PARTIAL SUBSTITUTION OF ASPHALT BINDER WITH REPROCESSED POLYETHYLENE WATER SACHETS.

BY

Jimoh, Yinusa A.* and Kolo, Solomon S. **, Department of Civil Engineering, University of Ilorin, Ilorin Nigeria* and Federal University of Technology, Minna Nigeria. **

*corresponding author e – mail: yaj@unilorin.edu.ng.org; dryajimoh@yahoo.com.

ABSTRACT

An economic analysis of the partial replacement of optimum bitumen content (OBC) with re - processed polyethylene water sachets (PWS) in the production of asphalt mixes as a cost saving measure in road works as well as its application as a pollution control strategy in an environment invested with non degradable waste materials is reported in this paper. The OBC was first determined according to Marshall Method for a heavy traffic binder course. The PWS emulsion, (prepared from 1:3 parts, by weight, of reprocessed PWS and a solvent at a temperature of 120^0C), was partially substituted for the optimum bitumen in the hot mix asphalt. The respective Marshall Stability for the unmodified and modified binder was 1400 kg and 1150 kg with corresponding flows of 2.6 mm and 3.2 mm. A 15% partial replacement of the OBC, that is; the proportion of the emulsion (percentage addition to optimum bitumen binder content) in the ratio of 1% reprocessed PWS: 5% of the bitumen had no adverse effect on the desired Marshall properties of the binder course for a heavy traffic, and indeed a financial savings as much as 3.75 % in the cost of asphalt concrete mix is also possible. These values proved that bitumen can partially be replaced with a reprocessed pure water sachet for economic advantage of road works while at the same time can facilitate the liberation of the environment of polyethylene wastes.

Keywords: Solvent, optimum binder content, reprocessed pure water sachets, Marshall Stability and Flow.

1.0 INTRODUCTION

1.1 Background

The demand for cheap and safe drinking water and packaging has resulted in the generation of wastes of non - degradable polyethylene (plastic and pure water sachets) in large quantities. Once the packaging objectives have been satisfied, the containers are discarded, creating great challenges for waste disposal and environmental pollution control. Sometimes, drainage channels are blocked to additionally serve as mosquitoes' breeding medium with the consequential health hazard. An alternate use of the polyethylene in concrete and pavement works has some economic advantage. Attempts of use as aggregates in highway development (recycled wastes and bye products) have been on for a very long time (over 100 years) in Australia and other parts of the world, (Amjad Khan et al (1999), Wilmot and Vorobieff (1997)); or recycled as plastics in bituminous / asphalt mixes, (Singh and Singh, 1983; Zoorob and Superma, 2000; Kulsfiresniha et al, 1988, Flynn, 1993 and Zoorob, 2000). Also the "recycled roads" initiative of the United States of America by the Intermodal Surface Transportation Efficiency Act of 1991 generated the needed catalyst which by the middle of 1990s had encouraged many Transportation Agencies in the US to be using, at least any three of the fly ash, rubber strands and chips, roofing shingles, plastics and glass as bitumen modifiers for pavement mixes;(Chesner, 1992) as long as the three key criteria for suitable use of waste and bye products for recycling in road construction works are satisfied. These criteria are (Collins and Gesielski (1994)) i) consistency in quality and meeting the specifications requirements ii) economically competing with the material being replaced in terms of total life cycle costs for a 20 year service period and iii) societal benefits of avoided disposal costs. In most of the cited cases of the usage of the polyethylene, reprocessing to other forms of state were not reported except the few attempts to strictly solve the environmental problem as an alternate and recycling use; (Kareem 2007) and some concrete works; (Raji et al. 2009). For the pure water sachets (PWS) to be used as binder, either partially or wholly in pavement mixes, certain reformation and or transformation had to take place in order to draw out on the fluid ability or viscosity property of the sachets in solution (or emulsion). A successful blending or partial replacement of bitumen will reduce the amount of bitumen binder in asphalt mixes and consequent savings in funding of pavement (road) works which would then imply; a) an addition, to existing list of probable bituminous material and the accompanying literature b) freer environment from flying pure water sachets, which currently are among the main sources of non-degradable environmental nuisances; and c) a reduction in the amount of bitumen for production of asphalt mixes, obviously an avenue for substantial foreign reserve depletion presently in Nigeria.

