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Some guidelines for the production and use of cold recycled asphalts in hot tropical regions

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Abstract

This paper details some guidelines for producing and using cold bituminous emulsion mixtures (CBEM) containing severely aged reclaimed asphalt pavement (RAP) in hot tropical climate. Such guidelines are lacking at the moment and have been identified as major barriers preventing developing countries with hot tropical climates from integrating recycling into their road maintenance/rehabilitation programmes. It is envisaged that employing such methods and materials for road rehabilitation/reconstruction would assist in stretching road funds, budgets for which in recent times have increasingly become inadequate in such developing countries. The use of such materials and methods would also promote sustainable and accelerated road development. Although there are a number of methods for recycling RAP materials, the cold in-plant recycling approach using bitumen emulsion has been chosen and considered more appropriate for such countries in order to ensure good quality control of the mixtures produced and so as not to require expensive equipment. It is by ensuring such quality control that the full benefits of recycling can be harnessed. The paper essentially focuses on two fundamental issues affecting mix (job mix), and structural design considerations for cold recycled bitumen emulsion mixtures. These are considered germane towards achieving success for such recycling programmes.

Keywords: Asphalt pavement recycling, Cold recycling, Bitumen emulsion, Reclaimed asphalt pavement, Job mix, Structural design

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1. Introduction

In the developed countries of the world of which most have temperate climates, emulsified bitumen had variously been used in times past as the binding medium for surface treatment works in which fresh aggregates were used (PIARC, 2008; Thanaya, 2003; Ibrahim, 1998; Asphalt Institute and Asphalt Emulsion Manufacturers Association, 1997; Needham, 1996). It had also been used on several occasions in cold recycling; most especially full depth reclamation works (ARRA, 2001; PIARC, 2003). ARRA (2001) also reported further that, in the developed countries, cold asphalt recycling and the use of RAP date back to the 1900s. Results from field trials of such cold mixes under these climates have been reported to be highly impressive and encouraging.

On the other hand, developing countries of the world most especially those located in Africa (though with the exemption of South Africa (PIARC, 2008; Jenkins, 2000), such as Nigeria, Ghana, Benin, Burkina Faso, Republic of Congo, among others are yet to realize the advantages of these sustainable materials, tools and techniques for road restoration (Eyo, 2004). The climate (hot) of these parts of the world promises to be an enhancing factor for such materials and methods over what obtains in other places, as most researchers are of the opinion that the presence of water in cold mixes is the main inhibitive factor to the development of early life strength in pavements made from such cold mixes.

PIARC (2008) in a recent survey involving 15 countries from five continents, i.e., Africa (3), Asia (2), Australia (1), Europe (8) and North America (1), identified some of the factors which are barriers to the uptake of recycling in the road construction industry as:

- Lack of client awareness of the benefits and performance of recycling,
- Lack of necessary regulation and legislation to encourage recycling,
- Lack of appropriate standards and specifications,
- Existing test methods which are unsuitable for alternative materials,
- Lack of appropriate quality controls (concerns over the reliability and quality control of new methods and alternative materials),
- The economics of recycling (the perception that new methods and materials will be more expensive than traditional ones),
- Conditions of contract (conditions of contract which do not encourage innovation or flexibility),
- Supply and demand (the difficulty of balancing supply and demand for alternative materials),
- Planning (difficulty getting planning permission for recycling centres in or near urban areas),
- Environmental concerns (concerns about pollution of the environment through leachate or dust generation).

While issues 1, 2, 6, 7, 8, 9 and 10 above are essentially non-technical, 3, 4 and 5 are technical, and must be determined through research and experience in countries where they are lacking. The guidelines presented in this paper succeeded an extensive research work (Oke, 2010) embarked upon to address some of the problems associated with the identified technical problems i.e. factors 3 and 4 mentioned above, which have been hindering cold mixes from being fully embraced in developing countries. The main hindrance to the implementation of cold recycling and pavement recycling generally in such countries is lack of guidelines and standards that would facilitate a smooth implementation.

Many researchers from works carried out mainly in the developed countries of the world have reported the major problems with cold mix as, low and slow development of stiffness of mix. These problems have been associated with lack of proper understanding of the interaction between the aged binder in the reclaimed asphalt pavement and the recycling agent applied during recycling and also slow curing of mix and high voids contents (Thanaya, 2007; Thanaya, 2003; Ibrahim, 1998; Needham, 1996) just to mention a few. Some of these problems, which are directly or indirectly tied to the high water content of the mix and binder properties, could potentially be alleviated by virtue of the prevailing climatic conditions (hot climate) in most of these developing countries. Also, the advantage that easier logistics are involved in the delivery of cold mix (Needham, 1996) compared to hot mix makes it more appropriate for road building in such developing countries where most areas are to say the least still relatively remote.

