Response of Cold Mix Asphalt Produced with Straight Run Bitumen blended with Polyethylene to Static Loading

Kolo S. S
Department of Civil Engineering, Federal University of Technology, Minna.

ABSTRACT

An alternative maintenance option for road surface repairs is the use of cold asphalt mix, which is environmentally friendly when produced with non-degradable waste pure water sachet that have assumed environmental nuisance within the rural and urban dwellings in developing nations. Consequently, the mechanical and performance characteristics for acceptability of cold mix asphalt produced from straight-run bitumen blended with dissolved waste pure water sachet were evaluated in order to ascertain the technical, engineering, environmentally and economic viability of a newly developed product for pavement maintenance. Cold mix asphalt binder was obtained by processing straight-run bitumen with chemically dissolved pure water sachet at temperature of 90^{o}C, chemical, surfactant and water blend. This experimental cold mix asphalt was produced in a large scale with a 2m^{3} capacity concrete mixer at specified design mix formula of 35% coarse aggregates, 65% fine aggregate and 10% mineral filler and the optimum binder. The experimental was subjected to laboratory Marshall tests, static loadings under the typical sub-tropical weather and climate in Minna, Niger state Nigeria.

Keywords: Bitumen, Cold-bitumen, Static Loading, consolidation,

1.0 Introduction

Bitumen is a non-crystalline viscous material, black or dark brown, which is substantially soluble in carbon disulphide (CS2), has adhesive and water-proofing qualities. It consists essentially of hydrocarbons and would typically comprise at least 80% carbon and 15% hydrogen, the remainder being oxygen, sulphur, nitrogen and traces of various metals (Brown, 1990). Bitumen is also a heavy, dark brown to black mineral substance and one of several mixtures of hydrocarbons. Bitumen is a strong, versatile weather and chemical-resistant binding material which adapts itself to a variety of uses. Bitumen binds crushed stone and gravel (commonly known as aggregate) into firm, tough surfaces, termed asphalt, for roads, streets, and airport run-ways. Asphalt (or Asphaltic concrete) is the mixture of mineral aggregates and binder, usually bitumen. The Asphalt production for decades now has been produced in the hot mix, at 160^{o}C with sophisticated equipment. This high temperature serves to decrease viscousity and eliminates moisture during the manufacturing process, resulting in a durable material. However, hot mix asphalt (HMA) is most commonly used for high-traffic areas, such as busy highways and airports. The risks of production, in terms of fossil fuel consumption, emission of toxic fumes etc. are very high. The hot state desirable for the bitumen and drying of the aggregates to produce the hot mix asphalt (HMA) has a lot of associated disadvantages, which include:-

(i) High cost of plant procurement, maintenance and running time.
(ii) Skilful personnel are required for proper asphalt mix production, laying and compaction.

(iii) Inability of storing, as the material must be used as soon as produced in the hot state.

(iv) Limited haulage distance (Movement) of the material because of stiffening effect of wind and air.

(v) High risks on safety of workers are involved during the production and laying process, (high temperature, release of hazardous gases to the air, etc.)

It will be environmentally and working-conditions friendly, if a better way of achieving this same product (mixes), which will assure the reduction or eliminate some or most of the enumerated disadvantages associated with the hot mix asphalt. The cold mix asphalt produced and worked at ambient (site) temperature can be used for the purpose with application of little heat before the usage. The binder e.g. bitumen, a viscous material either naturally occurring or some modification process should be able to maintain the required fluidity, just before or on exposure to air.

Cold asphalt works is the asphalt produced with the cold bitumen, and has a mixture of cold bitumen and aggregates. The cold asphalt has the advantage of reduced energy (working at lower temperatures) and hence contributes to reducing global warming. The influence of working temperature on the mechanical properties of the asphalt and the implication on the ability of the modified pavement (asphalt) to carry normal and abnormal traffic are some of the important aspects that need necessary attention for traffic load support.

Good Cold Mix Asphalt (CMA) or even warm mix asphalt should have the under-listed properties (about 10) to be advantageous over HMA (Carboncor Profile, 2010)

(i) Storage-ability

The hot asphalt is extremely cumbersome in that it has to be applied immediately after manufacture, with obvious pressure on contractors; whereas with the cold mix, it can be stored in pre-packed bags for an appreciable length of time, say up-to 12 months or more.

