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Volumetric and Abrasion Loss Properties of Asphalt Mix Modified with Used Toner Ink

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Abstract:
The research centered on the effect of used toner ink (UTI) as bitumen modifier in asphalt mix as paving materials with respect to the volumetric properties and durability. In this research, UTI are proportioned into the asphalt binder for mixing the asphalt concrete in percentages of 2%, 4%, 6%, 8% and 10%. Marshall and Cantabro loss tests were carried out on the hot asphalt mix. All the percentage proportion of used toner added was evaluated with the following parameters: voids in the mineral aggregates (VMA), voids in total mix (VTM), voids filled with asphalt (VFA), Marshall stability, flow value, and specific gravity. It was observed that asphalt mix with UTI performed better under loading as the UTI in the asphalt mix increases. The highest Marshall stability was observed to be 32,352N at 6% UTI, also there is reduction in the optimum bitumen content as the UTI, which helps in reducing the amount of bitumen needed in the course of asphalt pavement construction. In respect of this research further asphalt pavement design can be modified to provide pavement that can be more sustainable and durable over a long period of time, thereby reducing the cost of asphalt mix production.

Keywords: *Used toner ink, asphalt, volumetric, durability, modified, moisture*

1. Introduction

Globally, the world is striving towards sustainable development. Sustainability according to UN sustainable goals is the incorporation of economic, social objectiveness, and environmental health in order to establish a vibrant, healthy, distinct, and resilient infrastructures or communities for the present and future generations (REF). The use of waste has been identified as one of the ways to achieve sustainable infrastructures.

Used toner ink (UTI) is a waste material from printers and copier machines, resulting from either toner production process or printing operation (Yildirim and Kennedy 2003; Notani and Mokhtarnejad, 2018). Leftover toner either in the production process or printing operation becomes waste and is used as landfill. Landfilling of these waste materials have been shown by Notani *et al.* (2019) to have serious adverse effects on the environment due to the presence of heavy and semi-heavy oxides found in them such as ferric oxide (Fe_2O_3) and Lanthanum (La), which usually result in aquatic toxicity. As harmful as it is, researchers have discovered that the ferric oxide is highly dense and thus, change toner-modified binder into multiple phases if high quantity is used. Also, it contains titanium dioxide (TiO_2), mostly used in colour pigment. This allows for the resistance of asphalt binders to the adverse effects of high service temperature (Qian *et al*., 2019).

Yildirim *et al*. (2004) in their work shows that addition of toner to asphalt results in increased stiffness that indicates a higher fluid resistance. Various properties of asphalt binder have been shown to be improved by the addition of waste toner. Some of which are: resistance to deformation due to high temperature, viscoelastic properties (Notani and Mokhtarnejad, 2018), fatigue resistance, increased binder viscosity (Zhang *et al*., 2019; Pouranian *et al*., 2020); aging (Notani *et al*., 2021), Moisture susceptibility (Notani *et al.,* 2021).

Though some previous studies have shown the effect of toner on asphalt binder and mix, very few have been able to determine the volumetric and moisture susceptibility of asphalt mix modified with UTI. Therefore, this study considered the volumetric and moisture properties of toner modified asphalt.

1.1. Moisture Susceptibility of Asphalt

Moisture susceptibility is the evaluation of the durability of asphalt mixture at adverse temperature in the presence of water. According to Perez *et al*. (2012), Pouranian and Haddock, (2019), Wang *et al*. (2019), Zhang *et al.* (2017), and Kim *et al*. (2018), the primary mechanism of moisture susceptibility is an adhesive bond failure at interface between asphalt binder and aggregates due to loss of adhesion and strength of the bitumen film. Water activity enhances the stripping of the bitumen from the surface of aggregate grains, resulting in detachment, peeling, loosening and, consequently, deterioration of the mixture (Prabir, 2012). Moisture changes are one of the major causes of failure in road pavement (Prabir, 2012). As moisture infiltrates into the asphalt pavement, the cohesive force in the asphalt concrete get weakens and later reduces the adhesive bonds between the aggregate and asphalt. This prematurely causes the wear and tear of the surface of the pavement due to the traffic loading. Striping and raveling are two damages that frequently occur on pavement surface, once they start, they progress into a severe degradation of the wearing course and leads to potholes (Emery and Seddik, 1997).

