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Dissolved Pure Water Sachet as a Modifier of Optimum Binder Content in Asphalt Mixes

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Abstract

The Marshall properties of bitumen modified asphalt mix for wearing course of a flexible pavement were determined in the laboratory. The bitumen modification was achieved with dissolved pure water sachet in a petroleum bye product as a partial replacement of and additions to the optimum bitumen content. The variation of the Marshall Stability, flow and Voids in Mix (VIM), voids filled with binder (VFB) and voids in mineral aggregates (VMA) were monitored as the proportion of the emulsified dissolved sachets increased. The respective Marshall Stability values of 1,400 kg for unmodified bitumen binder; 1,150 kg at 15% partial replacement (1% dissolved pure water + 5 % optimum bitumen content = 6 % binder) and 1200 kg at 25 % addition (2% dissolved: pure water + 6 % optimum bitumen content = 8% binder) were recorded; which were both higher than the desired stability for heavily trafficked pavement. The dissolved pure water sachet modified asphalt through the two methods of application are equally effective to carry heavy traffic and still liberate the environment from the health hazards of the pure water waste sachets in rural and urban settlements. However, the modification method of additions to the optimum bitumen should be preferred because of its more consumption of the unwanted flying pure water sachet and save in quantity of bitumen in the production of asphaltic pavement mixes.

Key words: Dissolved pure water sachet, emulsion, optimum binder content, marshall stability, flow

1. Introduction

The non degradable thermoplastic polythene plastics used as commodity goods storage and packaging purposes accounts for over 60 million tons of annual wastes generation worldwide (Justo and Vaeeraragaven, 2002). It was also reported (Aremu, 2008) that 30 % of the domestic waste in a typical Nigerian city comprises of the polythene and plastic products in very large quantities; whose disposal has continued to constitute the great environmental pollution challenge and concern in big and small cities. The enormity of the problem of the pure water sachets is better imagined during or immediately after rains in urban areas, where the highway drainage channels conveniently serve as the dumping sites for the polythene bags. However, a consideration of processing this expedient material for a better alternate use by recycling to other beneficial products, can contribute more positively to material cost reduction; health, safety and environment (HSE) compliance in construction, of bituminous mixes for pavement works. Tyres, plastics, pipes, cement admixtures in physical shreds as fibre reinforced, (Singh and Singh, 1983); oil shale modified asphalt, (Katamine, 2000); plastic waste rubbles as aggregates in concrete pavements, (Zoorob and Superman, 2000 and Zoorob, 2000) and as successful bitumen modifier in asphalt mixes, (Amjad et al. 1999, Singh and Singh 1991, Kulshreshiha et al. 1988). The economic and environmental advantage of alternate use of these products have been demonstrated, (Jimoh and Kolo, 2010) with the reprocessed polyethylene pure water sachet modification of the optimum bitumen binder in asphalt mix production, but with partial replacement only. However, another modification procedure is to increase the pure water consumption by additions to the optimum bitumen of the modifier, thereby increase the rate of control of the non degradable wastes. While more consumption assures better environment, the reduction in the optimum bitumen binder is an added advantage in the cost of pavement works.

2. Materials and Methods

2.1 Materials

The materials used consist of the thermoplastic thrown away waste plastics (polyethylene) of pure water sachet which is reprocessed with a petroleum bye product solvent to miscible status with the non-crystalline S125 state run bitumen. The former material is a commodity heavily used in consumer products storage, while the latter is a black, brown or black brown solid viscous (at room temperature) and adhesive hydro carbon or derivatives, which can be sourced also from crude petroleum through fractional refinery processes. Bitumen softens gradually when heated and it is believed to have 54 % binder, 36 % mineral matter and organic matter of 10 %, (Brown, 1990). Bitumen is also a complex chemical mixture of molecules of a predominantly hydrocarbon nature with a minor amount of structurally analogous heterocyclic species and functional groups containing sulphur, nitrogen and oxygen atom, with some trace quantities of metals of vanadium, nickel, iron, magnesium and calcium which occur in the form of inorganic salts and oxides or in porphyry structure; (Singh and Singh, 1991; Brown, 1990, BSI, 1991).