(ii) Transportation

Whereas hot mix asphalt has to make use of well covered, insulated trucks with a maximum distance of 350 km, for the mix to maintain the desired workability, conversely cold mix requires a simple poly tarpaulin for its transportation to a longer distance without any fear of temperature related deterioration. This convenience is of particular relevance in the hot African region where temperature and heat from sun rays are high.

(iii) Labour and Machinery

Less sophistication and compatibility in both labour (personnel) and machineries are desired for the cold mix pavement

(iv) Temperature sensitivity (Point of Application)

Hot asphalt is extremely sensitive to climatic conditions and road temperature.

(v) Speed / Ease of application.

It is faster to apply the cold asphalt than the hot mix asphalt because of the high temperature during production and laying. There is clearly a number of more costly and time consuming application processes involved in hot mix asphalt.

(vi) Application process

Cold mix asphalt is applied when cold and its medium of application is water which makes it cheaper and safer to apply than hot mix asphalt which has a working temperature of not less than the 120^{o}C or more for laying in pavement works.

(vii) Cleaning
Cold asphalt is easily washed from the equipment with the help of water, while the washing of HMA is usually with lighter petroleum product.

(viii) Environmental Friendliness
The cold Asphalt product will be environmentally friendly, since hazardous gas is eliminated in the production process and at point of laying.

(ix) Binder Properties
The adhesive property is also to be enhanced with the addition of the process rubber and other fibres/modifiers in the mix.

Warm mix asphalt concrete (WAM) is also produced at a lower room temperature by adding bitumen emulsions, waxes, or zeolites to the basic asphalt components. This process benefits both the environment and the workers, as it results in less fossil fuel consumption, reduced emission of fumes at prevalent lower/safer working temperature. In cold mix asphalt concrete**,** the bitumen is emulsified in soapy water before being mixed with the aggregate, eliminating the need for high temperatures altogether. However, the asphalt produced is not as durable as hot mix asphalt concrete (HMAC) or WAM, and cold mix asphalt is therefore typically used for low traffic areas or to patch damaged HMAC (Niki Foster, 2010). However, at higher temperatures, that is 28^{o}C and above, the rutting susceptibility of asphalt mixes needs to be studied in the laboratory and at site. Comprehensive laboratory investigation is also required in order to study the influence of physical and mechanical properties of aggregates on rutting resistance or the permanent deformation behaviour of asphalt mixes, so that appropriate rationality of cold mix asphalt adoption for a particular region can be established.

2.0 Materials and Method

The process of converting the polythene wastes to miscible form with bitumen involves four major steps, which include; material sampling and evaluation for pavement works, preparation of dissolved Polyethylene emulsion and blending with straight-run bitumen, conversion of the blended / modified straight-run bitumen for bituminous cold mixes and characterisation of the cold bitumen for laboratory static load determination

The following materials were used for this work Polyethylene, Bitumen, Solvent, Aggregates, Water, Chemicals and surfactants / Emulsifier, sampled weight and Asphalt compactor.

2.1 Production of Dissolved polythene waste sachet in semi solid phase.

Preparation of the Polyethylene solution was achieved by pouring into a mixing bowl some quantity of the solvent just enough to dissolve Polyethylene (in the ratio of 1% of polythene to 3% of solvent); the volume of the solvent was immaterial since at the temperature at which asphalt was produced, most of the solvent would have evaporated. The solvent was initially heated to a temperature of about 40 ^{o}C; at this temperature PWS was then added and temperature was then raised to 80 ^{o}C. It was then removed from the hot plate for stirring. The mixed content, which include the solvent and the Polyethylene was then returned to the hot plate and covered for further heating to a temperature of 120 ^{o}C. Again the mixed content was removed from the hot plate and stirring continued, until a semi liquid mixture was achieved. The noticeable character of the mixture was the swelling of the Polyethylene in the solvent, which occurred almost immediately before the actual dissolution. The product was reserved for further / physical properties test in the laboratory.