To improve the properties of asphalt binder's to achieve a higher resistance against pavement distress; various researchers have considered the modification of asphalt binders with crumb rubber tyre, used engine oil, carbon black, waste water sachet, styrene-butadiene-styrene, and other materials (Vila-Cortavitarte et al., 2018; Baqersad *et al.,* 2019; Liu *et al*., 2019; Jahangiri *et al*., 2019; Wei *et al*., 2019; Pouranian and Shishehbor, 2020; Notani *et al*., 2020; Afolayan *et al*., 2021). Considering few researches in the areas of volumetric and moisture susceptibility of UTI in asphalt modification, this study focused on the analysis and investigation of the suitability of UTI on the volumetric properties of asphalt mix, with the sole objective of identifying the properties of asphalt mix modified with used toner and the evaluation of the effect of UTI on the stability.

2. Materials and Methods

2.1. Materials

The materials used for the experiment include: bitumen, fine aggregates, coarse aggregates, stone dust (filler), and used toner ink. The bitumen used is pen 60-70, obtained from Espro Asphalt Company located at Wasinmi along Ibadan-Ikire expressway, Oyo State, Nigeria. The aggregates were granite materials passing through sieves 12mm, 10.5mm, 450µm and 236µm sieve. These were air dried and sieve appropriately and classified into: coarse aggregate, fine aggregate and filler materials after being sieved. Table 1 and 2 present the physical properties of aggregates and bitumen used in this study.

Test	Method	Obtained Values	Standard Requirements
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%	-
Aggregate crushing value	BS 812: part 3	12%	Below 15%

Table 1: Physical Properties of Aggregates

Test	Method	Obtained Values		Standard Requirements
		CB	TMB	
Softening point	ASTM D36	500C	489C	47-490C
Penetration	ASTM D5	36.3mm	35.7	84-95mm
Ductility	ASTM D113	115.3cm	114.5	-
Flash point	ASTM D92	2800C	2750	275-3020C
Fire point	ASTM D92	3000C	3050	> 3020C
Specific gravity	ASTM D70	1.1	1.15	-

Table 2: Physical Properties of 60/70 Binder
CB = Conventional Binder, TMB = Toner Modified Binder

3. Methods

3.1. Sample Preparations

500 grams of bitumen was weighed. 0%, 2%, 4%, 6%, 8% and 10% of UTI were added in HMA mixture. The mixture was heated till the UTI melted and these was stirred thoroughly. The modified bitumen were then used in carrying out the test on asphalt aggregate to make an asphalt concrete with different bitumen content in the mix (4% – 6%). Hot aggregates were mixed with TMB at 160 ± 50C until all the aggregates were properly coated. The required amount of filler were then added and mixed thoroughly. All the mixtures were conditioned for 4 hours at 1500^{o}C and then compacted in the Marshall mold with a target of 4% air voids content.

3.2. Specific Gravity Test

The test is performed using the density bottle weighed with lids, the soil to be examined is added and weighed, and the density bottle is also weighed with water only, the test is repeated three times. Eqn. 1 shows the expression.

$$specific\ gravity\ of\ soil = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \tag{1}$$

Where, W_1 = weight of bottle + lid, W_2 = weight of bottle + soil sample, W_3 = weight of bottle + soil sample + water, and W_4 = weight of bottle + water.

3.3. Marshall Stability and Flow Test

These were carried out in accordance with ASTM D1559. The maximum load resistance in Kg or Newtons that the standard test specimen will develop at 60^0C is the Marshall Stability value. The flow test helps to provide information on the performance of the asphalt mix design. The stability portion of the test measures the maximum load supported by the bituminous material at a loading rate of 50.8 mm/minute. The test load is applied to the specimen and increased until it fails under loading, when the load just starts to decrease, the loading is ended and the maximum load (i.e. Marshall Stability) is recorded. During the loading test, dial gauge is attached which measures the specimen's plastic flow owing to the applied load. The flow value is recorded in 0.25mm (0.01inch) increment at the same time when the maximum load is reached.

3.4. Volumetric Properties

Major volumetric properties determined include: the theoretical specific gravity (Gt), the bulk specific gravity of the mix (Gm), percent air voids (Vv), percent volume of bitumen content (Vb), percent void in mineral aggregate (VMA) and percent voids filled with asphalt (VFA). Figure 1 shows the relationship between the properties.

