto a depth of 1/3rd volume of the container. The sample was compacted by subjecting it to about 25 gentle blows of the rounded end of the tamping rod. This process was repeated 2 more times, each time adding the aggregate sample to the metal cup and then compacting it with the tamping rod. Once the metal cup was filled to capacity, the weight of the sample was determined (W_1). The apparatus was adjusted such that it was rigid and stood level on thefloor. About 380 mm above the sample in the cup, the hammer was raised and allowed to fall freely on the sample. This process was repeated 15 times with a time interval of 1 s between each fall of the hammer. The crushed aggregate in the metal cup was carefully collected and passed through IS 2.36 mm sieve for duration of 1 minute. The fraction of the sample that was retained after passing through the sieve was weighed (W_2). The values of W_1 and W_2 were used to calculate the impact value of the sample.

Impact Value = (W_2/W_1) x 100%

Where, W_1 is the total weight of the sample used, and
W_2 is the weight of the crushed sample retained after passing through a IS 2.36 mm sieve

A coarse aggregate sample with a 'B' grading (as per ASTM C131) was selected for the Los Angeles abrasion test for hardness, and the sample was dried in an oven at 105 to 110˚C. Depending on the grade of the sample, the appropriate number and weight of the abrasive charges were selected. Both the sample and the abrasive charges were placed on the drum and the cover was secured. The machine was rotated at a speed of 30 to 33 rpm for a total of 500 revolutions with uniform peripheral speed. Once the required number of revolutions was completed, the sample was collected in a tray and passed through IS 1.70 mm sieve. The sample that was retained on the sieve was weighed with an accuracy of upto 1 g.

Abrasion value = $[(W_1 – W_2)/W_1]$ x 100%
Where, W_1 is the total weight of the sample used, and
W_2 is the weight of the sample retained after passing through a IS 1.70 mm sieve

3. Results And Discussion

The aggregate impact value test for toughness and the Los Angeles abrasion value test for hardness were performed for each of the samples given in Table 4.1. Impact values and abrasion values were calculated for each sample and the results are given in Table 5.1. Table 5.2 gives the classification of aggregates based on their impact values and Table 5.3 gives the classification of aggregates based on their abrasion values.

Table 5.1: Impact Values and Abrasion Values for Samples used in the Study

Sl. No.	Sample	Impact Value	Abrasion Value
1.	*Sample without coating*	*11.95%*	*17.70%*

2.	***Sample coated with 40g/500g Bitumen***	***2.72%***	***15.50%***
3.	*Sample coated with 40g/500g bitumen and 4% of 40 Mesh crumb Rubber*	*0.97%*	*16.40%*
4.	*Sample coated with 40g/500g bitumen and 3% of 40 Mesh crumb rubber*	*3.53%*	*17.50%*
5.	***Sample coated with 40g/500g bitumen and 3.5% of 40 Mesh crumb rubber***	***2.78%***	***15.50%***
6.	*Sample coated with 40g/500g bitumen and 1% of 10 Mesh crumb rubber*	*4.80%*	*17.50%*
7.	***Sample coated with 40g/500g bitumen and 2% of 10 Mesh crumb rubber***	***2.75%***	***15.45%***
8.	*Sample coated with 40g/500g bitumen and 3% of 10 Mesh crumb rubber*	*1.45%*	*14.00%*

Table 5.2: Classification of Aggregates Based on Impact Values

Aggregate Impact Value	Classification
<10%	*Exceptionally strong*
10–20%	*Strong*
20–30%	*Satisfactory for road surfacing*
>35%	*Weak for road surfacing*

Table 5.3: Suitable Abrasion Values for Different Types of Pavements

Maximum Permissible Abrasion Value	Type of Pavement
60%	*Water-bound macadam sub-base course*
50%	*Water-bound macadam base course with Bituminous surfacing*
50%	*Bituminous-bound macadam*
40%	*Water-bound macadam surfacing course*
40%	*Bituminous penetration macadam*
35%	*Bituminous surface dressing, cement concrete Surface course*
30%	*Bituminous concrete surface course*