2.2 Production and Laboratory Testing of Hot Mix and Cold Mix Asphalt.

In carrying out the above, the activities were group into the following

i) Characterisation of mix aggregates (coarse, fines and fillers) to satisfy the desired Marshall and General specifications for pavement wearing course for heavily trafficked roadways by FMW&H, 1997.
ii) Preparation of the cold mix asphalt.
iii) Testing the properties of the experimental cold mix asphalt and comparing the obtained result to other available cold mix asphalt in use in Nigeria.
iv) Laboratory loading of the Cold Mix Asphalt

2.3 Static Laboratory loading of cold mix specimen

The settlement response of the cold mix asphalt to static loading was monitored in the laboratory with an improved testing rig displayed in plate 1. The rig consists of a loading column with the vertical settlement (deformation) scale (dial gauge).

The cold asphalts used for this section were finished product of the various manufacturers see Table 3.3. In the laboratory evaluation of cold mix asphalt settlement, various loadings were sourced and placed on the compacted asphalt samples. The settlement/depression on each day was noted at specified intervals of time and recorded. The recorded time-settlement data are

presented in Tables 4.23 to 4.26 also shown in Table 4.27 to Table 4.30 is the void reduction table for four cold mix asphalt mixes. The duration of monitoring was 9 days under the laboratory conditions and under varying load magnitudes. See appendix 5 for raw data.

Presented below in Table 3.4 is the summary of loading regime used for the laboratory settlement monitoring exercise.

Table 3.4: Daily test procedure for each asphalt sample

Time	Time (hrs)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
15sec	0.0042	Place 75N load on the sample	Add another 75N, making loading on second day to be 150N	Unload 75N, making loading on Third day to be 75N	Return the 75N, making loading on fourth day to be 150N	Add 150N, making loading on fifth day to be 300N	Add another 300N, making loading on six day to be 600N	Unload 300N, making loading on day 7 to be 300N	Return the 300N, making loading on day 8 to be 600N	Add 150N, making loading on day 9 to be 750N
30sec	0.0083									
1min	0.0167									
2min	0.0333									
4min	0.0067									
8min	0.1333									
15min	0.25									
30min	0.5									
1hr	1									
2hrs	2									
4hrs	4									
8hrs	8									
12hrs	12									
24hrs	24									



Plate 1: The improvised testing machine under loading

3.0 Result and Discussion

3.1 The Bitumen and Aggregates Properties

In this section, the obtained properties of straight run bitumen, the modified cold bitumen and the other materials (aggregates) used for the study were presented:

Presented are the desired properties of all materials in Table 3.1 – 3.3 respectively for cold bitumen, aggregates index and gradation. The standard bench marks were also included in order to facilitate meaningful suitability assessment. The modified cold bitumen and available standard for cold bitumen was specially noted, since the standard for modified cold bitumen is not available.

Table 3.1: Properties of Modified Cold Bitu 103

S/No	Properties of Cold Bitumen	Obtained Values for Modified Cold Bitumen	Specifications for Cold Bitumen
1	Penetration at 25^{o}C	80	80 - 150
2	Coagulation of emulsion at low temperature	Nil	Nil
3	Flash Point (^{o}C)	300	220
4	Solubility (%)	99	99

The materials used in the asphalt productions, were tested in accordance to BS 812 procedures, to determine its conformity with the existing or known standard. Table 3.2 and 3.3 are the

indices and grading properties for the sampled aggregates which showed the compliance of the aggregates with the established BS 812 standard.

Table 3.2: The aggregates Indices Properties

S/No	Test Type (%)	Obtained Values (%)	Specifications	Remarks
1	Flakiness Index	13.3	Not Exceeding 25	adequate
2	Elongation Index	22.4	Not Exceeding 25	Good
3	Aggregates Crushing Value for 10 mm	26	Not Exceeding 30	adequate
4	Aggregates Impact Value for 14 mm	9.7	Not Exceeding 15	adequate
5	Aggregates Crushing Value for 14 mm	15	Not Exceeding 30	adequate

Table 3.3: Gradation of Aggregates

Sieve Size (mm)	14mm Aggregates	10mm Aggregates	Dust	Fillers
	%Passing	%Passing	%Passing	%Passing
20mm	100	100.00	100.00	100.00
14mm	98.09	100.00	100.00	100.00
10mm	46.15	71.68	100.00	100.00
6.3mm	6.64	18.80	100.00	97.97
2.36µm	4.46	1.90	85.73	92.04
1.18µm	3.72	1.27	67.02	81.83
600µm	2.92	1.22	49.63	61.12
300µm	2.28	1.15	33.38	25.50
150µm	1.75	1.00	19.68	6.04
75µm	1.22	0.96	17.22	4.10
Passing 75µm	0.00	0	0	0