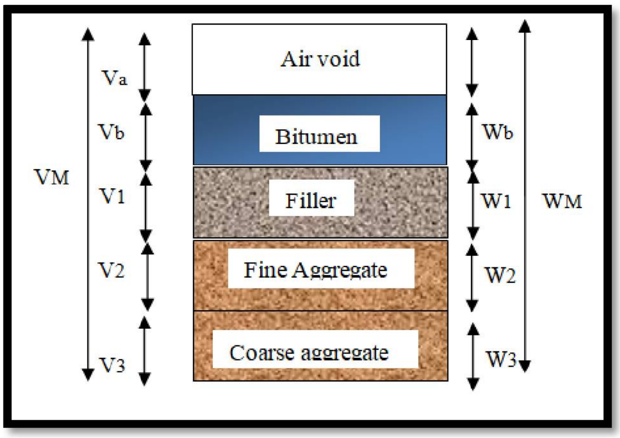

Figure 1: Volumetric Relationship of Asphalt Mix

- Theoretical specific gravity (G_t): Is the specific gravity of the asphalt mix without considering air voids. It was estimated as follows Eqn. 2.

$$Gt = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}} \tag{2}$$

Where: W_1 = weight of coarse aggregate in the total mix, W_2 = weight of fine aggregate in the total mix, W_3 = weight of filler in the total mix, W_b = weight of bitumen , G_1, G_2, G_3, G_b are the respective specific gravity of coarse aggregate, fine aggregate, filler and bitumen respectively.

- Bulk specific gravity (G_m): The bulk density was determined in accordance with ASTM D2726. Weight in air and water of the samples was taken and the equation below was used to compute the bulk density.

$$Gm = \frac{W_m}{W_m - W_w} \tag{3}$$

Where: W_m = weight of mix in air, Ww = weight of mix in water

- Air voids percent (V_v): air voids Vv, is the percent of air voids by volume in the specimen. It is determined in accordance to ASTM D3203.

$$v_V = \frac{(G_t - G_m)}{G_t} \tag{4}$$

Where, G_t = theoretical specific gravity of the mix, G_m = the mix or actual specific gravity of the mix.

- Percent volume of bitumen (V_b): The volume of bitumen (V_b) is the percent volume of bitumen to the total volume.
- Voids in mineral aggregate (VMA): Voids in mineral aggregate (VMA) is the volume of voids in the aggregate and is the sum of air voids and volume of bitumen, obtained as shown in Eqn. 5.

$$VMA = V_v + V_b \quad (5)$$

- Voids filled with asphalt (VFA): This is defined as the portion of voids in the mineral aggregate that contain asphalt binder. This represents the volume of effective asphalt content.

$$VFA = ((VMA - VTM)/VMA)\ x\ 100 \quad (6)$$

- Voids in total mix (VTM):This is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture that is expressed in percent of the bulk volume of the compacted paving mixture (Pavement interactive, 2017).

3.5. Cantabro Abrasion Test

This is used to determine the abrasion loss of compacted hot-mix asphalt specimens. The test helps to measure the breakdown of compacted specimens utilizing the Los Angeles Abrasion machine. The percent of weight loss (Cantabro loss) is an indication of permeable friction course (PFC) durability and relates to the quantity and quality of the asphalt binder. The percentage weight loss is measured and reported. After molding the specimens, cool to room temperature and weighed. The tested specimen was placed inside Los Angeles testing machine (the steel balls is not included). This was rotated at a speed of 33 revolutions per minute for 300 revolutions then the final weight of the specimen was recorded as some part is broken off during the rotation. The Cantabro loss was computed as follows.

$$CL = \frac{A - B}{A} x100 \quad (7)$$

Where: CL = Cantabro loss (%), A = Initial weight of specimen, and B = Final weight of specimen.

4. Results and Discussion

4.1. Specific Gravity Test

Figure 1 (a-f) shows the specific gravity of the asphalt mix resulting from the Marshall Stability and flow test carried out of the asphalt mix modified with UTI. It can be noted that the larger the size of the aggregate the higher its specific gravity, due to their weight in proportion to the density of equivalent water. It can be deduced that the specific gravity decreases as the bitumen content increases though the unmodified bitumen has the highest specific gravity of 2.25. The values obtained are within the standard requirements.