Pure water sachet is a low-density polythene which is heavily characterized by hydrocarbon chains (just as the bitumen) resulting to a tough material insolvable at room temperature, but does at high temperature in the presence of aromatic hydrocarbons. The density is in the range of 0.93 – 0.97 and melting point of about 115^{o}C, http://en.wikpedia, www.AUS-e-TUTE and Adetoyi, 1997. Polyethylene, shortened to PE in polymer chemistry is a two CH_2 groups connected by a double bond (CH2=CH2) in a crystal structure created through ion (cation or anion) coordination polymerization, as shown in Figure 1. Figure 2 shows a heap of the pure water sachet waste dump indicating the environmental pollution caused by the material. Table 1 shows the comparison of the properties of the two main materials (bitumen and polyethylene) while Table 2 gives respective sources used in the study.

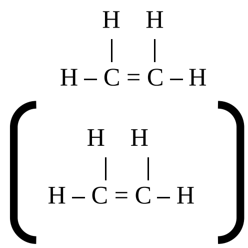

Figure 1: Molecular structure of ethane and polythene

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Fig. 2: Pure water sachet waste dump.

Table 1- Comparison of the properties of bitumen and polyethylene (pure water sachet)

Serial Number	Property	Bitumen	Polyethylene
1	Viscosity	It flows at temperature above a minimum specified	It coagulates on heat application, but flows in a solvent and heat
2	Transparency	Bitumen is not transparent and it is black brown in colour. It could brittle at very low temperature.	Has good transparency and is colourless at Very low temperature.
3	Temperature	The mixing temperature of bitumen (60/70) is 140°C	The melting temperature of polythene is 115°C
4	Heat Resistance	It losses its toughness and pliability easily as temperature is increased.	Retains its toughness and pliability over a wide temperature range.
5	Flexibility	Is flexible even before heat application.	Is also very flexible even before heat application
6	Strength	Not hard due to irregular packing of polymer chains	Not hard due to irregular packing of polymer chains
7	Solubility	Soluble in most solvent (e.g.) Petrol, kerosene, diesel e.t.c.	Insoluble in most solvent but soluble on heat application in some solvent
8	Adhesive	Very strong and durable adhesive that binds together a very wide variety of other materials without affecting their properties.	Its adhesive property is very low

Source: Shell Bitumen Handbook (1990)

Table 2- Source and physical characteristics of the materials for study.

Serial No	Material	Description / Characteristics	Sources	Remarks
1	Pure water sachet	It is colourless, density is between 0.91 – 0.94g/cm^3, its melting temperature is between 110 –160^{o}C. It is flexible and is not easily dissolved by petroleum products.	Life fresh pure water manufacturing company in Chanchaga, Minna, Niger State.	Package water sachet in dry form
2	Bitumen	It is black in colour, having a penetration between 60dmm – 70dmm at temperature of 25^{o}C, it s density ranges between 0.95 to 1.00kg/lit	P.W. (Nig) Ltd, Vom, Plateau State.	60/70 Bitumen Penetration
3	Solvent	DPK (Dual Purpose Kerosene)	P.W. (Nig) Ltd, Vom, Plateau State.	D.P.K
4	Aggregate	Must be hard enough to withstand wheel abrasion.	P.W. (Nig) Ltd, Vom, Plateau State.	Igneous rock
5	Water	Tested and fit for consumption	P.W. (Nig) Ltd, Vom, Plateau State.	Bore-hole, satisfies WHO standard

2.2 Laboratory works.

The preliminary laboratory works were conducted in four main stages (i) material sourcing and characterization according to BS 1377 (BSI, 1990) (ii) conversion of the pure water to blend-able state with the bitumen (iii) determination of the optimum bitumen content for HMA flexible wearing course of a heavily trafficked road, and (iv) evaluation of the bitumen – dissolved pure water sachet emulsion blend for the two methods of application as a modifier, that is, partial replacement or additions to the optimum bitumen. In order to determine the optimum binder content, the highest density, the highest stability, the specified flow and voids in the mix were considered as the performance parameters for the Marshall design which gave 6% of optimum bitumen binder. Also, the extraction test was performed on the HMA in order to confirm the gradation compliance of the aggregates used in the mix production.