3.3 Laboratory Evaluation/settlement

Observing the behaviour of the cold asphalt in Fig 1, it was discover that when loads are placed on the asphalts, it's settled rapidly in the first few minutes and later gain strength against the load but continue to settle at slower rate. This situation is presented below for various loadings and unloading scenarios. From Figure 1, the time dependent deformation was at different loading conditions

The figures shown below demonstrate different behaviour of cold asphalt when loaded and unloaded. The asphalt begins to re-compact itself as indicated in the stated figures above but when unloaded, the asphalt tries to spring back. This proves that asphalt mixes are resilient and the theory of consolidation may be appropriate for settlement analysis. The asphalt has the ability of retaining its properties when subjected to load; in as much as the load is not above the bearing capacity, such that the asphalt would not completely break down. Asphalt has elastic property; see Figure 2.

Table 3.4: Dial gauge reading of Experimental asphalt

Method of Loading		Place 75N load on the sample	Add another 75N, making loading on second day to be 150N	Unload 75N, making loading on Third day to be 75N	Return the 75N, making loading on fourth day to be 150N	Add 150N, making loading on fifth day to be 300N	Add another 300N, making loading on six day to be 600N	Unload 300N, making loading on day 7 to be 300N	Return the 300N, making loading on day 8 to be 600N	Add 150N, making loading on day 9 to be 750N
Time	**Time (h)**	**Day 1 Reading**	**Day 2 Reading**	**Day 3 Reading**	**Day 4 Reading**	**Day 5 Reading**	**Day 6 Reading**	**Day 7 Reading**	**Day 8 Reading**	**Day 9 Reading**
0	**0**	100.00	88.37	61.70	62.40	58.03	25.57	14.33	15.10	15.67
15sec	**0.0042**	99.50	81.33	61.57	62.03	53.67	25.23	14.33	15.40	15.33
30sec	**0.0083**	99.23	80.97	61.87	61.83	50.10	24.40	14.83	15.67	15.17
1min	**0.0167**	98.90	80.63	61.90	61.70	48.87	23.80	14.83	15.67	14.67
2min	**0.0333**	98.57	80.10	62.23	61.40	47.67	23.13	14.83	15.67	14.30
4min	**0.0067**	97.93	79.03	62.23	60.90	43.67	22.20	14.83	15.67	13.90
8min	**0.1333**	97.37	77.90	62.23	60.97	41.40	20.90	14.83	15.67	13.73
15min	**0.25**	96.53	77.00	62.23	60.93	39.80	19.60	14.83	15.67	13.53
30min	**0.5**	95.53	72.10	62.23	60.90	38.10	18.93	14.83	15.67	13.20
1hr	**1**	95.07	69.97	62.23	60.27	37.03	18.43	14.83	15.67	12.97
2hrs	**2**	93.67	68.27	62.23	59.93	35.20	17.10	14.83	15.67	12.67
4hrs	**4**	92.00	66.90	62.30	59.23	33.13	16.77	14.83	15.67	12.13
8hrs	**8**	91.20	65.20	62.30	59.00	30.93	15.67	14.83	15.67	11.83
12hrs	**12**	90.60	63.90	62.30	58.97	29.07	14.80	14.83	15.67	11.33
24hrs	**24**	88.37	61.70	62.40	58.03	25.57	14.33	15.10	15.67	10.97

