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Modification of Bitumen with Crumb Rubber Tyre, Used Engine Oil, and Waste Water Sachet for Asphalt Mixes.

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Abstract – The use of waste materials in pavement construction is one of the steps to reduce environmental concern globally. In this study, asphalt mix was modified with crumb rubber tyre (CRT), used engine oil (UEO), and waste water sachet (WWS) in 0%, 2%, 4%, 6%, 8% and 10%. Other materials used for this study include bitumen, coarse aggregates, and stone dust. The optimum bitumen content is found to be 4.6% for the asphalt mix without addictive this serves as the control mixture for the subsequent mixes. The stability of bitumen modified with CRT, UEO, and WWS increases as the percentage of modifier content decrease and then decreases with increase in the modifier content. This may be due to the lack of proper decomposition of the waste materials in the mixture. WWS has the highest stability value of 20.4N at 6% this indicates that WWS has more stability than CRT and UEO which implies that WWS can withstand any sudden shock or impact. Cantabro abrasion test result shows that modification of bitumen with CRT, UEO, and WWS in higher quantities does not increase resistance to abrasion and the subsequently mix durability. Hence, 8%, 2%, and 6% addition for CRT, UEO, and WWS respectively to bituminous mixture appears promising. Though CRT, UEO, and WWS can improve the physical properties of bitumen which in turn could affect the mechanical and volumetric properties of asphalt mixture the use of specific amounts (such as 6%) of CRT, UEO, and WWS as bitumen modifier in mixtures based on traffic volume can easily satisfy standard requirements which could help in reducing cost of asphaltic concrete and generate economic and environmental benefits.

Keywords: asphalt mix, bitumen, cantabro, modification, optimum bitumen content

1. Introduction

Over the years, the deterioration in roadway pavement in Nigeria is kept on increase. Various maintenance works are required to reduce pavement failure. This is due to heavy traffic load or increasing road users. Increase in road user, will lead to an increase in the pavement loading thus resulting in pavement failure.

The poor performance of bituminous mixtures under increased traffic volume and heavier axle load has led to the increased use and development of modified binders. Development of modified bitumen especially the use of discarded Pure Water Sachets (PWS) in pavement construction is one of the steps to reduce environmental concern in many countries (Wikipedia 2019). The research and development of modified bitumen (MB) began in Europe and its use has spread around the world. It has been recognized that the physical and mechanical properties and rheological behaviour of conventional asphalt compositions can be improved by the addition of Polyethylene (Lu and Isaccson, 2000). Meanwhile, almost every nook and cranny in Nigeria is littered with sachet water nylon, popularly called "pure water", the large volume of which in ordinary parlance, constitutes pollution and termed negative externality or economic (Adetunji *et al.*, 2010).

Presently the greatest environmental problem facing developing countries, especially Nigeria, is municipal and public waste management. The cities are stinking from heavy unmanageable solid waste causing pollution in the environment. Hence, the need to study the performance and characteristics of crumb rubber tyre (CRT), used engine oil (UEO), and waste water sachet (WWS) waste materials as modifiers in hot mix bitumen so as to determine their suitability in asphalt roads and other construction works.

CRT is recycled rubber produced from automotive and truck scrap tires. During the recycling process, steel and tire cord (fluff) are removed, leaving tire rubber with a granular consistency. UEO contains higher percentages of polycyclic aromatic hydrocarbons (PAHs) which are very dangerous to health. As a petroleum-based product, UEO has similar molecular structures as asphalt binder (DeDene 2011). Various researchers have investigated the potentials of applying waste oil as a modifier for asphalt. Past studies reported the changes in physical and chemical properties of asphalt binders/mixtures when waste oil is added. But few have been able to considered CRT, UEO, and WWS as a modifier for bitumen in asphalt mix. Hence, this study investigated the suitability and effects of CRT, UEO, and WWS as a modifier for bitumen in asphalt mix.

