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Determination of the Properties of Natural Rubber Crumb –Modified Bitumen Blends (NRCMB)

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Abstract

Bitumen is a complex mixture of organic molecules comprising mainly of hydrocarbons and it is use as a binder in constructions and in tarring of roads. This study was conducted to investigate some of the physical and mechanical properties of bitumen modified with natural rubber crumb (NRC) when cured and when left uncured. Five different blend ratios (2%, 6%, 10%, 14% and 18%) NRC by mass of the bitumen were used as modifiers. Penetration, softening point, Viscosity and Ductility tests were conducted on the ordinary bitumen and the blends. These basic property tests were used to explain the effect of natural rubber crumb and vulcanization on the binder (bitumen). Tests conducted gave a penetration value for ordinary bitumen 60/70 grade as 50.0mm and the value decreased to 32.5mm, 20.5mm, 19.8mm, 18.0mm and 17.4mm as the blend ratio increased from 2% to 18% respectively for the vulcanized mix and 46.0mm, 40.0mm, 36.0mm, 38.0mm and w41.0mm for the un-vulcanized blends as the blend ratio also increased from 25 to 18%. For softening point, 40^{0}C was enough to soften ordinary Bitumen but as the blend ratio increased from 2% to 18%, the temperature increased to 53.0^{0}C, 56.0^{0}C, 59.0^{0}C, 62.0^{0}C and 66.0^{0}C respectively for the vulcanized mix and for the uncured, 50.0^{0}C, 52.0^{0}C, 48.0^{0}C and 46.0^{0}C respectively. As the blending ratio increased, Viscosity also increased from 8seconds for the ordinary bitumen to 12sec, 23sec 50sec, 72sec and 84sec for the vulcanized mix and 10sec, 15sec, 27sec, 39sec and 48sec for the un-vulcanized mix respectively. Similarly, ductility also increased from 105cm for the ordinary bitumen to 124.0cm, 136.0cm, 151.0cm, 178.0cm and 200cm for the vulcanized blends and 115.0cm, 120.0cm, 129.0cm, 139.0cm and 152.0cm for the un-vulcanized mix respectively. These findings shows that NRC can be used to influence the chemical and physical properties of bitumen binder.

1.0. Introduction

An efficient and adequate system of transportation is inevitable for the development of any country. Of the different means of transportation, road transport is the most significant one. A high traffic intensity in terms of overloaded commercial vehicles and significant variations in daily and seasonal temperature of the pavement have been responsible for early development of distress symptoms like raveling, undulations, rutting, cracking, bleeding, shoving and pot holing of bituminous surfacing [1]. Road construction is currently paved with asphalt owing to its good flexibility apart from the price that is lower than that of concrete. Over the years, road structures have deteriorated more rapidly due to increases in service traffic density, axle loading and low maintenance services. To minimize the damage of pavement surface and increase durability of flexible pavement, it is necessary to improve the quality of bitumen by a material which can play the role as a binder to achieve the following properties; increasing viscosity and elasticity, diminution of temperature susceptibility, aging resistance and ameliorate of cohesion, resistance to permanent deformation (rutting) and fatigue cracking [2]. Formation of gullies poses one the greatest environmental hazards in many towns and villages in Nigeria [3] and a huge number of these gullies are as a result of failed roads.

Bitumen is a complex mixture of organic molecules. Elementary analysis of bitumen manufactured from a variety of crude sources show that most bitumen contains: Carbon 82-88%, Hydrogen 8-11%, Sulphur 0-6%, Oxygen 0-1.5%, and Nitrogen 0-1%. Although the chemical composition is very complex, it is possible to separate bitumen into four main chemical compositions [4]. These are: Asphaltenes, Resins, Aromatics, Saturates. The four groups are not well defined and there is inevitably some overlap between these groups.

The improvement of bitumen to have those properties with various methods is continually being researched. The use polymers to mix bitumen that is called "Polymer Modification Bitumen or Asphalt". Natural rubber is a kind of polymers used for modifying the asphalt properties. Some properties that are advantages such as stability, elasticity and fatigue resistance will be the better 9supplementary to bitumen properties and to extend aging of roads which can be help to save budget of maintenance [5].

