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INVESTIGATION OF THE INFLUENCE OF COW DUNG ASH AS FILLER AND POLYETHYLENE TEREPHTHALATE AS BITUMEN REPLACEMENT IN ASPHALT CONCRETE

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ABSTRACT

This study investigated the influence of Cow Dung Ash (CDA) and Polyethylene Terephthalate (PET) as partial replacement of filler and binder respectively on the volumetric and Marshall Properties of asphalt concrete in separate mixes. In one mix, the filler was partially replaced with CDA at 4, 8, 12, 16 and 20% while for the other mix, the bitumen was partially replaced with PET at 3, 6, 9, 12 and 15 %. Asphalt briquettes were produced in accordance with marshal procedure for wearing course of medium traffic roads and marshal stability, while properties of the mixes were obtained from the flow and volumetric parameters. Results showed that replacing the filler between 4% and 8% with CDA has the potential for use in asphalt concrete. Also, for mixes with PET replacement, percentages between 6 and 15% can be considered for wearing course of medium trafficked roads.

Keywords: *Polyethylene Terephthalate (PET); Cow dung ash (CDA); Asphalt concrete.*

Introduction

The design of asphalt paving mix with other engineering materials is mainly dependent on the selection of appropriate constituent materials to obtain the desired properties in the finished pavement structure so as to provide safe, economical, durable, and smooth pavements that are capable of carrying the anticipated loads. The aggregate serves as reinforcement and adds strength to the overall composite material and constitutes about 90 to 95% by weight of the total mixture (Mohammed *et al*., 2015). The binder (bitumen) binder coats and puts together aggregate particles to form a mixture resistant to traffic and climatic conditions. Mineral filler in hot mix asphalt is an important component of mixture as it plays an important role in stiffening and toughening an asphalt binder (Remisova, 2015). According to Antunes *et al*, (2016) the important filler properties are geometry (size, shape, angularity and texture and fractional voids) and composition (a small number of chemical compounds that affect asphalt-filler interactions). Higher mass of filler in a mixture improves cohesion and internal stability of mixture and increases asphalt modulus (Bahia *et al*., 2010). But high filler content can increase bitumen stiffness and there through influence workability of mixture (Airey, 2008). On the other side low filler content and high bitumen binder content can increase mixture sensitivity to rutting (Remisova, 2015). Most filler used in asphalt concrete is obtained from natural limestone and dolomite rocks. But various researchers are looking for alternatives or ways to improve this. Grabowski and Wilanowicz, (2011) for example, concluded that an addition of hydrated lime to fillers causes increasing finer particles content, specific surface and the Rigden Voids values as well as a decrease of volumetric mass concentration value.

Plastics are mainly highly polymerized compounds consisting of carbon and hydrogen, made from substances such as petroleum and natural gas (Ahmed *et al*., 2015). Out of the various forms, Plastic bottles are commonly used with the commercial name "Polyethylene terephthalate (PET)" bottles which are used for storing carbonated beverage and water. According to Archna *et al*. 2015, PET products although similar to other thermoplastic polyesters, are tough, especially the unfilled materials that show no breaks in the unnotched impact strength test at low temperatures (approximately ~40 °C). PET has low moisture absorption, a property that allows the material to maintain excellent dimensional stability through extremes of temperature and high humidity. (Rosato *et al*. 1991). PET is distinguished by excellent performance under static and dynamic loads, retaining dimensional stability even at elevated temperature (Tatsuoka et al, 2014). After its use the PET bottles become waste and as a result, should be disposed in proper manner. Municipal solid wastes (MSW), manufacturing processes and service industries produce a lot of waste plastic materials which are difficult to reuse, recycle and biodegrade (Hussein *et al*., 2018). Data from researchers show that PET can improve some properties of modified asphalt mixture (Ahmad et al, 2017).