2. Use of Locally Available Materials in Asphalt Mix

Researchers have studied the use of artificial materials to enhance the properties of asphalt mix. Afolayan *et al*. (2020) investigated the performance of stone mastic asphalt containing Palm Kernel (PK) and Coconut Shells (CS) and their ashes and inferred the use of 10% PK and CS can satisfy standard requirements. Ndoke (2006) also studied the performance of palm kernel shells as coarse aggregates in road binder courses with emphasis on strength of the asphalt concrete. In another study, Yacob (2016) discovered that Coconut Shell exhibits high carbon content and can withstand against abrasion and dynamics associated with repeated loading. To determine the effects of modifiers on asphalt mix, Oyedepo and Oluwajana (2014) studied the properties of bitumen modified tyre and found that it is suitable for asphalt mixture.

The use of waste materials in general is a subject of great concern by many researchers nowadays. This is not only from technological and scientific points of view, but also socially, and economically, in terms of cost and environmental issues. Therefore, it is important that the performance of CRT, UEO, and WWS as bitumen modifier be investigated.

3. **Materials and Methods**

3.1 Materials

Bitumen, granite (coarse) aggregates, stone-dust (fine aggregate), CRT, UEO, and WWS were obtained for use in this study. The bitumen used which served as binder was sourced from ASCA, sapele Construction Company in Odeda along Ibadan-Abeokuta expressway, Ogun State, Nigeria. The coarse and fine aggregates were obtained from local suppliers within Ede Osun State Nigeria. The UEO was obtained from mechanic workshop at first bank, Agip Area, Ede, Osun State. While the CRT were collected from vulcanizers workshops in Ede and WWS was gathered from refuse dump site beside Male hostel, North Campus, Federal Polytechnic Ede, Osun State. This was sun dried and taken to Mechanical Engineering Department, Federal Polytechnic Ede for grounding into powder form. Table 1 and 2 present the physical properties of aggregates and that of 80/100 bitumen used in this study for hot mix asphalt (HMA) mixtures based on ASTM D3515.

Table 1: Physical Properties of Aggregates

Test	Method	Obtained Values	Standard Requirements
		Conventional Aggregates	-
Specific gravity (coarse)	ASTM C127	2.66	-
Specific gravity (fine)	ASTM C128	2.63	-
Water absorption (coarse)	ASTM C127	0.32%	-
Water absorption (Fine)	ASTM C128	1.01	-
Aggregate impact value	BS 812: part 3	15.37%	Below 15%
Aggregate crushing value	BS 812: part 3	30%	Below 30%

Table 2: Physical Properties of 80/100 Binder

Test	Method	Obtained Values	Standard Requirements
Softening point	ASTM D36	50^0C	47-49^0C
Penetration	ASTM D5	36.3mm	84-95mm
Ductility	ASTM D113	115.3cm	-
Flash point	ASTM D92	280^0C	275-302^0C
Fire point	ASTM D92	300^0C	> 302^0C
Specific gravity	ASTM D70	1.1	-

Table 3: Binder Content

C**B** (%)	Modifiers (%)		
	CRT	UEO	WWS
100	-	-	-
98	2	2	2
96	4	4	4
94	6	6	6
92	8	8	8
80	10	10	10

CB = conventional bitumen, CRT = crumb rubber tyre, UOE = used engine oil, WWS = waste water sachet

3.2 Methods

Sample Preparations: In this study, CRT, UEO, and WWS were added to bitumen in order of 0%, 2%, 4%, 6%, 8%, and 10%. Softening point, penetration, ductility, flash point, fire point, and specific gravity test were conducted on the modified bitumen to obtain its physical properties. The modified binder in addition to conventional aggregates was used to produce asphalt mix. The 0% binder (100% CB mix) was performed as the control mix. HMA binder content is shown in Table 3.

Marshall mix design method was used to measure the optimum bituminous content (OBC) of HMA using CB only. 4.6% OBC was used in the mix for preparing samples containing various modifier content. The required amount of aggregates and fillers were weighed and placed in the oven at 200^0C for 2hours, and the required quantity of modified binder was also weighed and heated for a period of 1 hour at 150^0C.

Hot aggregates were mixed with binder at 160 ± 5^0C until all the aggregates were properly coated. The binder and the required amount of filler were then added and mixed thoroughly. All the mixtures were conditioned for 4 hours at 150^0C and then compacted in the Marshall mould with a target of 4% air voids content.

