

# The Effects of Waste Tire Rubber on Penetration, Softening Point, Viscosity, Ductility, Flash Point, Specific Gravity, Solubility and Aging of Bitumen Used in Kenya

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## ABSTRACT

This study was carried out to assess the effect of rubber on conventional bitumen used in road construction in Kenya. This study aimed at characterizing the effects of modifying bitumen with waste-crumbled rubber. The properties of penetration, softening point, viscosity, ductility, solubility, flash point, specific gravity and aging characteristics of bitumen were analysed. The samples of tire rubber were obtained from the dump sites location in Donholm and bitumen samples for penetration grade 80/100, were purchased from Colas East Africa in Nairobi County. The results obtained in this study showed that penetration of bituminous binders reduced from 88 to 41 tenths of a mm at 20 % rubber content. This implied that modified binders became more harder with addition of rubber as a modifier and can withstand fluctuating temperatures of asphalt pavements. Softening point, a candidate also crucial for pavement temperature susceptibility, increased from 48.8oC to 63.9oC at 20 % waste rubber content. This showed that the modified binders can withstand the elevated temperatures of asphalt pavement surfaces. The flashpoint and specific gravity of the neat and rubber-modified binders did not significantly because tire rubber is not very flammable and is of almost same specific gravity as bitumen of 1.1g/cc. Viscosity at 135oC increased from 304.3cSt to 330.7cSt at a waste rubber content of 12% and became unworkable at rubber content beyond 12% when determined using the

standard reverse flow viscometers method. Ductility at 25°C reduced from 135.5cm to 48.3cm as 3% to 20% waste tire rubber was added, implying that the rubber makes bituminous binders stiffer. Solubility decreased from 99.6% to 98.3% when 20% of rubber was added implying that addition of more rubber increased impurities in the bitumen. The loss on heating due to aging increased from 0.2% to 0.4% at 12% rubber content and further increased to 1.2% at 20% waste tire rubber content. This showed that the quantity of volatiles increased with addition of more waste tire rubber.

Keywords : Waste Rubber, Asphalt Pavement, Elevated Temperature, Bitumen, Highways, Kenya

## I. INTRODUCTION

The performance of Hot Mix Asphalt in countries that lie in the tropics has not always satisfied the need of road users, where in some cases, road pavements have failed after a short time of construction and use according to Department for International Development (DID, 2002). High temperatures of 27°C characterized by the climate in these countries on average, making the bitumen used softer than normal (DID, 2002). This calls for the need to enhance bitumen used and develop a design of mix that can withstand an extensive range of temperature variations. Asphalt pavement defects include rutting, cracking, potholes, surface disintegration, and stripping cases (DID, 2002) which are shown Figures 1.1 - 1.5 below.

### 1.1: Asphalt Pavement Failures

#### 1.1.1: Pavement Rutting

According to data from the Ministry of Transport and Infrastructure, the Figures below are some of the asphalt pavement failures noticed on the Kenyan road A109 along Mombasa Road (MOTI, 2013). Several sections from Machakos turn-off (Figure 1.1) experienced several road pavements distresses. This was the situation of severe rutting and shoving on Mombasa Road at Salama Town (Figure 1.2), Sultan

Hamud (Figure 1.3), Emali Town (Figure 1.4) and Makindu Town (Figure 1.5) along the busy class-A highway in 2013 which have since been rehabilitated.



Figure 1.1: Rutting on Mombasa Road, Machakos Turn off



Figure 1.2: Rutting on Mombasa Road, Salama Town



Figure 1.3: Rutting on Mombasa Road, Sultan Hamud Town



Figure 1.4: Rutting on Mombasa Road, Emali Town



Figure 1.5: Rutting on Mombasa Road, Makindu Town

This study was undertaken to determine the possibility of improving the loss in the good properties of bitumen binders, leading to the deterioration of bitumen pavements in Kenya (Zhang et al., 2018). The effects of traffic loading on road pavements cause natural aging processes resulting in

poor performance of bitumen binders (Chen et al., 2019).

### 1.1.2: Pavement Cracking

Pavement cracking Figures 1.6 (a) and (b) are manifested by large interconnected rectangles that are not due to heavier loads but are a result of the rigidity of bitumen at high and low temperatures (ORN 18, 1999). Oxidation is the irreversible chemical reaction between oxygen molecules and the component species of bulk asphalt resulting in a change in the physical and/or mechanical properties of asphalt. Oxidative aging of asphalt is believed to be caused by the generation of oxygen-containing polar chemical functionalities on asphalt molecules (Okan Sirin et al., 2018).

Bitumen oxidation in a pavement is a complex process where the bitumen organic components undergo a reaction with atmospheric oxygen and ultraviolet (UV) radiation from the sun for a prolonged time and as a result, the pavement surface is hardened, which leads to pavement cracking at low temperatures under traffic loading as shown in Figures 1.6 (a) and (b) (Okan Sirin et al., 2018).



