

## **Using Powder of Waste Robber Tire with Bitumen for Sustainable Construction**

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### **Abstract:**

The alarming increase on environmental degradation due to the effect of old rubber tires among other rubber waste is becoming worrisome. The escalation of vehicles moving on poor Nigerian roads generate huge waste robber tires. Bituminous felt used in flexible pavement construction, damp proof course and membrane is becoming unaffordable due to many factors, such as lockdown caused by global pandemic of COVID-19, among others. This study aimed at evaluating the possibility of a partial replacement of ordinary bitumen by tire rubber waste, with the purpose to reduce not only the amount of rubber wastes dispersed in the nature, but also the material cost, while keeping or improving the bitumen product performance. The study used robber waste powder as partial replacement to ordinary bitumen by 5%, 10%, 15%, and 20% of its weight and, with adequate samples, properties of the bitumen product were investigated, after checking the standard quality of used bitumen 60/70 grade. It was established that more adequate results were achieved at 5% of replacement, which showed the penetration value of 61.66 tenths mm, the softening point value of 52.750C, and the viscosity of 134 sec. Regarding the cost estimation of this new bitumen, a cost reduction of around 15.3% was realized. Therefore, the use of robber waste powder would contribute not only to the reduction of the quantity of respective waste in the environment, but also influence the material affordability. The use of other grades of bitumen than 60/70, as well as the strength and durability performance may be a good scope for further studies.

**Keywords:** Bitumen product, heating, penetration, softening point, waste rubber tire, viscosity.

### **1. Introduction**

Bituminous materials are used widely all over the world in different construction areas like roof waterproofing products, damp proof course/membrane, asphalt for highway, etc. All bituminous materials consist primarily of bitumen which has strong adhesive properties, and a consistency ranging from liquid to solid. On one side, bitumen has been in use as a binding material for many years, and alongside its

performance, it does not only offer a short lifespan of pavements, due to fatigue on loading, etc. (Nagórska et al., 2015), but also its cost has been high and not affordable due to many factors. On the other side, the dumping of old robber tires resulting from traffic increases in developing cities remains a big environmental issue. About 60% of waste tires are disposed of in the urban and rural areas, and they are causing a huge problem both economically and ecologically, (Mbereyaho et al 2020). Recently, studies have been proposing the use of waste robber tire in partial replacement of aggregates for flexible pavement, as a sustainable solution of cleansing the environment (Ongarbaev et al., 2013; Mashaan et al., 2014). The comparison between flexible and rigid pavement regarding their application and respective life span proved that most of the Nigerian roads are built with flexible pavement which in some cases, was not lasting longer due to many reasons like high traffic, excessive loading of trucks, poor adhesion between asphalt and aggregate, the ageing process, as well as materials properties. Locally, the use of old rubber tires would be of many benefits as its amount was increasing, and a sizeable portion was disposed improperly in located and operated dumpsites, resulting in adverse impacts on the environment and health, as they are not degradable (MININFRA, 2019). Currently, the only little amount of waste rubber tires was being used in the fabrication of local shoes.

The main aim of this experimental study was to search for an answer to the following question: Can the tire rubber waste be used in form of a powder as a partial replacement in bitumen, so that to achieve not only an affordable and strong bitumen product, but also to contribute to the environment protection? Therefore, the general objective is to conduct the assessment of properties for bitumen mixed with tire rubber waste powder, and the cost estimation of the new bitumen product. The specific objectives are the following, among others: to identify properties of bitumen and underline the weakness, to collect and prepare the tire rubber waste, to mix the ordinary bitumen with rubber wastes powder and test the new product, as well as to estimate its cost. The tests result like penetration, softening point and viscosity are used to confirm the quality of the newly manufactured bitumen. However, other investigations like on the strength and durability performance, or the use of another grade of bitumen may be a good area for further study. For a matter of consistency, in this study, the ordinary bitumen means standard or conventional bitumen, while bitumen product means bitumen mixed with rubber waste, under laboratory conditions.