2.3 Conversion of pure water sachet to semi – solid.

The pure water sachet has to be converted to a form, which will be miscible with bitumen as mixing the pure water sachet directly with bitumen do not form a paste. The objective was achieved with a solvent that is capable of breaking the cross link bond after many dissolution trials, enumerated in subsequent poetion of this section:

a) Direct heating - melting the pure water sachet ordinarily by heat application, but instead of melting it was coagulating, forming a hard substance. Even after it was shred into smaller pieces while trying to melt, the same observation was noticed.
b) Direct application to bitumen - Direct application of the sachet to the bitumen both in whole and the shred forms was attempted but miscibility was not achieved,
c) Use of chemical - Among other chemicals used were toluene, ethanol, benzene etc but none was able to dissolve the pure water sachet appropriately.
d) Solvent to solvent accompanied with an intensive heating of the like manner cross-link solvent, a petroleum distilled bye product (the Dual Purpose Kerosene (DPK)) with the pre water sachet, which eventually gave the required solubility.

The DPK is also a cross-linked polymer (Mergerison and East, 1976 and Staszewska et al., 1980) as the pure water sachet polythene.

The sachet in solution was achieved by first heating the solvent in a mixing bowl, to a temperature of about 40^oC, and then pouring the pure water sachet into the mixing bowl which contained some quantity of the solvent just enough to dissolve the pure water sachet (in the ratio of 1 % of pure water sachet to 3 % of solvent), by volume. The mixture was then returned to the hot plate, adequately covered and raised to a temperature of 80^0C. It was again removed from the hot plate for stirring. The mixed content, that is the solvent and the pure water sachet are then returned to the hot plate and covered for further heating to a temperature of about 120^oC. This process was continued until a semi liquid mixture was achieved. The noticeable physical character of the mixture was the swelling of the pure water sachet in the solvent, which occurred almost immediately before its actual dissolution. The detail of the reprocessing is reported elsewhere (Kolo, 2008).

2.4. The HMA test specimens

Eleven Marshall Specimens of the HMA wearing course at 6 % optimum bitumen content for heavy traffic were produced to reflect various percentages of the dissolved waste pure water sachet. The specimens were prepared in the laboratory at two main regimes of five specimens for partial replacement while keeping the optimum bitumen constant at 6 %; five for additions to the optimum bitumen and one specimen at the 6 % bitumen binder, unmodified as a control. For the bitumen replacement test and keeping the 6 % optimum, the addition of processed polyethylene was done in percentages while same percentages were added for the addition according to the schedule displayed in Table 3. Trial mixes were produced, compacted and tested according to the Marshall method for the various total binder content. The corresponding Marshall parameters for the two binder modification procedures were subsequently determined and summarized in Table 4. The results are also displayed in Figures 3 – 8.

Table 3- DPWS bitumen modification schedule

S/No	Bitumen (%)	DPWS (%)	Total (%)	Remark
1	6	0	6	Unmodified
2	5	1	6	Partial replacement of OBC+ binder
3	4	2	6	
4	3	3	6	
5	2	4	6	
6	1	5	6	
7	6	1	7	Addition to OBC+
8	6	2	8	
9	6	3	9	
10	6	4	10	
11	6	5	11	

+ Optimum bitumen content

Table 4- Results of two optimum bitumen modification procedures.