Figures 1.6 (a): Pavement cracking of asphalt pavement



Figures 1.6 (b): Pavement cracking of asphalt pavement

Kenya is a vast country lying in the tropics with varying climatic conditions, terrains, construction materials, and mixed traffic conditions of heavy and light road loads. The main transport corridor from the port of Mombasa through the capital city of Nairobi to the border towns traverses through different climatic conditions with different temperatures and rainfall (World Bank, 2020). Because of this, there is a need to use quality binders on our roads for satisfactory pavement performance. Scrap tires are readily and locally available and, to some extent, waste for disposal. The waste tires at Donholm dump site in Nairobi County shown in Figures 1.7 (a) and (b) depict the challenge of waste tire disposal in Kenya.



Figure 1.7 (a): Waste tires at Donholm in Nairobi County



Figure 1.7 (b): Waste tires at Donholm in Nairobi County

In recent times, it is becoming apparent that waste rubber and plastic disposal is becoming a challenge to environmentalists in Kenya Figures 1.7 (a) and (b). For instance, all vehicles running on the Kenyan roads today use rubber tires, and the question remains as to where they end up at the end of use (Figures 1.7 (a) and (b)). Kenya enacted the Environmental Management and Coordination Act (EMCA) in 1999 to help as a platform to deal with environmental issues. The relevant environmental laws are anchored in EMCA 1999, which gave birth to National Environmental Management Authority (NEMA). However, the most striking and missing link is the issue of specific disposal of waste tires and the role of NEMA, which is tasked to regulate matters to do with the environment. At the current rate, the tires presently produced in the world will undoubtedly increase in the future as automotive industries are growing exponentially (Yuen Fook & Balaraman, 2018). During their manufacture and depending on the tire's intended use, some compounds of copper, cadmium, and zinc end up in the final product (UNEP, 2011).

The raw materials for the manufacture of tires contain butadiene and styrene, which are hazardous to human health and carcinogenic. Burning tires produce styrene, a benzene derivative (Carman, 1997). Several products of decomposition are emitted during the burning of tires, including carbon, zinc oxide, titanium dioxide, silicon dioxide, cadmium, lead, and

other heavy metals (UNEP, 2011). According to UNEP (2011), sulphur compounds, polycyclic aromatic hydrocarbons (PAHs), aromatic oils, carbon and nitrogen oxides, particulates, and various light-end aromatic hydrocarbons (such as toluene, xylene, and benzene) are also emitted. UNEP (2011) pointed out that burning tires (in the open air emit smoke that has carbon dioxide and carbon monoxide, which are part of the greenhouse gases and contribute to the greenhouse effect (UNEP, 2011).

## 1.2 : Composition of Bitumen

According to Kaseer et al. (2019), bitumen is one of the products that comes from the chemical distillation of crude petroleum at 350-380 °C with the pressure considerably higher than atmospheric. The two sources of asphalt are natural deposits and petroleum residues (Rudyk, 2018). Chemical characterization of bitumen is complicated because bitumen is a compound combination of 300 to 2000 chemical elements (Michele Porto et al., 2019). Bitumen's chemical composition is highly complex (Ensley et al., 1984). According to the most accepted analysis by Topal et al., (2012), bitumen can be classified into the following three main fractions Asphaltenes, Maltenes, and Carbenes.

### 1.2.1: Asphaltenes

Asphaltenes is mainly composed of carbon (80–88 %) and hydrogen atoms (10–12 %), thereby has a hydrocarbon content of around 90 %, and the rest of the components are made up of heteroatoms and metals (Okan Sirin et al. 2018). Heteroatoms include nitrogen (0-2 %), oxygen (0-2 %), and Sulphur (0-9 %). Metal atoms include vanadium, nickel, and iron, which are in minimal trace quantities of less than 1 %. Hydrocarbons form the core composition of asphalt, whereas heteroatoms form many of asphalt's distinctive physical and chemical components by reacting with molecules.

Asphaltenes are not soluble in hydrocarbon solvents that are light, petroleum ether included. Asphaltenes contain oxygen, nitrogen, sulfur, metals vanadium, nickel and iron in the form of complexes such as metallo-porphyrins with long aliphatic chains (up to 30 carbon atoms), and pyrrolic and pyridinic rings (Porto et al., 2019).