There are many modification processes and additives that are currently used in bitumen modifications, such as styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) natural rubber (NB) and crumb rubber modifier (CRM). The use of commercial polymers, such as SBS and SBR in road and pavement construction will increase the construction cost as they are highly expensive materials [6]. This research will focus on modifying bitumen with Natural Rubber Crumb (NRC). This is because NRC is readily available in Nigeria and also it is affordable compared to the other additives previously investigated.

Natural rubber is developed in latex form from rubber trees, which is by provenance, an agricultural commodity, mostly belonging by the spurge family name *Euphorbiaceae [7]*. Rubber is harvested mainly in the form of latex tapped from rubber tree. In addition to its raw rubber compound, water and minor impurities such as proteins and resins are included in this latex form [8]. Among the natural rubber used in asphalt modification from previous research are mostly in the form of latex because mixing with natural rubber latex provides the most efficient product compared with other form in equal quantity [9] and some other used Ribbed Smoked Sheet (RSS) and Liquid Natural Rubber (LNR). In spite of its effectiveness as a modifier, this potential application seems to increase domestic consumption as much as possible in order to add value to domestic natural rubber dealing and at the same time give better overall performance in the bituminous mixes toward better flexible roads [10].

In view of its chemical properties, which normally in latex appearance, this polymer make up in cis-1,4-polyisoprene with a chemical formula of $(C_5H_8)_n$ that composed of carbon and hydrogen atoms alone with high molecular weight [11]. Due to its double bond presence in each repeated unit, polyisoprene can be created synthetically (synthetic natural rubber) and also susceptible to undergo vulcanization. Vulcanization is the process of adding sulphur into latex to improve raw rubber constituents in which change the thermoplastic elastomer properties of natural rubber into a thermoset [12]. Natural rubber largely exhibits elasticity due to its high stretch ratio and resilience characteristic. This happens due to a lot of complex molecular chains of polyisoprene, when under loading, performed almost linear chains and wrinkled back to its position when the load is removed [13]. As it is agricultural product, natural rubber is a renewable material and the only biomass that strain crystallizes that occur spontaneously at low temperature or when it is stretched, hence lowering the elasticity value [14]. Since vulcanization is suggested, rubber creates disulfide bonds between chains, limiting its degree of freedom and the chains speedily tighten. Thus, the rubber is harder and less extensible because of increasing in elastic force. It should be noted that the final

properties of rubber item depend highly on modifiers and fillers such as carbon black, factice, whiting and a host of others instead of the polymer itself.
The aim of this research is to investigate the effect of rubber-bitumen interaction and its mechanical properties such as Penetration, Melting point, Viscosity and Ductility. This is to develop an understanding of the level and blend ratio in which natural rubber modifier expands and diffuses into the bitumen binder, the causes and measuring the effect the modifier will have on the binder.

2.0 Materials and Methods

2.1 Collection of Samples

Natural Rubber (ribbed smoked sheet) was obtained from Pamol rubber factory, Oghara, Ethiope West Local Government Area, Delta state and the bitumen binder used for this research was obtained from Total Petroleum PLC, Warri-North, Delta State.

2.2 Preparation of Samples

The dried rubber sheet was masticated with two roll mill at temperature of 70^0c for 30 minutes and then cut into pieces. The natural rubber of smaller sizes were dissolved in toluene in a bid to make it liquid. Vulcanization procedure was done by adding the various curing agents (Sulphur, zinc oxide, and mercaptobenzothiazole) to bitumen at ratios of 2%, 6%, 10%, 14% and 18% by weight, blended together at 85^{o}C to 95^{o}C for 2-3hrs. The blend was stirred constantly for the period to homogenize the mix and was incubated at 80^0c for 12hrs for it to cure properly. This was done for the samples that were vulcanized while the uncured samples were blended and incubated with the same conditions without the addition of curing/vulcanizing agents.
The properties of the ordinary bitumen and natural rubber modified bitumen blends (i.e. 0, 2, 6, 10, 14, 18% samples) both vulcanized and un-vulcanized samples were tested for penetration value, ductility, softening point, and viscosity.