## 2. Literature Review

Even if the scope is wide, already different studies have been carried out with waste rubber tires, either alone or with other waste materials to establish their influence on the conventional construction materials, especially when they are used as aggregates for concrete or asphalt. Waste tires have been under use in both concrete and mortars as well as in asphalt mixtures, under different forms and applied methods (Oikonomou and Mavridou, 2009). During their study on the use of rubber crumb for preparation of asphalt-concrete mixtures, Ongarbaev et al. (2013) demonstrated that characteristics of prepared samples had improved and concluded that the respective application to road construction would allow decreasing the environmental pollution with industrial wastes. A study on asphalt concrete made with scrapped tire rubber established the improvement of the resistance to permanent deformation as well as to high temperatures (Gito, 2017). In their overview study, Adeyemi and Awoyera (2019) underlined numerous studies on the use of rubber wastes in concrete; they confirmed improvement of the mechanical properties, compared with conventional concrete, dispute the reported depreciation tendency. In their study about the use of tire rubber waste in different percentages as an additive in foam concrete, Mehrani et al. (2019) concluded that the optimum rubber content of 5% would give the highest workability and strength. Li et al. (2019) conducted a comprehensive review on utilization and reuse of waste tire rubber in concrete as aggregates, and demonstrated how the mechanical properties of concrete, including compressive and flexural strengths, as well as water absorption of concrete, can change.

The use of waste plastic and waste rubber tires in flexible highway pavements may increase both the Marshal stability value and the density of the mix with comparison to 60/70 grade bitumen (Rokade, 2012). While investigating the effect of waste plastic and crumb rubber on physical properties of bitumen, among other conclusions, Chirag (2013) established that the properties of bitumen such as penetration, softening point and ductility were improved with the addition of the waste plastic and crumb rubber. Lo Presti (2013) conducted a literature review study on recycled tire rubber modified bitumen for road asphalt mixtures; dispute many advantages realized, he observed some technology struggle and offered some suggestions for its improvement. In his study, Magar (2014) investigated the modification of bitumen with 15% by weight of crumb rubber with varying sizes and gave recommended sizes to obtain the best results. During their review study on using crumb rubber in the reinforcement of asphalt pavement, Mashaan et al. (2014)

confirmed that utilization of crumb rubber from scrap automobile tire was not only beneficial in terms of cost reduction but also had a less ecological impact in keeping the environment clean. Prasad and Sowmya (2015) also conducted a study on bituminous modification using waste plastic (PET) and crumb rubber and suggested that 6% modifiers by weight of bitumen would be suitable for pavement stability and this use could solve the problem of environmental damage. During their study with the purpose to establish the good mix proportion for rubberized bitumen, Rupesh and Rajesh (2015) concluded that 12% of crumb rubber by weight of bitumen was more suitable for road pavement. The study on the effect of waste tires rubber in asphalt mix showed that the properties of rubber-asphalt mixture are improved in comparison with normal asphalt pavement and recommended an addition of 10% by bitumen weight (Yazan, 2016). The mix of VG-30 bitumen with waste rubber tires as a replacement of aggregates offered permissible material for bituminous road construction (Kumar and Rajakumara, 2016). The investigation on utilization of rubber waste in construction of flexible pavement by Deshmukh and Kshirsagar (2017) observed the improvement of bitumen properties such as penetration value, softening point test, ductility test. A study on bitumen modified with tire rubber powder (TR), waste cooking oil (WCO) and bagasse ash (BA), established that up to 20% of bitumen can be successfully replaced without affecting its performance (Junaid et al., 2019). The application of recycled waste rubber and waste plastic (WRP) into asphalt binder improved both the workability and mechanical properties, and enhanced environment protection (Ling et al., 2019). Finally, Alaa (2019) in his experimental study to show the possibility of tire rubber usage in sand soils, established its influence on the stress-strain and deformation behavior of the mixtures. All other related works but not reviewed in this study are also recognized. This study investigated the performance of bitumen product with partial replacement by tire rubber waste powder, and estimated its affordability when the mixing process was conducted under laboratory conditions.