### 1.2.2: Maltenes

Maltenes dissolve in hydrocarbon solvents and carbenes fraction cannot dissolve in carbon tetrachloride (Topal et al., 2012). Maltenes are composed of four elements: nitrogen base, first acidaffins, second acidaffins, and Paraffins. The maltene portion can be further sub classified into oils and resins. Maltenes are then divided into saturate aromatic, and resin (Michele Porto et al., 2019) which jointly with asphaltene, are known as the bitumen SARA (Saturate, Aromatic, Resin, Asphaltene) fraction, as shown in Figure 1.8

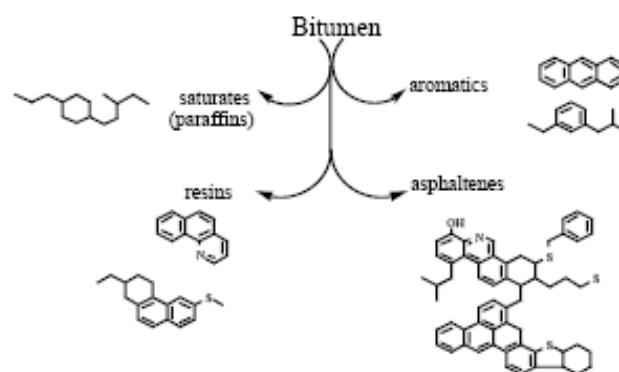


Figure 1.8: Bitumen SARA structure  
(Masson et al., 2001)

The asphaltenes correspond to a compound mixture of elements, according to Mullins (2008), are defined by their solubility features, not by a specific chemical categorization. A typical physical definition of asphaltenes is that they can dissolve in toluene and not in n-heptane. Mullins (2008) states that other lower-carbon alkanes are at times used to separate asphaltenes.

The asphaltene portion and fraction of the maltene form the discrete phase. The lower molecular weight

maltenes are said to form the unbroken phase (Topal et al., 2012). It is considered that Asphaltenes are tiny particles enclosed by a resin as the outside layer. The oil acts as a mode through which the asphaltene resin can survive. Asphaltenes make up the body, resins provide gumminess and ductility, and oils contribute to the thickness and flow (Topal et al., 2012). As demonstrated by UV-fluorescence spectroscopy, Fourier transform infrared spectroscopy (FTR), and NMR spectroscopy (Scotti et al., 1998; Mullins, 1998), asphaltene molecules are made up of approximately 4-10 units of fused aromatic rings and some aliphatic chains as ring constituents, as shown in Figures 1.9 (a) and (b)

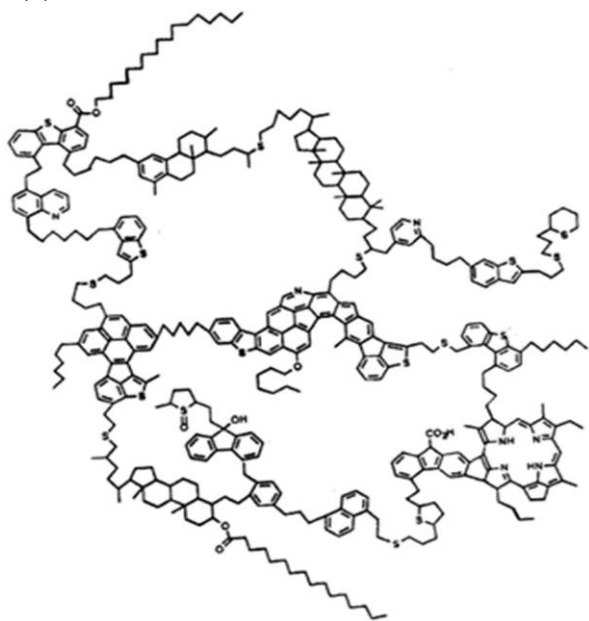


Figure 1.9 (a) Archipelago structure

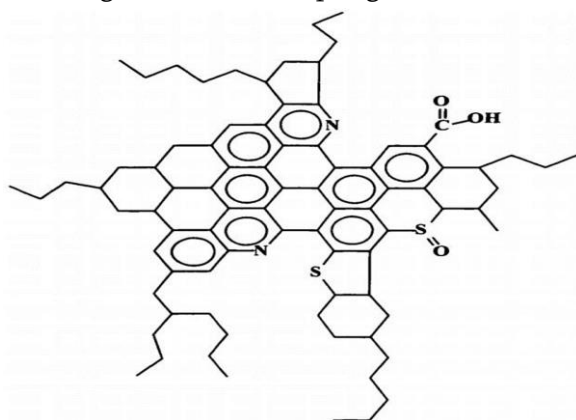


Figure 1.9 (b) Continent structure

Figure 1.9 (a) Asphaltene hypothetical and Figure 1.9 (b) Continental structures as per (Mullins, 2008, Murgich, et al, 1999)

### 1.2.3 Carbenes

Carbenes cannot dissolve in carbon tetrachloride but can dissolve in carbon disulfide (Scotti, 1998). The carbenes are present in minimal amounts in asphalt.