Table 1. Blend for vulcanized mix

% BLENDING	2%	6%	10%	14%	18%
BITUMEN	200g	200g	200g	200g	200g
RUBBER	4g	12g	20g	28g	36g
SULPHUR	1.6g	2.4g	4g	5.6g	7.2g
ZINC OXIDE	5g	5g	5g	5g	5g
MCBT	2g	2g	2g	2g	2g

Table 2. Blend for un-vulcanized mix

% BLENDING	2%	6%	10%	14%	18%
BITUMEN	200g	200g	200g	200g	200g
RUBBER	4g	12g	20g	28g	36g

2.3 Test for Mechanical Properties of Samples

Four tests were carried out on the Natural modified Bitumen blends to determines their performances on vulcanization and when left un-vulcanized. These tests are Penetration, Melting point, Viscosity and Ductility.

2.3.1 Penetration Value Test

The penetration test determines the hardness or softness of bitumen. The penetration of a bituminous material is the distance in tenths of a millimeter that a standard needle will penetrate vertically in to a sample of the material under standard conditions of temperature, load and time. The sample was maintained at a temperature of 25°C. The bitumen was softened (heated to about 60^{o}C) to a pouring consistency, stirred and was poured into a container to depth of 15cm, then it was placed in a temperature controlled water bath for one hour. The sample with container was taken out and the needle was arranged to make contact with the surface of the sample. The dial is set to zero or the initial reading is taken and the needle was released under pressed weight of 100gm for 5 seconds, the test was carried out for three different times. The final readings were taken on dial gauge and mean values were recorded as penetration value.

2.3.2 Softening Point Test

Softening point is the degree of temperature in which the sample will start to change from solid to liquid state. The temperature at which the substance attains a particular degree of softening under specified condition of test. Softening point was used to determine the temperature at which a phase change occurs in the binder. A softening point apparatus was used for this experiment.
The binder mix (sample) is fed into the ring. The ball is placed on top the ring holding the binder mix. The beaker is filled with water and the set-up is placed inside the beaker that the water submerged the apparatus. A thermometer is placed in the ring holder which helps to record the temperature at which the phase changes. The heat is turned on and at the temperature where the ball hit the bottom of the apparatus is recorded as the softening point temperature of the binder. At this temperature, the binder transits from solid state to liquid state.
The softening points of the ordinary bitumen and NR-bitumen samples are determined at three different times and the means are recorded as the softening points. Graph of mean softening points were plotted against %VNR

2.3.3 Viscosity

Viscosity is defined as inverse of fluidity. High or low fluidity at mixing and compaction has been used to result in lower stability values. The viscosity of ordinary bitumen and natural rubber-bitumen samples are investigated by using Thermal Brookfield Viscometer at 135^{0}C. The test was carried out for three different times and the mean was determined which are the viscosity value and were recorded, and a graph of mean viscosity was plotted against %VNR.

2.3.4 Ductility Test

The bitumen sample was melted to a temperature of 75 to 100°C above the approximate softening point and then poured in the casting assembly and placed on a brass plate, after a solution of glycerin and dextrin was applied at all surfaces of the mould exposed to bitumen. 30 to 40 minutes after the sample was poured into the plate assembly along with the sample was placed in water bath maintained at 27°C for 30 minutes. The sides of mould were removed and the clips were carefully hooked on the machine without causing any initial strain. The pointer was set to read zero. The machine started and the two clips were thus pulled apart horizontally. While the test is in operation, it was checked whether the sample was immersed in water at depth of at least 10 mm. The distance at which the bitumen thread of each specimen breaks, was recorded (in mm). The test was carried out for three different times and the mean was reported as ductility values. And a graph of mean values was plotted against %NR.