### **3. Materials and Methods**

3.1. The study objectives stated above, were achieved using action research and well-elaborated methodology. The available waste was checked regarding its quantity and dumping. Then followed by the samples collection, treatment and cleaning to remove organic and inorganic impurities like grasses, mud, etc. The tire rubber waste was cut and heated, and then mixed with bitumen under partial replacement of 5%, 10%, 15%, and 20% bitumen weight. These percentages were selected as practical values to make more feasible the measurement of the portion.

Laboratory tests including penetration, viscosity, and softening point were performed for both ordinary bitumen and bitumen product. The sites used to carry out different preparation works and tests were cleaned to be free from all impurities. The materials sources and preparation process are presented below.

### 3.2. Materials Used and Source

Ordinary bitumen:

in this study, bitumen from Ministry of Works Marini of 60/70 grade was used to investigate the impact of waste tire rubber.



Fig. 1 Shows Bitumen While Preparing the Penetration Samples.



Fig. 2. Depository Sites of Rubber Tire

Before its use, tire waste was treated to ensure accurate results are achieved. The preparation procedure is described as follows: the cleansing and washing, exposure to the atmosphere for removal of the moisture, cutting into small pieces, and their burning with butane flame until the yielding into black powder is completed. The Fig. 3 and Fig. 4 show the rubber waste burning and bitumen heating, respectively.



Fig. 3. Rubber Waste Burning

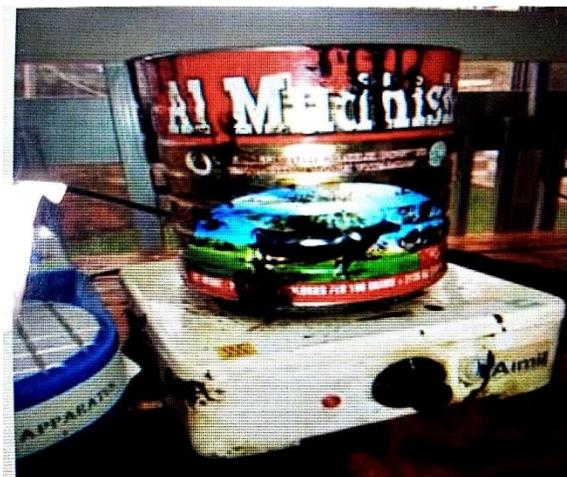


Fig.4. Bitumen Heating

### 3.3. Preparation of Bitumen and Its Mixing with Rubber Waste

The 4 kg of bitumen in the semi-solid state is heated in a 5-litre capacity metal container at 160°C, until it turns into a fluid without any bubble, so that it can be easily removed from the container (Fig. 4). Then the burned tire rubber waste powder is added, gradually replacing bitumen with 0%, 5%, 10%, 15%, and 20% of its weight. The blend was mixed manually for about 4-5 minutes. The mixture was then heated at 160°C and the whole mass was stirred using a mechanical stirrer for about 20 minutes. Care was taken to maintain the temperature between 160°C - 170°C. The bitumen product was cooled to room temperature and suitably stored for testing.

### 3.4. Laboratory Tests

#### Penetration test:

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle would penetrate vertically in 5 seconds. A grade of 60/70 bitumen means the penetration value is in the range 60 to

70 at standard test conditions. In this study, the penetration test was carried out on each sample of bitumen products where obtained data are analyzed to establish the rubber powder percentage corresponding to a better penetration value. The materials used to carry out the test are standard needle, penetrometer apparatus, cans, heater, water, thermometer, kerosene, glycerin. The main tools used for penetration tests are shown in Fig. 5.



