ISSN No:-2456-2165

A Comparative Study of Strength Characteristics of Cold and Hot Asphalt Mixes Available for Road Maintenance in Lagos State

A.C. Apata[1], U.U. Imoh[2]
[1] Department of Civil Engineering, University of Lagos State, Nigeria
[2] Department of Civil Engineering, Akwa Ibom State University, Nigeria

Abstract:- The frequent failure of roadways in Nigeria is of great concern to highway users, particularly highway engineers. Some factors contributing to this situation include lack of adequate pavement/road maintenance programme. Traditionally, the material used in pavement maintenance operations is hot mix asphalt concrete (HMA). However, the use of cold patch imported from South Africa as seal coat in road maintenance in Lagos is becoming increasingly popular. Apart from the literature accompanying the products and which specify some properties and products advantages, there is no reported investigation into the engineering characteristics and likely performance of these products in Nigeria. In this study, HMA and cold patch materials were investigated. Tests carried out on the materials include bitumen content estimation (HMA, cold patch), gradation of aggregates (HMA, cold patch), Marshall stability and flow (HMA) and specific gravity, density and voids analysis (HMA). From the limited investigations conducted in this study, it was concluded that, the HMA mixtures were generally satisfactory, the aggregates recovered from cold patch samples did not conform to the FMW gradation specifications for either wearing course or binder course. The binder content in the cold patch was also too high for normal asphalt mixtures. Consequently, it was recommended that the use of cold patch for pavement maintenance in Lagos State should be with caution until more investigations are conducted.

Keywords:- *Cold Patch, Hot Asphalt Mixes (HMA), Pavement, Maintenance and Highway.*

I. INTRODUCTION

The post 1900 period saw the rapid growth of the automobile and the decline of horse-drawn vehicles and bicycles that brought about changes in highway construction. The faster automobile began to cause serious dust problems on roads, and the use of oils and other agents to cut down dust started. This

prompted experiments in 1905 with coal tars and crude oil in Jackson, Tennessee, U.S.A. to determine their benefit in pavement construction. The conclusion. The conclusion drawn from experiments was that highways used heavily by high-speed motorcars should be built with bituminous macadam surfaces and that existing roads subjected to similar high-speed traffic should be resurfaced using bituminous materials.

In Nigeria, the first bituminous surfacing done outside the limits of a township was laid in 1926 on that section of the Lagos-Abeokuta road, which lay within the then colony province (Olugbekan, 1995). Ever since, pavements design, construction, maintenance and evaluation methods had witnessed continuous research efforts that would ensure necessary improvements.

The frequent failure of our roadways has become a concern that attracts not only the attention of the highway users but the engineers in particular. Crashes are common features of road transportation in Nigeria. Carnage arising there from has therefore become one of the country's banes of socio-economic development. Oyeyemi (2003) submits that hardly any day passes without news of casualties and property loss on the highways as a result of road accidents. The principal factor of these road accidents is attributed to the bad state of our highways in the country. For example, according to Adedimila (2004), many of the accidents, both fatal and minor, on our roads are caused as a result of drivers trying to escape or avoid badly deteriorated portions of the roads.

Sufficient attention has not been put into road maintenance here in Lagos and Nigeria as a whole due to series of factors as outlined below:

- Lack of adequate pavement/road maintenance programmes.
- Lack of funding.
- Lack of proper monitoring of road Network.
- Low level of experienced maintenance engineers.

The use of cold patch as seal coat in road maintenance in Lagos is becoming increasingly popular. Apart from the literature accompanying the products and which specify some properties and products advantages, there is no reported investigation into the properties and likely performance of these products in Nigeria, and Lagos in particular. It is very important that the products are evaluated to ascertain their properties and likely performance.

ISSN No:-2456-2165

➢ *What is pavement maintenance?*

Pavement maintenance is not easy to define. Highway departments agree in general to what it is but there are some minor differences, chiefly in scope. Some call pavement improvement maintenance; others include only the work, which keeps the pavement in its "as constructed" condition. There also is some disagreement as to whether repairs made necessary by unusual events such as earthquakes, landslides, forest fires, windstorms, or severe traffic accidents should properly be classified maintenance (Asphalt Institute, 1983).

Taking all of these into consideration the definition of pavement maintenance, which seems most nearly to fit, is "the routine work performed to keep a pavement under normal conditions of traffic, normal forces of nature, as nearly as possible in its constructed condition" (Asphalt Institute, 1983).

Maintenance is a process that retards deterioration by restoring or improving pavement performance to acceptable levels of service. Traditionally, highway maintenance programmers in American and Canadian agencies commanded a relatively low priority. Over the years, the US government has heavily emphasized new construction and major restructuring and turned a blind eye toward maintenance work (Akhras and Foo, 1995). In Europe where the roads are relatively smoother and far sturdier, maintenance and repair work often begin before damage is even visible (Washington, 1992).

➢ *Why is maintenance necessary?*

Roads age and deteriorate with time due to either environment attack or damage done by vehicles or both. The Federal Highway Administration (FHWA) admits that 52% of the United States' road system, which is the world's largest, with a total of 6,300,000 km of highways and roads, is in miserable condition. Poor highway systems have led to loss of countless lives and cost of $120 billion a year as a result congestion and accidents (Washington, 1992). In Ontario, the percentage of the province's highways rated poor or sub-standard has risen from less than 40% in 1979 to 60% in 1992 (Chong, et. al., 1989).

In Nigeria and as at 1996, only 50 percent of the paved Federal roads, 30 percent of the paved state roads and 5 percent of the local government roads are in good condition. The conditions of these roads are generally fair or poor as contained in Table 1.1 (FMWH, 2000).

All pavements require maintenance, the chief reason being that stresses producing minor defects are constantly working in all pavements. Such stresses may be caused by change in temperature, moisture content, by traffic or by small movements in the underlying or adjacent earth. The crack, holes, depressions and other types of distress are the visible evidence of pavement wear. They are simply the end results of the process of wear, which begins when construction ends. In urban areas, ditches dug through the pavement for water lines and other utilities are a major cause of pavement maintenance (Asphalt Institute, 1983).

Table 1: Condition of Paved Roads in Nigeria as at 1996

Road Type	**Road Condition**		
	Good	**Fair**	**Poor**
Federal Roads	50%	20%	30%
State Roads	30%	30%	40%
Local Government Roads	5%	20%	75%

Source: FMWH, 2000

Fortunately, there is a growing realization that existing road systems represent enormous economic resources that need to be managed and maintained. To extend our roadways' usable life, greater attention has been focused on maintenance activities. As a result of the more and more important role of pavement maintenance, maintenance budgets had recently been increasing steadily at the expense of new construction cost (Asphalt Institute, 1983).

Pavement maintenance involves field inspection, evaluation, identifying existing problems, and selecting the most effective remedial measure to correct the deficiencies. Regular inspection and minor repairs prevent or reduce the occurrence of subsequent major problems. because of the large stock of aging roadways and the low number of experienced maintenance engineers, pavement inspections and repair work are irregular and are not being conducted as often as needed. To improve efficiency and consistency, a method of disseminating knowledge from experts to non-experts and local personnel is needed (Asphalt Institute, 1983).

II. MATERIALS FOR MAINTENANCE

In general, the materials used in pavement construction and maintenance consists hot mix asphalt (HMA) and surface dressing using liquid asphalt (cut back and asphalt emulsion). However, the use of cold patch, a prefabricated road meaning material imported from South Africa, is gaining ground in the maintenance of roads in Lagos Stare. Since cold patch remains workable in any weather condition, regardless of the length or type of outdoors storage and since it can simply be laid onto the distressed area, leaving it to subsequent motor vehicle traffic to provide the necessary compaction, boxing out of potholes is unnecessary. Cold patch is made of higher grade of asphalt,

ISSN No:-2456-2165

aggregate and various additives such as fibres and proprietary solvent. It is also a repair product that is manufactured on Kraft paper onto which bitumen rubber binder holds bitumen pre-coated aggregate of various sizes. It is supplied in sheets ofi. 1.0m x 0.75m dimensions and mass between 4kg and 17kgii. depending on aggregate size. It is highly flexible and water resistant.