Therefore in specific terms, the paper will examine i) the miscibility of bitumen and polyethylene ii) a comparison of the Asphalt Marshall parameters (of stability, flow and stiffness, Marshals Quotient) of the mixes produced at optimum binder with those of the reprocessed PWS modified bitumen as a partial replacement of the optimum bitumen iii) the potentials of bitumen/polyethylene blend as an amelioration technique for environment pollution control of polyethylene (PWS) and iv) the estimation of the economic advantage of the substitution of the optimum bitumen with the reprocessed PWS emulsion in asphalt mixes and hence road works in general.

2.0 METHODOLOGY

2.1 Conversion of Pure Water Sachet to Miscible state with Bitumen.

Table 1 presents the comparison of bitumen and the pure water sachet as polyethylene families while Table 2 is a list of the materials used for the study indicating their respective sources and physical properties. The laboratory work was carried out in two major stages: - (1) Conversion of the pure water sachet to blend able state with bitumen and (2) Evaluation of the bitumen - reprocessed pure water sachet blend for hot rolled asphalt mix, according to the Marshall Design method.

Some pure water sachets were heated in a bowl, first to a temperature of 40 °C, and then poured into another mixing bowl which contained an excessive quantity of the solvent in the ratio of 1 % of pure water sachet to 3 % of the solvent. The mixture was then returned to the hot plate, adequately covered and raised to a temperature of 80 °C. Again the content was removed from the hot plate at the temperature to allow for effective stirring after some few minutes when the mixed content was then returned to the hot plate and covered for further heating to a temperature of 120 °C. The process was continued until a semi liquid emulsion was formed. However, while heating the pure water sachet before actual dissolution, there was noticed a slight swelling and colour change from white to sky blue, which on testing had a density of 0.90 kg/m^3 and a specific gravity of 0.89.

Table 1: Comparison between bitumen and pure water sachet (same polyethylene family)

Serial Number	Property	Bitumen	Polyethylene
1	Viscosity	It flows at temperature above a minimum specified	It coagulates on heat application, 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 colourless at Very low temperature
3	Temperature	The mixing temperature of bitumen (60/70) is 140 °C	The melting temperature of polyth is 115 °C

4	Heat Resistance	It loses its toughness and pliability easily as temperature is increased.	Retains its toughness and plia over a wide temperature range.
5	Flexibility	Is flexible even before heat application.	Is also very flexible even before application
6	Strength	Not hard due to irregular packing of polymer chains	Not hard due to irregular packi polymer chains
7	Solubility	Soluble in most solvent (e.g.) Petrol, kerosene, diesel e.t.c.	Insoluble in most solvent but s on heat application in some solve
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: Properties of Materials for the Study.

Serial No	Material	Description / Characteristics	Sources	Remarks
1	Polyethylene	It is colorless, density is between 0.91 – 0.94 g/cm^3, its melting temperature is between 110 –160 ^oC. It is flexible and is not easily dissolved by petroleum products.	Life fresh pure water manufacturing company in Chanchaga, Minna Niger State	Package wat sachet in dry form
2	Bitumen	It is black in colour, having a penetration between 60 – 700 dmm at temperature of 25^oC, is density ranges between 0.95 to 1.00 kg/lit	P.W. (Nig) Ltd, Vom Plateau State.	60/70 Bitu 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 V

				stand
6	Bucket	Cylindrical Shape and made of metal	P.W. (Nig) Ltd, Vom Plateau State.	Metal

2.2. Laboratory Determination of the Optimum Binder Content (OBC).

The aggregates and the mineral filler were mixed together as determined by the appropriate job mix formula and in accordance with the Marshall procedure, Shell Manual Series, MS - 2. An optimum binder content of 6 % was determined for a wearing course for a heavy traffic pavement based on the Marshall Specification values for a heavy traffic.

2. 3. Optimum Bitumen Substitution Tests.

