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Laboratory Investigation of using Agricultural and Solid Waste in Hot-Mix Asphalt for Road Pavement

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ABSTRACT

Disposal of huge amount of discarded waste materials being generated in large quantity causes environmental hazards. This study utilized the discarded waste materials as partial replacement of constituents in asphaltic concrete. Crushed palm kernel shells (CPKS) and crushed periwinkle shells (CPWS) were used to partially replace fine aggregate at 10%, 20%, 30%, 40% and 50% by weight of total aggregate. In addition, crumb tyres (CT) was used to partially replace bitumen. Properties of modified asphalt mixtures such as Marshall Stability and flow value were investigated in accordance with ASTM D1559. Laboratory results show that CPKS and CPWS have an optimum stability value of 3.03 kN and 3.06 kN at 30% and 20% replacement respectively. The addition of CT gives an optimum stability value of 2.76kN at 30% replacement. At the best performing percentage replacement obtained, CPKS, CPWS and CT can be used in the production of binder course for light to medium trafficked roads according to the Asphalt Institutes Standard 1997. This will reduce the construction cost and thus bring about sustainable development.

Keywords: Bitumen, Solid waste, Hot-Mix Asphalt, Marshall Stability Test, Pavement.

1. INTRODUCTION

The increasing cost of conventional materials such as bitumen and aggregate used in the production of asphalt for road construction has hindered the pace of infrastructural development in developing countries like Nigeria. In addition, the volume of waste generation and disposal is on the increase around the world especially in developing countries like Nigeria. In Nigeria, about 1.5 million tons of palm kernel shells are produced per annum; most of which are often dumped as waste products Nuhu-Koko (1990). With the intension of preserving the living environment and in line with Sustainable Development Goal 9 (SDG Goal 9) of the United Nations (UN) that requires the development of innovative technology to repurpose old materials, there is the need for research in the recycling and reuse of the waste materials. The need for engineering consideration of the use of cheaper and locally available materials to reduce the construction cost for sustainable development (Dj. Mendjel *et al*. 2018; Balakrishna *et al*. 2017) cannot be over-emphasized. Therefore, there is the need to provide alternative or locally available materials to replace the conventional materials, to construct durable infrastructure for sustainable development at affordable cost (Ukpaka Chukwuemeka Peter and Okochi Godspower Ikechukwu, 2018; Murthy *et al*. 2017; Akshay Baxi *et al*. 2018). This paper presents the results of study on the reuse of waste materials such as palm kernel shells (CPKS), crushed periwinkle shells (CPWS) and crumb tyres as partial replacement for fine aggregate and bitumen in asphaltic concrete.

2. LITERATURE REVIEW

Asphalt is a composite material used to construct the surface layer of a flexible pavement. Large dependency on the conventional materials for asphalt production results in high and increasing cost of these materials that has greatly hindered the development of road pavement facilities in developing countries like Nigeria.

Shubham *et al*. (2017) worked on the evaluation of modified bituminous concrete mix; they found that partial replacement of bitumen with waste plastic gives an increase of 16% strength while rubber material gives about 50% increment in strength as compared to the conventional mix. Accordingly, Olutaiwo and Owolabi (2015) carried out an investigative study on the effects of partial replacement of coarse aggregate with graded palm kernel shells in asphalt binder course. Marshall Stability test conducted established that PKS was a viable agricultural waste product that could be used as coarse aggregate at a specific percentage in the production of asphaltic binder courses for light to medium trafficked roads.

In addition, Ndoke (2006) investigated the potential of palm kernel shells as coarse aggregate in road binder course; he focused on the strength of the asphalt as required by the Marshall Stability and flow values. He inferred that PKS could be utilized to replace coarse aggregate up to 10% for heavy traffic roads and 100% replacement was possible for light traffic roads in rural areas. In the research carried out by Mohammed *et al.* (2014) on the preliminary assessment of some properties of asphaltic concrete, using crushed palm kernel shell to partially replace fine aggregate (sand); the study established that the replacement of some proportions of fine aggregate (sand) with crushed palm kernel shells has the capacity to positively affect some properties of asphaltic concrete.