### 2.1: Study area

The study was carried out in Nairobi County, Kenya's capital city with a population of 4,397,073 from the national population census (GOK, 2019). The metropolitan area which includes Counties of Machakos, Kiambu and Kajiado has a population of 9,354,580 (GOK, 2019). The study area lies at latitude of  $1^{\circ} 9'S$ ,  $1^{\circ} 28'S$  and longitude of  $36^{\circ} 4'E$ ,  $37^{\circ} 10'E$

### 2.2: Chemicals and reagents used

This study was done using several chemicals and reagents which served different purposes. Trichloroethylene was used in finding out the solubility of asphalt binders for cleaning the viscosity reverse flow viscometers. Methylene Chloride for determine solubility of asphalt binders and also for cleaning the viscosity reverse flow viscometers. Glycerol in immersion chambers for determination of viscosity and flash point.

### 2.3: Instruments and apparatus used

The instruments used in this research included Penetrometer for penetration value of binders, a Ring-and Ball apparatus for temperature at which bitumen sample starts to melt. Cleveland Open Cup to determine Flash point for asphalt binders. Ductilometer for ductility of asphalt binders while reverse flow viscometers were used to obtain the viscosity of the asphalt binders. Analytical balances were also used for weighing samples and ovens used for heating of samples.

## 2.4: Sample collection

Fresh uncontaminated samples of straight run bitumen 80/100 conforming to standard requirements in the Standard Specification for Road and Bridge Construction were sourced from bitumen importers Colas East Africa where 40 liters was considered sufficient for this study. Aggregates were sourced from locally available aggregate dealers Aristocrats Limited. Aggregates were tested for conformity to toughness, durability, resistance to abrasion and flakiness as specified in the Road Design Manual Part III (Ministry of Transport and Communication, 1987). The tests that were done on both the neat and rubber modified bitumen were Penetration, Softening point, Flash point, Ductility, Aging test, Viscosity, Specific gravity, and Solubility. These tests were carried out to assess how modification of bitumen with waste tire rubber (Figures 1.7 (a) and (b)) affected the properties of unmodified straight run bitumen.

All these tests were done as per AASHTO, (2006) and their equivalent ASTM test methods (2006).

## 2.5: Bitumen modification and analysis

The tests that were done on both the neat and tire rubber modified bitumen to determine effect of rubber on the penetration, softening point, flash point, ductility, viscosity, specific gravity, aging test and solubility of bitumen samples.

### 2.5.1: Penetration

Penetration was done using a Penetrometer (AASHTO: T 49-06 Standard, 2006). Eight clean tins, one for the neat and the others for varying percentages of tire rubber were used to analyze penetration through sample 80/100 tenths of a millimeter. The seven tins were each filled halfway with 3kg of bitumen samples. Ground rubber was added under heat into the seven of the tins in varying percentages of weight of rubber by weight of bitumen in the percentages of 3 %, 5 %, 8 %, 12 %, 15 %, 18 % and 20 % and thoroughly mixed well by stirring using an electric stirrer. Eight sets of penetration cans were

also prepared and the preheated bitumen samples from the eight sets was poured into separate penetration cans to a minimum of 10 millimeter above the estimated penetration depth and analyzed using penetrometer equipment which allowed the needle to drop vertically downwards into the sample for five seconds and gives the distance of penetration to the nearest 0.1mm, the readings were recorded.

### 2.5.2: Softening Point

The heat level under which bitumen sample starts melting is known as the Softening point and was determined using a Ring-and Ball Apparatus (AASHTO: T 53-06 Standard, 2006). The apparatus consists of two rings and a 3.5 g standard ball and centering guides. Eight heated rings were placed on a metal plate with a coating of glycerol and filled with the heated liquid bitumen samples and allowed to cool (AASHTO: T 53-06 Standard, 2006). The centering guides were placed on each of the rings followed by the standard balls. The cold samples were then each placed in a container of cold water and the softening point determined using the Ring and Ball apparatus. The apparatus consists of a ring holder designed to support the two rings in a horizontal position in water or glycerol container. The temperature at which the samples melted and fell off the rings was measured automatically and recorded.

### 2.5.3 : Flash Point

Flash point was determined using the Cleveland Open Cup (AASHTO D 92, 2006) where the temperature at which the bitumen sample could catch fire was determined. This test is important because it ensures that handling of samples is done at temperatures at which there is no risk of fire outbreak (ASTM D 92, 2018). The bitumen samples were heated in an open cup to a high enough temperature that can make it catch fire in an open flame. The heat level under which it ignited was recorded as the flash point. The aim was to determine how rubber can affect and influence the flash point.

#### 2.5.4: Ductility Determination

Ductility is used to describe the ductile and tensile nature of bituminous binders. Ductility was determined by AASHTO T 51-06 standard (2006) method using a ductility machine called Ductilometer (ASTM D113, 2017). Ductilometer machine pulled the sample in a standard size briquette at a specified speed of 5cm per minute and the distance at which the stretched sample breaks was noted.