The optimum bitumen content was being reduced by certain percentages of the reprocessed PWS solution, but however ensured that the already determined optimum binder content of 6 % maintained. The optimum binder was maintained in order to meani highlight the essence of the substitution, because a binder less t optimum would result in lower asphalt. Marshall Test specimens produced using the schedule displ Table 3 and tested under the M machine for the determination corresponding parameters. The compositions are respectively 20 %, % and 5% for the 12.7 and 9 aggregates, the Quarry and the filler, all totaling a mass of 1200 gra

Table 3: Partial replacements for bit asphalt mix pr

Serial Number	Bitumen		Reprocessed Pure water sachets		Total	
	%	gram	%	Gram	%	gram
1	6	72	0	0	6	72
2	5	60	1	12	6	72
3	4	48	2	24	6	72
4	3	36	3	36	6	72
5	2	24	4	48	6	72
6	1	12	5	60	6	72

2.4 The Economic Analysis of the Partial Substitution of the Optimum Bitumen Content.

The trend of the influence of the partial substitution of the optimum bitumen content with the reprocessed PWS Modified Asphalt Mixes for the various Marshall design properties are displayed in Fig. 1 - 6. Considering the requirements for the asphalt mixes by the Nigerian General Specifications, 1997 (Table VI-17) and Table III-2 of the Marshall Design Manual MS – 2 for a heavy trafficked pavement, the respective desirable replacement of optimum bitumen with the reprocessed PWS was estimated from the inspection of these curves. The outcome is presented in Table 4 which indicated that the desirable partial substitution of the optimum bitumen content with the reprocessed PWS for a Hot Mix Asphalt (HMA) varies between 17 % for the flow property and 68 % for the stability. This is equivalent to an average of 36 %; that is a ratio of about 2 parts of the reprocessed PWS to 4 parts of the optimum bitumen content, by weight; making up the designed 6 % optimum binder content.

Table 4: Determination of Desirable Substitution of the Optimum Bitumen.

S/N	Property	Specification for binder/wearing course, Heavy Traffic	Desirable reprocessed PWS partial substitution (%).
1	Optimum Bitumen content	4.5 – 8.0	-
2	Marshall Stability, (kN) , minimum.	3.5 – 3.6	68
3	Flow, mm	2 – 6	17
4	Voids in total Mix, %	3 – 8	36
5	Voids Filled with Bitumen, %	65 – 82	17
6	Voids in Mineral Aggregates, %	11 – 23	26

The implied savings in cost with this result can be obtained by solving equations (1) and (2).

$$C = M^* \sum C_i W_i \quad (1)$$

$$\text{Cost Contribution of bitumen} = C_b W_b / \sum W_i C_i \quad (2)$$

where C is the unit cost of provision and complete installation (construction) of asphalt pavement in a typical contract project, (=N= /m^3); C_i is the basic price for each component of the material constituting the asphalt mix, (=N= /ton); W_i is the fraction of the weight of each of the respective component of the material (%) and M, a Magnification factor to account for the cost of the processing and workmanship over the basic unit prices of the component materials in the final form of an asphalt ro pavement, always greater than Unity. C_b the unit cost for bitumen and W_b the fracti of weight of bitumen in the mix. The dens of asphalt concrete mix is assumed to 2.20 ton/