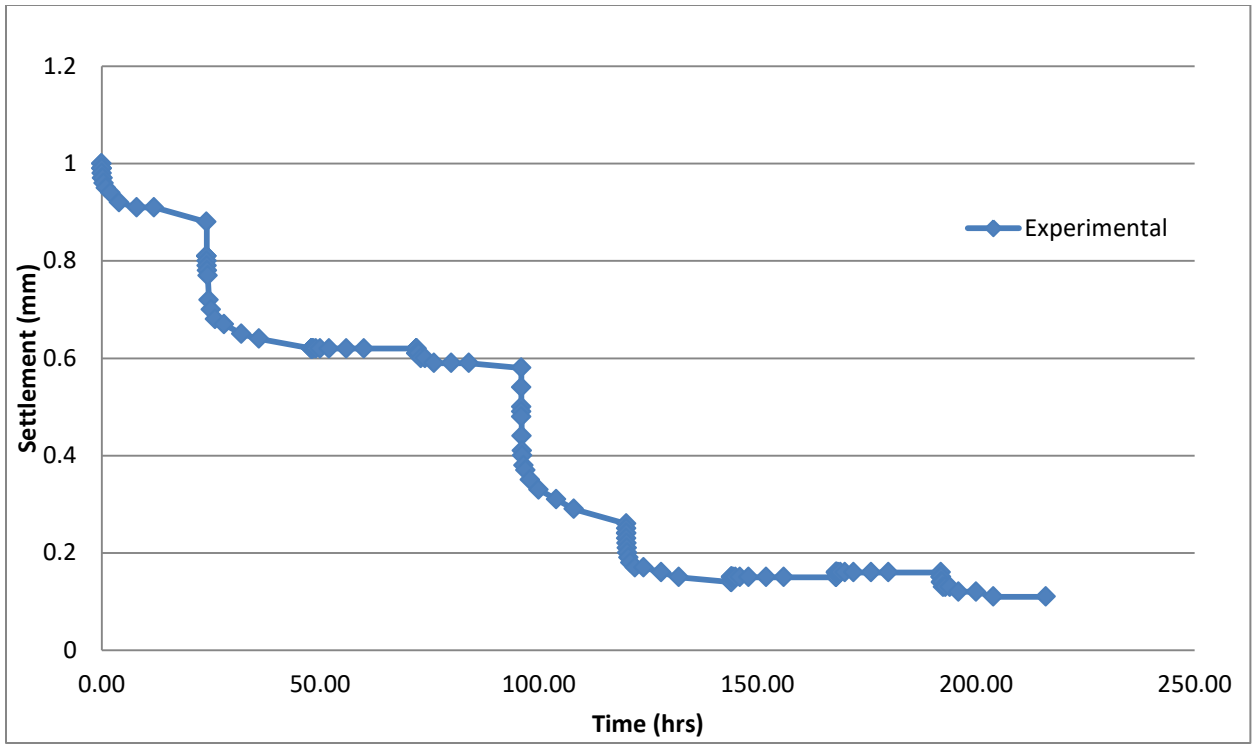


Fig. 1: Settlement of Experimental asphalts after 9 days

Also presented below in Fig. 2 is the graph of voids reduction against loading for the sample this situation also presents a situation where the voids present in the asphaltic mix gradually disappeared with loading thereby reducing the thickness of such asphalt and making it incapable to bear the imposed traffic loading because is a continual reduction in thickness. This therefore suggests that if loading are known and the rate of settlement is determined, then the pavement lifespan can be determine as at the time of construction. It is therefore necessary that road, when constructed should be allowed with settlement rate in this case settlement rate against loading was calculated as been Cr (initial compression), Cc (compression index), a_v (volume compressibility) and Magnitude of settlement after 20years for the cold asphalt as determined from the graphs below. For experimental cold mix asphalt Cr was obtained to be 0.0029, Cc was 0.0149, a_v was 0.000209 while magnitude of settlement after 20 years was 4.33mm. All the above implies rate of deformation of the asphalt, from the above values it's was observed that the cold mix asphalt are within allowable range of settlement. The slope of experimental cold mix asphalt was categorised into three parts the primary settlement of 0.48 % which is a rapid settlement when road are just open to traffic, the secondary of settlement of 0.0101 % which follows the primary settlement but is gradual while the third settlement of 0.00909 % is the tertiary settlement is very slow but result into pavement failure.