% of added pure water sachet to 6% bitumen	Marshall Stability(Kg)	Flow	Apparent Dens ity	Void in Total Mix	Void in mineral Aggregate	Void filled with Bitumen
-5	800	3.5	2.39	6.34	19.40	72.68
-4	875	3.5	2.38	6.30	19.38	72.65
-3	907	3.4	2.24	5.88	19.02	74.44
-2	1075	3.2	2.26	5.05	18.29	78.02
-1	1155	3.0	2.28	4.20	17.57	81.96
0	1313	2.7	2.29	4.18	17.21	79.02
1	1391	2.6	2.32	0.85	17.96	94.71
2	1321	2.8	2.30	0.43	19.19	101.35
3	1216	3.0	2.28	0	21.46	100.70
4	1041	3.1	2.26	0	23.00	103.43
5	962	3.1	2.20	0	25.55	99.69

4. Results and Discussions

4.1 Pure water sachet (PWS) conversion for bitumen blending.

The pure water sachet retained its premium properties as listed earlier after its conversion but turns to liquid state on application of heat. This fact indicates that dissolved pure water sachet is readily miscible with bitumen with the reprocessed sachet and that the bitumen and pure water sachet have similar polarity and hence miscible /blend-able. This implies further that the dissolved pure water can maintain respective premium properties during storage and in service. The most desired property of the polyethylene by bitumen is its viscosity properties and its ability to retard oxidation of bitumen, there-by prolonging the life of the asphaltic pavement. The fact that the bitumen and the sachet bags are highly characterized with heavy carbon molecules encourages their miscibility. It is important to state that while the DPK was on the hot plate it was adequately covered and was not over heated. Also on removal from fire, addition of the PWS was done so as to prevent eventual fire out break by working at a temperature of not more than 120^{o}C which is not up to 140^{o}C, the boiling point of 60/70 standard penetration state run bitumen. The import of the outcome of the blending exercise is that pure water sachet, a predominantly hydrocarbon based compound (polythene), is miscible with bitumen when dissolved in Dual purpose kerosene (DPK), another polymer but has at a heated and boiling temperature of 120^{o}C in the common laboratory setting.

4.2 Optimum binder content modification.

The Marshall properties for the test specimens show a general trend that is not too different from the mixes with the unmodified binder, as indicated in the various figures. The apparent density curve shown in Fig.3 for the bitumen and processed polyethylene as the binder also shows that at about 14% replacement, the density dropped and rose again at about 50% replacement. This may be explained by the differences in the specific gravity of the two components of the binder, the state run bitumen's specific gravity is 1.01 while for the DPWS, and it is 0.95. Also, the swelling at first instance of the PWS during the conversion without any gain in weight is another reason for the gradual drop in the density as the PWS proportion increases. None the less, the apparent density indicates that as more dissolved pure water sachet is added to the bitumen, the pavement becomes lighter but still able to bear the imposed traffic load and serve the useful life time of the pavement since the desired values of the optimum bitumen modification (Highway Manual, 1972) were never exceeded. Also as can be observed from the graph, there is a negative fall of the density from the left to the right of the graph in the optimum replacement portion until the ratio of -2, when it begins to rise. Incidentally another change in sign occurred again when the binder modification by DPWS addition reaches the ratio of +2. This trend shows that the influence on the properties is in different senses for the two modification procedures. The optimum replacement approach (indicated by the x – axis) introduces an increase in the properties as the replacement ratio decreases, while for an addition to the optimum, the apparent density increases as the proportion increases.