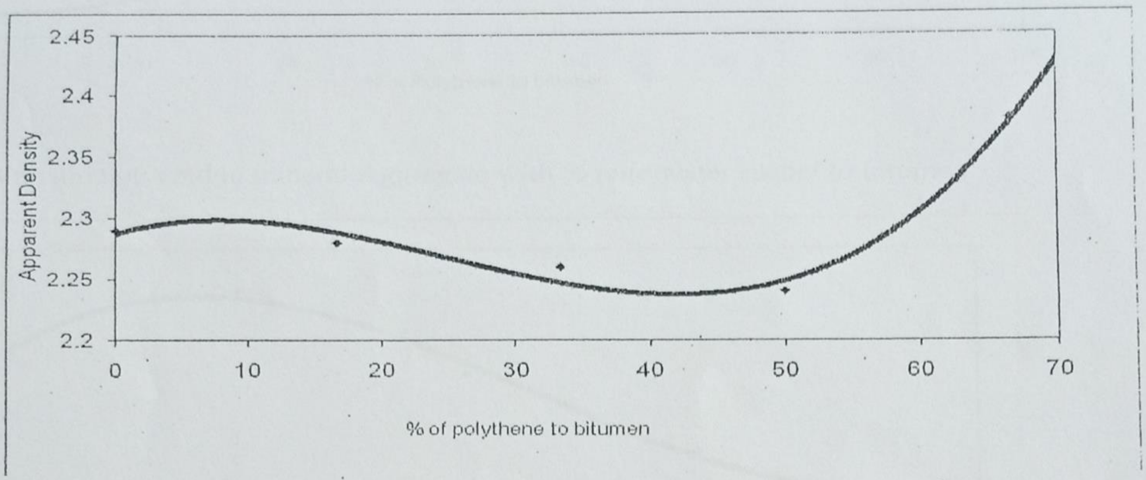

Figure 1: Variation of apparent density with % pure water sachet to bitumen

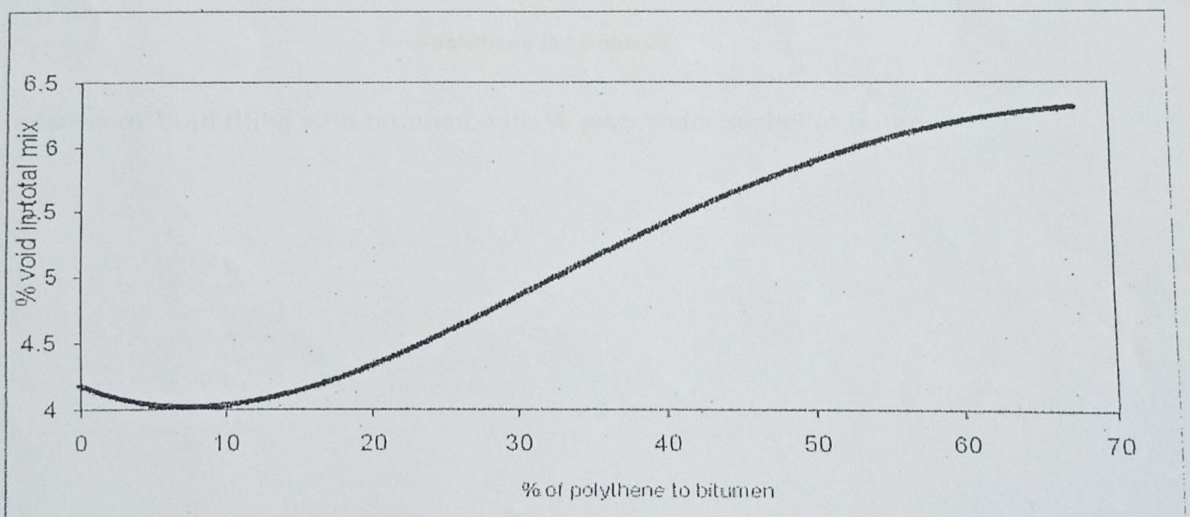

Fig. 2: Variation of Void in total mix with % pure water sachet to bitumen

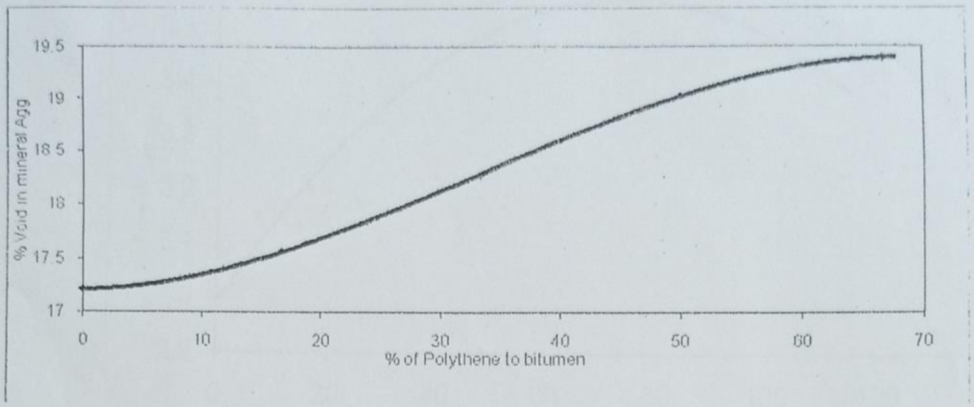

Fig. 3: Variation of Void in mineral Aggregate with % pure water sachet to bitumen