Fig. 5. Some Apparatus for the Penetrometer Test. (a) Penetrometer; (B) Penetration Needles Softening Point Test:

The softening point test is used to measure and specify the temperature at which bituminous binders would soften. It represents a certain state of consistency. In this study, the softening point test was carried out on each sample of the bitumen product to establish the percentage at which the product will provide more resistance to temperature action. The materials used to carry out the test are softening apparatus, pair of rings and balls, water, glycerin, metal plate, knives.



Fig. 6. Tools for Softening Test. (A) 600 ml Glass Container; (B) Rings; (C) Rings and Steel Ball

**Viscosity test:** This test determines the dynamic viscosity of the bitumen. The viscosity is greatly influenced by temperature under which it is spread into the voids and it coats the aggregates. In this study, the viscosity test is carried out in order to establish the practical percentage at which bitumen product would provide better viscosity. Materials used are viscometer, thermometer, Brookfield, glycerin, graduated cylinder, stopwatch. The viscometer with bitumen samples should be plugged into the voltage source to raise the temperature up to 600C.

Some of tools for viscosity test. (a) viscometer; (b) thermometer; (c) graduated cylinder; (d) lubricant

### 3.5. Cost Estimation of the Modified Bitumen

The cost estimation was simply executed using the unit cost method, by considering the following factors: the unit cost for ordinary bitumen in the market, the bitumen quantity replaced, and the cost of rubber waste (if any). All test results are presented in section 4.

## 4. Results and discussion

### 4.1. Penetration Test Results (in 1/10 mm)

The results for the test with ordinary bitumen are presented in Table 1.

Test No	Reading 2	Reading 2	Reading 2	Average
1	65	65	63	65.00
2	69	70	66	68.33
3	65	61	63	63.00
		Average		65.43

For bitumen product, the penetration test was conducted for samples prepared with partial replacement by 5%, 10%, 15%, and 20% of waste rubber tires, respectively. Three trials were conducted, and the average results are given in Table 2.

Test No	Reading 5%	Reading 10%	Reading 15%	Reading 20%
1	65.33	58.33	53.67	46.67
2	61.33	57.33	56.67	46.67
3	58.33	57.67	53.33	46.33
Average	61.66	57.78	54.56	46.56

#### 4.2. Softening Test Results

The results from the softening point test show the temperature at which the ordinary bitumen should soften.

The results for test with ordinary bitumen are presented in Table 3.

Final reading	Ball one	Ball two	Average
Softening point Deg. C	48.9	49.8	49.35

The results for the bitumen product are presented in Table 4.

#### 4.3. Viscosity Test Results

For ordinary bitumen, results obtained in seconds are presented in Table 5. Regarding the bitumen product, the respective results are given in Table 6.

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#### 4.4. Estimated Cost of the Bitumen Product

In this study, it was assumed that the tire rubber waste is obtained for free from the false dumping sites in nature. At the time of this study, the bitumen quality 60/70

cost was varying between N272,000 and N317,410 per 500 metric tons (500,000 litres). While proceeding as suggested, it is established that the cost of the bitumen product with 5% of rubber waste would vary from N258,460 to N301,540). Table 4

S/N	Softening point Test 5%		Softening point Test 10%		Softening point Test 15%		Softening point Test 20%	
	Ball 1	Ball 2	Ball 1	Ball 2	Ball 1	Ball 2	Ball 1	Ball 2
Reading								
T deg.C	42.6	42.75	52.5	53.6	55.7	56.6	57.3	59.0
Average	<b>52.75</b>		<b>53.05</b>		<b>56.15</b>		<b>58.15</b>	

Table 5. Data collection for viscosity test of ordinary bitumen

Volume/ml	50	55	60
Time/sec	124	136	142

Table 6. Viscosity test results for bitumen product

Viscosity test for 5% of waste rubber tires					
Volume/ml	40	50	60	70	80
Time/sec	101	134	150	168	180