Marshall Tests

Marshall Stability and Flow Tests: These were accomplished in accordance with ASTM D1559.The Marshall Stability value is the maximum load resistance in Kg or Newtons that the standard test specimen will develop at 60^oC. While the flow value is the total movement or strain in unit of 0.25mm occurring in the specimen between no load and maximum load during the stability test. The density and air voids tests were determined in accordance with ASTM D2726 and ASTM D3203 respectively. Weight in air and water of the samples was taken and the bulk density was computed. The voids in mineral aggregates (VMA) and voids filled with asphalt (VFB) Tests were determined according to standards.

Cantabro Abrasion Test**:** Cantabro Loss is used to determine the abrasion loss of compacted asphalt mix specimens. The test measures the breakdown of compacted specimens utilizing the Los Angeles Abrasion machine. The percent of weight loss (Cantabro Loss) is an indication of durability and relates to the quantity and quality of the asphalt binder. The percentage of weight loss is measured and reported. The mixture is produced in the laboratory in accordance with specification. The compacted specimens are then cooled to room temperature and weighed. These are placed in the Los Angeles testing machine without including the steel balls. The machine is rotated at a speed of 33 revolutions per minute for 300 revolutions. The loose materials broken off the test specimen are discarded and the test specimens are weighed.

4. Results and Discussion

4.1 Physical Properties of Modified Bitumen

Softening Point: As indicated in Figure 1a, at 0% CRT content, the softening point of bitumen was 50^oC this increased to 66^oC at 2% CRT and later decrease at 4% to 53.5^oC it then increase to 55.5^oC, 65^oC, and 75^oC for 6%, 8%, and 10% CRT respectively. As shown, the softening point increases with increase in percentage addition of CRT. On addition of 2% UEO to the bitumen the softening point value was 74^oC, 45^oC for 4%, 42.5% for 6% this then increased to 50^oC for 8% addition and later decreased to 49.5^oC for 10%. This may be due to the viscosity of UEO. As WWS was added to the bitumen, the softening point increased from 55^oC at 2% to 74^oC at 6%, and later decrease to 54^oC and 51^oC for 8% and 10% respectively. All the percentage additions of CRT and WWS to bitumen are beyond the specified softness of 47-49^0C (ASTM D36).This implies that modified bitumen with CRT and WWS makes the mixture to be soften beyond the required standard for HMA mix. This may be due to rate of heating and the grade of bitumen (the harder the grade, the more will be the softening point). Additions of UEO to bitumen between 4-10% are within the specifications required for HMA. At temperature beyond the soften point, the bitumen will begin to melt and thus, result in sticky pavement.

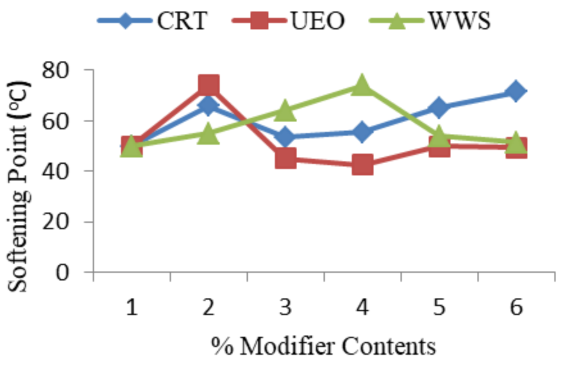
Penetration: Figure 1b shows the penetration results of the modified bitumen at 0% the penetration value was 36.3mm. This decreased to 30mm at 2% CRT, 28.7mm at 4%, 23.7mm at 6%, 27mm at 8%, and 30mm at 10%. The comparison of the penetration values of 0% modified bitumen with UEO modifier shows an increase in value for 4%, 6%, 8%, and 10%. For WWS, the penetration at 2% is 35mm this decreased to 14mm at 10%. The low penetration values of modified bitumen could have been caused by pouring temperature, size of needles, weight placed on the needle, and the test temperature.

Ductility: The result of ductility test for 0% modifier is 115.5cm as shown in Figure 1(c). At 2% addition of CRT is decreases to 22.7cm, 26.5cm at 4%, 27.7cm at 6%, 27.5cm at 8% and 26.80cm at 10%. Modification of bitumen with UEO showed a reduction in the ductility value from 75cm at 2% to 47.5cm at 10%. For WWS 64.3cm was obtained at 2%, 64.3cm at 4%, 69.8cm at 6%, 97.7cm at 8%, and 43.5cm at 10%. Among the three modifiers, UEO has the highest ductility when added to bitumen. This tends to meet the minimum requirements as compared to CRT and WWS.