This observation is common to the other Marshall properties of the mixes produced with the modified bitumen. For instance, the voids in total mix (VIM) line (Fig.4) indicates a negative fall from the left to the right of the graph indicating rapid reduction in the void within the total mix that can result to sliding of the mix. The addition of too much binder to the aggregates implies no enough space between the aggregates for compaction. Therefore instead of compacting, sliding will be observed for any application of force or pressure. This was also the case of other properties in connection with voids. The replacement of the optimum binder with a ratio of 1:5 % does not cause any change in the property (constant at 4 %) but drastically reduced to 1 % when the modification by addition to optimum is 1 %:7 % (6+1) in the HMA. The indication of the curve for the variation of the voids in total is that bitumen ratio reduction in the mix at the initial point has no effect on the voids since it has been replaced by polyethylene. But on further replacement, the VIM increased. The Void filled with bitumen (VFB) curve shows that maximum void that can be filled with the modified bitumen is about 18 % of optimum bitumen replacement after which there is a drop in value, indicating that the mix is probably permeable to water.

It is apparent, from all the figures, that the modification of optimum bitumen binder in the two cases does not show any adverse effect on the desired properties of the HMA for flexible pavement. For instance, for the density, VIM, VFB, flow and Marshall Stability (Fig. 3 - 8), the variation is in close agreement with respect to the corresponding Nigerian General Specifications, 1997. See particularly for the case of stability for wearing course for heavy traffic, (Fig. 8). A considerable decrease in the load bearing capacity of the pavement as the dissolved pure water content proportion is been varied was possible with the addition done up to 30 % for a stability of 1,300 kg. The Marshall Stability curve further shows that the ability to carry heavy load peak at 1,400 kg. But having a closer examination of the result and comparing with the standards, replacement of bitumen with dissolved pure water sachet can be done up to 15 % and still maintaining stability of about 1,150 kg; which is still far higher than the 350 kg specified by the general specifications for roads and bridges, (FGN, 1997) for heavy traffic on Nigeria roads. This implies that the capability of the resulting Asphalt mix can withstand heavy traffic of Category E and F, which is about 4,500 vpd of carrier exceeding 3 tons loaded weight (FGN, 1972). The results also indicate a 1 %:5 % replacement to be adequate without reducing the desired stability of 900 kg. It therefore implies that about 15 % by weight of bitumen can be saved with the inclusion of PWS in the production of asphaltic pavement for a wearing course. However a higher modification ratio is desirable for the addition to the optimum, about 5 %. Similar deductions are applicable for the flow property. The consumption of the waste pure water sachet for the latter case is extremely higher and hence portends a more environmental effectiveness.

Specifically for the flow property, the reduction in bitumen via the replacement of the optimum indicates a reduced deformation rate. The case of addition to optimum indicate a sag value at about 1.5 – 2.0 bitumen addition; which is equivalent to a 25 % proportion. This implies that deformation rate is reducing with the inclusion of polythene to asphaltic pavement by any of the two possible approaches of modification. In general and the fact that miscibility with bitumen was achieved with replacement or adding to proportion of bitumen in the total binder content for wearing course was done without any appreciable loss of traffic load carrying capacity of the pavement is a positive indication of the recycling potential for the pure water sachet. This alternate use will clear the environment of the nuisance of the pure water sachet wastes.