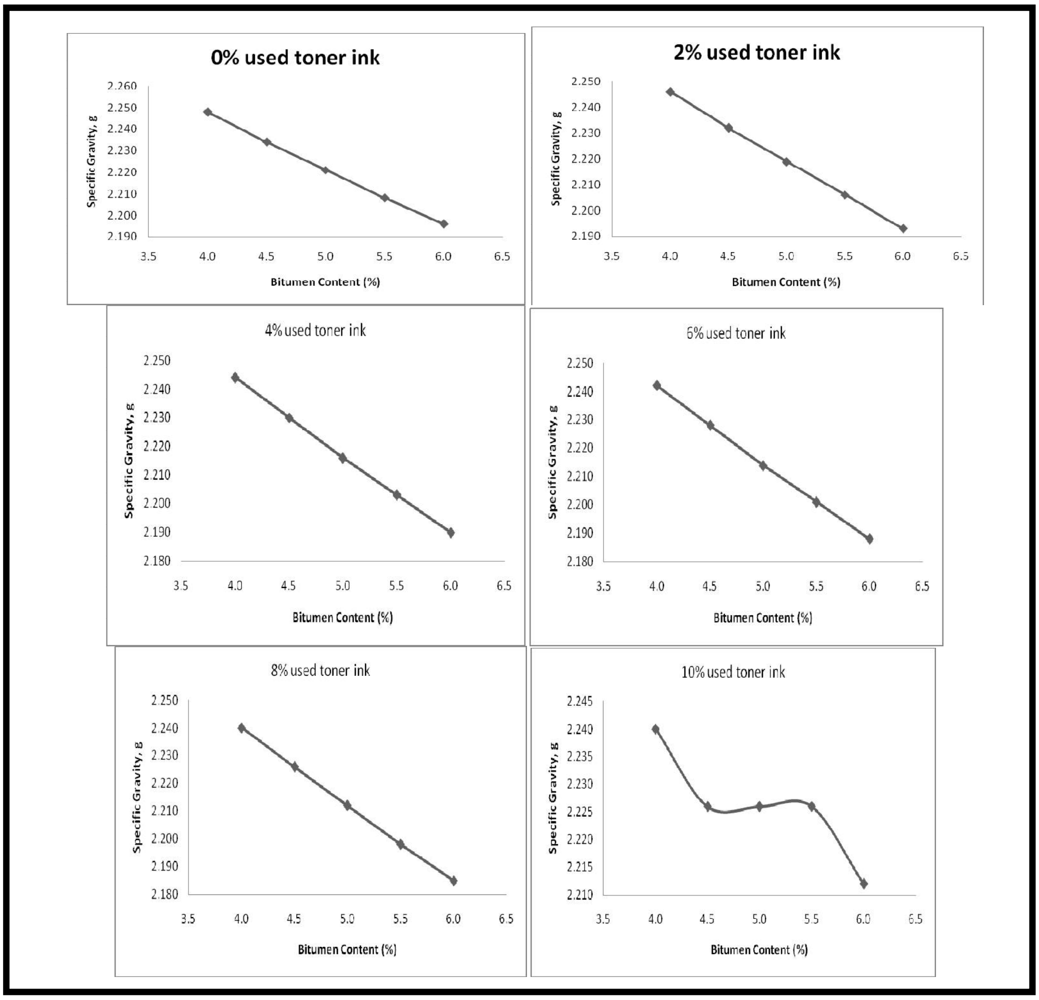

Figure 2: Specific Gravity of the Asphalt Mix at Various % Addition of Toner Ink

4.2. Marshall Test

4.2.1. Stability and Flow Test

The Marshall stability for 0% UTI was 16.34 kN. The results of the asphalt samples for different proportion of bitumen content modified with UTI indicates that at 2% and 4% addition, the stability increased to 21.38 kN and 24.53 kN respectively. From Figure 2(a) At 6%, 8%, and 10% addition, the stability decreased to 17.76 kN, 16.48 kN, and 11.12 kN respectively. Higher stability at 2% and 4% indicates stiffer and more resistant mixture. This is consistent with the findings of Solaimanian *et al*. (1998) and Notani *et al*. (2021).

The flow value increased slightly as the percentage of UTI increased up to 2% addition with a value of 5.08 mm this may be as a result of weak bond created by the aggregates. As the UTI increased, the flow value decreased with 4%, 6%, 8%, and 10% having a value of 4.62 mm, 4.06 mm, 4.36 mm, and 4.26 mm respectively as shown in Figure 2(b). The flow values are consistent with the recommended values for Nigeria road.