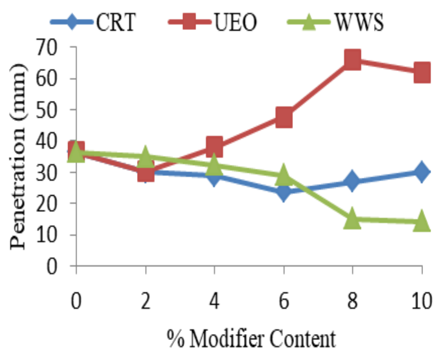
Flash Point: Is the lowest temperature whose application causes the binder material to ignite for at least 5 seconds. The results obtained are shown in Figure 1(d). Bitumen modified with CRT has flash point values ranging between 200^{o}C at 2% to 230^{o}C at 10%. The flash point value for UEO was 140^{o}C at 2%, 140^{o}C at 4%, 152^{o}C. 220^{o}C at 8%, and 261^{o}C at 10%. WWS modified bitumen has flash point value of 192^{o}C at 2% which then decreased to 135^{o}C at 10%. The small values obtained for UEO indicates that the modified bitumen is highly flammable compared to CRT and WWS.

Fire Point: Results of the fire point test is shown in Figure 1(e). At 0% modifiers, the fire point was 300^{o}C this decreased to 240^{o}C at 2% CRT and later increased to 230^{o}C at 10%. With UEO as modifier, the fire point values decreases at 2%, 4%, 6%, and increases at 8% and 10%. WWS shows an increase in fire point of the modified bitumen with values ranging from 170^{o}C to 250^{o}C. This high temperature will prevent the materials from been at risk of ignition as compared to UEO.

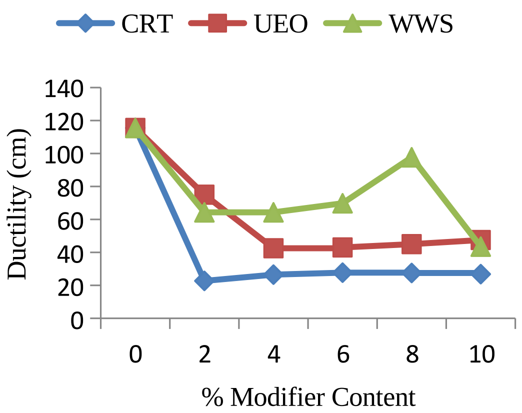
Specific Gravity: Figure 1(f) shows the specific gravity of the modified bitumen. Values obtained for CRT, UEO, and WWS are within the standard specified. With the highest value been 1.120 at 10% WWS. And thus, allow for volumetric conversions during the mix design.