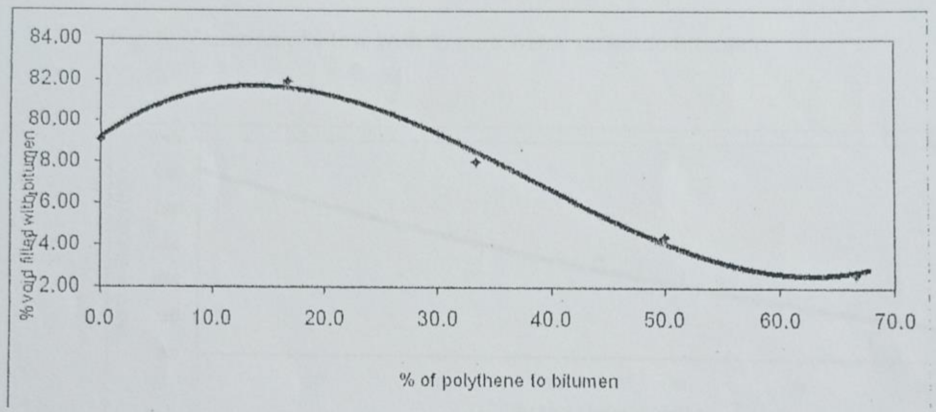

Fig. 4: Variation of Void filled with bitumen with % pure water sachet to bitumen