Cattle manure harbours microbial constituents that make it a potential source of pollution in the environment and infections in humans. Knowledge of, and microbial assessment of manure is crucial in a bid to prevent public health and environmental hazards through the development of better management practices and policies that should govern manure handling (Christy *et al,* 2016). Using Federal University of Agriculture Abeokuta (FUNAAB) as a case study, it is common knowledge that there is a daily, nomadic practice of herding cattle around the campus, for adequate grazing. This, inevitably, results in litters of cow dung around the campus, which have been observed to be left to decay. This process of fallowing and decaying consequently results in a smelly environment, polluting the air, and releasing gaseous toxins which are detrimental to lives.

In a more general view, cow dung and PET bottles as wastes, if not properly controlled and recycled, are a serious source of danger to public health because PET bottles block drain and gutters which consequently result in flooding, PET bottles release toxic gas into the atmosphere when burnt, PET bottles and containers serve as breeding habitat for mosquitoes when filled with rain water and Cow dung, when left, uncontrolled, releases foul smell and toxic gas into the atmosphere.

This investigation is important because it seeks to make use of cow dung ash as partial replacement of fillers and Polyethylene Terephthalate (PET) as partial replacement of bitumen in different mixes.

Materials and Methods

The materials used for this research include conventional coarse and fine aggregates (granite and sharp sand respectively), filler material (granite dust), cow dung, polyethylene terephthalate (PET) bottles and bitumen. The research involved a few stages including; the sourcing and preliminary tests of materials, production of the cow dung ash (CDA), determination of optimum bitumen content, evaluation of the effect of CDA as a partial replacement of filler and PET as partial replacement of binder on properties of asphalt concrete in varying percentages and statistical analysis of the results.

Materials

The cow dung used in the experiment was obtained from the surrounding area of College of Veterinary Medicine, Federal University of Agriculture, Abeokuta (FUNAAB) Nigeria. The PET bottles were also obtained from FUNAAB campus. The coarse aggregate and fillers were obtained from a quarry in Abeokuta, Nigeria. The fine aggregate was obtained from a local distributor while the bitumen was obtained from a local market in Abeokuta, Nigeria.

Production of CDA and PET bottles,

The cow dung was sun dried for fourteen days and pounded into granules before burning in a closed furnace at a temperature of 500ºC for five hours to produce the white, powdery substance, which was used to replace mineral filler.
The PET bottles were first shredded to small bits to ease melting before been used as binder replacement

Determination of aggregate mix design and optimum bitumen content

A suitable blend of aggregate was obtained from sieve analysis results and tested for optimum bitumen content with bitumen trial percentage of 5, 5.5, 6, 6.5 and 7%. The average values of bitumen content at the maximum stability, maximum density and 4% air voids according to standards was selected as the optimum bitumen content.

Evaluation of the effect of CDA as partial replacement of filler on the volumetric and Marshall Properties of asphalt concrete

The CDA was used to replace the filler material at 4, 8, 12, 16 and 20 % in the asphalt mix. The materials were mixed together and compacted according to Marshall procedure with 50 blows on both sides to obtain cylindrical samples for the Marshall stability tests. Volumetric parameters such as density, void in total mix, voids filled with bitumen as well as marshal stability and flow were carried out on asphalt cores to evaluate the strength of the mixes.

Evaluation of the effect of PET as partial replacement of bitumen on the volumetric and Marshall Properties of asphalt concrete

The polyethylene terephthalate (PET) was used to replace the bitumen at 3, 6, 9, 12 and 15% in the asphalt mix. The materials were mixed together and compacted according to Marshall procedures with 50 blows on both sides to obtain cylindrical samples for the Marshall stability tests. Volumetric parameters such as density, void in total mix, voids filled with bitumen as well as marshal stability and flow were carried out on asphalt cores to evaluate the strength of the mixes.

Data Analysis

The Data set obtained were analyzed with a statistical package (SPSS, BMI incorporated v 20) using one-way Analysis of Variance (ANOVA), and mean separated with Duncan Multiple Range Test (DMRT) as a single post-Hoc Test. Regression model with p-values were obtained at a significant level of 0.05.

Results and discussion

Preliminary test of materials

The results of the preliminary tests of aggregates are shown in the Table 1. The properties of all materials met specified standards of materials to be used in asphalt concrete. Table 2 shows the sieve analysis of the aggregates and their aggregate gradation curves are shown in figures 1. A mix design of 55% coarse aggregate, 31% fine aggregates and 14% filler material was obtained as the job mix formula for this research.