Some of the merits of cold patch are:

- It provides a highly flexible and water proof seal.
- No heating equipment or expensive application tools are required.
- After application, the road is immediately opened for traffic use.
- Prevention of reflective cracking.
- Improvement of areas with poor skid resistance.

➢ *Aim of the Paper*

The objectives of the study include:

- To characterize material constituents of cold patch by first extracting asphalt binder from the product.
- To conduct laboratory tests to obtain necessary engineering properties of cold patch in relation to use in pavement maintenance.
- To compare such properties obtained in (2) with the corresponding values for HMA.
- To make appropriate recommendations on use of HMA and cold patch in pavement maintenance.
- The relevance of cold and hot mixes in asphalt pavement maintenance to highway and traffic engineers stems from the fact that the failure of pavements, which could lead to the entire highway failure, could reasonably be prevented by suing these materials. Limited funding and demands on existing resources have shifted the emphasis of government from reconstruction to preservation, rehabilitation and/or extending the service life of the existing roadways (ARRA, 2001).
- For the most part, hot mix paving asphalt produced by coasting crushed aggregate with asphalt cement has been used in pavement maintenance at high costs. In the case of high-performance cold patch materials, additives specially formulated for each aggregate are incorporated to allow the cold mix to be applied in lower temperatures, and to achieve a slow course, which helps to promote long life for the end user (www.USColdPatch.com). This along with individual mix designs and quality control procedures ensures high quality patching materials.
- It is also hoped that this project report will solve at least one of many problems facing road maintenance agencies in Nigeria, which is the continuous search for a suitable and adequate management system for such an operation. If cold patch maintenance is found to be satisfactory, the roadway service life span will be increased, and expensive reconstruction which has become part of the system will be a thing of the past.

➢ *Pavement Types*

Two general types of pavement considered for use on highways are:
Rigid Pavements
Flexible Pavements

There is however another type, composite pavements, that is defined by Wright (1996) and Haas and Hudson (1982) as one that combines dissimilar pavement types, i.e., flexible and rigid pavements, usually comprising a concrete or cement-treated base course and a wearing surface of asphaltic concrete. It can also be an asphalt concrete surface (usually an overlay) over an old Portland cement concrete pavement. Hass and Hudson further suggested that a more useful approach is to assign this type of pavement to one of the other two types (rigid and flexible), depending on the basic load carrying element and not the visible surface type.

This project is concerned with flexible payment. The need for the choice of a flexible pavement for this project stems from the fact that flexible pavement is most commonly available, as it constitutes the major type of highway pavements in Nigeria.

The Highway Design Manual published by the Federal Ministry of Works and Housing (FMW&H, 1973) defined flexible payments as “those having sufficient low bending resistance to maintain intimate contact with the underlying structure yet having the required stability furnished by aggregate interlock, particle friction and/or surface tension to support the traffic, e.g., macadam crushed stone, gravel, and all bituminous types not supported on a rigid base”. It also defined rigid pavements as “those, which, due to high bending resistance distribute loads to the foundation over a comparatively large area, e.g., Portland cement and brick, stone block or bituminous pavement on a Portland cement concrete base”. Also, according to the Design Manual, flexible payments are used for light and medium traffic roads, ramps frontage roads and shoulders, while asphalt concrete payment, also a flexible pavement, is used on heavily travelled roads if economically justified. Similarly, according to the Manual, rigid pavement is used on heavily travelled through traffic lanes where economically justified.

➢ *Hot Mix Asphalt (HMA)*

According to The Asphalt Institute (Asphalt Institute, 1984), HMA is defined as “a combination of aggregates uniformly mixed and coated with asphalt cement.” Both aggregates and asphalt cement must be heated prior to mixing. The aggregates and asphalt are combined in an asphalt mixing plant in which they are headed, proportioned and mixed to produce the desired paving mixture. After mixing, the hot-mix is transported to the paving site, and, while still hot, spread and compacted to a uniform layer with a uniform and smooth surface.

HMA may be produced from a variety of aggregate combinations (gradation), each having its own particular characteristics suited to specific design and construction uses. Asphalt concrete is a type of hot mix asphalt that meets strict requirements, and should be accurately defined. It is a high-quality, carefully controlled hot mixture of asphalt cement and well-graded, high-quality aggregates thoroughly compacted into a uniform dense mass typified by dense-graded paving mixes (Asphalt Institute, 1983a). Authorities responsible for road design and construction have specifications for road construction materials, including aggregate type and gradation. In Nigeria, the Federal Ministry of Works has recommendations for aggregate gradation and amount of asphalt to be used for both wearing and binder courses as later presented in chapter 4 (FMW&H, 1997).

➢ *Cold Patch*

Cold patch is made of asphalt, aggregate and a solvent. There are many varieties of cold patch used in bituminous pavement maintenance. Two of these varieties are as follows:

- BRP Cold Patch (produced in South Africa)
- Cold Patch (produced in the U.S.A.)

➢ *BRP Cold Patch [BRP, 2005]*

The BRP road maintenance products, otherwise known as 'Cold Patch', and which is investigated in this work, is produced by a South African based company, A.J. Broom Road Products Limited. Masta Services Company Limited markets the product in Nigeria. The cold patch is claimed to be capable of replacing hot mix asphalt in road maintenance and it is also claimed to be quick, simple and economical to install, creates minimum disruption to traffic, conforms to specification, eliminates waste, reduces skilled labor intensity and provides a long service life repair of nine years.

The product has many variations that can be installed on domestic driveways, national roads and motorways. The products are claimed to be driver alert and traffic calming, having an excellent track record in eliminating accidents in high-risk areas and the calming of traffic in both rural and urban areas.

➢ *Product*

The cold patch is a factory fabricated road repair product that is manufactured on kraft paper onto which a bitumen rubber binder holds bitumen pre-coated aggregates of various sizes. It is supplied in sheets, the dimensions of which are 1.0m by 0.75m with a thickness of between 6.7mm and 19mm, and a mass of between 4 kg and 17 kg, depending on the aggregate size. A typical sample of the product is illustrated in Figure 2.4. The product is claimed to be highly flexible and totally water proof road repair product that has been tested in the field in varying traffic and climatic conditions since 1986 with great success.

➢ *Binder Specification*

The binder used in the production of BRP cold patch is as follows:

80/100 pen bitumen with 22% rubber crumb

60/70 pen bitumen with 25% rubber crumb

➢ *Applications*

The product has a wide range of applications. Areas of application include the following:-

- Pothole repairs
- Crocodile Crack repairs
- Longitudinal Crack repairs
- Block Crack repairs
- Edge break repairs

The use of cold patch as thickened edge to protect carriageway edges by means of a flexible interface between different materials is illustrated in Figure 2.