### Viscosity test for 10% of waste rubber tires

Volume/ml	40	50	60	70	80
Time/sec	123	162	168	184	192

### Viscosity test for 15% of waste rubber tires

Volume/ml	40	50	60	70	80
Time/sec	174	193	212	268	304

### Viscosity test for 20% of waste rubber tires

Volume/ml	40	50	60	70	80
Time/sec	900	1140	1500	1680	1800

## 4.5. Analysis of Results

### 4.5.1. Penetration test results

The comparison was done between ordinary bitumen and bitumen product with 0%, 5%, 10%, 15%, and 20% of tires rubber waste. From the results shown in Table 1 and Table 2, it can be seen that the penetration value for ordinary bitumen was 65.43 mm, while the penetration value for bitumen product was gradually decreasing with an increase of rubber waste. It is worth to note that the lower penetration value means the higher strength of bitumen which makes a harder grade of asphalt and offers additional strength to the road structure. Fig. 8 shows the variation of penetration values in the function of the % of rubber waste.

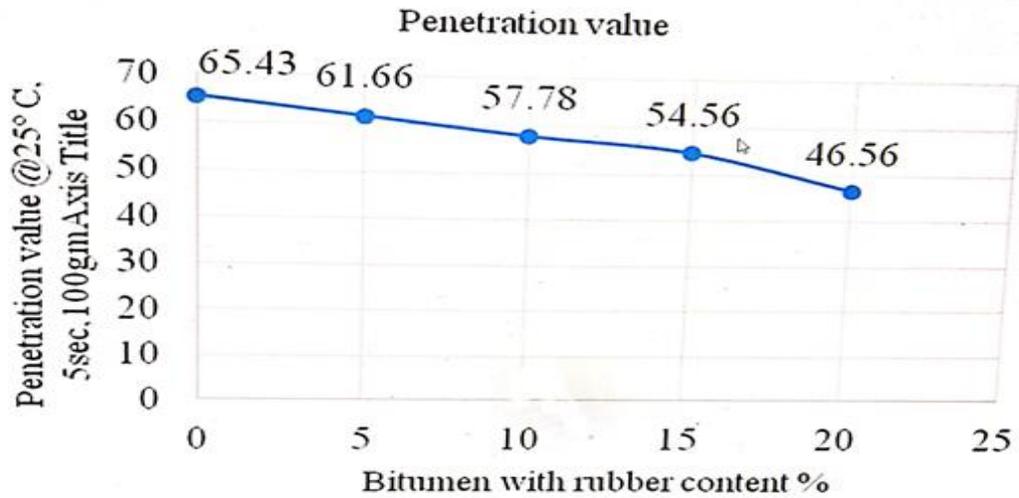


Fig. 8. Penetration value versus % of rubber waste

The addition of tire waste into bitumen improved the penetration properties by increasing its hardness.

#### 4.5.2. Softening point test results

The results illustrated in Table 3 and Table 4 show that the softening point for ordinary bitumen found is 49.350C, while the addition of tire rubber waste adversely affected the temperature by increasing the softening point. Fig. 9 shows the variation of softening temperature with % of tire rubber waste.