3.0 Results and Discussions

For this study, we have used 60/70 grade bitumen obtained from NNPC Warri depot. When the bitumen is tested for the viscosity, penetration, softening point and ductility without adding polymer (rubber) it shows the following results: Penetration 40mm, Sotening point temperature 40^0C, Viscosity 8seconds and Ductility 112mm.
This bitumen is used as base bitumen and then it is further modified with natural rubber crumb (NRC) at different percentage for vulcanized and un-vulcanized mix.

Table 3: Results for Vulcanized Mix Tests

TEST (%NRC)	PENETRATION (mm)	SOFTENING POINT (^{O}C)	VISCOSITY (sec)	DUCTILITY (mm)
2%	32.50	53.00	12.00	124.00
6%	20.50	56.00	23.00	136.00
10%	19.80	59.00	50.00	151.00
14%	18.00	62.00	72.00	178.00
18%	17.40	66.00	84.00	200.00

Table 4: Results for Vulcanized Mix Tests

TEST (%NRC)	PENETRATION (mm)	SOFTENING POINT (^{O}C)	VISCOSITY (sec)	DUCTILITY (mm)
2%	32.50	53.00	12.00	124.00
6%	20.50	56.00	23.00	136.00
10%	19.80	59.00	50.00	151.00
14%	18.00	62.00	72.00	178.00
18%	17.40	66.00	84.00	200.00

3.1 Penetration

In terms of penetration value, the base bitumen used to test is 60/70 Grade and its penetration value is 50mm. Modifying the bitumen by adding the natural rubber crumb (NRC) at ratios of 2, 6, 10, 14 and 18% and vulcanizing, showed penetration values of 32.5, 20.5, 19.8, 18.0, and 17.4mm respectively. It was observed that as the rubber concentration is increased, the penetration value was reduced. The reduction in penetration value shows the tendency of strength and ability to resist sheer force such as that caused by underground water, erosion, and the force caused by vehicle wheels, loads and heavy objects. For the un-vulcanized mix, as the NRC was added the penetration values of the binder are 46.0, 40.0, 36.0, 38.0, and 41.0 respectively. As the rubber content was increased, the penetration values decreased and had the minimal penetration value (36mm) when 10% rubber by weight of the bitumen was added. Increasing the rubber content to 14 and 18% by weight of the bitumen, the penetration value increased to 38mm and 41mm respectively. It was shown that excess NRC affected the dispersion of rubber in bitumen causing the bitumen to be softer and thus have a higher penetration value.