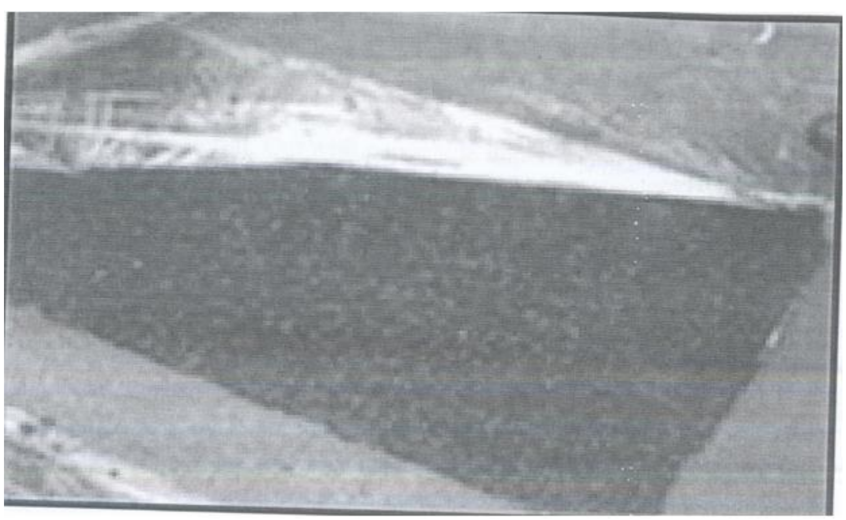

Fig 1: Typical BRP Cold Patch Product

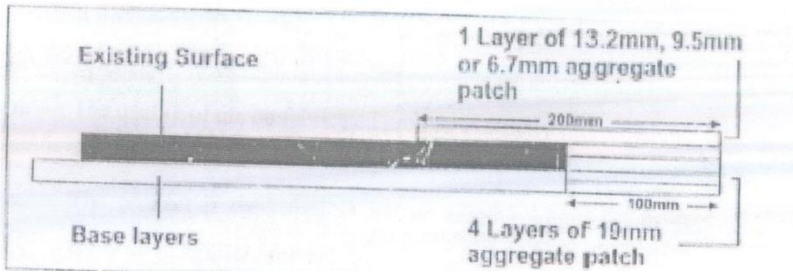

Fig 2: Use of BRP Cold Patch as Thickened Edge for Carriageway

- *Application Procedure*

The procedure for the application of cold patch includes the following steps:

- The area must be swept free of all dust and loose material. Preferably use a squeegee for application but a hand broom may be used to sweep area. Ensure area is dry.
- Demarcate area to receive emulsion, using chalk.
- Even application of emulsion tack coat to surface to be repaired at a rate of 0.75 litre/m^2. When temperature is below 10^{o}C, the paper (back) of cold patch is also treated with emulsion.
- Emulsion is allowed to 'break' or 'set' completely (changes from brown to black and becomes sticky).
- Cut or use pre-cut material. Cut with paper side uppermost. Ensure packaging tape is removed from paper side of patch.
- Placement of cold patch, paper side down and without removing the paper backing.
- With a brush, apply a small quantity of emulsion to joints and edges – "blind with sand".
- Reopen road to traffic immediately; no need for compaction.

- *Road Maintenance*

The major problem for highway engineers today is to keep the existing road network open for passage. This is as true of the developed world as it is of the developing world, the only difference being that of scale. Following the post Second World War and post independence, road building boomed in the developed and developing countries. Governments and road authorities are now faced with huge ubiquitous networks of paved and unpaved roads and pathways to be maintained, with dwindling funds with which to do it.

Road maintenance in developing countries must satisfy five requirements. The first requirement is *to maintain the flow of traffic* in defined conditions. The second is *to ensure the safety of road users*, and the third is *to conserve the assets represented by the roads* by preserving the road structure and its associated drainage systems in good condition. The fourth requirement concerns the *comfort of road users*, which should not be overlooked and finally there are *aesthetic considerations* to preserve the appearance of the road in relation to the surrounding countryside.

The above objectives can usually be achieved by seeking to preserve the character given to the road by its designer; a sound and uniform carriageway, clean and unencumbered verges and sound structures. As the resources of the maintenance services are always limited they must be used according to the order of priority given in the five requirements listed above. To ensure that the financial resources available for maintenance are in line with those available for construction, an estimate should always be made of the recurrent maintenance costs that will follow the construction or improvement of a road.

Criteria	**Road Classification**			**FMW&H Specifications**
	Class I **Heavy Traffic**	**Class II** **Medium Traffic**	**Class III** **Low Traffic**	
Design CBR, %	80 or 100 (Minimum)	60 or 70 (Minimum)	50 (Minimum)	80 (Min) 30 (Min) Subbase
(LL) x (Fines, % Passing 0.075 mm)	600 (Maximum)	900 (Maximum)	1250 (Maximum)	1050 (Maximum) 125-375 (For Gravel Base)
Liquid Limit (LL)	30 or 45 (Maximum)	40 (Maximum)		30 (Maximum)*
Plasticity Index (PI)	10 or 15 (Maximum)	12 (Maximum)		12 (Maximum)
(PI) x (Fines, % Passing 0.075 mm)	350 (Maximum)	350-400	500 (Maximum)	120 (Maximum) 100-300 (For Gravel Base)
Los Angeles Abrasion	65 (Maximum)	65 (Maximum)		

*Limit may be exceeded at Engineer's discretion

Source: Ajayi, 1986

Maintenance activities can be *short-term routine maintenance*, largely manual, and *long-term maintenance* activities carried out less frequently and usually involving the use of mechanical equipment. Neglect of short-term (routine) maintenance leads to a general deterioration of the road, possibly to serious failure and certainly to expensive major maintenance work.

➢ *Short-Term (Routine) Maintenance*

Short-term maintenance includes all the operations, which are carried out daily, largely by hand using simple tools, by a gang permanently employed in these activities. Such maintenance operations can be carried out on pavement surfaces or shoulders, verges and drainage ditches.

➢ *Bituminous Road Surfacing*

Deterioration of a bituminised surface is slower than that of a gravel surface and routine maintenance can be confined to the simplest repairs such as sealing cracks and a little hand patching. For this fluid cutback bitumen, such as MC 70 or MC 250, or bitumen emulsion, which does not require heating, would be suitable. The blinding material should be similar in size to that already in used on the road. It is most important that regular reports on the overall condition of the surfacing be made so that major maintenance, usually a surface dressing, can be planned well ahead.

➢ *Earth or Gravel Road Surfacing*

The maintenance of an earth or gravel surface is a more complex operation than that of a well-constructed bituminous road. A characteristic of many gravel roads is the formation of corrugations. Their rapidly of formation, their severity and wavelength depend principally on the amount and type of traffic and on the type of soil. In general, heavy, fast-moving vehicles on granular soils promote the most rapid formation of corrugations. Work must be directed principally to corrections the profile of the road at regular intervals so as to prevent the growth of corrugations to an unacceptable level. This involves retrieving the material flung to the edge of the road and re-spreading it over the road surface, incipient corrugations must be removed before they become compacted by the traffic.

Useful work can be done with only hand tools, rakes, shovels, picks and brushes, but outputs are low. Far better results may be achieved with locally made implements such as heavier brushes, 'drags', and simple grader blades towed by light tractors. The more elaborate types of brush are tractor-drawn at about 8 to 16 km/h. they incorporate several rows of bristles and find their main application on lightly trafficked roads in spreading loose dry material and in dispersing corrugations before they become compacted. The frequency with which brushing should be carried out depends on the traffic intensity and the rapidity with which the corruptions reform.

➢ *Long-Term Maintenance*

Long-term maintenance comprises major repair and refurbishing and it requires the use of mechanical equipment operated by skilled men supported by an adequate force of unskilled labor. Long-term maintenance activities are carried out on earth and gravel roads, bituminous-surfaced roads and bridges and culverts. However, further discussion on long-term maintenance in the following section is focused only on bituminous surfaced road maintenance materials.

➢ *Road Maintenance Materials*

Traditionally, materials used in the maintenance of bituminous surfaced roads are surface dressing and hot mix asphalt concrete. However, the used of cold patch, especially the variety which is a prefabricated bituminous mix imported from South Africa, has been introduced by the Lagos State Government. The following sections contain brief descriptions of these maintenance materials.