From table 5.2, an aggregate impact value of less than 10% is considered especially strong for road surfacing, whereas an impact value of more than 35% is considered unsuitable for road surfacing. Therefore, lower impact values indicate better suitability of the sample for road construction purposes. As seen in Table 5.1, impact values of all samples are below 20% which indicates that all the samples are exceptionally strong and suitable for road surfacing. It is interesting to note that the impact value of the sample without any coating is 11.95% and it drops considerably when the aggregate sample is coated with either bitumen or bitumen + crumb rubber. Therefore, coating the coarse aggregate sample before using it for construction can considerably decrease the impact value and increase the strength of the sample. As can be seen from Table 5.1, the impact values of aggregate particles coated with bitumen and 3.5% 40 Mesh crumb rubber, and particles coated with bitumen and 2% 10 Mesh crumb rubber are almost similar to the impact value of coarse aggregate particle without any coating, indicating that these two crumb rubber concentrations can be used to replace unmodified bitumen coating on the coarse aggregate particles.

When the concentration of crumb rubber is increased to 4%, the impact value decreases considerably from the impact value of the conventional unmodified bitumen coating, and when the crumb rubber is decreased to 1%, a significant increase in the impact value is observed. Therefore, 3.5% 40 Mesh and 2% 10 Mesh crumb rubber are the most suitable concentrations that can be added to the bitumen coating so that waste tyres may be recycled and the amount of bitumen used may be decreased.

Abrasion values were calculated to ascertain the hardness of the sample, and Table 5.3 gives the applications of samples with different abrasion values. According to the table, the maximum possible abrasion values for constructing different types of pavements should be between 30% and 60%. From Table 5.1, all samples have abrasion values of less than 20% indicating that they are permissible for used in road construction. Similar to impact values, the sample without any coating had the maximum abrasion value of 17.7% which decreased with the addition of coating of either bitumen or bitumen coated with crumb rubber. As is evident from Table 5.1, the abrasion value of aggregate particles coated with bitumen and 3.5% 40 Mesh crumb rubber is the same as the abrasion value of unmodified bitumen coating, and the abrasion value of particles coated with bitumen and 2% 10 Mesh crumb rubber is almost similar to the impact value of coarse aggregate particle without any coating, indicating that the set weight of crumb rubber concentrations can be used to replace unmodified bitumen coating on the coarse aggregate particles. When the concentration of crumb rubber is either increased or decreased, the abrasion value increases as compared to that of the conventional unmodified bitumen coating. Therefore, considering both the impact value and the abrasion value, 3.5% 40 Mesh and 2% 10 Mesh crumb rubber are the most suitable concentrations that can be used to modify bitumen for coating coarse aggregate particles, ensuring that the properties of the conventionally used particles do not change and waste tyres are suitably recycled.

4. Conclusion

This study was undertaken to determine and compare the impact values and abrasion values of coarse aggregate sample without coating and sample with coating of unmodified or modified bitumen containing crumb rubber in different concentrations. From the results of our study, addition of 3.5% 40 Mesh or 2% 10 Mesh crumb rubber can provide a modified bitumen coating of coarse aggregate sample that is tough and hard, thereby making it suitable for pavement construction. Our findings are in contrast to other studies which have used crumb rubber at a concentration of 5% and above; however, it has been shown that the stability and durability of samples decrease as the concentration of crumb rubber increases and at higher concentrations of crumb rubber, the sample tends to disintegrate. As a result, it is important to test lower concentrations of crumb rubber and assess its properties for making flexible pavements that are stronger, tougher, more resistant to damages, more durable, and safer for pavement users.

This study is significant in several aspects. Firstly, it makes use of crumb rubber from waste tyres, proving its usefulness in the construction of flexible pavements and validating this as a means of recycling waste tyres that are disposed in insurmountable amounts annually all over the world. Secondly, the study proves that the toughness and hardness of coarse aggregate samples coated with bitumen modified with crumb rubber is quite high making it suitable for road construction purposes. Thirdly, it uses a concentration of 3% to 4% crumb rubber for coating the samples as the particles tend to disintegrate at higher concentrations of crumb rubber in the coating. Therefore, this study proves that lower concentrations of crumb rubber might be more suitable for preparing coarse aggregate particles for road construction rather than concentrations of the order of 10% to 15% and may impart higher safety, efficacy, and usefulness to the aggregate samples thus prepared. Future studies need to further characterize the use of 2% and 3.5% crumb rubber in coating aggregate particles and determine its suitability over higher concentrations of crumb rubber.

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