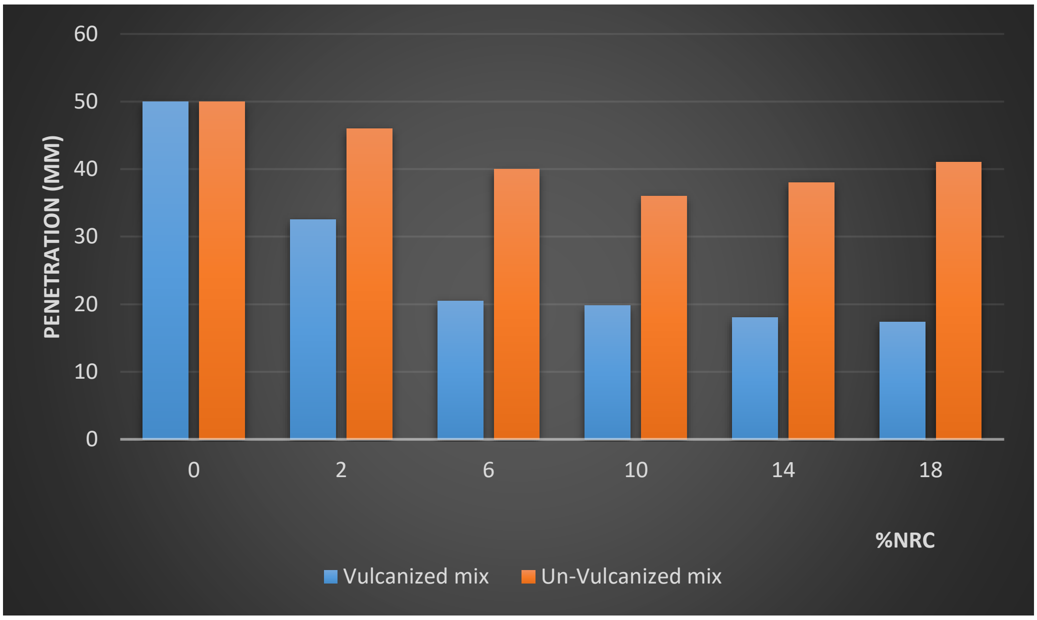

Figure 1: Penetration

3.2 Softening Point

Test result on softening point for the un-modified 60/70 Grade bitumen is 40^{0}C. On modifying with rubber in ratios of 2, 6, 10, 14 and 18% by weight of the bitumen and vulcanizing gave softening temperatures of 53, 56, 59, 62 and 66.0^{o}C. As the rubber content is increased, the temperature at which the binder changes phase from solid to liquid becomes higher. The suitable explanation to this observation is that rubber is a macromolecule with long chain and has a three dimensional network which diffuses into the bitumen composed of polar aromatic materials dispersed in paraffin materials making the residual mix to be hard resulting to a difficulty in softening the mix. The higher softening point is very practical for temperate countries. For the un-vulcanized mix, 2, 6, 10, 14 and 18% by weight of the rubber was added and the softening temperature are 49.0, 50.0, 52.0, 48.0, and 46.0^{o}C respectively. The hardness of the mix was increasing as the rubber content increased and was maximum (52^{o}C) at 10% by weight rubber of the bitumen and it decreased on adding 14 and 18% by weight of rubber from 48.0 to 46.0^{o}C respectively. This may be due to the fact that un-vulcanized rubber does not show toughness and tenacity and thus becomes softer and susceptible to the effect of temperature as the un-vulcanized rubber content is increased. For un-vulcanized mix, 10% showed maximum hardness and toughness.