III. MATERIALS AND METHODS

Two types of materials, cold patch and hot mix asphalt concrete were used for this study. The constituents of the materials are outlined in the following sections.

➢ *Materials Used for Cold Patch*

The following materials were used for cold patch production:

- Kraft paper
- Bitumen rubber binder
- Fine Aggregate
- Coarse Aggregate

The cold patch samples were already produced by the manufactures in South Africa, imported to Nigeria and obtained from the Lagos State Ministry of Works and Infrastructure. The characteristics of the recovered aggregates after extraction tests are presented.

Table 1: Summary of Experimental Programme

Type of Test	Materials Tested		Source	Laboratory Where Tested
Extraction	HMA	Wearing Course Binder Course	LSGAP, JB JB	J.B.
	Cold Patch		LSMWI	
Gradation test	HMA	As in Extraction test	As in Extraction Test	J.B.
	Cold Patch		LSMWI	
Marshall test	HMA	As in Extraction test	As in Extraction Test	J.B.

Specific gravity test, Density test, Mixture calculations	HMA	As in Extraction test	As in Extraction Test	J.B.
	Cold Patch			

Source: Researcher's Computation, 2008

➢ *Materials Used for Hot Mix Asphalt Concrete (HMA)*

The following materials were used for the production of hot mix asphalt concrete:

- Coarse Aggregate
- Fine Aggregate
- Filler
- Bitumen

The mixtures tested in this study were obtained from different sources presented in Table 3.1.

The aggregates were granite chippings stored in the Asphalt Plant Yards of both Julius Berger and the Lagos State Government. The aggregates were characterized after the bitumen extraction tests on the collected HMA samples.

The binder used in the production of HMA was 60/70-pen grade bitumen. The characteristics of the bitumen as contained in the certificate of quality issued by the West African Bitumen Emulsion Company (WABECO) in Kaduna to the Lagos State Government are as shown in Appendix A.

➢ *Bitumen Content of Cold Patch Samples*

The cold patch samples were obtained from Lagos State Ministry of Works and Infrastructure, Alaina. The materials are currently used for maintenance of damaged portions of road surface as potholes, cracks or any other failures. The extraction, which was conducted inside Julius Berger Laboratory, Papa using Centrifugal Extractor, involved, weighing the cold patch materials and later putting them in an oven to become semi-liquid. The content was dissolved using trichloroethylene as the solvent and filtering the solution through a fine porosity filter. The residue retained after filtering the solution was then determined. However, the bitumen extraction test was not conclusive because the binder had already been coated with rubber, which proved inseparable since no equipment was available to separate the bitumen from the rubber.

Fig 3: Bitumen Content Determination by Extraction

➢ *Bitumen Content of HMA Materials*

The bitumen content of HMA was also determined by bitumen extraction test. In the process a 1.5kg portion of the asphalt concrete was soaked in a quantity of tricholene (trichloroethylene). Bitumen, the active cementing portion of asphaltic concrete is by definition soluble in trichloroethylene [Asphalt Institute, 1986]. This process dissolves out the bitumen contained in the asphaltic concrete. The bitumen extraction is then achieved using the extraction machine by successive draining of the mixture of bitumen and tricholene and addition of fresh tricholene after each process of draining and filtration. The drained off mixture of bitumen and tricholene was filtered through a fine porosity filter and the residue retained was added to the insoluble aggregate materials.

ISSN No:-2456-2165

There were fine (filler) materials of the mix that had passed into the mixture of the bitumen. The materials were further recovered in a filler cup by centrifuging the solution and the weight of the filler added to that of the aggregates.

The draining processes continued until the resulting mixture was clear of any bitumen stain. The aggregates were then dried in the oven at a temperature range of 105ºC to 110ºC, cooled and weighed. The calculation carried out to determine the bitumen percentage is presented in Appendix B.

- *Gradation of Aggregates*

Gradation test is one of the non-destructive quality tests. It refers to the quantity expressed in percentage by weight of various particle sizes of which a sample of aggregate is composed. This is determined by separating the aggregates into portions, which are retained on a number of sieves or screens having specific openings, which are suitably graded from coarse to fine. The results obtained may be expressed either as total percentage passing or retained on each sieve or as the percentages retained between successive sieves. The total percentage passing method is very convenient for the graphical representation or a grading and is most widely used in graded aggregate specifications.

Gradation is the characteristic of a road aggregate on which perhaps the greatest emphasis is placed in a specifications; it is also probably the cause of the majority of controversies, which arise between the supplier and the road builder relative to the suitability of aggregate. This is important because of its direct influence on both the quality and the cost of a completed pavement.

The limit place on a particular gradation depends on the nature of the work in which the aggregate is to be employed. Thus, for instance, the grading of a material to be used in a dense bituminous surfacing, which depends considerably on gradation for its denseness and consequent stability, is more critical than the grading of an aggregate for use in macadam, in which stability is heavily depended aggregates on the interlock of the aggregate particles. When well-graded aggregates have to undergo extensive handling or transporting, segregation of sizes may occur which can be relatively costly to remedy.

When aggregate particles are to be bound together by cement or bitumen, a variation in the grading of an aggregate will result in a change in the amount of binder required to produce a material of given stability and quality. Proper aggregate grading contributes to the uniformity, workability and plasticity of the material as it is mixed.

In this study, the recovered aggregates were sieved with a set of sieves on a mechanical shaker (Figure 3.2), and the amounts of each aggregate size passing were collected. The recovered aggregates were dried in the oven at 200 – 250ºC, cooled and weighed prior to sieving.

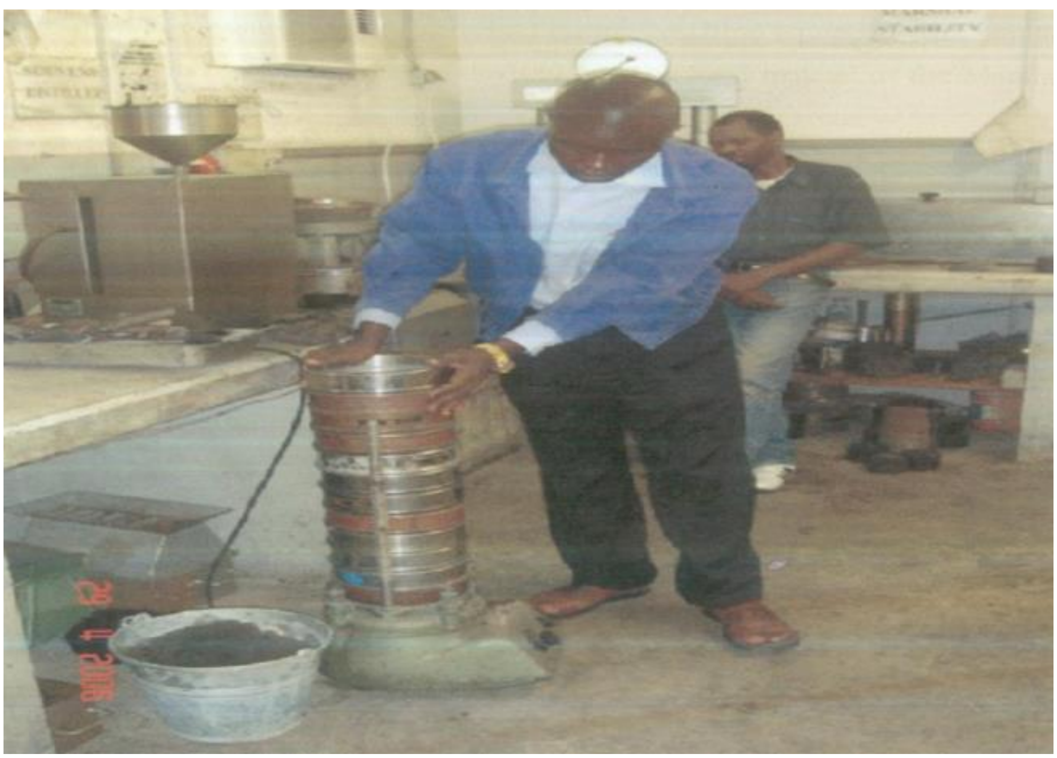

Fig 4: Grading of Aggregates

➢ *Marshall Stability and Flow Determination*

It should be noted that Marshall stability and flow tests were conducted only for HMA samples, as it was not possible to prepare test specimens from available cold patch samples.