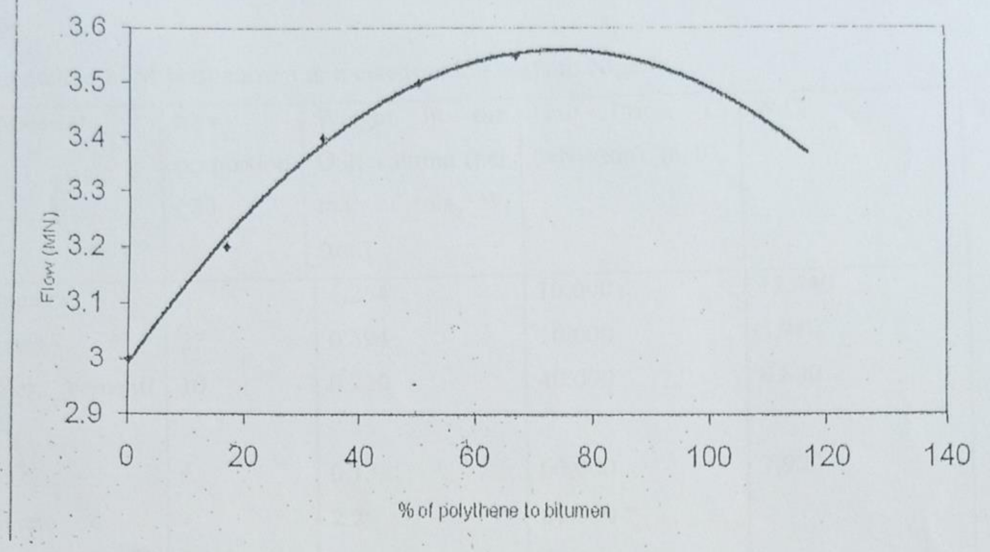

Fig. 5: Variation of Flow with % pure water sachet to bitumen

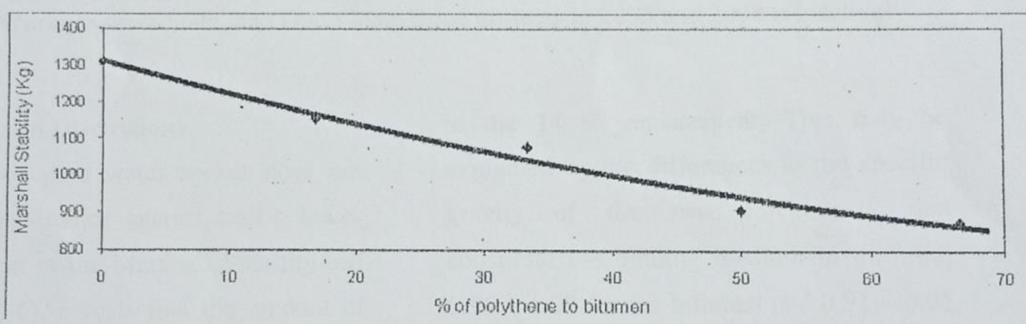

Fig. 6: Variation of Marshall Stability with % pure water sachet to bitumen

With the job mix formula adopted and the prevailing basic unit prices of the materials used for hot-rolled asphalt mix for construction projects in Ondo State (2006) and Kwara State (2005) Nigeria; M was computed to be 2.25 while the contribution of the bitumen binder alone was estimated to be 22 %. The details are as presented in

Table 5. Also, the contribution of the b item of pavement in a road project w computed to be as much as 50 – 70 (Hassne, 2003; Makinde, 2004 and Oluso 1997). The cost of the binder alone therefore equivalent to about 15% of that the entire road wo

Table 5: Computation of M with current unit construction costs in Nigeria.

Component Material	Mix proportion (%)	Weight in the Unit volume (per m3) of mix, W_i (ton)	Unit Price, C_i (=N=/ton) (a, b),	W_iC_i
Coarse Aggregates	57	1.254	10,000	12,540
Fine Aggregates	27	0.594	10,000	5,940
Mineral Filler, cement/ lime	10	0.220	40,000	8,800
Bitumen	6	0.132	60,000	7,920
Asphalt Concrete	-	2.2	87,500 *	

* Computed from the contract unit price of =N=3,000 per 40mm thick hot asphalt mix from. Ministry of Works, Kwara State, and Ondo State Road projects in 2003 and 2008 respectively.

3.0 Results and Discussions.

The dissolved pure water sachet does not add to the resistance against traffic loads. An inspection of the Marshall Stability test results (Fig. 6), reveals that the amount of dissolved pure water sachet that can successfully replace bitumen in the production of asphalt pavement without actually affecting its traffic load supporting (stability) properties is up to 15 %. The apparent density curve shown in Fig. 2 for the bitumen and dissolved pure water sachet as the binding medium shows that at about 14 % replacement, the density dropped and rose again at about 50 % replacement; thus indicating that the density is appreciated up to the 14 % replacement. This may be explained by the differences in the specific gravity of the two components that constitute the binding medium in the mix; 0.95 – 1.00 for the bitumen and 0.91 – 0.95 for the PWS. Also, the swelling at first instance of the reprocessed PWS during the conversion without any gain in weight is another reason for the gradual drop in the density as the dissolved pure water sachet proportion increases.

Fig. 2 shows the variation of voids in total mix (VIM) with the proportion of the dissolved pure water sachet to bitumen. The indication of this curve is that the bitumen ratio reduction in the mix at the initial point has no effect on the voids since it has been replaced by dissolved pure water sachet. But on further replacement it was noticed that VIM increased. Also presented in Fig. 4 is the Void filled with bitumen (VFB) curve. The maximum void that can be filled with the modified bitumen, which is about 18 % replacement after which there is a drop in value indicates that the mix can probably be susceptible to permeability by water. It therefore implies that a partial substitution beyond 18 % should not be encouraged. Further from Fig. 5, the variation in flow with percentage of dissolved pure water sachet to bitumen indicates that the more the replacement of bitumen with dissolved pure water sachet in the asphalt mixes, the more its potentials to deform. This has the implication for the sliding of pavement and durability when it is subjected to further traffic. The Marshall Stability curve presented in the Fig. 6 shows that the ability to carry heavy load drops as compared with that of unmodified optimum bitumen which has its peak at 1,400 kg; see Fig.1. But with a closer examination of the result and comparing with the specified standards, it shows that replacement of bitumen with dissolved pure water sachet can be done up to 15 % and still maintaining the stability of 1,150 kg. This figure is still far higher than the specified standard by Nigerian General Specifications (1997) of 350 kg. This implies that the resulting asphalt mix with the PWS modified binder can withstand heavy traffic loading of Category E and F, (which is equivalent to 4,500 vehicles per day of loaded weight exceeding 3 tons) without any fear of inadequate support as at when the optimum content of the state run bitumen was used for the production of the hot mix asphalt.