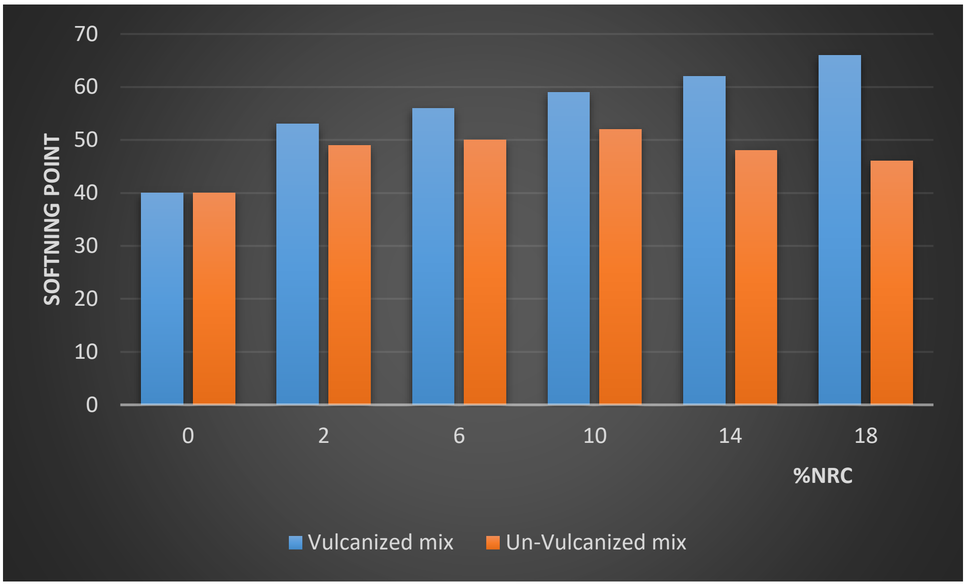

Figure 2: Softening point

3.3 Viscosity

Test result on viscosity for the un-modified 60/70 Grade bitumen is 8 seconds. On modifying with rubber in ratios 2, 6, 10, 14 and 18% by weight of the bitumen plus vulcanizing gave viscosity of 12, 23, 50, 72 and 84 seconds respectively. The viscosity increased as the rubber content increased and thus has a higher resistance to flow as the rubber content is increased. The same observation was made by Charles Albert [15] when they also used CR to modify bitumen. Nopparat [9] suggested that very high resistance to flow will affect bitumen mixture with aggregate as the mixer will be unable to spray the asphalt being mixed with aggregate and it may cause the mixture system to clog. For the un-vulcanized mix, the viscosity also increased steadily as the vulcanized mix though with lesser values. The values moved from 10, 15, 27, 39 and 48 seconds as the weight of the rubber increased from 2% to 18%. This result indicated that the fluid property and the resistance to flow is lesser compared to the un-vulcanized mix.

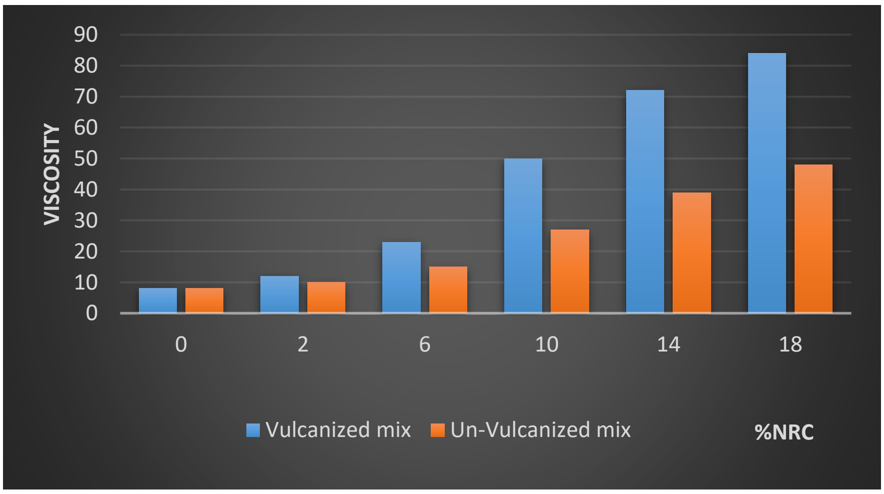

Figure 3: Viscosity

3.4 **Ductility**

Test result on ductility for the un-modified bitumen is 112mm. On modifying with rubber in ratios of 2, 6, 10, 14 and 18% by weight of the bitumen and vulcanizing gave ductility of 124, 136, 151, 178, 200mm respectively. The steady increase in ductility is as a result of the rubber introducing its characteristic of being elastic to the mix. The ductility reports the ability and extent to which the material can stretch before it breaks. As the rubber content is increased, the extent to which the binder mix can stretch is improved. It also reported torsion recovery of the residual mix.

For the un-vulcanized mix, 2, 6, 10, 14 and 18% by weight of the rubber was added and the ductility are 115, 120, 129, 139, 152mm. just as for the vulcanized mix, the ability for the binder mix to stretch increases as the rubber content is increased but not as much as that of the vulcanized mix. This is probably because the elastic nature of the polymer is improved on vulcanization.