Table 1: Preliminary tests on materials

Property	Specifications	Coarse Aggregate	Fine Aggregates	Granite dust	CDA	Bitumen
Specific Gravity	ASTM D 854	2.68	2.63	2.58	2.78	0.99
Penetration (mm)	AASHTO T-49	-	-	-	-	37
Flash Point (°C)		-	-	-	-	236.7
Fire Point (°C)	IS : 1209-1978	-	-	-	-	325

Table 2: Sieve analysis of aggregates and filler

Sieve Size (mm)	Percentage Passing (%)		
	Coarse aggregate	Fine aggregate	Filler
12.7	100	100	100
10.00	100	100	100
4.75	0.5	92.9	100
2.36	0	67.4	100
1.18	0	50.7	100
0.60	0	31.5	100
0.30	0	12.3	99.8
0.15	0	3.8	83.6
0.075	0	1.4	100

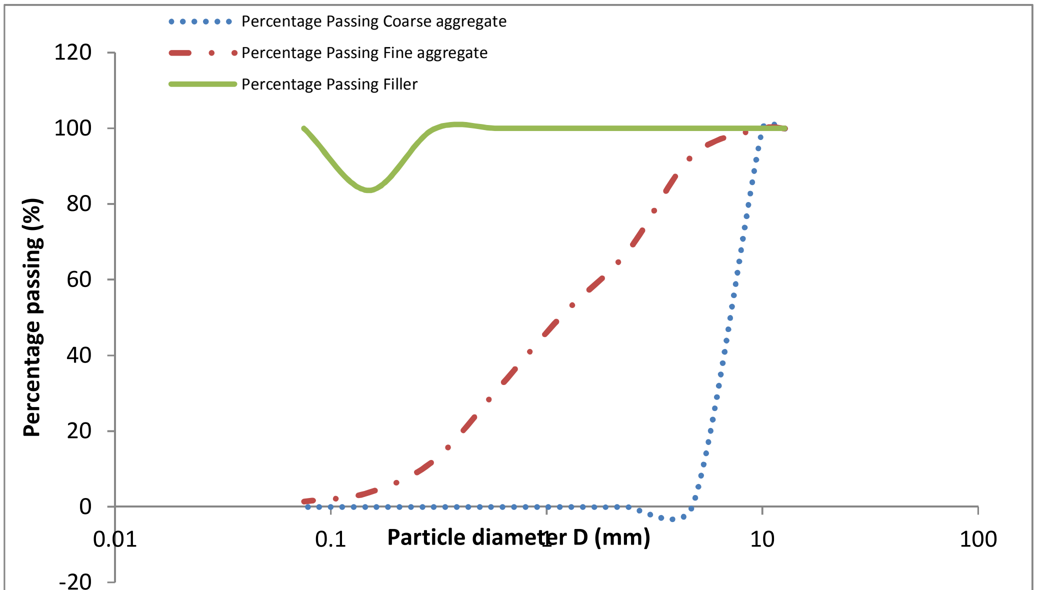


Figure 1: Particle size distribution of aggregates and filler

Optimum bitumen content (OBC)

Table 4 presents result for the trial mixes with 5, 5.5, 6, 6.5 and 7% of bitumen. The optimum bitumen content (OBC) was obtained as 6%.

Table 4: Marshall Stability, flow and Volumetric properties to determine the Optimum Bitumen Content

Parameters	Asphalt Institute specification for medium traffic roads	Bitumen Content (%)				
		5	5.5	6	6.5	7
Marshall Stability (kN)	≥5	7.47	7.25	7.3	7.28	7.2
Flow (mm)	2-4	3	3.5	4	4	3.2
Va (%)	3-5	4.5	3.8	5	4.1	3.9
VFA (%)	65-78	77.24	81	75.5	79.33	80.50
VMA (%)		11.75	12.12	11.48	11.96	12.06
Bulk Density (g/cm^3)		2.35	2.37	2.34	2.39	2.41

*Note: Va= Air voids, VFA= Voids filled with Asphalt, VMA= Voids in mineral aggregate.