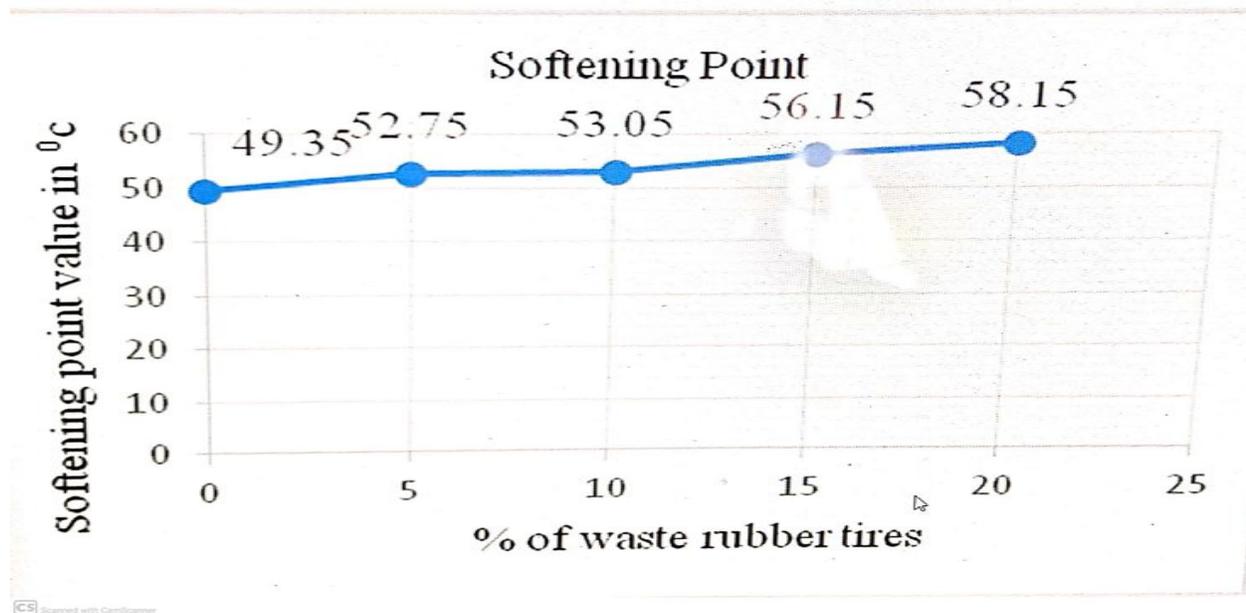


Fig. 9. Softening point Value versus % of rubber waste

As for the penetration, the addition of tire rubber waste in bitumen improved the softening property of bitumen.

#### 4.5.3. Viscosity test results

With regards to the viscosity, results illustrated in Table 5 and Table 6 show that the viscosity value in seconds at 600C for 50 ml of ordinary bitumen was 124 sec. The addition of rubber waste in ordinary bitumen adversely affected the flow of bitumen by increasing the viscosity. The Fig.10 shows the variation of viscosity in seconds with increase in % of tire rubber waste.