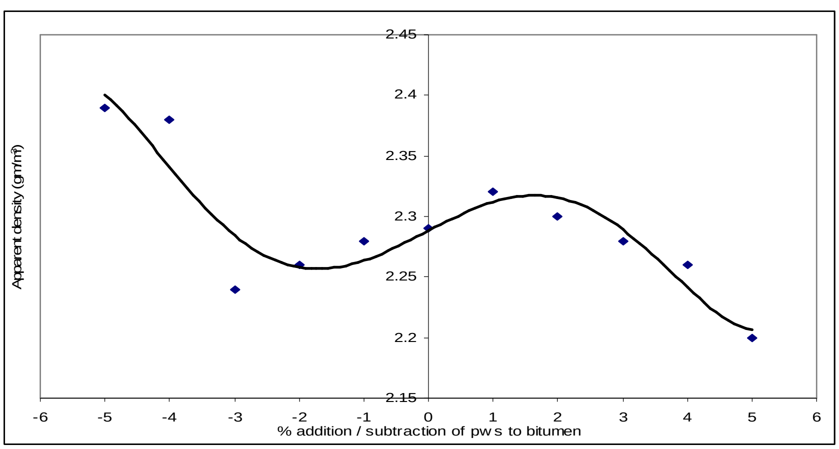

Fig 3: Combined apparent densities

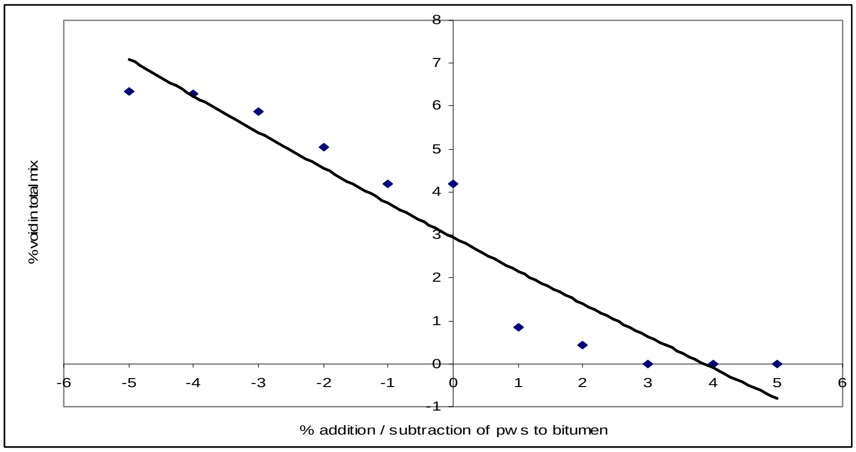

Fig 4: Combined voids in total mix

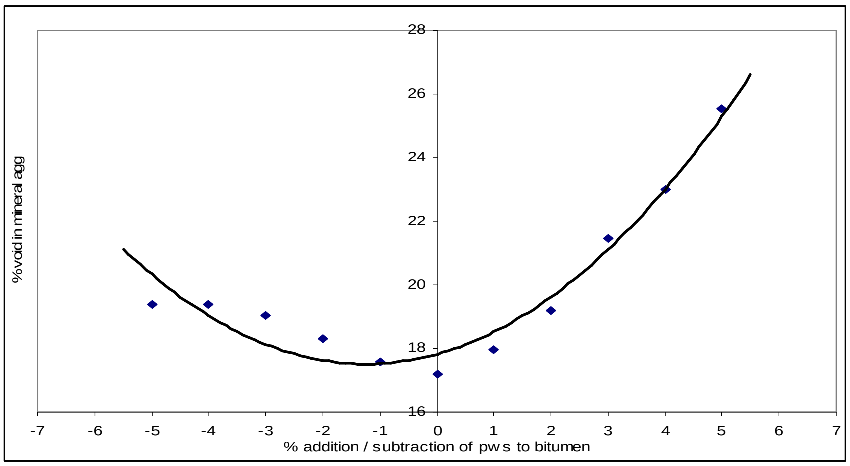

Fig. 5: Combined void in mineral aggregate

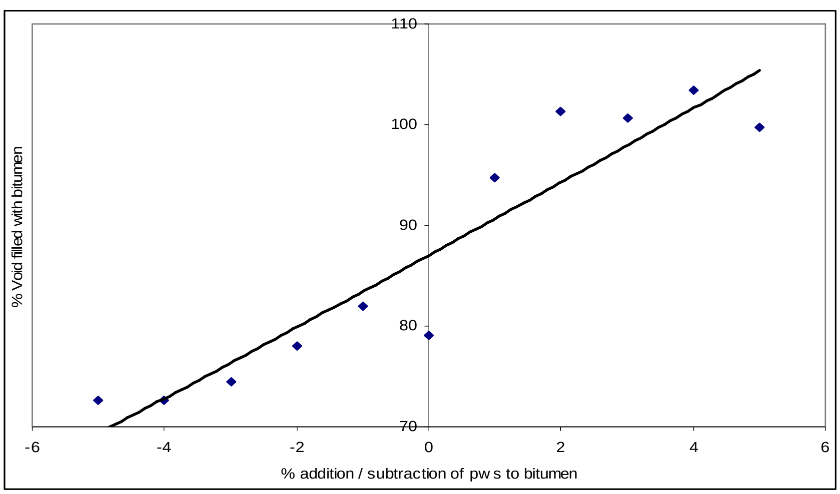

Fig. 6: Combined void filled with bitumen

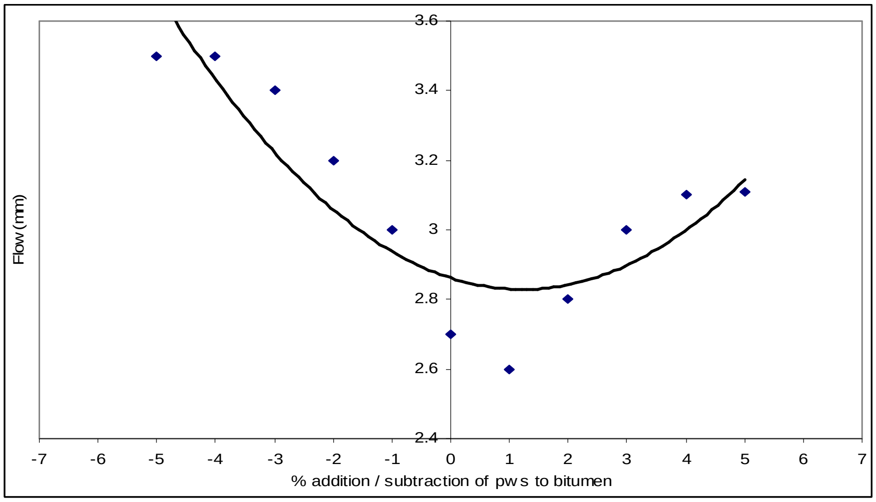

Fig. 7: Combined flow

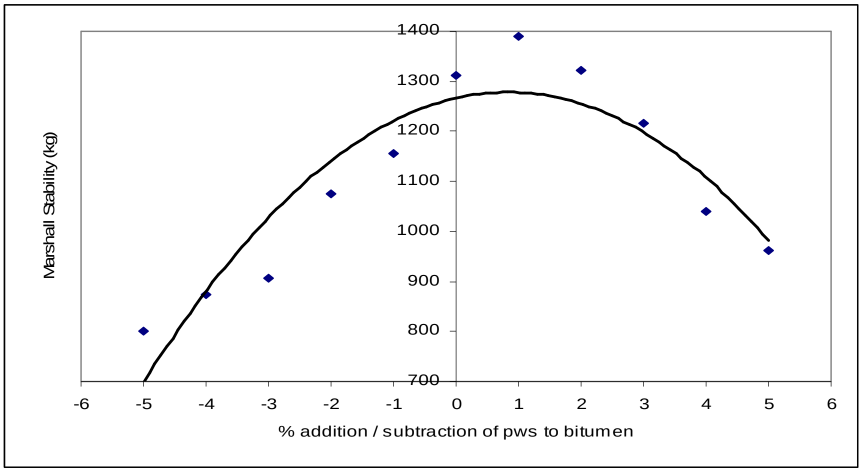

Fig. 8. Combined Marshall Stability

5. Conclusions

The following conclusions can be made from this study:

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a) The DPWS can be combined with bitumen to exhibit the desired flow and stability of an HMA wearing or bearing course for a flexible pavement at 15 % replacement of the optimum binder content and 25 % additions by weight of total mix (in emulsified condition).
b) The bitumen modification method of additions to the optimum binder is more effective for pollution control because of higher demand of the waste, 25 % compared to 15 %.
c) The utilization of the pure water sachet for the preparation of modified bitumen for HMA mixes for road works is an alternative recycling and substantial increase in the scrap value for this undesirable waste material.

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