The elongation achieved in centimeters when the stretched sample breaks is the ductility of the binder. Ductility is the distance to which a briquette specimen of the binder can elongate at specific temperature and rate of pull. In doing this test sixteen ductility molds were filled separately with preheated bitumen samples. At room temperatures the cold molds were placed in a Ductilometer and pulled at the standard speed of 5cm per minute and the distance at which the stretched samples broke was noted as its ductility in centimeters. The test was performed at ambient temperatures of 25°C and is believed to reflect the homogeneity of the binder and its ability to flow.

#### 2.5.5: Viscosity Determination

Viscosity is the measure of resistance to flow of a liquid in m<sup>2</sup>/sec or in centistokes. Kinematic viscosities of the neat and modified binders were determined using (AASHTO T 201, 2015) standard (ASTM D 2170-95,1995). The method embraces use of U-Tube modified reverse flow viscometer at 135°C. The thermometers used were standardized at total immersion in oil bath controlled to 135°C. 20 ml of test specimen of each of the eight samples were permitted to stream through the viscometer and the time measured to within 0.1sec the time it takes the leading edge of the meniscus to move from the first timing mark to the second was recorded. If a sample gave an efflux of less than 60 sec another viscometer of smaller capillary was used to repeat the test. A total of three readings were made for each of the samples

tested. The kinematic viscosity is given by the calibration constant of the viscometer multiplied by the time taken in seconds.

For standard viscometers the time of flow of affixed fluid volume is directly proportional to its kinematic viscosity. Kinematic viscosity = Ct, where; “C” is the calibration constant of the viscometer and “t” is the efflux time.

#### 2.5.6: Specific gravity

The test was performed using AASTHO T228-06 (2006) standard an equivalent of ASTM D70-97 (2017). The sample was heated until it became sufficiently fluid to flow. A clean pycnometer was filled with water and mass of pycnometer plus water denoted as (B) noted. Weight of the empty pycnometer was taken as (A). The sample was poured into the pycnometer to about three quarters its full capacity without touching the sides of the pycnometer and allowed to cool for one hour and the mass of the pycnometer plus sample taken and noted as (C).

$$\text{Specific gravity} = (C-A)/((B-A)-(D-C))$$

Where; A=mass of pycnometer

B=mass of pycnometer+water

C=mass of pycnometer +sample

D=mass of pycnometer +sable +water

#### 2.5.7: Solubility determination

The test was performed using AASTHO T44-03 (2014) standard an equivalent of ASTM D2042-97, (2015). 2g of sample was transferred into 125mL Erlenmeyer flask and allowed to cool. 100mL of trichloroethylen was added in small amounts until the sample dissolved. The sample was filtered through glass fiber pad and the insoluble material was washed dried and weighed. The percent soluble was given as;

$$\% \text{ Solubility} = (B-(C-A))/B * 100$$

Where; A=mas of crucible+filter

B= mass of sample

C=mass of crucible+filter+insoluble material



### 2.5.8: Aging test determination

This test was performed using AASHTO T 240-06 (2006) standard test method where bitumen was heated while placed in an oven for 5 hours and 30 minutes at 163 °C and the effects of air and heat was determined from the changes in physical tests values as measured before. The method (AASHTO T 240-06, 2006), indicates the aging of bitumen during hot mixing and laying at about 150 °C as indicated by viscosity and other rheological measurements.

The samples were placed in a ventilated oven with a plate rotating 5-6 times per minute and maintained at 163 °C for 5 hours 30minutes. The samples were

placed when hot in pans approximately 55mm diameter and 35mm thickness. The aged samples were removed and previously done tests of penetration, softening point, flash point, ductility, and viscosity were repeated.

## II. RESULTS AND DISCUSSION

### 3.1: Test Results for Neat straight Run Bitumen

The neat bitumen was analyzed for conformity to the standard test given in the Standard Specification for Roads and Bridges (1986), which gave the results shown in Table 3.1

Table 3.1 : Penetration depth for neat bitumen (80/100 grade)

Test Description	Neat Bitumen	Specification as Per STD Spec (1986)		
		Minimum	Maximum	
Penetration Grade 80/100				
Penetration 25 °C (100g, 5s) 0.1mm	88	80	100	
Penetration (after RTFOT) %	77	50		
<b>Original Pen.</b>				
Softening point (Ring and Ball) °C (NEAT)	48.8	45	52	
Softening Point (after RTFOT) °C	50.2	45		
Flash Point (Cleveland Open Cup) °C	250+	225		
Viscosity at 135 °C (VIRGIN) cSt	304.3			
Viscosity at 135°C (AFTER RTFOT) cSt	315.1	CHANGE		
Ductility at 25°C (cm)	135.5	100		
Ductility at 25°C (AFTER RTFOT), cm	124.8	75		
Specific gravity at 25 °C, g/cc	1	1	1.05	
Thin Film Oven Test (TFOT) 5 hrs. at 163 0c) %	0.2		0.5	
Solubility in Trichloroethylene (%)	99.9	99		

Table 3.1 shows that the neat sample was a penetration grade 80/100 bitumen with penetration of 88 and all the other parameters conforming to specifications for 80/100 penetration grade bitumen and therefore was deemed fit for this study (Ministry of Roads and Public Works (1986).