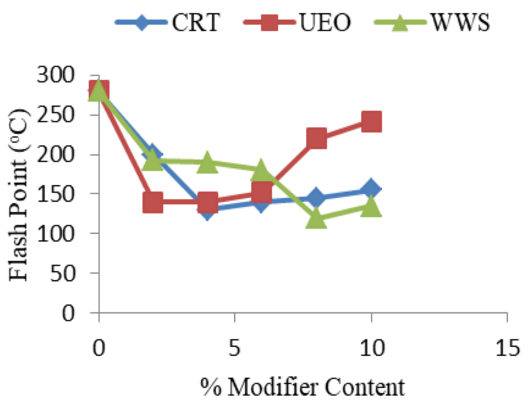
(a) Softening Point of Modified Bitumen



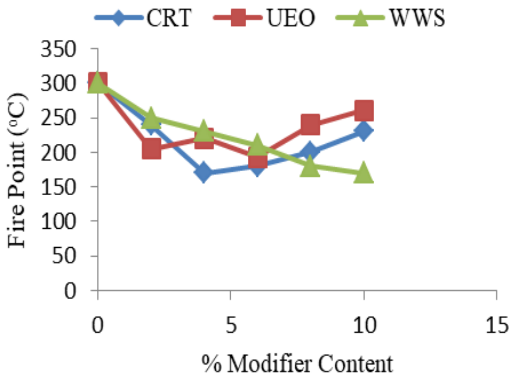
(b) Penetration of Modified Bitumen

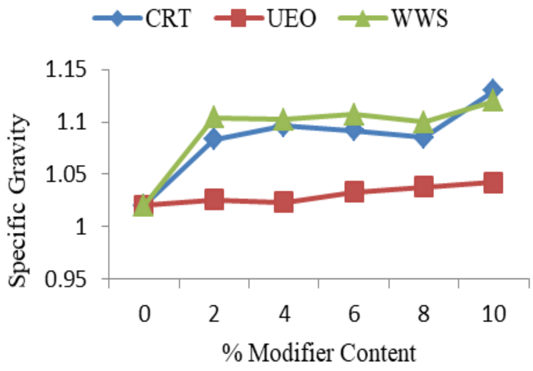


(c) Ductility of Modified Bitumen



(d) Flash Point of Modified Bitumen





(e) Fire Point of Modified Bitumen (f) Specific Gravity of Modified Bitumen

Fig. 1: Results of Physical Property Tests on Modified Bitumen

4.2 Engineering Test on Asphalt Mix

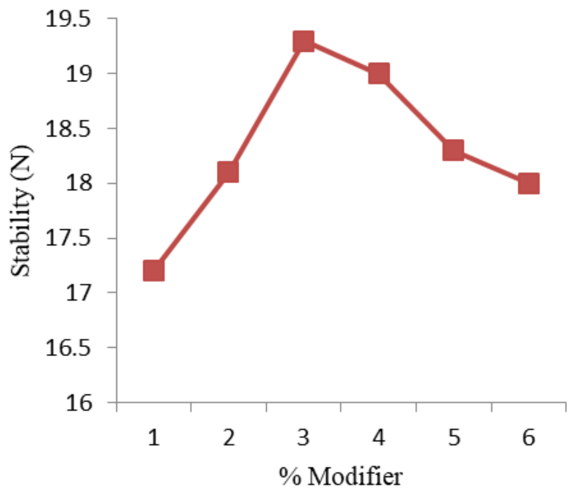
Marshal stability

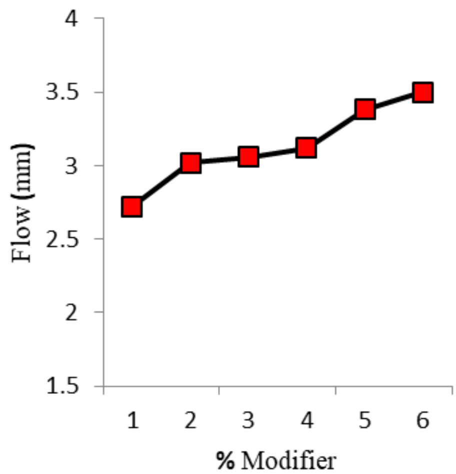
Stability and Flow Test

Marshal stability result for CRT is shown in Figure 2(a). It is evident that the presence of CRT in the asphalt mix effectively improves the stability values which will result in an improvement of mixture toughness. This result indicates that the mixture using CRT would have higher performance than using the control mixture. Variation of marshal stability and flow value with modified CRT content are given in Figure 2(a and b) this indicate that the stability of bitumen modified with CRT for asphalt mix increases initially reaches maximum value and then decreases with increase in CRT content. The flow value of asphalt mix with conventional bitumen is 2.72.

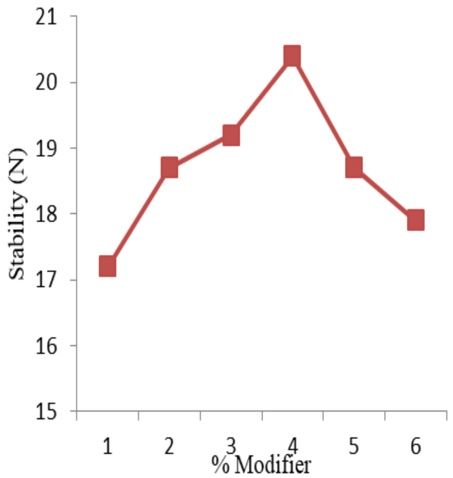
The modification of bitumen with UEO has better properties than those of conventional bitumen and results in an asphalt mixture with improved performance in comparison to the conventional asphalt mixture. Figure 2(c & d) indicates that the stability of bitumen modified with UEO for asphalt mix increases initially reaches a maximum value and then decreases with increase in UEO content. With bituminous mixture been an inconsistent non-uniform, multi-phased composite material consisting of aggregate and sticky bitumen, excessive UEO may not disperse uniformly as result stability decreases at high UEO content.