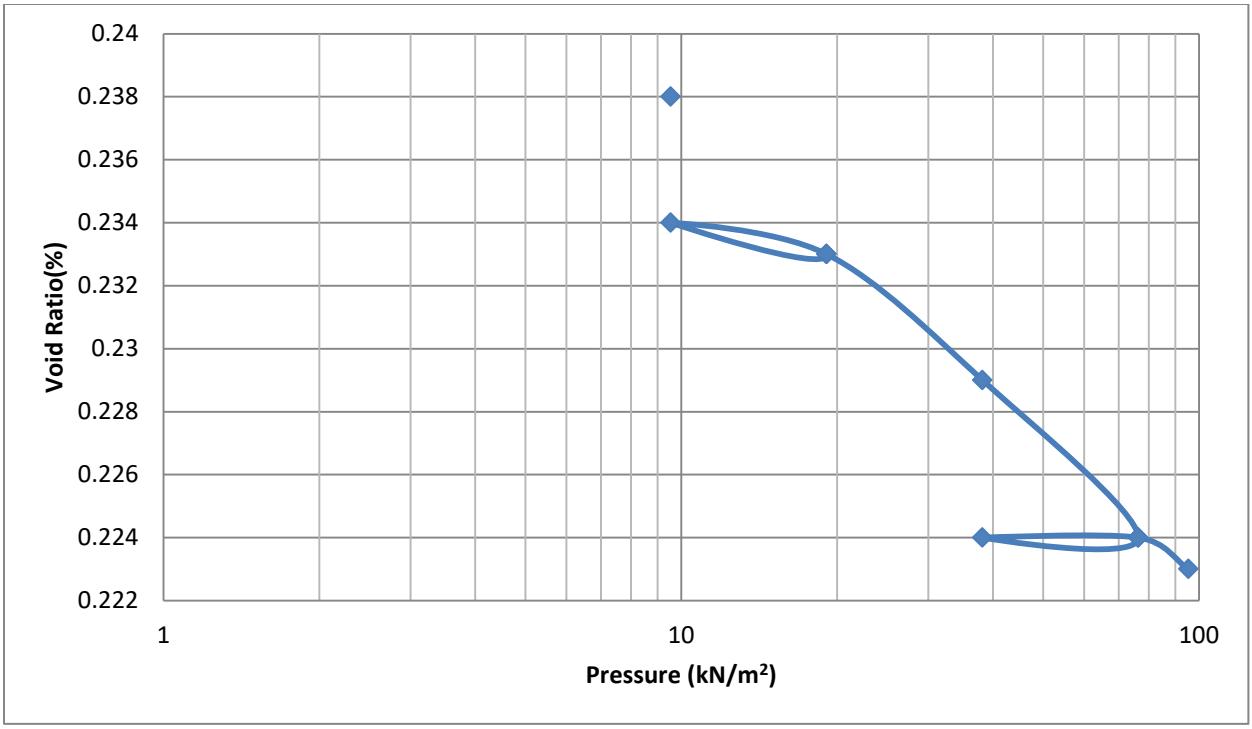


Fig. 2: Graph of void reduction against pressure for Experimental Cold asphalt

4.0 Conclusions

The findings of the study include;

a) Cold mix asphalt can be produced at ordinary temperature with a concrete mixer on small scale with state run bitumen mixed with chemically dissolved non-degradable pure water sachets wastes.
b) The Marshall Stability, flow and density of the experimental cold mix asphalt were 5.08kN, 4.0mm and 1.98g/cc.
c) The experimental cold mix asphalt substantially complied with specifications, stability greater than 3.5kN, flow within 2 – 4mm and voids filled with bitumen of less than 80%.
d) The elasticity and resilient modulus properties of the cold mix asphalt was determined.
e) The cold mix asphalt settles with time, exhibiting higher stability when air dried.
f) The time dependent rate of deformation of the cold mix asphalt could be described in similar manner as applicable to saturated clay soil with the coefficient of consolidation; and that the coefficient of deformation is dependent on the magnitude of the prevailing pressure.
g) Based on the mechanical properties investigated, the experimental cold mix asphalt had the superior performance over the existing commercial mixes in use in Nigeria. This type of cold asphalt should be encouraged because its improved quality of the environment as a result of the conversion of the nuissuating heaps of waste pure water sachets should be encouraged.

5.0 References

Abaza, K. A. and Abu-Eisheh, S. A.(2003), “An optimum design approach for flexible pavements”, The International Journal of Pavement Engineering, Vol. 4(1), pp.1-11.

Akzo Nobel (2005), “Product overview surfactants in Europe, Akzo noble surface chemistry AB, stenungsund, Sweden.

Alan James and Akzo Nobel (2006),”Overview of Asphalt Emulsion” Surface Chemistry, Transportation research board, 500 fifth Street NW Washington DC 20001, www.TRB.org

American Association of State Highway and Transportation Officials (AASHTO). 2004. “Determining the Percentage Deleterious Materials present in Aggregates Blend”, AASHTO Designation T112.