### 3.2 : Test Results for Rubber Modified Bitumen

The modification of the neat bitumen with varying percentage tire rubber ranges from 3 %, 5 %, 8 %, 10 %, 12 %, 15 %, 18 %, and 20 %, the following results were obtained for the different proportions (Table 3.2).

Table 3.2 : Test results for the tire rubber modified bitumen 80/100 grade

Test description	Results									Specification for 80/100 as Per STD Spec	
	0%	3 %	5 %	8 %	10%	12%	15%	18%	20%	MIN	MAX
Rubber Added %	0%	3 %	5 %	8 %	10%	12%	15%	18%	20%		
Penetration 25°C (100g, 5s) 0.1mm	88	81	79	72	66	61	55	44	41	80	100
Penetration (After RTFOT) % Original Pen.	77	71	65	60	56	47	42	38	33	50	
Softening point (Ring and Ball) °C (NEAT)	48.8	49.2	50.6	54.2	55.4	56.2	59.1	62.3	63.9	45	52
Softening Point (after RTFOT) °C	50.2	50.7	50.9	60.3	61.1	61.6	63.0	66.8	67.2	45	
Flash Point (Cleveland Open Cup) °C	250+	250+	250+	250+	250+	250+	250+	250+	250+	225	
Viscosity at 135 °C (VIRGIN) cSt	304.3	316.3	322.7	325.6	328.9	330.7	-	-	-		
Viscosity at 135°C (AFTER RTFOT) cSt	315.1	330.4	331.9	333.8	-	-	-	-	-		
Ductility at 25°C, cm	135.5	121.2	111.5	89.1	77.4	60.0	55.3	50.9	48.3	100	
Ductility at 25°C (AFTER RTFOT), cm	124.8	111.2	103.1	79.3	68.6	51.6	44.2	39.1	32.6	75	
Specific gravity at 25°C, g/cc	1.00	1.01	1.02	1.02	1.03	1.04	1.05	1.06	1.07	1.00	1.05
Thin Film Oven Test (TFOT), Aging Test (Loss on Heating), %	0.2	0.1	0.2	0.2	0.2	0.4	0.7	0.9	1.2		0.5
Solubility in Trichloroethylene, %	99.9	99.6	99.6	99.5	99.3	99.1	99.0	98.8	98.3	99	

### 3.2.1: Penetration

The addition of varying percentages of tire rubber to neat bitumen 80/100 penetration grade altered the properties of the bitumen significantly (Table 3.2). The penetration reduced from 81 to 41 as the percentage of rubber was increased from 3% to 20% (Table 3.2). The aged samples gave penetration values slightly lower from 71 – 33 (From Table 3.2) as the percentage of tire rubber was increased from 3% to 20% (Table 3.2) notably that all the penetration values reduced as more rubber was added (Figure 3.1). The variation in penetration was because the aged samples became harder due to aging.

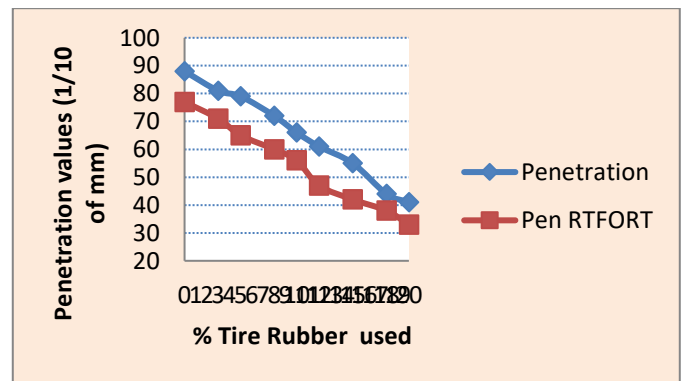


Figure 3.1 : Penetration of bitumen sample against percentage tire rubber used

### 3.2.2: Softening Point

The softening point of both the neat and rubber modified bitumen increased as more tire rubber was added. Addition of 3% and 5% tire rubber gave 49.2

°C and 50.6°C which did not have a significant effect on the softening point of bitumen (Table 3.2). Addition of 8% of rubber gave 54.2 °C as softening point (Figure 3.2). The softening point increased drastically for the aged modified bitumen to 67.2 °C when 20% of rubber was added, but was at 63.9 °C for the unmodified bitumen (Table 3.2). This implied that modified aged bitumen was less susceptible to temperature induced deterioration (Swetha & Rani., 2014) and thus field conditions of high pavement surface temperatures will be a factor of less concern in tire rubber modified asphalt concrete mixes (Figure 3.2). This implied that tire rubber modified bitumen was less susceptible to temperature variations compared to unmodified bitumen.