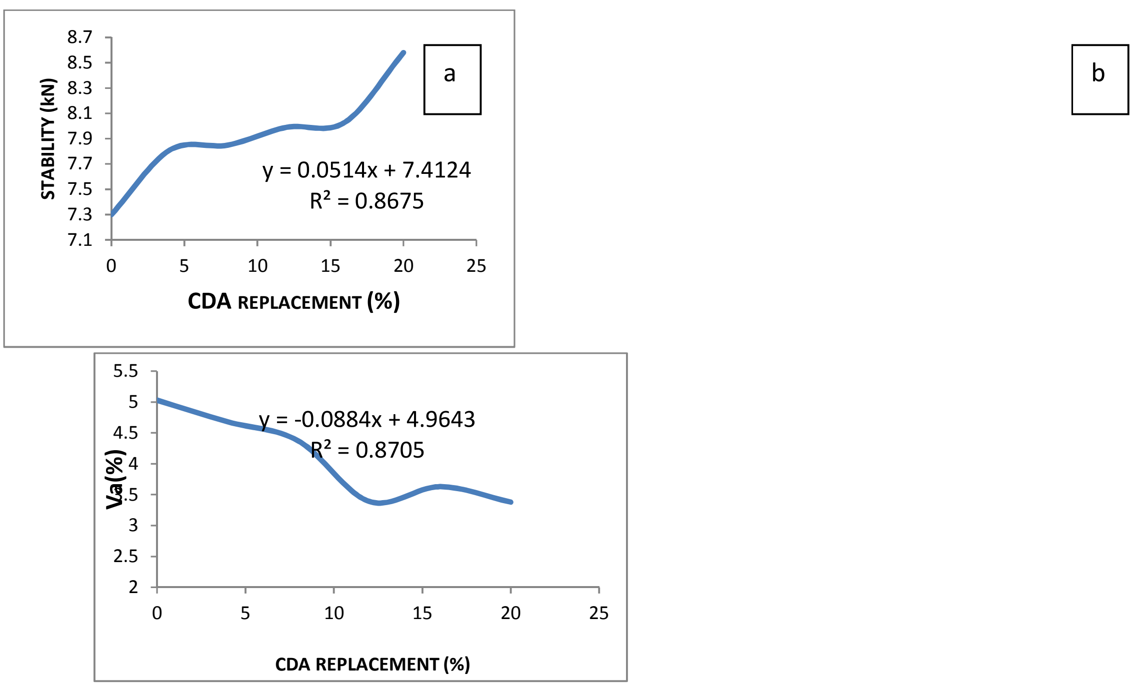
Marshall Stability, flow and volumetric properties of asphalt concrete with filler partially replaced with CDA

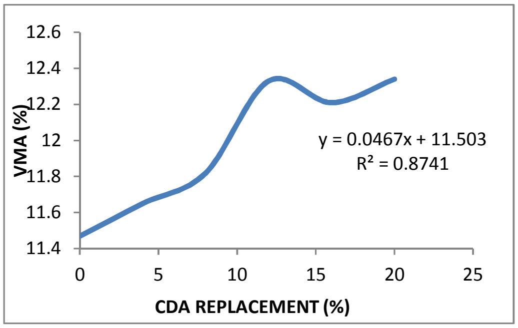
Table 5 shows the results of, Marshall Stability, flow and volumetric properties of asphalt concrete with filler partially replaced with CDA. Most of the results are within the limits of specification including the control mix. The optimum stability and percentage air void value for this type of mix was recorded to be between 4% and 8%. This is an implication that partial replacement of filler with CDA between 4% and 8% can be considered for use in hot mixed asphalt to improve the strength of wearing course of medium traffic roads. Figure 2 shows the relationship between the percentage replacement and stability, Va, VFA, VMA and bulk density using regression model with their R^2 values and prediction equations. As displayed in the figure 2e, no significant relationship existed between percentage CDA replacement and bulk density. However, a very strong inverse relationship existed between the percentage CDA replacement and air voids (figure 2b) with R^2 of 0.8705, an indication that 87% of the variations observed in Va were being accounted for by percentage of CDA in the Mix. Also, stability, VMA and VFA values were significantly affected by percentage CDA replacement. While 86.75% of the variations observed in stability values(figure 2a) were accounted for by percent CDA replacement, about 87.4% and 76.78% of the variations in VMA and VFA values were being accounted for by percent CDA replacement respectively (Figure 2c and 2d respectively).