Oyedepo and Oluwajana (2014) and Adewaleb *et al.* (2015) investigated the properties of bitumen modified with used tyres. Basic tests like penetration, softening point, viscosity, flash and fire point and ductility test were done by using shredded waste tyres which varied from 0% to 20% by weight of 60/70 penetration grade bitumen at 160^{0}C using dry mix method. Penetration value decreased with addition of 20% tyres while significant increase in softening point, viscosity, flash and fire point were obtained with the corresponding values of 80.9^{O}C, 250.96 sec and 189/280.12^{O}C respectively were obtained. Furthermore, Oyedepo *et al.* (2015) investigated the use of PKS as partial replacement for aggregate in asphaltic concrete; (CPKS) and PKS were added at 20, 40, 50, 60 and 80% by weight of total aggregates to replace the fine and coarse aggregates in asphaltic concrete. It was concluded that modifying bituminous materials would reduce the cost of highway maintenance and construction.

In the research by Suched and Thanakorn (2016) on laboratory investigation of the performances of cement and fly ash modified asphalt concrete mixtures, results indicated that cement and/or fly ash were advantageous in terms of improved strength, stiffness and protection against stripping of asphalt mixture. The findings also showed that the strength, stiffness and moisture susceptibility performances of the asphalt concrete mixtures enhanced by filler are similar to the performance of the polymer modified asphalt mixture.

The impacts of modifying bituminous concrete with crumb rubber and waste shredded thermo-plastics was investigated by Harish and Shirakumar (2013); huge increments in properties like Marshall stability and indirect tensile strength were observed in comparison with traditional mix. Dahunsi *et al.* (2013) performed a research on the utilisation of shredded pure water sachets (PWS) to modify bitumen at various percentages. They affirmed that increase in viscosity decreases with subsequent increase in PWS while the values of the softening point increased with respect to increase in PWS.

It was reported that New Zealand produces around 3 million waste tyres per year, with estimates varying from 2.2 to 4 million waste tyres per year (Sweet, 2004). However, Sweet (2004) also reported that this number is expected to increase due to increase in the number of vehicle and importing of used tyres. According to Ebewele and Ozong (1990) and Aisien *et al.* (2002), an estimated 5 million scrap tyres from truck, cars and motorcycles existed in Nigeria in 1983; with an annual generation rate of 15%, this was projected to about 15 million scrap tyres. Therefore, this paper carries out laboratory investigation on the use non-conventional material in hot-mix asphalt for road pavement that will bring benefits to highway maintenance and rehabilitation and improved pavement performance.

2.1. Overview of the Waste Materials

Palm kernel shells (PKS) shown in Figure 1 are derived from the oil palm tree (*Elaeis guineensis*), an economically valuable tree, and native to western Africa and widespread throughout the tropics (Omange, 2001). They are used in agriculture for the production of palm oil. The African oil palm *Elaeis guineensis* is native to West Africa, occurring between Angola and Gambia. The group name is derived from the Greek word for oil, *elaion,* while the name of species referred to its country of origin (Sulyman and Junaid, 1990). In Nigeria, about 1.5 million tons of PKS are produced every year; most of which are dumped as waste products (Nuhu-Koko, 1990). The waste could be converted to wealth by using it in the production of asphaltic concrete.

Periwinkles (*Nodilittorina radiata*) shown in Figure 2 are little greenish blue marine snails with spiral cone shaped she and round gap. They are regular in the riverine territories and seaside areas of Nigeria where they are utilized for food. The hard shells, which are seen as wastes is of high environmental concern as it is characterised by unpleasant odour and constitutes an unpleasing appearance in open-dump sites situated at strategic places, are now being considered as coarse aggregates in full or partial replacement for expensive, unaffordable or unavailable crushed stones or local washed gravel.

Figure 1 Palm Kernel Shell

Figure 2 Periwinkle Shell

Improperly managed waste tyres can create critical ecological concerns which includes fires and breeding space for mosquitoes when dumped or stored in large heaps, and harm to landfills when disposed on the land. Burning tyres discharge dangerous air poisons and may create poisonous oils. Burning tyres release toxic air pollutants and may generate toxic oils. According to NIPPON steel technical report number 86 July 2002, the number of waste tyres released, however, also increased from 0.36 million tons in 1970 to over 1 million tons in 1997, posing a serious problem related to the preservation of the environment. Minnesota Pollution Control Agency (MPCA) 2012 found that crumb rubber could be utilised in asphalt paving or as a substitute for rubber or similar elastic material. Tyre shreds are used as lightweight fillers in the construction of public roads. Tyrechips used as a substitute for ordinary aggregate in construction when the extent of substitution isn't more than one to one by volume. This does exclude utilization of tyre chips as general construction filler or clean fill. Recycled Tyres Rubber (RTR) obtained from waste tyres shown in Figure 3 has been used in asphalt by the paving industry since the 1960's. RTR has been utilised as modifier of asphalt binder and asphalt mixture additive in gap-graded and open-graded asphalt mixtures and surface treatments.