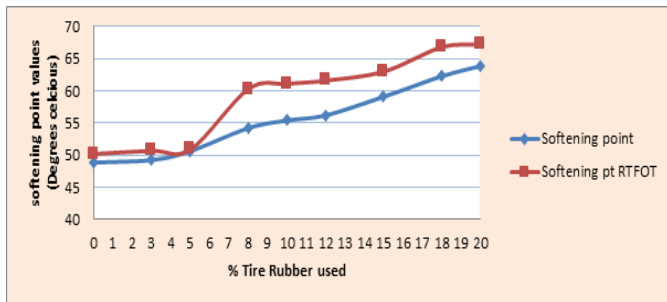


Figure 3.2 : The softening point of bitumen sample against percentage tire rubber used

**3.2.3: Flash Point**

Flash point for both unmodified (Table 3.1) and tire rubber modified bitumen was all above the standard required minimum of 225°C (Table 3.2) as per the Standard Specification for Roads and Bridges (1986). This implied that use of tire rubber in bitumen modification did not pose any risk of fire outbreak during preparation of the mixes at high temperatures.

**3.2.4: Viscosity**

From the results obtained it was noted that viscosity of unaged rubber modified bituminous binders increased as more tire rubber was added from 31.3 cSt to 322.7 cSt at 135 °C with 3 % to 5 % added tire rubber (Table 3.2). Addition of 12 % rubber gave the maximum value of viscosity of 330.7 cSt. (Figure 3.3). It was noted that the viscosity at 135 °C of more than

12 % tire rubber added was undeterminable using standard reverse flow viscometers as the tire rubber modified bitumen became very viscous to flow through the viscometers. This implied that percentages higher than 12 % of tire rubber modified bituminous binders could be a candidate for fatigue cracking in tire rubber modified asphalt concrete mixes at low pavement temperature (Kishore & Gottala., 2015)

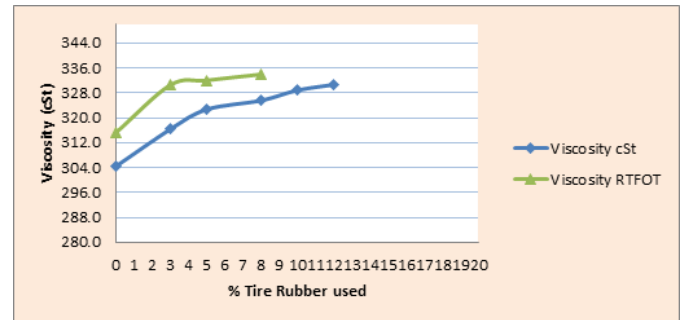


Figure 3.3: The viscosity of modified bitumen sample against percentage tire rubber used

**3.2.5: Ductility**

Ductility of both the unaged bitumen binder decreased from 121.2cm at 25°C to 48.3cm at 25°C while the aged tire rubber modified bitumen decreased as more tire rubber was added from 111.2cm at 25°C to 32.6cm at 25°C as tire rubber was increased from 3 % to 20 % (Table 3.2). It was further noted that tire rubber addition to bituminous binders reduces the ductility of the binders by 10 % at 3 % to 64.4 % at 20 % tire rubber added (Table 3.2) thereby suggesting that the binders became stiffer with addition of more tire rubber (Swetha, & Rani 2014).

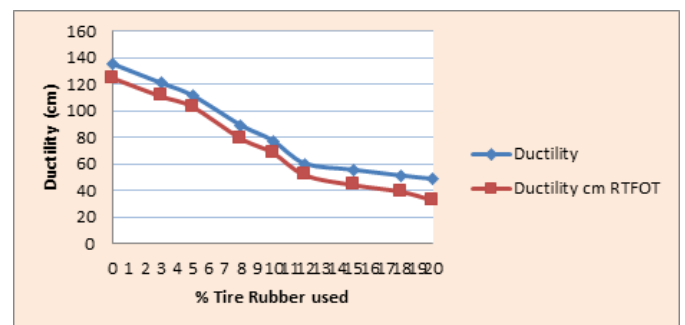


Figure 3.4 : The ductility of bitumen sample against percentage tire rubber used

This factor is of concern in addressing the ever-increasing traffic and heavier loads on the Kenyan roads.