Figure 2(e and f) shows the effect of WWS content on stability and flow value of the asphalt mixture. The Figure shows that as the additive contents increases the stability value increases initially reaches a maximum and then decreases. Due to the characteristics of bituminous mixture excessive WWS may not disperse uniformly in the mixture. As a result stability decreases at high WWS contents. The flow value of asphalt mix with conventional bitumen is 2.72 and after that there is an increase as shown. This may be due to the increase in the amount of additive contents.

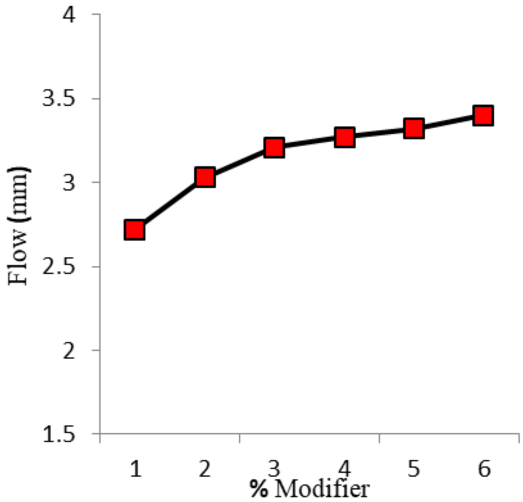




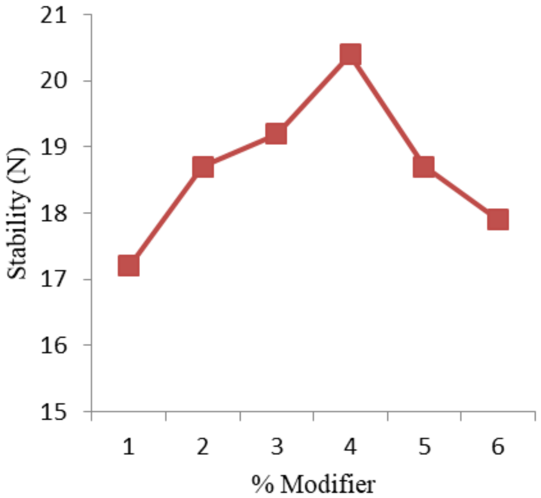
(a) Stability for CRT Modified Mix **(b) Flow for CRT Modified Mix**



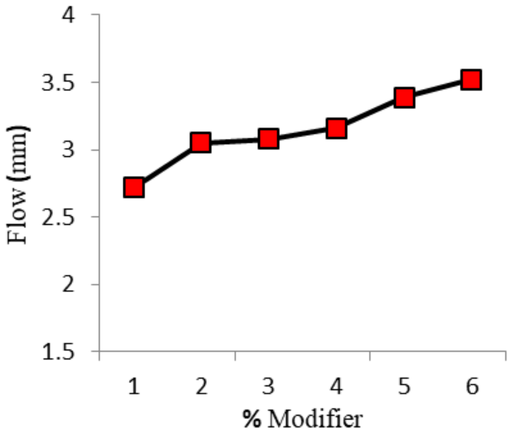
(c) Stability for UEO Modified Mix



(d) Flow for UEO Modified Mix



(e) Stability for WWS Modified Mix



(f) Flow for WWS Modified Mix

Fig. 2: Stability and Flow Results of Modified Asphalt Mix

Cantabro

Cantabro test was used to determine the resistance to abrasion loss. The abrasion loss of porous asphalt decreases as the CRT content increases as shown in Figure 3. Generally the value differs with the type of gradation and material used as modifier. Where 8% exhibit the highest abrasion loss and followed by 4%, 2%, 10% and 6% respectively. For UEO, the abrasion loss of porous asphalt decreases as the UEO content increases, 2% exhibit the highest abrasion loss and followed by 10%, 6%, 4%, 8% and 0% respectively. Based on WWS, the abrasion loss of porous asphalt decreases as the WWS content increases. Figure 3 shows that the value differs with the type of gradation and material used as modifier. Where 6% exhibit the highest abrasion loss and followed by 4%, 2%, 10%, 8% and 0% respectively.