Figure 3 Waste Tyres Stockpile

3. MATERIALS AND METHOD

3.1. Materials

The periwinkle shells were obtained from Rumuji town, Rivers State while, palm kernel shells and the crumb tyres were sourced in Akure, Ondo State Nigeria. Impurities, for example, soils and other dirt were expelled and the shells were sun dried and oven dried at a temperature of 40^{O}C and crushed. The mineral filler, stone dust, river sand and granite of various sizes were carefully selected and free from deleterious materials. A 70/80 penetration grade bitumen was procured from Ondo State Asphalt Company (OSAC) Akure.

3.2. Method

Aggregates test such as aggregate crushing value (ACV) and aggregate impact value (AIV) were conducted in accordance with BS 812-110; 1990. In addition, bitumen penetration test, water in bitumen test, flash and fire test in accordance with ASTM D5-97 and BS 2000-487; 2009 was performed on bituminous binders to evaluate their properties and suitability as road construction materials.

3.2.1. Bitumen Penetration Test (ASTM D5-97)

The penetration test is used as a measure of consistency. A higher penetration value is an indication of softer consistency. Figure 4 shows the penetration test and softening point test of binders.

Figure 4 Penetration Test

Figure 5 Water in Bitumen Experimental Set Up

3.2.2. Water in Bitumen Test (ASTM D95-99)

It is alluring that the bitumen contains least water content to avoid foaming of the bitumen when it is heated above the boiling point of water. The water in bitumen is determined by blending a measured weight of sample in an undiluted petroleum distillate that is free from water, heating and distilling of the water. The weight of the water condensed and gathered is expressed as percentage by weight of the original sample.

Calculate the water in the sample, as weight or volume percent, in accordance with the basis on which the sample was taken, as follows:

$$\text{water}(\%) = \frac{(\text{volume in water trap-water in solvent})}{\text{volume in test sample}} \qquad (1)$$

3.2.3. Flash and Fire Point Test (ASTM D92-01)

The flash point and fire point test method is a dynamic method and depends on definite rates of temperature increases to control the precision of the test method. It's essential use is for viscous materials that have flash point of 79°C (175°F) and above. It is also used to determine fire point, which is a temperature above the flash point, at which the test specimen will support combustion for a minimum of 5s. Figure 6.0 shows the flash and fire experimental set up. The surrounding barometric pressure was observed and recorded at the time of the test. When there is a pressure difference from 101.3 kPa (760 mm Hg), the flash point or fire point is corrected, or both, as follows:

$$\text{Flash point} = C + 0.25(101.32 - K)(2)$$
$$\text{Flash point} = F + 0.06(760 - P)(3)$$
$$\text{Fire point} = C + 0.033(760 - P)\ (4)$$

where:

C is observed flash point, °C, F is observed flash point, °F, P is ambient barometric pressure, mm Hg, and K is ambient barometric pressure, kPa. Using the corrected flash point or fire point, both, as determined in the above step, round the values to the nearest 1°C (2°F) and record.

Figure 6 Flash and Fire Experimental set up

3.2.4. Marshal Specimen Preparation

An approximate of 1200 g test specimen was batched by weight while, 5% filler, 55% fine Aggregate, 40% coarse aggregate, and 6% of 70/80 penetration grade bitumen was mixed thoroughly using mixer at a temperature of 165°C. When binder completely covers the aggregate, then the mix was laid in pre-heated mold (100-140°C) for compaction. The mixture was compacted with 50 blows both at the top and at bottom to obtain cylindrical samples in Figure 7 for Marshall Stability tests. The percentage replacement of fine aggregate with CPK and CPWS is 10%, 20%, 30%, 40% and 50% respectively. In addition, the tyres are y shred so that the steel belts and fibres can be separated from the rubber. In the 'wet' process, the CT modifier shown in Figure 4 is added to the bitumen at 10%, 20%, 30%, 40%, and 50% while heating to 180–210ºC. Marshal and flow stability tests were performed in accordance with ASTM D6927-06 using Marshall Stability Testing Machine shown in Figure 8.