On the average, the production of a Hot Rolled Asphalt (HRA) with a partial substitution is acceptable up to 35 % of total mix, which is bitumen 5 % and reprocessed pure water sachet 1 %. See Table 4 and Fig. 2 – 6 (for the various respective parameters) in very close comparison with the standard Nigerian specification for a heavy traffic. It therefore implies that about 16.7 % by weight of bitumen can be saved with the inclusion of reprocessed PWS in the production of asphalt wearing mixes. The arrangement will probably improve such properties as the durability because of the observed reduction in the voids and hence the bitumen exposure to oxidation. The mix will lose its binding properties due to the presence of the dissolved pure water sachet which although will not oxidize neither will it decompose at normal temperature. The 32 % partial substitution of the bitumen recorded for the desired stability, implies that i) only two thirds of the straight run bitumen would be needed for heavy traffic level and ii) the optimum binder of 6 % of total mix can be partially replaced with the Processed Water Sachet for the Martial Stability Value of 350 kg, normally considered adequate for the heavy traffic flexible pavement. Similar observations are apparent for the other specified design values for pavement works in Nigeria.

The corresponding savings in cost would be 7 % (22 % of 32 %) of total expenditure for road works. The resulting sum of money of 210 million naira becomes appreciable when one considers the three trillions of Nigerian Naira budgeted and awarded contract for road works in Nigeria as recently (2009) reported in the national dailies, eg, the punch newspapers. Aside, an amount of three (3) billion Nigerian Naira would be saved as a result of not burning away the 20 % pure water sachets estimated composition of the Nigerian municipal waste (Aremu, 2009). A total fund of 15 billion naira was estimated as wasted annually through incineration of recyclable waste materials in Nigeria, (Okeke, 2008).

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion.

The following conclusions can be deduced from this study:

a). The pure water sachet, a polyethylene can be solvent dissolved at a laboratory temperature of 120 °C to a material of density of 0.95 g/cc which is miscible with a 60/70 straight run bitumen to serve as the binding medium in asphalt mixes.

b) The stability of the produced asphalt mixes shows no appreciable difference in their values up to about 15 % replacement but further additions in the proportion of the emulsified pure water sachet up to 6 % of total mix (by weight) showed a gradual decrease in the ability of sample to sustain deformation from heavy traffic movement as a result of the manifestation of lower Marshall Quotient values.

c) The unmodified bitumen alone has Marshall Stability Value (MSV) of l, 400 kg and that when replacement is being considered (i.e. addition of dissolved pure water sachet), it could be up to a good MSV of 1,130 kg for a 15 % replacement of bitumen, which is also capable of carrying the heavy traffic.

d) The partial replacement of the OBC was estimated to be equivalent to a savings of 3.75 % in the construction of asphalt pavement.

e) The conversion of the pure water sachet to usage as a valuable partial substitution for optimum bitumen in asphalt mixes will reduce waste, which already constitutes an environmental nuisance in both rural and urban settlements.

4.2 Recommendations

Partial replacement of the optimum bitumen content with dissolved pure water sachet to achieve a 25 % savings in the cost of bitumen should be encouraged for hot mix asphalt production because it can also free the environment of non-biodegradable pure water sachets. A 30 % replacement is recommended on the basis of the findings of this study.

5.0 REFERENCES:

Abdul Kareem S.A (2007), "Personal communication on usefulness and conversion of pure water sachet" University of Ilorin, llorin Nigeria

Amjad Khan, Gangadhar, Murali Mohan, Suresh R, Kumar H, Vinay Raykar, (1999) "Effective Utilisation of waste Plastics in Asphalting of Roads" B. Engineering Project Report Department of Chemical, R.V . College of Engineering, Bangolore, Unpublished.