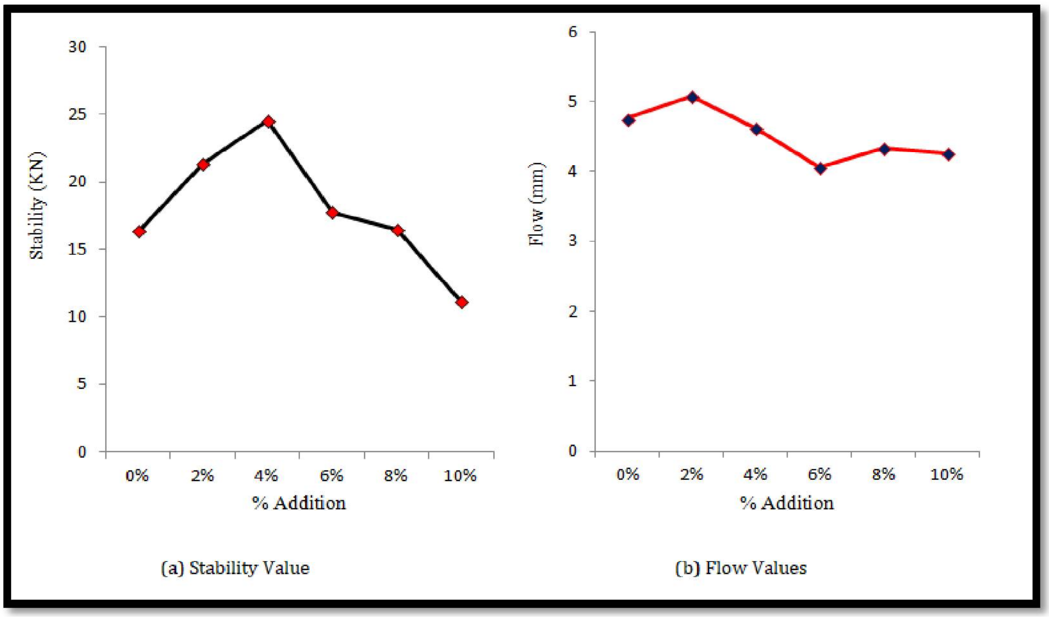

Figure 3: Marshall Stability and Flow for UTI Modified Asphalt Mix

4.3. Volumetric Properties

4.3.1. Density and Air Voids Test

Figure 3(a & b) shows the effects of UTI on the density and void in the total mix (VTM). Mixture containing 0% UTI has a measured density of 2.11 g/cm^3. The result indicates that the density of UTI modified asphalt mix decreases with increase in the percentage addition.

In terms of VTM, HMA samples were produced and compacted with target of 4-6% VTM content. When the VTM is low, bleeding, loss of mixture stability, and rutting may occur (Robert *et al.,* 2009) and also when the VTM is high, durability and stripping problem may arise (Robert *et al*., 2004). From the Figure it can be observed that the VTM decreases as the bitumen content increases. The control asphalt mix and asphalt mix with 10% UTI has VTM that satisfies the JKR standard i.e. 3.63% and 3.68% respectively.