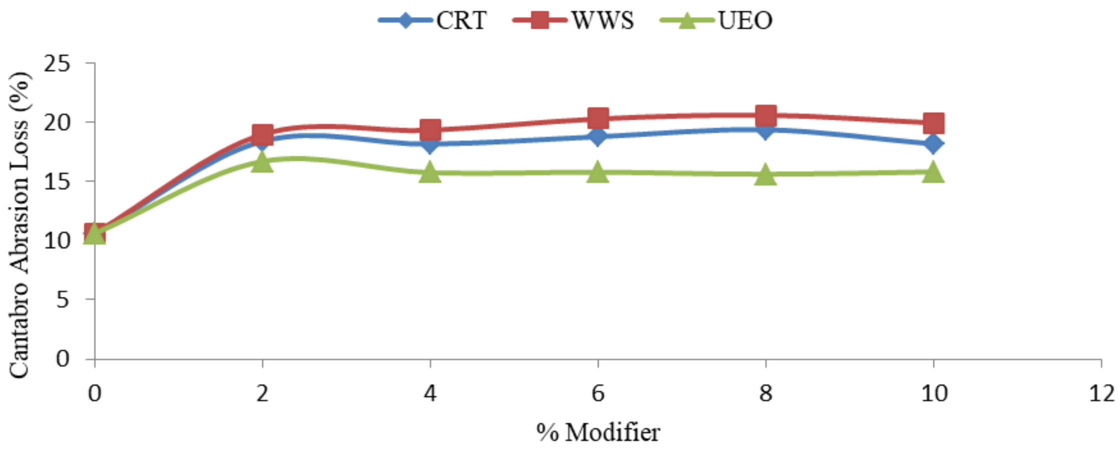


Fig. 3: Cantabro Test Result for CRT, UEO, and WWS Modified Asphalt Mix

5. Conclusion

This study presented the laboratory results obtained from the modification of bitumen with CRT, UEO, and WWS on the performance of HMA, the following conclusion are obtained:

- The OBC for conventional bitumen as recommended by standard is between 4%-6%. Based on the test conducted, the OBC of CRT, UEO, and WWS modified bitumen were within the range specified by the standard.
- The maximum stability value obtained is 19.3N by using CRT as modifier at OBC of 4.6%, 19N for UEO at 4% modifier and 20.4N was obtained at 6% when WWS was used as modifier. This indicates that WWS has more stability than CRT and UEO which implies that WWS can withstand any sudden shock or impact.
- Though CRT, UEO, and WWS can improve the physical properties of bitumen which in turn could affect the mechanical and volumetric properties of asphalt mixture the use of specific amounts (such as 6%) of CRT, UEO, and WWS as bitumen modifier in mixtures based on traffic volume can easily satisfy standard requirements which could help in reducing cost of asphaltic concrete and generate economic and environmental benefits.
- Based on the Cantabro durability test, it can be concluded that modification of bitumen with CRT, UEO, and WWS in higher quantities does not increase resistance to abrasion and the subsequent mix durability. Hence, 8%, 2%, and 6% addition for CRT, UEO, and WWS respectively to bituminous mixture appears promising.
- Generally, it can be inferred that this study as promoted suitable technology sustainable development through waste recycling to produce a new material in an environment friendly manner.

6. Recommendations

Based on the study conducted, the following recommendation can be made:

1. Bitumen modified with CRT, UEO, and WWS is adequate for asphalt mix and can enhance the service life of flexible pavement.
2. Further study is needed in the use of combination of CRT, UEO, and WWS to modify bitumen for asphalt mix

3. Practical application of modified asphalt mix is required in road construction in order to ascertain the behaviour of the mix under load and environmental conditions.

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