**3.2.6: Specific Gravity**

Addition of waste tire rubber to bituminous binders had little effect on the specific gravity of bituminous binders (Table 3.2) though the specific gravity increased as more tire rubber was added (Figure 3.5) hence rubber modified binders can withstand higher traffic loads as the binder became stiffer with addition of rubber (Swetha & Rani., 2014).

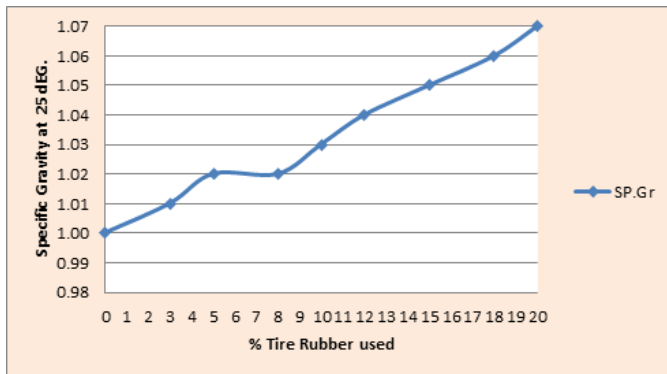


Figure 3.5 : The specific gravity of bitumen sample against percentage tire rubber used

**3.2.7: Loss on Heating/Aging test**

When the rubber modified bitumen was aged, there was a tremendous loss on heating as more tire rubber was added (Figure 3.6). The addition of 15 % tire rubber and above was more prone to loss on heating which implied that addition of more tire rubber increased the quantity of volatiles by 0.7 % in the tire rubber modified binders (Table 3.2). Therefore, the optimum rubber content should be a quantity less than 15 % tire rubber added as above this the maximum (Kishore & Gottala, 2015) specification of less than 0.5 % given in Table 3.2 was violated.

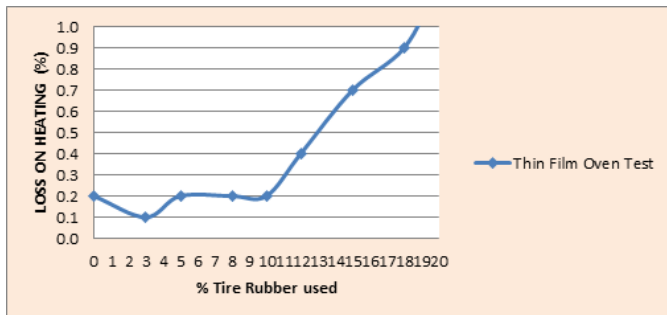


Figure 3.6 : Quantity loss of volatiles on heating of bitumen sample against percentage tire rubber used

**3.2.8: Solubility**

Data obtained from this study showed that the solubility of rubber bituminous binders decreased from 99.6% as more tire rubber was added (Table 3.2) to 98.3 % at 20 % rubber added. The common practice is that bitumen binder solubility in trichloroethylene should not be way below 99 %. The study showed that 15% tire rubber content had 99.0% solubility thus higher percentages of rubber in bitumen modification could be prone to many impurities thereby compromising the quality of the binder (Figure 3.7).

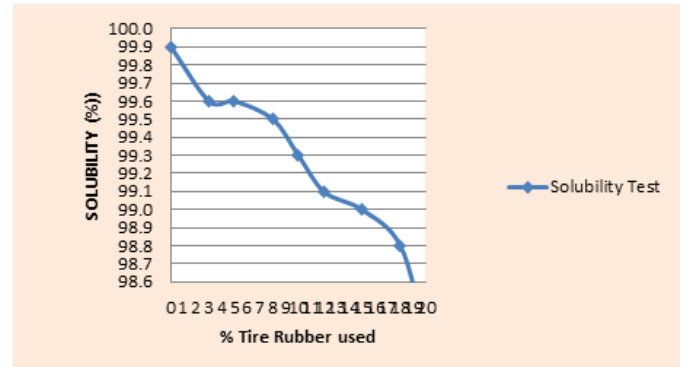


Figure 3.7 : The solubility of rubber bituminous binder sample against percentage tire rubber used.

**III.CONCLUSION**

This research culminated to a number of findings when waste tire rubber was used to modify bitumen. The study showed that penetration of rubber tire modified bitumen depends on the amount of rubber added with the penetration value reducing as more rubber is added. There was uniform reduction in penetration as more rubber was added on aged tire rubber modified bitumen. It was also noted that the softening point and viscosity increased as more tire rubber was added implying that addition of rubber to bitumen makes it less susceptible to temperature induced damage. However, loss on heating increased as more tire rubber was added implying that too much rubber could be detrimental to improving the

characteristic of bitumen. It was also found that solubility decreased as more rubber implying that the bitumen could become more contaminated with addition of too much tire rubber. Ductility reduced with addition of more tire rubber to bitumen making the bitumen stiffer thus less susceptible to increased temperatures.

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