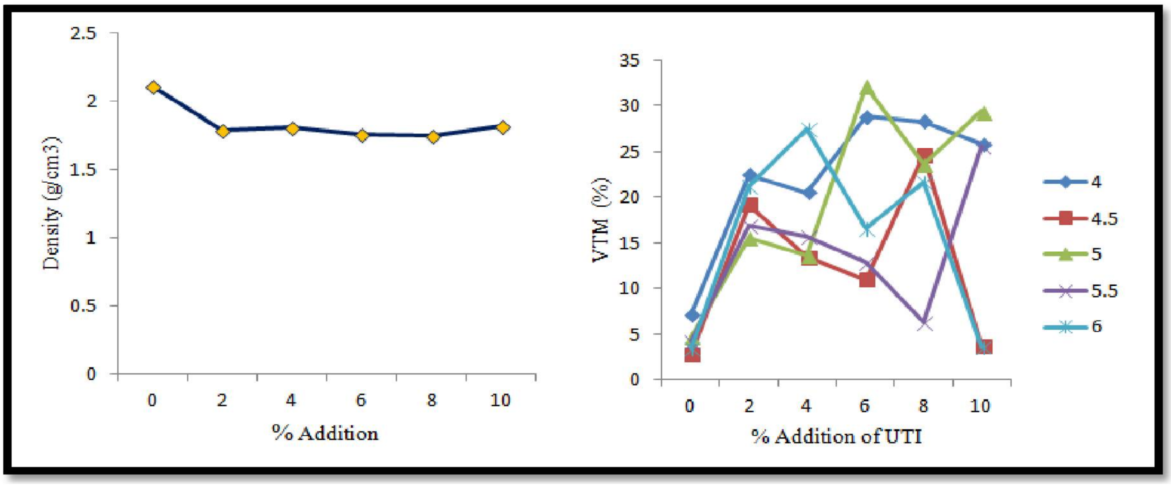

Figure 4: Density and Void in the Mix (VTM) of the Asphalt Mix

4.4. Voids in the Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA)

VMA is the total volume of voids within the mass of the proportioned aggregate used in the asphalt mix (Robert *et al.*, 2009). It has been discovered that the performance of an asphalt mix is dependent on the voids present in it, when the void is low it constitutes the problem of durability and when it is high, stability problem may arise. Mixture with 0% UTI has estimated values of VMA and VFA to range from 24.69 – 25.36% and 33.46-50.35% for bitumen content ranging from 4-6%. From Figure 4(a) the VMA decreases as the bitumen content increases, though contradict to the investigation of Brown *et al*. (2005). Asphalt mix without UTI is seen to have the highest VMA of 50.63% and asphalt mix with 10% UTI has the lowest at 23.37%, though the modified asphalt is seen to have lower VMA compared to the control mix. Modifying an asphalt binder with UTI enhanced the stability.

The portion of voids in the mineral aggregate that contain asphalt binder is referred to as VFA (Paving system, 2016). From Figure 4(b), the VFA can be noted to have been increasing as bitumen content increases except when it reaches higher percentage. It should be noted that the VFA must be maintained in construction as to avoid deficiency of asphalt paving mixture (Oluwasola *et al.*, 2016). The optimum bitumen content generally decreases as the percentage of UTI increases.