The equipment required for the testing of the 102mm (4 in) diameter x 64 mm ($2^1/_2$ in) height specimens was as follows:

- Marshall test machine, a compression-testing device. It is designed to apply loads to test specimens through semi-circular testing heads at a constant rate of strain of 51 cm (2 in) per minute (Figure 3.3). It is equipped with a calibrated proving ring for determine the applied testing load, a Marshall stability testing head for use in testing the specimen, and a Marshall flow meter for deformation-measuring devices may be used instead of the Marshall testing frame.
- Water bath, at least 150 mm (6 in) deep and thermostatically controlled to 60°C $\pm 1°C (140°F \pm 1.8°F)$. The tank should have a perforated false bottom or be equipped with a shelf for suspending specimens at least 50 mm (2 in) above the bottom of the bath.

The Marshall Stability value is the maximum resistance in kg or Newton that the standard test specimen will develop at 60°C (140°F). A flow meter records the strain at the maximum load when failure occurs.

The flow value is the total movement of strain in units of 0.25 mm occurring in the specimen between no load and maximum load during the stability test.

Fig.3: Marshall Stability and Flow Determination

To prepare the specimens samples weighing 1.2kg each were used. The samples were headed again before transferring to the moulds for compaction. Filter papers were inserted at both ends. After compaction the specimens were extracted from the mould by using extrusion jack or arbour press. The extruded specimens were then placed on a smooth, level surface until ready for testing.

➢ *Stability and Flow Tests*

After the bulk specific gravity of the tests specimen has been determined, the stability and flow tests were performed as follows:

- A 101.6 mm (4 in) diameter metal cylinder was inserted in the testing head, placing the flow meter over the guide rod and adjusting the flow meter to read zero.
- Specimens were immersed in water bath at $60°C \pm 1°C (140°F \pm 1.8°C)$ for 30 to 40 minutes before testing.
- The inside surface of the testing head was thoroughly cleaned. Temperature of head was maintained at 21° to 37.8°C (70° to 100°F) using a water bath when required. Guide rods were lubricated with a thin film of oil so that upper test head will slide freely without binding. As a proving ring was used to measure applied load, the dial indicator was firmly fixed and "zeroed" for the "no-load" position.
- With testing apparatus in readiness, the test specimen was removed from water bath and the surface carefully dried. The specimen was placed in the lower testing head and centered; then the upper testing head was fitted into position and the complete assembly centered in loading device. The flow meter was placed over the marked guide road as noted in (a) above.
- The testing load was applied to the specimen at constant rate of deformation, 51 mm (2 in) per minute, until failure occurred. The point of failure was defined by the maximum load reading obtained. The total number of Newtons required to produce failure of the specimen at 60°C (140°F) was recorded as its Marshall stability value.
- While stability test was in progress, the flow meter was held firmly in position over the guide rod and then removed as the load began to decrease, taking and recording readings. This reading was the flow value for the specimen, expressed in units of 0.25 mm (1/100 in). For example, if the specimen deformed 3.8 mm (0.15 in) the flow value would be 15.
- The entire procedure, both stability and flow tests, starting with the removal of the specimen from the water bath, was completed within a period of thirty seconds.

➢ *Analysis – Mixture Calculations*

The following expressions were used in the calculation of mixture properties (Adedimila, 2005).

- *Asphalt Content (Percent by weight of total mixture),* P_{AS}

$$P_{AS} = \frac{W_{AS}}{W_{AS}+W_{AG}}(100) \quad - \quad - \quad (3.1)$$

Where:
W_{AS} = Weight of asphalt
W_{AG} = Weight of aggregate

- *Theoretical Maximum Specific Gravity of Mixture,* G_{MAX}

$$G_{MAX} = \frac{100}{\frac{P_{AS}}{G_{AS}}+\frac{P_{CA}}{G_{CA}}+\frac{P_{FA}}{G_{FA}}+\frac{P_{MF}}{G_{MF}}} \quad - \quad - \quad (3.2)$$

Where:
$P_{CA,}P_{FA,}P_{MF,}$ = Percentage of coarse aggregate, fine aggregate and mineral filler, respectively, by weight of total mixture.
$G_{AS,}G_{CA,}G_{FA,}$and G_{MF} = Measured specific gravity values of asphalt, coarse aggregate, fine aggregate and mineral filler, respectively.

- *Theoretical Maximum Density of Mixture,* γ_{MAX}

$$\gamma_{MAX} = G_{MAX}\gamma_W \quad - \quad - \quad (3.3)$$

Where:
γ_W = Density of Water

- *Volume of Air Voids as Percentage of Volume of Mixture,* V_A

$$V_A = \frac{\gamma_{MAX}-\gamma_{MIX}}{\gamma_{MAX}} \quad - \quad - \quad (3.4)$$

Where:
γ_{MIX} = Measured density of mixture

- *Voids in the Mineral Aggregate (VMA),* $V_{V,}$%

$$V_V = \frac{1-V_{AG}}{1}100 \quad - \quad - \quad (3.5)$$

Where:
V_{AG} = Volume of aggregate, in a unit of volume of mixture

- *Voids Filled with Asphalt, V_F,%*

$$V_F = \frac{V_{AS}}{V_V}100 = \frac{V_{AS}}{1-V_{AG}}100 \quad - \quad (3.6)$$

V_{AS} = Volume of asphalt, in a unit volume of mixture

IV. RESULTS

➢ *Aggregate Gradation*

The detailed results of sieve analysis for some of the aggregate samples recovered from the hot mix asphalt (HMA) and cold patch samples are presented in Appendix C. A summary of the results is presented in Table 4.1.

Figure 4.1 shows the graphical representation of the aggregate gradation curves for HMA wearing course from Julius Berger and from Lagos State Asphalt Plant Yard. The curves are superimposed on the FMW gradation envelope for wearing course. Table 4.2 contains the FWM gradation envelope for binder and wearing courses. As shown in Figure 4.1, the recovered aggregates from Julius Berger wearing course in this study conforms very well to the FMW specifications. However, the gradation for the Lagos State Government Asphalt Plant (LSGAP) wearing course does not conform to the FMW specifications, calling for modifications in its gradation prior to future use.

Figure 4.2 shows the gradation curve for binder course samples obtained from Julius Berger Asphalt Plant. The gradation curve is superimposed on the gradation envelope specified by FMW for binder course. It is evident from Figure 4.2 that the gradation does not conform to FMW specifications.

Table 4.1 shows that there is virtually no difference in the gradation values for Julius Berger wearing and binder courses. Thus, the aggregates meant for binder course are actually the same in gradation as the wearing course as it also satisfies the FMW specifications for wearing course.