Aremu, S. A, (2009), "Estimation of Parameters for Effective Collection of Municipal Waste Bins", A Ph. D Seminar, Department of Civil Engineering, University of Ilorin, Ilorin Nigeria, June, 21pp..

Chesner, Warren, "Waste Glass and Sewage Sludge Use in Asphalt Pavements" in Utilisation of Waste Materials in Civil Engineering Construction: Proceedings of Sessions sponsored by the Materials Engineering Division, ASCE, 1992, 296 – 307.

Collins, Robert J. and Giesielski, Stanley, "Recycling and Use of waste Materials and bye products in Highway Construction", NHHRP Synthesis 199, Transportation Research Council, 1994.

Federal Ministry of Works (1997) "Nigeria General Specifications (Roads and Bridges) Volume II, Federal Republic of Nigeria.

Federal Republic of Nigeria (1972) "Highway Manual" Part I Road Design. Federal Ministry of Works and Housing.

Flynn, Larry (1993) "Recycle of Plastic Finds Home in Asphalt Binder" Journal of Public Roads, Vol. 58, No 2.

Hassane, O. "Analyzing the Factors Affecting the Cost of Road Construction in Niger Republic: Case Study of Niamey - Dosso Road;" B. Eng Civil Project Report, University of Ilorin, Ilorin - Nigeria; February 2003, 56pp.

Kolo Stephen S (2007) "Effects of Bitumen Modification with Polyethylene (pws) in Asphalt Mixes for Road Works and Pollution control" M. Eng Thesis Submitted to Department of Civil Engineering, University of Ilorin, and Unpublished.

Kulsfiresniha A. K., Singh B. P. and Sharma Y. N. (1988). "Study of the Effect of Plastic Modifier on Bituminous Mix Properties" Europeans polymer journal, No I., 24 - 35.

Makinde, Funmilayo M., (2004), "Statistical Analysis of Road Construction Cost (A Case Study of Middle Belt Nigeria); B. Eng. Civil Project Report, University of Ilorin, Ilorin Nigeria, Dec. , Unpublished, 56pp

Olusoga, E. B. T., (1997), "Cost Analysis of Highway Construction Costs in Ondo State, Nigeria", B. Eng Civil Project Report, University of Ilorin, Ilorin Nigeria, Feb.; Unpublished, 40pp.

Okeke, Izuchukwu, (2008), "Recycling Option out of Refuse Menace – Recycling as panacea to Refuse problems," Weekend Magazine, the Herald Newspapers, August 1st, pp26-27.

Raji S. A., Abdulkareem S. A. and G. O. Oluokun (2009), Effects of reprocessed Polyethylene Water Sachets (PWS) on the strength and fire resistance of Cement Concrete; Journal of Research Information in Civil Engineering (RICE), Department of Civil Engineering, University of Ilorin, Ilorin Nigeria, Vol. 5, No. 1.

Staszewska D., Kovar J. and Bohdanecky D. (1980), "Colloid and Polymer Science" Europeans Polymer Journal, Vol. 258, pp 600.

Singh Y. P. and Singh R. P. (1983). "Recycled Plastic Finds Home in Asphalt Binder" Europeans polymer journal, vol. 19, No 6, pp 539.

Stephen Brown (1990), "The Shell Bitumen Handbook" Published by Shell Bitumen. United Kingdom.

The Asphalt Institute (2003), Mix Design Methods for Asphalt Concrete and other Hot – Mix Types (MS-2)", the Asphalt Institute Publication, College Park, Maryland.

Wilmot T. and Vorobieff G. (1997), Is Road Recycling A good Community Policy? Viewed 25 July 2004; http://www.auststab.com.au/ts15.pdf

Zoorob S.E and Superma L. B. (2000). "Laboratory design and investigation of proportion of bituminous composite containing waste recycled plastics, aggregate replacement (Plastiphalt), CIB Symposium on Construction and Environment (Theory into practice) Sao, Brazil.

Zoorob S.E. (2000) "Laboratory design and performance of improved bituminous composites utilizing plastics packaging waste" Conference on Technology Watch and Innovation in Construction Industry, Belgium, Building Research Institute, Brussels. Belgium.