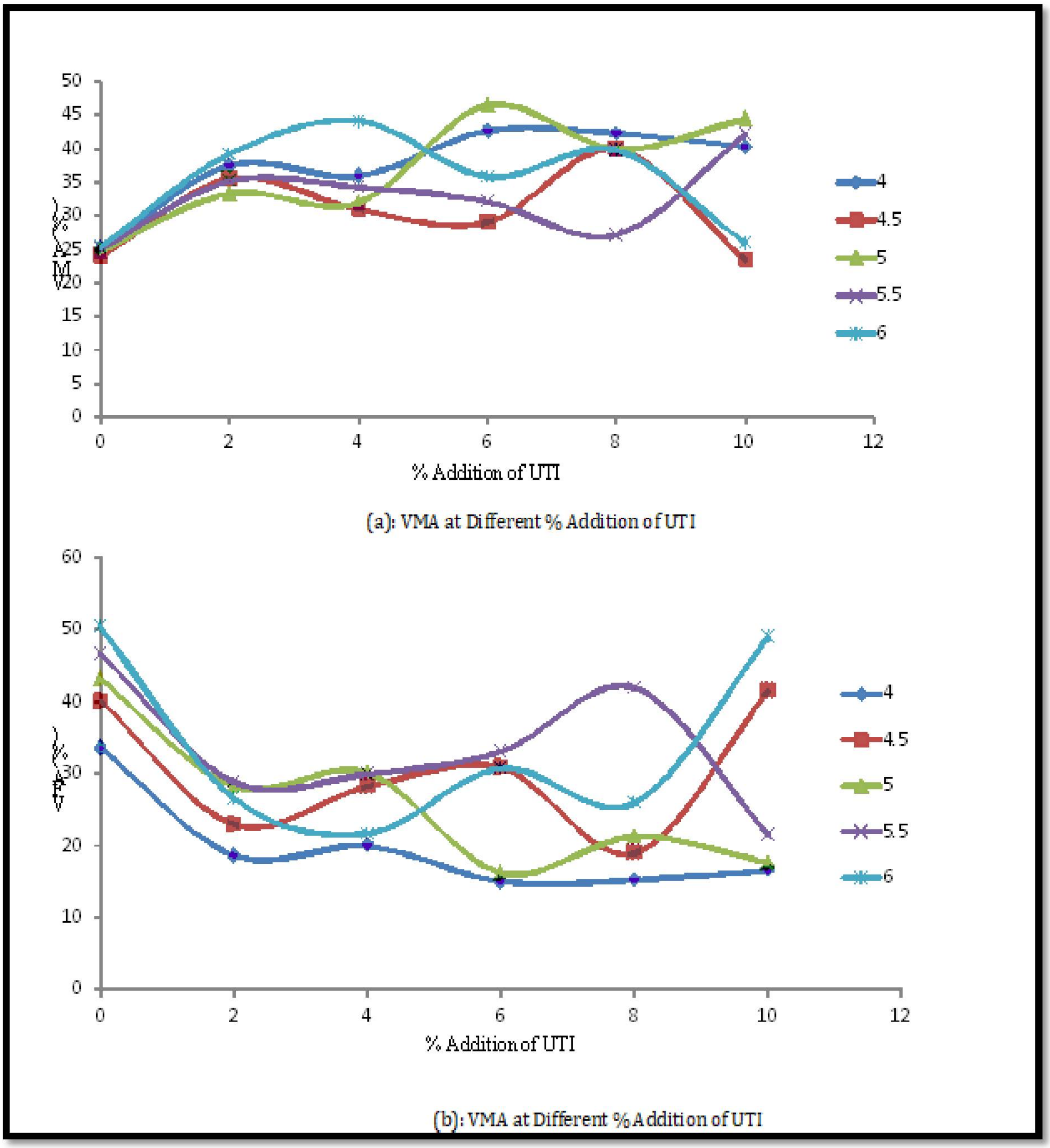

Figure 5: (a & b): VMA and VFA of the Mix at Different % Addition of UTI

4.5. Cantabro Loss

Figure 5(a-e), shows the Cantabro loss of the asphalt with respect to the bitumen content, and the percentage of UTI in the mix. The loss in the asphalt mix decreases gradually as the bitumen content increases up to the optimum bitumen content of the modified asphalt mix as obtained from Marshall Stability test. The amount of abrasion loss indicates the inter-aggregate particle cohesion loss in the asphalt mixes tested. The lower the abrasion loss, the less prone the mixtures to disintegration. As shown in the figures, the rate at which there was loss generally decreases with increase in the percentage of used toner ink added to the mix. The lowest Cantabro loss in each modification was noted to be 19% when 10% UTI was used, 10% loss when 8% UTI was used, 22% loss when 6% UTI was used, 18% loss when 4% UTI was used, 26% loss when 2% UTI was used and 38% loss when 0% UTI was used in the mix. In accordance with ASTM D7064-08 and AASHTO PP 77-14, a satisfactory performed asphalt mix can have up to 20% Cantabro loss. Therefore from the above, only asphalt modified with 10%, 8% and 4% UTI meets up with the standard for Cantabro loss in asphalt mix.