Table 5: Marshall test results and Volumetric properties of asphalt concrete with filler partially replaced with CDA in with according to asphalt institute (AI) specifications.

Parameters	Asphalt Institute specification for medium traffic roads	CDA REPLACEMENT (%)					
		0	4	8	12	16	20
Marshall Stability (kN)	≥5	7.30[a]	7.81[b]	7.85[b]	7.99[c]	8.03[c]	8.58[d]
Flow (mm)	2-4	4	4	4	4	4	4
Va (%)	3-5	5.00[c]	4.68[bc]	4.37[b]	3.39[a]	3.63[a]	3.38[a]
VFA (%)	65-78	75.50[a]	76.98[b]	79.31[b]	80.02[bc]	80.16[bc]	80.92[c]
VMA (%)		11.47[a]	11.65[ab]	11.82[b]	12.33[c]	12.21[c]	12.34[c]
Bulk Density (g/cm^3)		2.34[a]	2.33[a]	2.35[a]	2.36[a]	2.33[a]	2.34[a]

[a,b,c] Values with different superscript in a row are statistically different from each other ($p<0.05$)





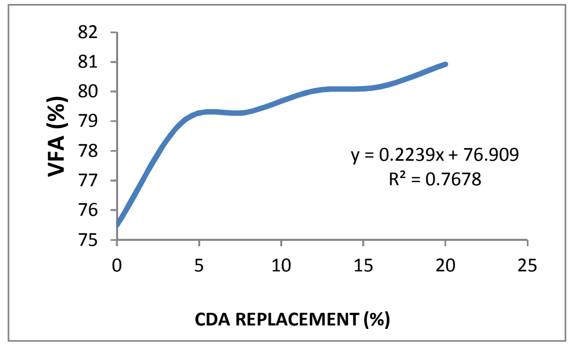


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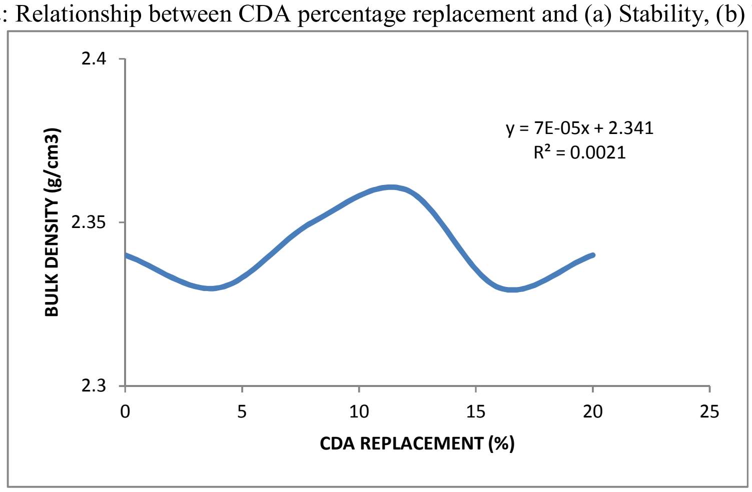
Figure 2: Relationship between CDA percentage replacement and (a) Stability, (b) Va, (c) VMA, (d) VFA and