Table 4.1: Gradation Values for Recovered Aggregates

BS Sieve Size	Sieve Opening mm	Cumulative Percentage Passing			
		Wearing Course	Wearing Course	Binder Course	Cold Patch
		LSGAP	Julius Berger		LSMWI
$1\,{}^{1}/_{4}$"	31.5				
1	25				
${}^{3}/_{4}$"	19	100	100	100	100
${}^{1}/_{2}$"	12.5	98.3	95.4	95.9	17
${}^{3}/_{8}$"	9.5	97.2	87.6	87.9	6
${}^{1}/_{4}$"	6.3	89.9	75.1	75.3	4.4
${}^{3}/_{16}$"	4.75	83.4	68.1	68.3	3
7	2.26	58.4	51.7	52.5	2
14	1.18	39.5	37.3	38.3	1
25	0.6	26.3	28.6	29.4	0
52	0.3	16.1	19.1	19.6	
100	0.15	8.4	14.5	15.2	
200	0.075		11.1	11.6	

Table 4.2: Grading Envelopes for Binder and Wearing Courses

Sieve Size	% By Weight Passing	
	Binder Course	Wearing Course
31.8 mm	100	100
25.0 mm	90-100	100
19.0 mm	70-90	100
12.5 mm	55-80	85-100
9.5 mm	47-70	75-92
6.4 mm	40-60	65-82
2.8 mm	27-45	50-65
1.25 mm	20-34	36-51
600 µm	14-27	26-40
300 µm	8-20	18-30
150 µm	5-15	13-24
75 µm	2-7	7-14
Bitumen content, % by weight of aggregate	4.5-6.5	5-8.0

