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RESPONSE OF COLD MIX ASPHALT PRODUCED WITH STRAIGHT RUN BITUMEN BLENDED WITH POLYETHYLENE TO STATIC LOADING

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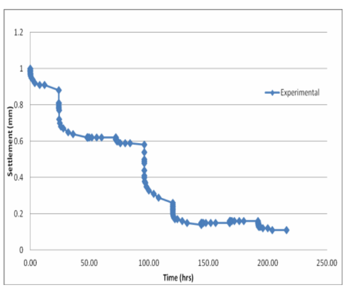
Graphical abstract



Abstract

Road surfacing repairs is usually done with hot mix asphalt, with concomitant challenges of risk of fire hazard and global warming, while working at desired temperatures for fluid flow of the viscous binder in the production of the bituminous materials. An alternative maintenance option is the use of cold mix asphalt, which is environmentally friendly and acts as a pollution control when produced with non-degradable polythene packaging wastes which are freely disposed off in open spaces within the rural and urban dwellings in developing nations. The successful addition of this material will (i) Free the environment from the flying polyethylene wastes (ii) Reduce the consumption rate for the bitumen and (iii) Reduce the rate of oxidation of bitumen. Cold mix asphalt binder was obtained by processing some quantity of straight-run bitumen with chemically dissolved polyethylene wastes sachets at temperature of 90 ^{o}C, with an alkaline emulsifier, chemical surfactant and water. The mix asphalt was produced at specified design mix formula of 35% coarse aggregates, 65% fine aggregate, 10% mineral filler and the optimum binder of 6%. The obtained sample was subjected to an improvised laboratory Marshall Tests, static loadings under the typical sub-tropical weather and climate in Minna, Niger state, Nigeria. It was discovered that the consolidation theory by Terzaghi perfectly applied to the asphaltic settlement and that in 20 years the magnitude of settlement will be 4.33mm and the result also shows that the asphalt is elastic in nature.

Keywords: Bitumen, cold-bitumen, static loading, consolidation, asphalt

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 [1]. Asphalt production for decades, has been produced in the hot form, at 160^{o}C with sophisticated equipment. This high temperature serves to decrease viscosity and eliminates moisture during the production process, resulting in a durable material. However, hot mix asphalt (HMA) is most commonly used for high-traffic roads, 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 is necessary for the bitumen and the drying of the aggregates in order to produce the HMA but has a lot of associated disadvantages, which include: High cost of plant procurement, maintenance and running cost; Skilful personnel are required for proper asphalt mix production, laying and compaction; Inability of storing as the material must be used as soon as produced in the hot state; Limited haulage distance of the material because of stiffening effect of wind and air; 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 HMA, the better replacement is the cold mix asphalt (CMA)

The cold asphalt has the advantage of reduced energy (working at lower temperatures) and hence contributes to reduction in global warming [2]. The influence of working temperature on the mechanical properties of the asphalt and the implication on the ability of the modified asphalt to carry normal and abnormal traffic are some of the important aspects that need necessary attention for traffic load support. Good CMA should have the under-listed properties to be advantageous over HMA [3].

(i) Storage-ability
The HMA 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 HMA 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)
HMA is extremely sensitive to climatic conditions and road temperature.

(v) Speed / Ease of application.
It is faster to apply the cold asphalt than the HMA 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°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 processed rubber and other fibres/modifiers in the mix.

In cold mix asphalt concrete, the bitumen emulsion is being mixed with the aggregate, eliminating the need for high temperatures altogether. However, the asphalt produced is not as durable as HMA or Warm Mix Asphalt (WMA), CMA is therefore typically used for low traffic areas or to patch damaged HMA [4]. However, at higher temperatures, that is 28°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 METHODOLOGY

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 [5].

The following materials were used for this work Polyethylene, Cold Bitumen, Solvent, Aggregates, Water, Sampled weight and Asphalt compactor [6].

2.1 Polyethylene Solution Preparation

Polyethylene solution was prepared by mixing Polyethylene and solvent in the ratio of 1:3. The solvent was initially heated to a temperature of about 40^{o}C; at this temperature polyethylene was then added and temperature was then raised to 80^{o}C before stirring and further heated to a temperature of 120^{o}C. The mixed content was removed from the hot plate and stirred continuously, until a semi liquid mixture was achieved. The product was reserved for further / physical properties test in the laboratory [7].

2.2 Production and Laboratory Testing of Cold Mix Asphalt

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

i) Characterisation of mix aggregates (coarse, fines and fillers) to satisfy the desired Marshall and General specifications requirement for pavement wearing course for heavily trafficked roadways by [8, 9, 10].

ii) Preparation of the cold mix asphalt [11, 12].

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

Terzaghi principle of soil consolidation was used for this research work. According to [13] "consolidation is any process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume" [13]. The settlement response of the cold mix asphalt to static loading was monitored in the laboratory with an improvised testing rig displayed in Plate 1. The rig consists of a loading column with the vertical settlement (deformation) scale (dial gauge) and the loading and days were in conformity with that recommended by [13, 14].

The monitoring of the settlement and loading was done in categories stated in Table 1. The settlement/depression on each day was recorded. The recorded time-settlement is presented in Table 1. The duration of monitoring was 9 days under the laboratory conditions and under varying load magnitudes [15, 16, 17] see Table 1.