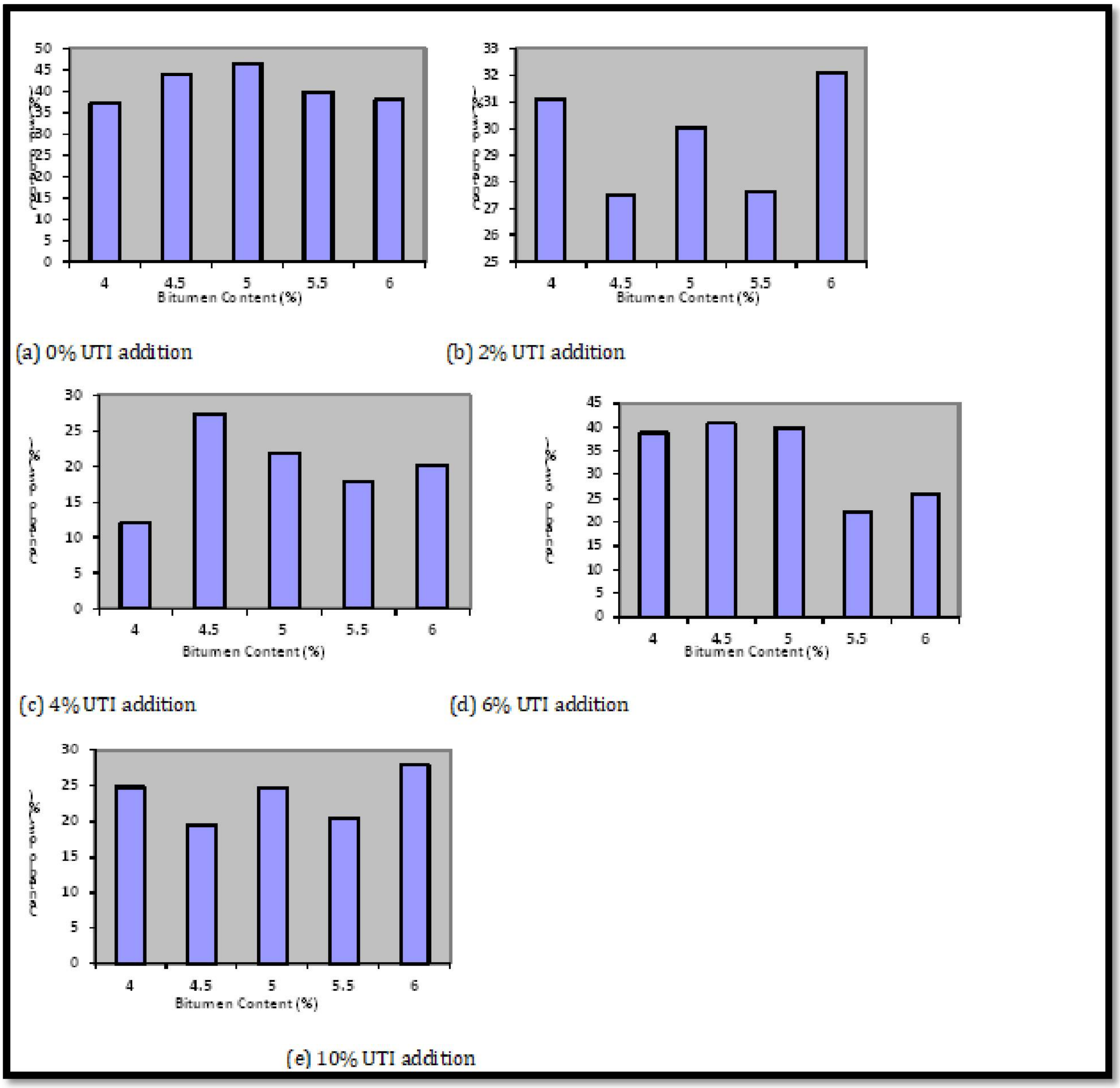

Figure 6(a-e): Cantabro Loss at Different % Addition of UTI in Asphalt Mix

5. Conclusion

This study presented the experimental result of the effect of UTI on volumetric and moisture susceptibility of Asphalt mix, the following conclusion are obtained:

- Addition of used toner ink up to 6% resulted in high stability. Therefore, modification of the asphalt mix with used toner ink can be successfully achieved to this percentage.
- The volumetric properties of the asphalt mix have been improved when considerably percentage of used toner ink was added.
- The optimum bitumen content of the asphalt mix is reduced up to 4% modification which will provide better economy of materials when used in construction industry.
- The Cantabro loss evaluated on each modification has greatly improved the asphalt mix such that when used toner ink was added to the asphalt mix up to 10% will perform satisfactory with reduction in the loss.

  Used toner ink can be added efficiently and provide cost effective high-performance road surfacing since the optimum bitumen content as the percentage used toner increases. The loss resulted as a result of modifying the asphalt binder can be avoided if the bitumen content is increased up to the optimum content derived from Marshall Stability test.

- The mixture analysis indicates higher strength and stability for toner-modified asphalt concrete compared with unmodified mixtures.

6. Recommendations

From this research, it can be noted that the addition of used toner ink improved the durability of asphalt mix generally in construction and also reduce the cost of using bitumen when used toner was added to it. The following are hereby recommended.

- The modification of asphalt binder with used toner ink up to certain percentage help to improve its stability under loading and assure good mix.
- Further research can also be carried out to adequately access the used of some other waste materials with relevant properties which can reduce cantabro loss.
- Also, higher percentage of used toner ink can be used to determine the effect of further addition of used toner on the asphalt mix though should not be greater than the economy notification when used in construction.

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