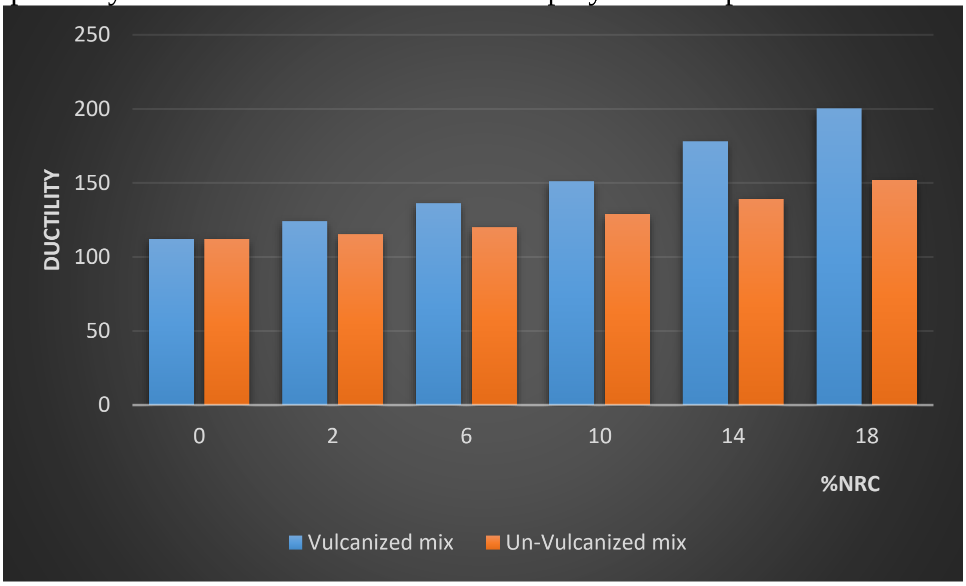

Figure 4: Ductility

4.0. Conclusion

From the experiments to the analysis of results, it can be concluded that the performance characteristics with respect to minimizing failures such as fatigue, cracking, rutting, moisture and temperature susceptibility improves when bitumen is modified with natural rubber crumb (NRC). Vulcanization also affects the resulting mix as a significant difference is observed for penetration value and softening point temperature when the vulcanized mix was compared with un-vulcanized mix while no significant difference was observed in the ductility and viscosity property when the vulcanized and un-vulcanized mix was also compared.

Conflict Of Interest

The authors declare no conflict of interest in this work.

Reference

[1] Krishnapriya M. G (2015) Performance Evaluation of Natural Rubber Modified Bituminous mixes. *International journal of civil, structural, environmental and infrastructural engineering research and development* 5(1) 121-134

[2] Goodrich J.L (1988). Asphalt and polymer modified asphalt properties related to the performance of the asphaltic concrete mixes. In: Technologists PotAoAp, editor; p. 116-75

[3] E.O Mezie (2020). Investigation into the causes of Gully Erosion in parts of Anambra state. Journal of Science and Technology Research 2(1) 2020 pp. 139-149

[4] Airey, G. D., Hunter and Collop A. C. (2008). The Effect of asphalt mixture gradation and compaction energy on aggregate degradation. Construction and Building materials, 22:5 972-980

[5] Naha, S. Mashaan, Asim Hassan, Mahrez Abdelazizb (2012). An overview of crumb rubber modified asphalt. International journal of physical science volume 7 (2). Pp. 116-170.

[6] Becker Y., Mendez M. P., and Rodriguez Y. (2001). Polymer modified asphalt. Vision Technologica, 9 (1), pp. 39-50.

[7] Maria Castro, Jose A. Sanchez (2006). Fatigue and healing of asphalt mixtures: Discriminative analysis of Fatigue curves. ASCE Journal of transportation.
[8] Bouchet C. (1999). Study of the modification of properties of the rubber due to the bituminous treatment. MEng final year report, school of Civil Engineering, the University of Nottingham.
[9] James E. Mark, Baruk, Erman (2005). Science and technology of rubber. Page 768
[10] [10] Nopparat Vinchilolchai, Jaratsri Panmi, Nuchanet Na-Raning (2012). Modification of asphalt cement by natural rubber for pavement construction.
[11] Y. Ikeda, S. Kohjiya (2014). Chemistry, manufacture and application of natural rubber. Woodhead/Elsevier, Oxford. Chapter 4.
[12] A. Y. Coran (2013). The science and technology of rubber. Academic press, 4th edition Chapter 7; Edited by B. Ermen, J. E. Mark, C. M. Roland
[13] J. S. Chen, M. C. Liao and H. H. Tsai (2002). Evaluation and optimization of the engineering properties of polymer-modified asphalt. ASM International Practice failure analysis; Volume 2.
[14] H. Urakawa, Y. Yugudi (2002). Polymer gels fundamentals and applications edited by H. B. Bohida, Y. Osada. ACS, Washington DC.
[15] Charles Holbert, Jaroslaw Drelich (1997). Viscosity of Bitumen rubber blend (New paving material). Department of Metallurgical engineering, University of Utah, Page 452.