(e) Bulk density of asphalt concrete using regression model

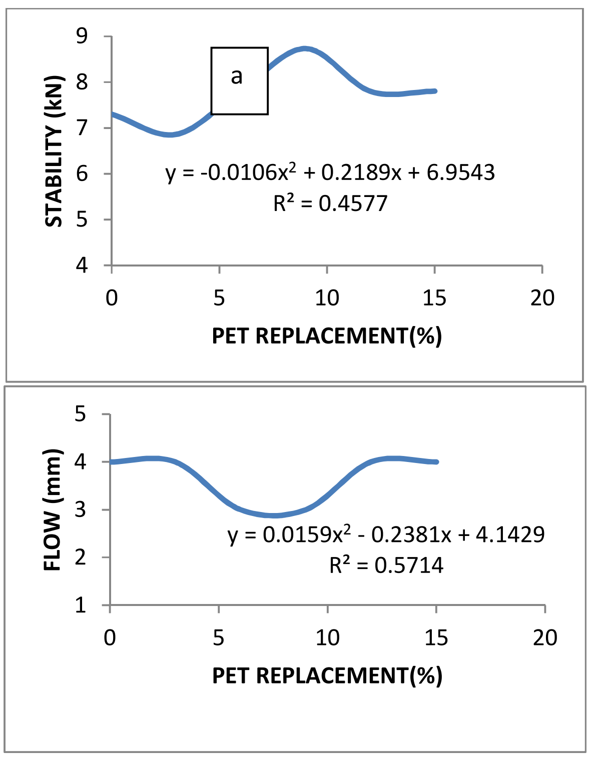
Marshall Stability, flow and volumetric properties of asphalt concrete with bitumen partially replaced with PET

Table 6 shows the results of, Marshall Stability, flow and volumetric properties of asphalt concrete with filler partially replaced with PET. All the results are within the limits of specification including the control mix. The optimum stability and percentage air void value for this type of mix was recorded to be between 6% and 15%. This is an implication that partial replacement of bitumen with PET from 6% to 15% can be considered for use in hot mixed asphalt to improve the performance of wearing course of medium traffic roads. However, at 12% replacement, the percent air void is very low about (2.24%), which means that utilizing this replacement at this proportion will most likely cause rutting and bleeding of the flexible pavement because there will not be enough air voids for the bitumen to occupy during traffic loading. Figure 3 shows the relationship between the percentage replacement and stability, flow, Va, VFA, VMA and bulk density using regression model with their R^2 values and prediction equations. As displayed in the figure, there was significant relationship between percentage PET replacement and all parameters except stability (R^2 =0.4577).

Table 6: Marshall test results and Volumetric properties of asphalt concrete with bitumen partially replaced with PET according to asphalt institute (AI) specifications.

Parameters	Asphalt Institute specification for medium traffic roads	PET REPLACEMENT (%)					
		0	3	6	9	12	15
Marshall Stability (KN)	≥5	7.30^{b}	6.86^{a}	7.82^{c}	8.73^{d}	7.80^{c}	7.80^{c}
Flow (mm)	2-4	4	4	3	3	4	4
Va (%)	3-5	5.00^{d}	3.47^{bc}	3.64^{c}	3.08^{b}	2.24^{a}	3.31^{bc}
VFA (%)	65-78	75.50^{b}	74.47^{ab}	74.27^{ab}	73.94^{a}	73.79^{a}	73.86^{a}
VMA (%)		11.47^{a}	12.29^{bc}	12.20^{b}	12.49^{c}	12.94^{d}	12.37^{bc}
Bulk Density (g/cm^3)		2.34^{c}	2.35^{c}	2.31^{bc}	2.24^{a}	2.24^{a}	2.27^{ab}

[a,b,c,d] Values with different superscript in a row are statistically different from each other ($p<0.05$)