Source: FMW, 1997

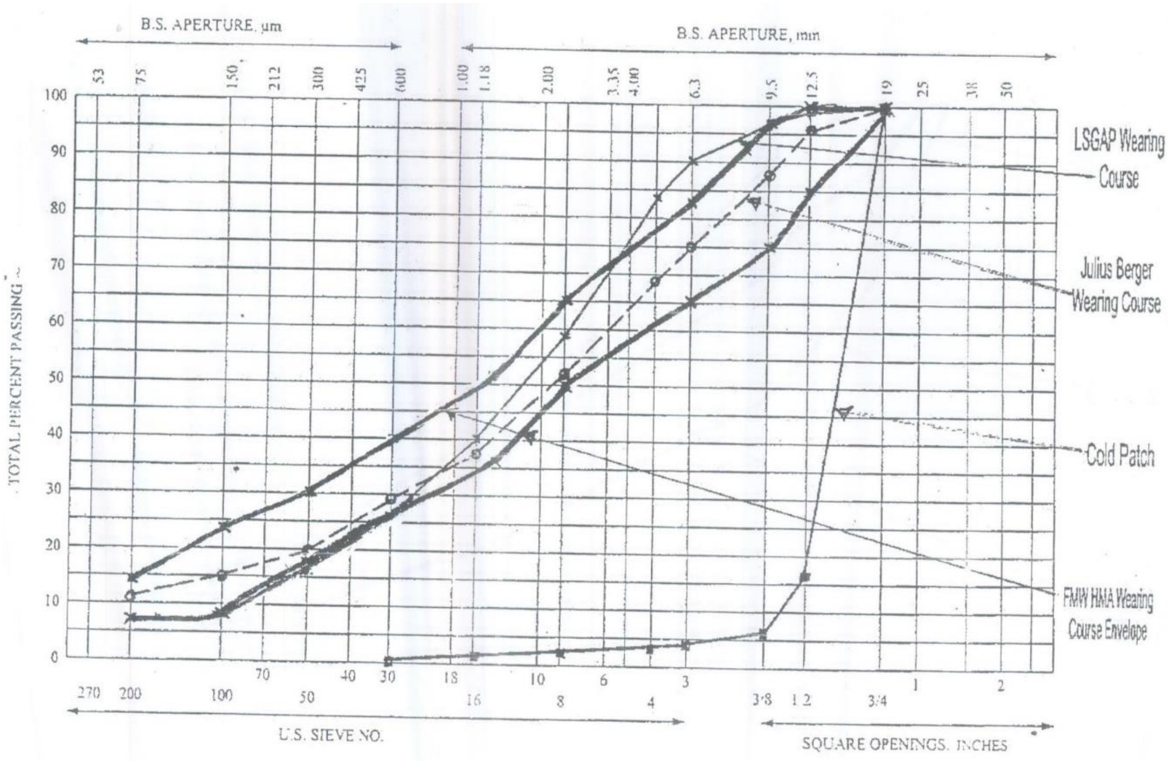

Fig 4.1: Gradation Curves for HMA Wearing Courses and Cold Patch Samples

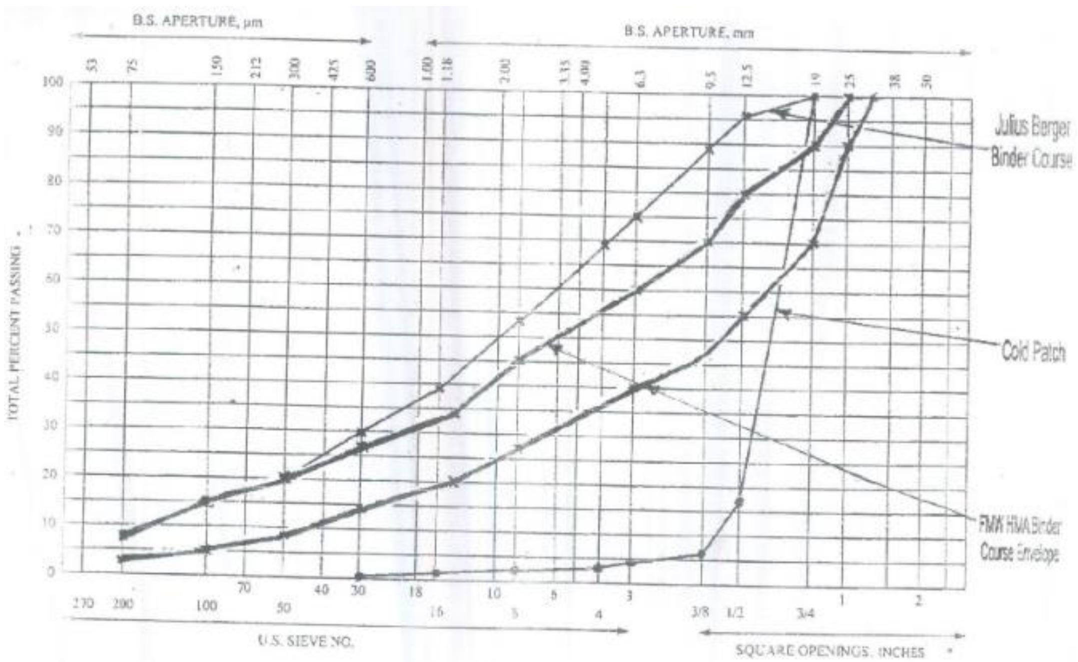

Fig 4.2: Gradation Curves for HMA Binder Course and Cold Patch Samples

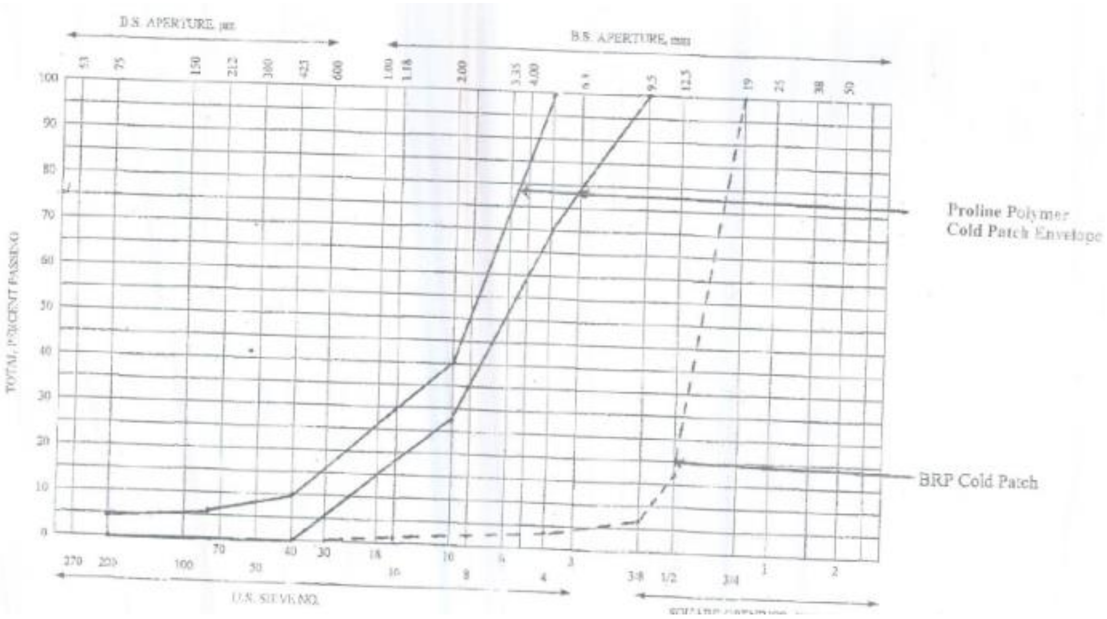

Fig 4.3: Comparison of Gradation Curve of BRP Cold Patch with Specifications for Proline Polymer Cold Patch

Finally, the gradation curve for cold patch aggregates is presented in Figures 4.1 and 4.2. Since cold patch is used for the repair of failed pavement surfaces, the gradation curve is superimposed on the FMW specified gradation envelopes for wearing and binder courses. The figures reveal that the cold patch gradation does not conform to FMW specifications for wearing and binder courses. Further, it was observed that the gradation curve for the investigated BPR cold patch was equally outside the range of specified gradations for QPR cold patch (Figure 4.3) and Proline polymer cold patch (Figure 4.4) used in the U.S. Consequently, the use of BPR cold patch for pavement maintenance is suspect.

➢ *Binder Content*

The bitumen contents for the various mixtures are presented in Table 4.3 as percentage by weight of aggregate. Average values range from 4.5% for (binder course) to 6.1% (for wearing course). The corresponding value for cold patch is 12.8%.

As shown in Table 4.3, the wearing course mixes obtained from both Julius Berger and LSGAP are satisfactory with respect to bitumen content while that of binder course is marginally satisfactory. However, the 12.8% obtained for cold patch is rather high and may lead to bleeding, rutting and shoving of the pavement at high temperatures in high traffic areas. Consequently, the use of such products should be with caution until more investigations are conducted.

➢ *Marshall Stability and Flow*

Marshall stability tests were conducted only on HMA samples, as it was not possible to prepare Marshall test specimens from the cold patch samples obtained from Lagos State Ministry of Works and Infrastructures (LSMWI).

Average stability values range from 13.23 kN for binder course to 20.31 kN for wearing course. These values are relatively high and show that the mixes are very satisfactory with respect to stability for base course and wearing course construction as shown in Table 4.4 (FMWH, 1997) and Table 4.5 (Asphalt Institute, 1984).

Table 4.3: Test Results for Hot Mix Asphalt and Cold Patch Samples

HMA Type	Wearing Course	Wearing Course	Binder Course	Cold Patch
Source	LSGAP	Julius Berger Asphalt Plant		LSMWI
Property				
Bitumen Content, %*	5.6 (5.0-8.0)	6.1 (5.0-8.0)	4.5 (4.5-6.5)	12.8
Stability, kN	20.31	14.79	13.23	
Flow, 0.25 mm	4.50	3.47	3.51	
% Air Voids	4.18	4.60	4.04	
% Voids Filled	76.80	75.40	71.96	
Specific Gravity	2.48	2.48	2.45	2.48
Density, g/cc	2.378	2.364	2.351	2.378

*The FMW specifications for respective mixes shown in parentheses

Table 4.4: Properties of Compacted Asphalt Concrete

Property	Base Course	Wearing Course
Optimum bitumen content	4.5%-6.5%	5.0%-8.0%
Stability, not less than	3.5 kN	3.5 kN
Flow, 0.25 mm	8 – 24	8 – 16
Voids in total mixture	3% - 8%	3% – 5%
Voids filled with bitumen	65% – 72%	75% – 82%

Source: FMWH, 1997

Table 4.5: Marshall Mix Design Criteria

Property	Light traffic: Surface and Base		Medium traffic: Surface and Base		Heavy traffic: Surface and Base	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Compaction: No. of blows to each end of specimen	35		50		75	
Stability, N	2224		3336		6672	
Flow, 0.25 mm	8	20	8	18	8	16
% Air Voids	3	5	3	5	3	5
% Voids Filled with Bitumen	70	80	65	78	65	78
Voids in Mineral Aggregate (VMA), %	20-30		20-30		20-30	

Source: Asphalt Institute, 1984

The Marshall flow values in Table 4.3 range from 3.47 to 4.50. In general, a minimum flow value of 8 is recommended for asphalt mixtures (Table 4.4 and 4.5). This suggests that the mixtures in this study are rather stiff and may not exhibit sufficient flexibility under traffic.

- *Air Void Content*

As shown in Table 4.3, the percentage air voids in the mixtures range between 4.04 and 4.60. these values are satisfactory with respect to the FMW recommended values for base course (3% to 8%) and for wearing course (3% to 5%) as contained in Table 4.4. They are also satisfactory with respect to values recommended by the Asphalt Institute (3% to 5%) for all conditions of traffic (Table 4.5).

Similarly, values of the percentage voids filled with bitumen are 76.80 and 75.40 for wearing course, and 71.96 for binder course. These values are also satisfactory with respect to the specifications of the Federal Ministry of Works (Table 4.4).

- *Suitability of the Mixtures*

The various properties of the mixtures evaluated in this study were presented in the above sections. It appears the HMA mixtures are generally satisfactory for construction and maintenance purposes. It can be observed, however, that the Marshall stability values are generally high while the flow values are correspondingly low.

A selected mix design is usually the most economical which will satisfactorily meet all of the established criteria. Mixes with abnormally high values of Marshall Stability and abnormally low flow values are often less desirable because pavements of such mixes tend to be more rigid or brittle and may crack under heavy volumes of traffic (Asphalt Institute, 1984). This situation is especially critical if the sub-base and sub-grade materials beneath the pavement are weak and permit moderate to relatively high deflections under the actual traffic (Zoorob, 2002).

In mixture design, the design bitumen content should be a compromise selected to balance all of the mix properties. Normally, the mix design criteria will produce a narrow range of acceptable bitumen contents that pass all of the guidelines in Table 4.5 and the bitumen content selection is then adjusted within this narrow range to achieve a mix property that will satisfy the needs of a specific project (Figure 4.5). Different properties are more critical for different circumstances, depending on traffic loading and volume, pavement structure, climate, construction equipment, and other factors. Thus, the balancing process that is carried out prior to establishing the final design bitumen content is not the same for every pavement and for every mix design.