Table 1 Daily Test Procedure

Time	Time (hrs)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
15sec	0.0042									
30sec	0.0083									
1min	0.0167									
2min	0.0333									
4min	0.0067									
8min	0.1333									
15min	0.25	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
30min	0.5									
1hr	1									
2hrs	2									
4hrs	4									
8hrs	8									
12hrs	12									
24hrs	24									

3.0 RESULTS AND DISCUSSION

3.1 The Bitumen and Aggregates Properties

The obtained properties of the modified cold bitumen and the aggregates used for the study are presented. The aggregates used in the asphalt productions, were tested in accordance to BS 812 [18] procedures, to determine its conformity with known standard. Presented in Table 2 is properties of cold bitumen, Table 3 and Table 4 are the indices and grading properties for the sampled aggregates which showed the compliance of the aggregates with the established standard [18]. The standard bench marks were also included in order to facilitate meaningful suitability assessment. Observing Table 2, all the desired cold bitumen properties were met and the bitumen is at its best with the improvement of the bitumen by the dissolved polyethylene waste.

Table 3 also confirms the adequacy of the selected materials for the research work, the properties of the aggregates is within the specified limit by BS 812. Table 4, is the material gradation for the chosen aggregates, which eventually gave a blending mix of 35% coarse aggregates, 65% fine aggregates and 10% mineral filler with a binder content of 6% at which combination the cold asphalt was produced.

The settlement for nine days phenomenal was demonstrated in Figure 1 and Figure 2. The Figures show clearly that, there is usually reduction in the void i.e settlement but on removal of load, the asphalt tries to bounce up and when load is returned the settlement continues, this is well demonstrated in Figure 2. Detail of the settlement can be seen in Table 5. Asphalt can therefore be said to be elastic in their behaviour.

Plate 1 Improvised Testing Machine under Loading

Table 2 Properties of Modified Cold Bitumen

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

Table 3 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 4 Gradation of Aggregates

Sieve Size (mm)	14mm Aggregates %Passing	10mm Aggregates %Passing	Dust %Passing	Fillers %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

3.2 Laboratory Evaluation

The Marshall Stability, flow and density of the cold mix asphalt were 5.08kN, 4.0mm and 1.98g/cc. This shows that the mix is in conformity with specified specification for road asphalt. Observing the behaviour of the cold asphalt in Figure 1, it was discovered that when loads are placed on the asphalts, it settled rapidly in the first few minutes and later gained strength against the load but continues to settle at slower rate.

The figure demonstrates behaviour of cold asphalt when loaded and unloaded. When loaded the asphalt re-compacts itself as indicated in Figure 1 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 as shown in Figure 1.

Also presented in Figure 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 with time because of the 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 a road, when constructed should be provided with settlement value in this case settlement rate against loading was calculated as being Cr (initial compression), Cc (compression index), av (volume compressibility) and Magnitude of settlement after 20 years for the cold asphalt determined from Figure 2. The cold mix asphalt Cr was obtained to be 0.0029, Cc was 0.0149, av 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 was observed that the cold mix asphalt falls within allowable range of settlement. The slope of the asphalt was categorised into three parts: the primary settlement of 0.48 %, which is a rapid settlement when road is just opened to traffic, the secondary settlement of 0.0101 % which follows the primary settlement is gradual while the third settlement of 0.00909% is the tertiary settlement which is very slow but results into pavement failure.

Table 5 Dial gauge Reading of Experimental Asphalt

Method of Loading		Place 75N load on the sample	Add another 75N	Unload 75N	Return the 75N	Add 150N	Add another 300N	Unload 300N	Return the 300N	Add 150N
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

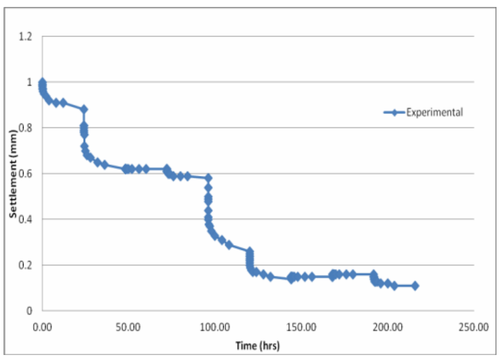


Figure 1 Settlement of Asphalts after 9 days

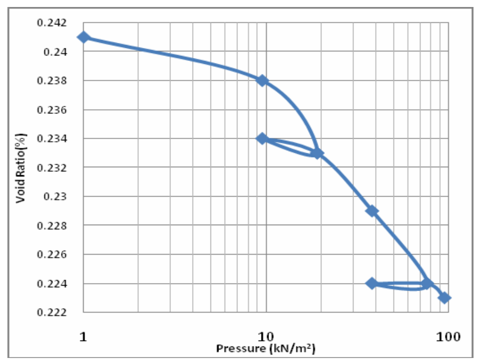


Figure 2 Void reduction against pressure

4.0 CONCLUSION

The findings of the study include:

(a) Cold mix asphalt can be produced at ordinary temperature with straight-run bitumen mixed with DPK dissolved non-degradable pure water sachets wastes [7].
(b) The Marshall Stability, flow and density of the experimental cold mix asphalt were 5.08kN, 4.0mm and 1.98 g/cc respectively [19].
(c) The cold mix asphalt substantially complied with specifications with stability greater than 3.5kN, flow within 2 – 4mm and voids filled with bitumen of less than 80 %.
(d) 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.
(e) This type of cold asphalt should be encouraged because of its improved quality of the environment as a result of the conversion of the nauseating heaps of waste pure water sachets to useable form.

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