Figure 7 Cylindrical Specimen for Marshal Stability Test

Figure 8 Marshall Stability Machine

4. RESULT AND DISCUSSION

4.1. Laboratory Test Results

The results of aggregate impact value (AIV) and aggregate crushing value (ACV) test carried out on mineral aggregates, crushed palm kernel shell, crushed periwinkle shell and crumb tyres are presented in Table 1. Table 2 is the summary of results on water in bitumen test (Dean and Stark method), penetration test, and flash and fire point test. 3.9% was obtained for the moisture in bitumen, which is less than the maximum permitted limit of 5%. The flash and fire point designated values are below 400^{0}C. The result obtained showed that the flash point obtained is 310.7^{o}C and the fire point obtained is 328.7^{o}C, these values are within the specified value range of 280 – 300 ^{O}C for flash point and 300 – 320^{O}C for fire point.

Table 1 Summary of Test on Aggregate Impact value and Aggregate Crushing Value

Tests Conducted	Coarse Aggregate			Average	Specified Limit (%)		Remark
	1st Test	2nd Test	3rd Test				
AIV %	22.45	16.77	17.25	18.82	**<10** 10-20 20-30 >35	Exceptionally tough / Strong Very tough / Strong Good for pavement surface course Weak for pavement surface course	Satisfactory for road surfacing
ACV %	19.5	20.30	21.20	20.33	Not more than 30% for Surface or wearing course		Good for wearing course

Table 2 Summary of Tests on Water in Bitumen and Penetration

S/No.	Water in Bitumen Test		Penetration Test			Flash Point (^{0}C)	Fire Point (^{0}C)	Remarks
	Test Samples	Values	Sample					
			A	**B**	**C**	**Recommended value is between 175°C -400°C**		
1	Wt. of Bitumen	100g	74.0	76.0	77.0	Value obtained= 310.7°C	Value obtained= 328.7°C	Satisfactory
2	Receiver used	10ml	77.0	72.0	80.0			
3	Water in receiver	3.8ml	79.0	74.0	79.0			
4	Water content (%)	3.80%						
	Average		76.67	74.0	76.44			
	Max. Permissible	5%						
	Remarks	Satisfactory						

4.2. Result of Marshall Test

4.2.1. Stability Test Result

Figure 9 and 10 shows stability curves for CPKS and CPWS. The result of Marshall Stability test showed that CPWS at 20% give the best performance with the highest Marshall stability value of 3.06 kN. CPKS at 20% partial replacement also showed a good performance with 3.03 kN as Marshall stability value. However, this performance is less than that of CPWS. The performance of the asphalt produced with CT as partial replacement gives 2.76 kN at 30% partial replacement.