Asphalt Academy, (2002), “The design and use of foam bitumen treatedmaterials. Interim Technical Guideline No 2, Pretoria South Africa.

Asphalt Institute & Asphalt Emulsion Manufacturers Association (2006), “Asphalt emulsions: a basic asphalt emulsion manua”, Manual Series No.19, 3rd edn, AI & AEMA, United States.

Asphalt Institute, (1996). “Superpave TM Mix Design” Superpave Series SP-2, Lexington, Kentucky, USA.

Asphalt Institute, (2003). “Asphalt Hand Book,” Manual series No. 04, Six Edition, Kentucky, USA.

Brown, E. R. (1990). Density of Asphalt Concrete – How much is needed? Transportation Research Record 1282, Transportation Research Board, Washington D. C.

Brown, E.R., and Cross, S.A. (1992), “A National Study of Rutting in Hot Mix Asphalt (HMA) Pavements”, NCAT Report 92-5, National Centre for Asphalt Technology.

Brown, R.R., and Bassett, C.E. (1990), “Effects of Maximum Aggregate Size on Rutting Potential and Other Properties of Asphalt –Aggregate Mixtures”, Transportation Research Record 1259, pp. 107-119.

Carboncor Profile, (2010), “Brochure and Information”, Carboncor Road Technology, Nigeria, Felicia koloeso Street, Lagos.

Carpenter, S. H., (1993), “Permanent deformation: Field evaluation”, Transport research record 1417 Materials and Construction, Asphalt concrete mixtures. Transportation Research Board, National Academy Press, Washington.

Cheung, C.Y. (1995), “Mechanical behaviour of bitumen and bituminous mixes”. Ph.D. Thesis, University of Cambridge, Unpublished, Online.

Delmar R. S., (2008), “Asphalt Emulsion Technology”, Transportation Research Board, 500fifth

street, NW Washington, Dc 20001, www.trb.org.
Federal Ministry of Works (1997) "Nigeria General Specifications (Roads and Bridges) Volume II, Federal Republic of Nigeria.

Holleran, G, Reed, J.R. & Kirk, J.V. (2001), 'Polymer modification of bitumen for life extension', International Road Federation world meeting, 14th, 2001, Paris, France, IRF, Paris. Pp23.

Huang, B., Xiang Shu and Xinwei Chen. (2007), "Effects of mineral fillers on hot-mix asphalt laboratory measured properties", International Journal of Pavement Engineering" 8:1, pp1-9.

Huang, H., (1995), "Analysis of Accelerated Pavement Tests and Finite element Modelling of Rutting Phenomenon", Ph.D. Thesis, Purdue University.
James, A (2006), "Overview of asphalt emulsions", in DR Salomon, (ed) Asphalt Emulsion Technology: Transportation Research Circular E-C102, Transportation Research Board, Washington DC., pp.1-15.

Kolo S. S. and Jimoh Y. A (2010), Effect dissolved waste pure water sachets on the strength properties of asphalt pavement/mixes", Global Journal of Engineering and Teechnology, Vol. 3, No. 3, Pp 487-495.

Morris, J., (1973), "The Prediction of Permanent Deformation in Asphalt Concrete Pavements", Ph.D. Thesis, University of Waterloo, Ontario,Canada.
Niki, F (2010) "what are different types of asphalt, Google search.

Ortigao J.A.R., (1995). Soil Mechanics in the light of critical State Theories, An introduction, A.A. Balkema, Rotterdam, Brookfield.
Roberts, F.L.; Kandhal, P.S.; Brown, E.R.; Lee, D.Y. and Kennedy, T.W.,(1996), "Hot Mix Asphalt Materials, Mixture Design, and Construction", National Asphalt Pavement Association Education Foundation, Lanham, MD.
Shashidhar, N., Needham, S.P., Chollar, B.H. and Romero, P. (1999). "Prediction of the performance of mineral fillers in stone matrix asphalt" J. Assoc. Asphalt Paving Technologists, 68, pp 222–251.
Shearer, T. R., (1998), "A Numerical model to Calculate land Subsidence, applied at Hangu in China", Engineering Geology, 49(2), pp 85-95.