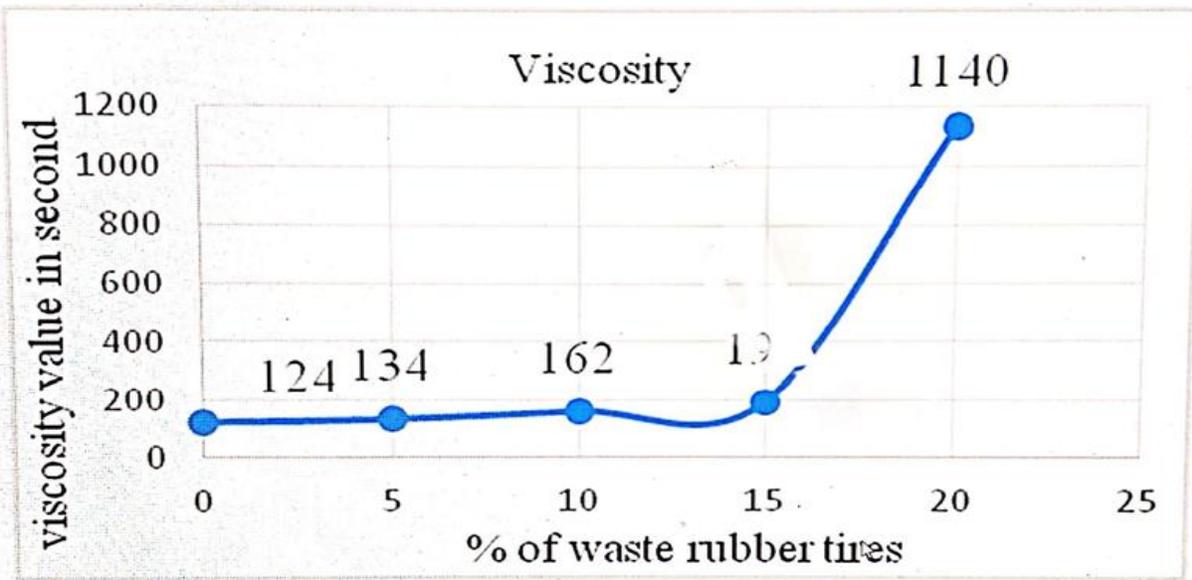


Fig. 10. Viscosity value versus % of tire rubber waste

The increase of viscosity value shows how the bitumen product sticks with the aggregates when used in asphalt preparation.

#### 4.5.4. Cost estimations of the bitumen product and other advantages

The calculated cost of bitumen product shows a decrease of around 13,600RwF - 15,870RwF (around 20USD). This would mean that the replacement of bitumen by 5% of rubber wastes can reduce the cost of 500m<sup>3</sup> bitumen by 5.3%. Therefore, for a big quantity of works with bitumen application, the reduction of used bitumen as well as the decrease of tire rubber waste in the nature would be important.

#### 4.6. Discussion

From the above analysis in section 4.5, the improvement of the bituminous properties with the addition of tire rubber waste rubber was observed. These results

are in line with previous studies (Chirag, 2013; Rupesh and Rajesh, 2015; Gito, 2017; Yazan, 2016; Li et al. 2019). The bitumen product properties tested at 5% of tire rubber waste showed the following results: the penetration value, 61.66 in tenths mm, softening point, 52.750C and viscosity, 134 sec. These results are in line with the AASHTO standards (AASHTO, 2014) which recommend that the penetration values of bitumen with grade 60/70 should be in the ranging of 60 and 70 tenths millimeter, the softening point values from 48 to 560C, while its minimum viscosity should be 100 sec. Therefore, for the used bitumen 60/70 grade, this replacement of 5% should be recommended. From results on cost estimation of bitumen, it was shown that the extensive use of waste rubber tires in bitumen would not only make the respective construction relatively affordable, but also save the environment. This is also in line with some previous results (Ongarbaev et al., 2013; Mashaan et al., 2014).

## **5. Conclusion and Recommendation**

The main objective of this study was to investigate the use and influence of tire rubber waste powder in bitumen products. It was confirmed that the quantity of rubber waste was increasing in nature due to the development of tire manufacturing industries and challenges regarding the respective waste disposal. Also, it was observed that while the application of bitumen in construction was increasing, the bitumen cost was not much affordable. While available studies have been considering rubber waste as aggregates and in addition to bitumen, this study used rubber waste powder as partial replacement to bitumen and checked properties of the modified bitumen. The penetration, viscosity and softening tests were conducted with ordinary and bitumen products with a replacement of 0%, 5%, 10%, 15%, and 20% by respective rubber waste. The established test results were in line with standards values. For the used bitumen of 60/70 grade, the study observed that penetration values were decreasing with an increase of % of rubber waste, and the standard value was achieved at 5% of replacement. Therefore, it was recommended that the replacement should be limited to 5% by weight of bitumen, in order to achieve the same grade. Regarding the cost estimation of bitumen, a cost reduction of around 5.3% was realized. Based on all those results, it is concluded that the application with the replacement of rubber waste powder in bitumen product would contribute not only to the gradual reduction of the quantity of respective waste in the environment, but also in some measures influence on the bitumen material affordability. The use of tire rubber waste powder can also improve the performance of bituminous flexible pavement. In order to protect the environment against

inhuman gases from the burning of tire rubber waste, the use of incineration burning method is recommended. Finally, further studies either using other grades of bitumen than 60/70 or checking other bitumen properties like strength, durability, etc. are welcome.

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