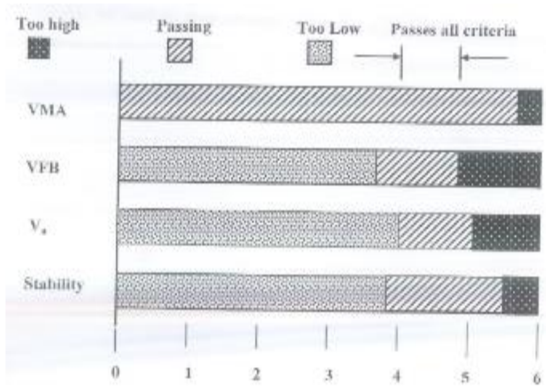

Fig 4.5: Range of Acceptable Bitumen

In many cases the most difficult mix design property to achieve is the minimum amount of voids in the mineral aggregate. The goal is to furnish enough space for the bitumen so it can provide adequate adhesion to bind the aggregate particles, but without bleeding when temperatures rise and the bitumen expands.

ISSN No:-2456-2165

Consequently, it is recommended that a proper mixture design should precede the final recommended bitumen content that will satisfy all the desirable properties of the mixture.

For the cold patch, the investigation carried out in this study is pioneering in nature. The limited samples available for testing and the non-availability of some testing equipment, especially to separate rubber from recovered bitumen, makes the results obtained rather limited and inconclusive. It is hoped that future studies will attempt to overcome these challenges in order to be able to ascertain the suitability or otherwise of the cold patch materials. Meanwhile, it is also recommended that particular attention be paid to road sections where the materials have been used and its performance observed and evaluated.

V. CONCLUSIONS

The following conclusions were made:

- Aggregates used for the preparation of hot mix asphalt (HMA) wearing course from Lagos State Government Asphalt Plant were not satisfactory with respect to the Federal Ministry of Works gradation specifications. Amendments to the gradation should be made prior to future use.
- Aggregates for wearing course from Julius Berger Asphalt Plant were very satisfactory with respect to gradation. However, the gradation for the binder course was virtually the same as that of the wearing course. Attempt should be made to obtain an aggregate whose gradation conforms to the FMW specifications for binder course.
- For cold patch, the recovered aggregates did not conform to the FMW gradation specifications for either wearing course or binder course. Consequently, the adequacy of such material for pavement maintenance appears questionable.
- The HMA wearing and binder courses from Lagos State and Julius Berger Asphalt Plants were satisfactory with respect to bitumen content. However, the bitumen content of cold patch samples appeared rather high, with a high probability of bleeding, rutting and shoving of the pavement maintained with such materials, especially at high temperatures.
- The use of cold patch for pavement maintenance should be with caution until more investigations are conducted.

RECOMMENDATIONS

The following specific and general recommendations were made:

➢ *Specific Recommendations*

- Supervising consultants must ensure the use of high quality construction materials. All materials, including aggregate quantity and gradation, must conform to necessary FMW specifications.
- Proper mixtures design must always precede the recommended design bitumen content that will be satisfactory with respect to all desirable properties of the mixture.
- Importers of cold patch materials currently being imported from South Africa for pavement maintenance must made to produce certificates showing all desirable engineering characteristics of the mixture and its constituents. Further studies on the cold patch are recommended. Such studies include the engineering characteristics of the mixture and also of the aggregates and bitumen used in its manufacture. The binder should be recovered from the mixture and appropriate technology employed to separate rubber from the recovered bitumen for appropriate characterization.
- The use of cold patch for pavement maintenance in Lagos State must be with caution until more investigations are conducted to ascertain its qualities as pavement maintenance material. Meanwhile, efforts must be made to monitor the performance of sections of road pavements maintained with cold patch.

➢ *General Recommendations*

The following general recommendations were made:

- Determined to stamp out the menace of incessant collapse of pavements, the government should assign engineers on a regular basis to a particular portion of road, and henceforth regularly visit the road to ascertain the extent of damage and the level of deterioration of the road and come up with the type of maintenance needed.
- A stitch in time saves nine. There is a need to carry out repair works on deteriorating pavements in Nigeria at the early stages of the failures.
- It is sad to note that there is only one pavement evaluation unit in Nigeria, which is located in Kaduna. There is high need, therefore, to establish at least one functional well equipped pavement evaluation unit in each state of the Federation. This will help to carry out periodic pavement evaluation on our roads.
- During construction of any road in Nigeria, a part from engineers from government Ministries, the Nigeria Society of Engineers should also have a delegate to ascertain the quality of materials being used and adhering strictly to the FMW specifications.
- In the past there were Highway Police; it will be beneficial if they again become functional in order to monitor the use of our highways and to ensure that pavements are not vandalized, burnt, cut and highway furniture are not removed, tampered with or destroyed, and also to ensure that refuse are not dumped indiscriminately on the pavements and the drainage structures.

REFERENCES

[1]. Adedimila, A.S. (2004). Lecture Notes on CEG 823 – Highway Construction and Maintenance, M.Sc. Class, Civil and Environmental Engineering Dept., University of Lagos, Lagos.

[2]. Adedimila, A.S. (2005). Lecture Notes on CEG 829 – Bituminous Materials I, M.Sc. Class, Civil and Environmental Engineering Dept., University of Lagos, Lagos.

[3]. Ajayi, L.A. (1986). Thoughts on Road Failure in Nigeria; The Nigerian Engineer Vol. 22, No. 1. Lagos.
[4]. Akhras, G. & Foo, S.H.C. (1995). Knowledge-based Advisory System for Flexible Pavement Routine Maintenance: Discussion. Canadian Journal of Civil Engineering, Vol. 22, p. 212. Being a Written Discussion of the same titled Paper by Hanna, P.B., Hanna, A.S. & Papagiannakis, T.A. (1993), Canadian Journal of Civil Engineering, Vol. 20, pp. 154-163.
[5]. ARRA (2001). Basic Asphalt Recycling Manual, Asphalt Recycling and Reclaiming Association.
[6]. Asphalt Institute (1983a). Asphalt Technology and Construction Practice, Instructor's Guide, Education Series No. 1 (ES-1), Asphalt Institute Building, College Park, Maryland, USA.
[7]. Asphalt Institute (1984). Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, Manual Series No. 2 (MS-2), Asphalt Institute Building, College Park, Maryland, USA.
[8]. Asphalt Institute (1986). Introduction to Asphalt, Manual Series No. 5 (MS-5), Asphalt Institute Building, College, College Park, Maryland, USA.
[9]. Chong, G.J., Phang, W.A. & Wrong, G.A. (1989). Manual for Condition Rating of Flexible Pavements, Distress Manifestation. Rep SP – 024, Ontario.
[10]. FMW&H (1973). Highway Manual, Part I – Design, Federal Ministry of Works and Housing, Abuja.
[11]. FMW&H (1997). General Specifications (Roads and Bridges), Vol. II, Federal Ministry of Works and Housing, Abuja.
[12]. FMW&H (2000). Task Force for Road Maintenance, Federal Ministry of Works and Housing,
[13]. Haas, R. & Hudson, W.R. (1982). Pavement Management Systems, Robert E. Krieger Publishing Company, Malabar, Florida.
[14]. Olugbekan, S. (1995). Road Development in Nigeria. Yesterday, Today, and Tomorrow. The Nigeria Engineer, Journal of The Nigerian Society of Engineers, Vol. 33, No. 3, pp. 12-18, Lagos.
[15]. Oyeyemi, B.O. (2003). Strands in Road Traffic Administration in Nigeria. Clemeve Media Konsult, Ibadan.
[16]. Washington, Bruce Van Voorst (1992). Why America Has So Many Potholes, Article, Time Magazine, May 4. (www.time.com/time/magazine/article/0,9171,975457, 00.html)
[17]. Wright, P.H. (1996). Highway Engineering, John Wiley & Sons, Inc., New York.
[18]. Zoorob, S. E. (2002). Design and Construction of Hot-Mix Bituminous Surfacing and Road Bases. In *Highways – The Location, Design, Construction and Maintenance of Road Pavements by O'Flaherty, C.A., Heinemann, 4th Ed.*