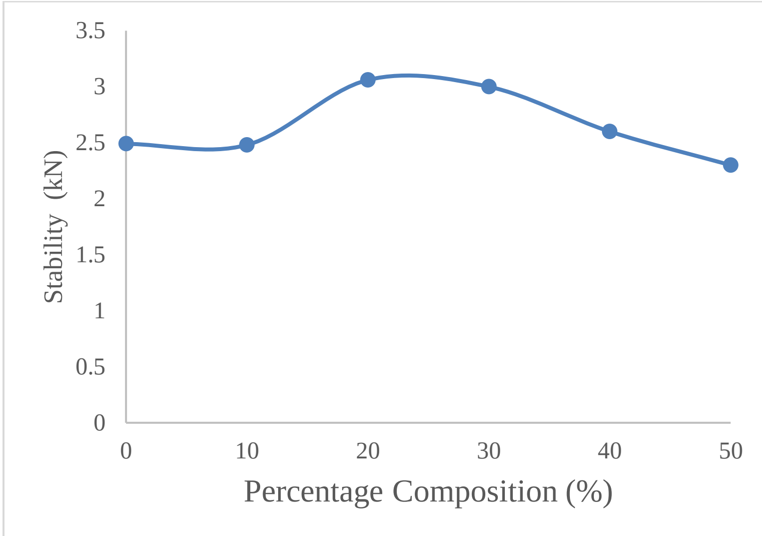

Figure 9 Stability Curve of Crushed Periwinkle Shell

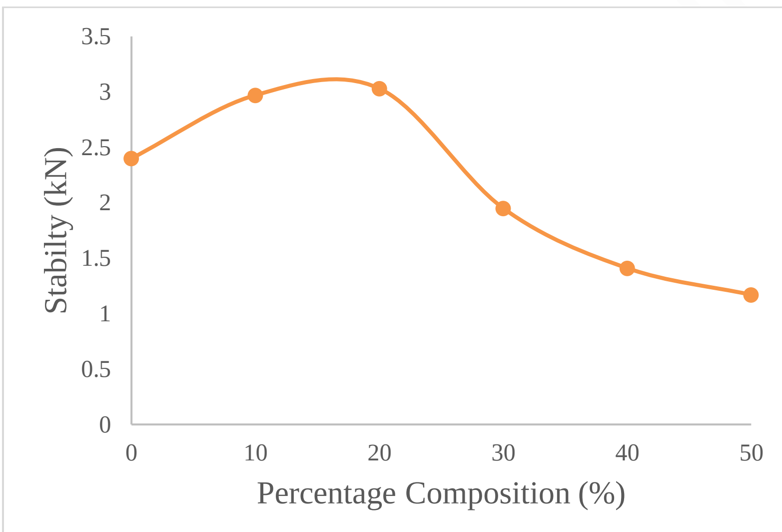

Figure 10 Stability Curve of Crushed Palm Kernel Shell

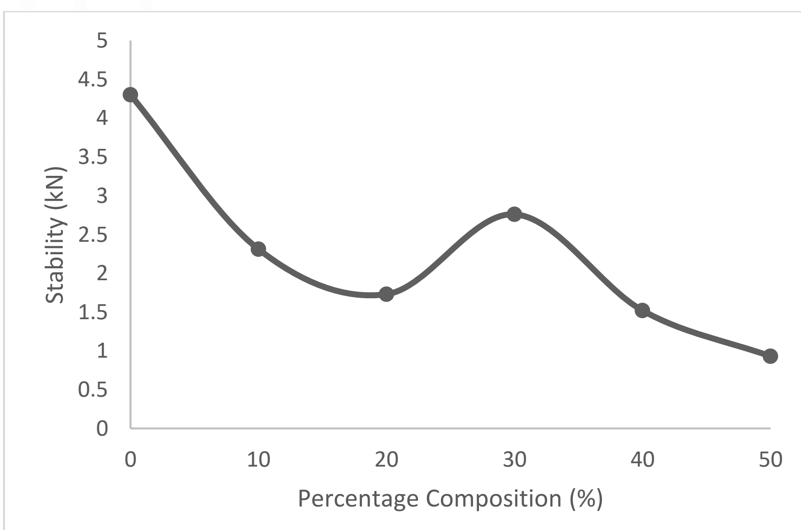

Figure 11 Stability Curve of Crumb Tyres

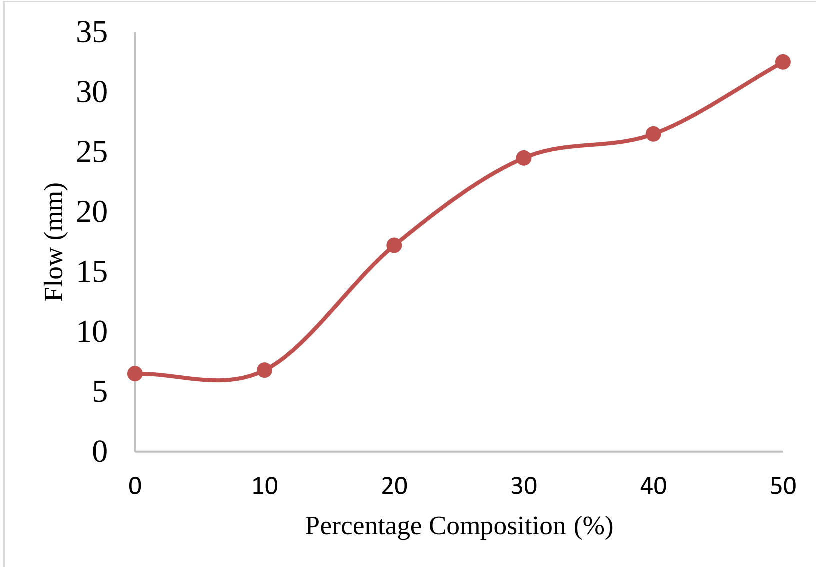

Figure 12 Flow Curve of Crushed Periwinkle Shell

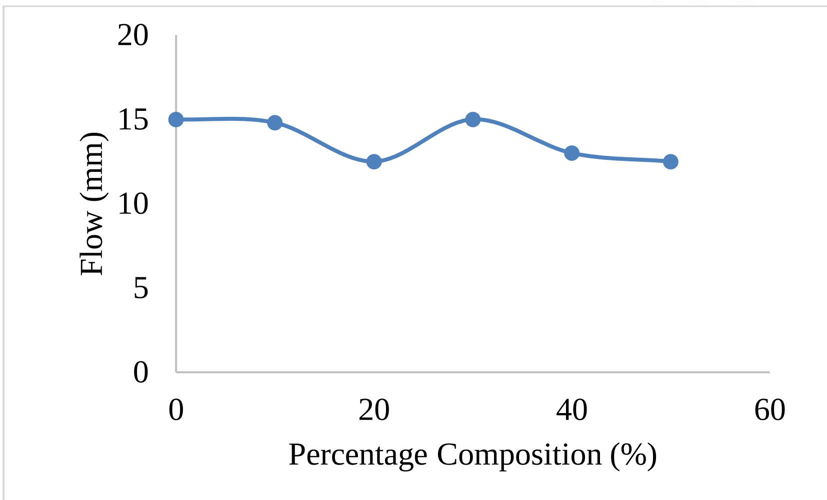

Figure 13 Flow Value Curve of Crushed Palm Kernel Shell

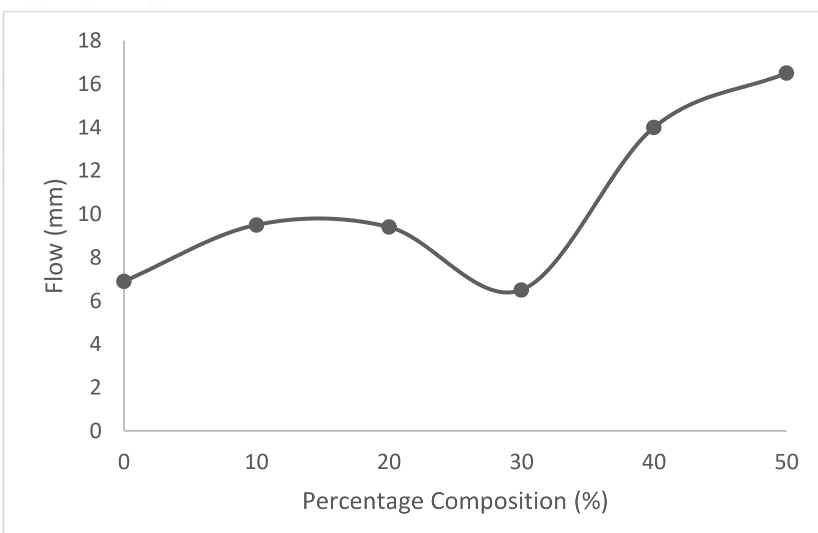

Figure 14 Flow Value Curve of Crumb Tyres

4.2.2. Flow Test Result

Figure 12 and 13 shows flow curves for CPKS and CPWS respectively. The result of flow test obtained gives 15 mm, 14.8 mm, 12.5 mm, 15 mm, 13 mm and 12.5 mm for crushed periwinkle shell, 6 mm, 6.8 mm, 17.2 mm, 24.5 mm, 26.5 mm and 32.5 mm for crushed palm kernel shell, for partial replacement of fine aggregates of 0%, 10%, 20%, 30%, 40%, and 50% respectively. In addition, Figure 14 shows the Stability curve for crumb tyres. The result of flow test obtained for CT obtained gives 6.9 mm, 9.5 mm, 9.4 mm, 6.5 mm, 14 mm and 16.5 mm for CT for partial replacement of bitumen of 0%, 10%, 20%, 30%, 40%, and 50% respectively.

5. CONCLUSION

The result of the Marshall tests indicates that the use of CPWS and CPKS can be used as a partial replacement for fine aggregate in the construction of light traffic roads. The optimal percentage replacement for both the crushed periwinkle shell and the crushed palm kernel shell is at 20%, which gave a stability value of 3.06 kN and 3.03 kN for respectively which values are higher than the value recommended by Asphalt Institute as Typical Marshall Design Criteria. Crumb tyres can also be used as partial replacement of fine aggregate at 10% and 30% replacement for construction of light traffic roads. The use of these wastes in construction will help to reduce the pressure on the conventional materials and serves as an alternative means of waste management. Lastly, these wastes, when used as partial replacement in asphalt will help to reduce road construction cost for communities that have these materials in abundance.

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