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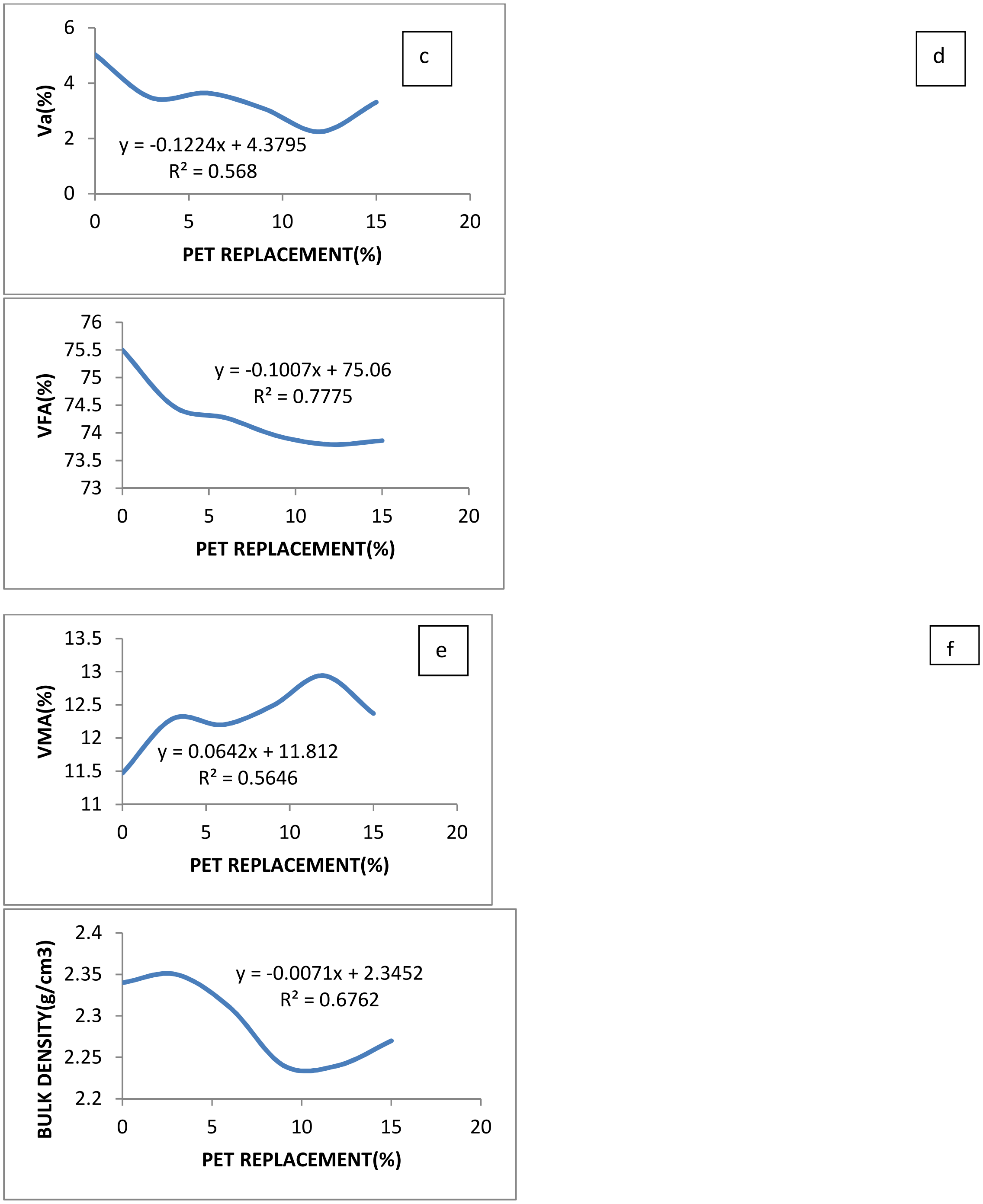

Figure 3: Relationship between PET percentage replacement and (a) Stability, (b) Flow, (c)Va, (d) VFA, (e) VMA and (f) Bulk density of asphalt concrete using regression model

Conclusion

According to the results of the experimental investigations on the performance of asphalt concrete with cow dung ash as partial replacement of granite dust filler it was observed that 4 and 8% cow dung ash have good potential to improve the properties tested for in the asphalt concrete. This implies these mixes have the potential to be used as wearing course of medium trafficked roads. For the mixes with PET as partial replacement of the bitumen, similar improvement in the asphalt concrete properties was observed for percentages between 6 and 15%. This also implies that PET has very good potential in replacing bitumen in asphalt concrete to be used for wearing course of medium trafficked roads.

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