The guidelines are provided with the production of bitumen emulsion stabilised RAPs for roads in the hot tropical belt of the world in view. The guideline parallels those developed in the UK that provide a framework which encourages both innovation and the use of recycled materials (PIARC, 2008). This guideline essentially focuses on two fundamental issues affecting mix (job mix), and structural design considerations for cold recycled bitumen emulsion mixtures. These are considered germane towards achieving success for such recycling programmes. Issues affecting construction considerations which are equally very important but not covered in this paper are well detailed by ARRA (2001), Wirtgen (2004) and Merrill et al. (2004).

Although there are a number of methods for recycling RAP materials, the cold in-plant recycling approach using bitumen emulsion has been chosen and considered more appropriate for such countries in order to ensure good quality control of the mixtures produced and so as not to require expensive equipment. It is by ensuring such quality control that the full benefits of recycling can be harnessed.

2. Laboratory mix design considerations for the use of cold recycled bituminous emulsion mixtures

Mix design essentially entails the formulation in the right proportions of materials (aggregate + binder + filler) that will constitute the asphalt mixture whether cold, warm or hot mixed. While such an exercise which involves mainly virgin materials prepared hot is straight forward though still regarded under some circumstances as a complex material by some researchers (Collop, 2009), the inclusion of RAP as full or partial substitute for virgin aggregates makes the case more complex still. This is because RAP in itself is a composite (conglomerate of aggregate and aged binder which could even be polymer modified type) material that must be characterised and checked for its integrity or nature before it is used in the mix. This indeed is an additional but very important exercise most especially for developing countries where information on the history of such reclaimed pavements might be difficult to come by. Furthermore, it is considered important to do this even when such history is known since RAP though depending on its nature/integrity and the percentage it constitutes in the mix, can significantly affect/alter the overall mechanical behaviour of the mix contrary to the desired expectations of the pavement designer when the true nature of the RAP is not considered.

As earlier mentioned, the cold recycling *ex situ* (in-plant) approach chosen in this work allows for proper assessment of RAPs before they are used. Although factors that must be considered for pavement recyclability have likewise been extensively dealt in the Basic Asphalt Recycling Manual (ARRA, 2001), Wirtgen Cold Recycling Manual (2004) and Merrill et al. (2004), it is believed that this method is applicable in both new construction and rehabilitation works. This is because cold asphalt produced in-plant has better potential for consistency in properties compared to the *in situ* approach since there is room for proper quality control. Furthermore, cold recycling whether *in situ* or *ex situ* is almost always found applicable where there is a major need for the improvement of structural capacity of road pavements (ARRA, 2001), which in procedure, is closely related to new construction.

It implies thus that once the project evaluation, economic analysis and preliminary selection favour cold recycling, then proper pavement assessment, structural capacity assessment, material properties assessment, traffic assessment, constructability assessment and environmental implications as suggested by ARRA (2001) and Wirtgen (2004) must be carried out. When all these necessary steps have been taken, then the mix design which is the focus of this section is conducted.

These guidelines have been produced in concert with the suggestions of ARRA (2001), AI & AEMA (1997), Wirtgen (2004), Merrill et al. (2004), Ibrahim (1998), Thanaya (2003) and Smith and Jones (1998) just to mention a few. However they have been done in the light of countries located in hot tropical climates. It should also be noted that the cold asphalt materials in question here are applicable in the construction of road base of flexible road pavements and hydraulic binders though advantageous, have not been considered.

3. RAP characterisation

The importance of proper RAP characterisation cannot be over emphasised whenever RAP materials are to be used in the production of cold mixtures. This obviously is the first step in the process of job mix design as the integrity of the RAP is ascertained in the process. This characterisation is done by conducting a composition analysis using relevant standards (BS598-102:2003, BSEN 933-1 and BS598-101:2004). This will give information on the content of residual bitumen in RAP and as well the gradation of extracted aggregates from RAP. It is advised that the properties of the recovered bitumen be ascertained subsequently in order to know the design approach to follow i.e. whether to treat RAP as black rock or not. It is envisaged from the findings of Oke (2010) that RAP with residual bitumen of 5dmm penetration is active under hot tropical conditions although the extent of the activity is difficult to quantify. A suggested method for recovering the aged residual binder in RAP is BS EN12697-4:200. Some of the suggested tests are:

1. Physical properties of recovered bitumen from the mix
    a. Penetration at 25^{0}C
    b. Softening point

c. Viscosity

2. If possible the stiffness properties in the form of Complex Modulus at 25^0C

If the penetration is below 5dmm, there is no need to conduct the other tests on the binder. The RAP should be treated as black rock i.e. as virgin aggregate. Processing of the RAP follows i.e. crushed and screened to required sizes suitable for a 20mm DBM as stated in ORN 31 & 19 (see Table 1 and Figure1). Smith and Jones (1998) suggested that such mixes are able to give satisfactory support to road pavements in hot tropical climates where overloading is a problem. In order to meet the gradation requirements of 20mm DBM, virgin aggregates could be introduced to make up for the deficient sizes.

When the penetration of the residual bitumen is 5dmm and up to 20dmm, the other tests listed above are worth conducting in order to gain a fuller understanding of the behaviour of the residual bitumen. These are useful in determining the proper grade of recycling additive i.e. recycling agent for the cold recycling. However, caution must be taken in deciding on the grade of additive (recycling agent) since the extent of possible rejuvenation or not of the residual binder cannot be ascertained at the moment. For residual bitumen with the range of penetration 5dmm – 20dmm, bitumen emulsion containing base bitumen of 50dmm was found suitable. Meanwhile, the determination of the gradation of the extracted aggregate is necessary since the residual binder is considered to be active under hot tropical conditions. It is believed that fines and fillers alike which are trapped in residual aged bitumen begin to contribute to the properties of the cold mixture upon the softening or possible rejuvenation of such residual aged binder thus potentially affecting the volumetrics of the mixture. This is considered appropriate.

Table 1. Gradation Properties of ORN 19&31 for 20mm DBM

Size (mm)	Maximum Density (% Passing)	ORN Lower Bound	ORN Upper Bound
28	100.00	100.00	100.00
20	85.95	95.00	100.00
14	73.20	65.00	85.00
10	62.92	52.00	72.00
6.3	51.11	39.00	55.00
3.35	38.46	32.00	46.00
0.3	12.99	7.00	21.00
0.075	6.96	2.00	9.00

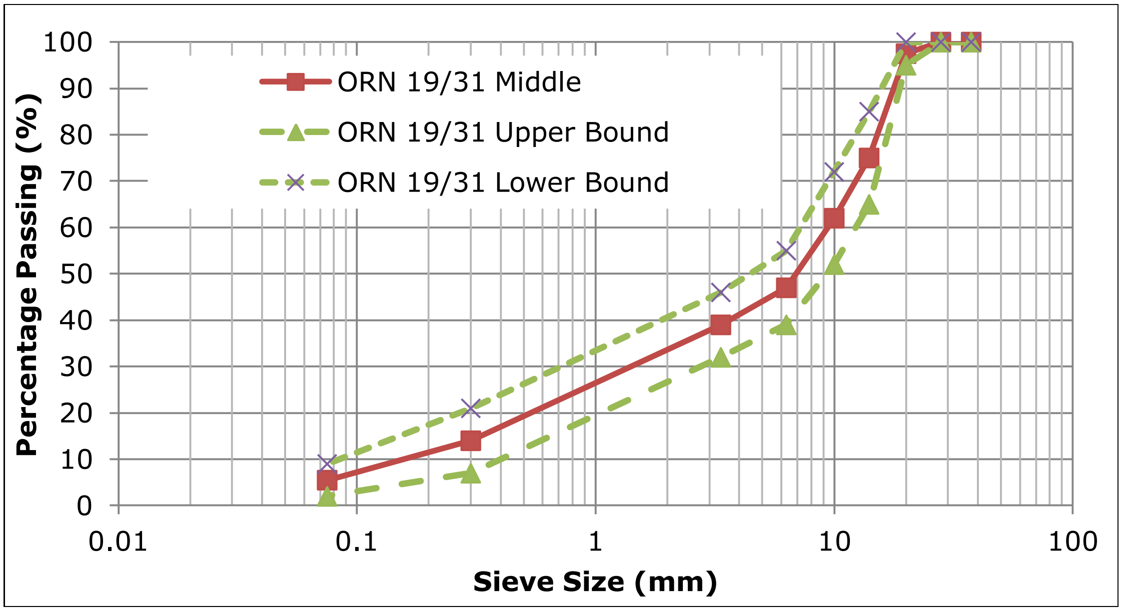

Figure 1. Gradation Curve for 20mm DBM

The deficient sizes in the extracted aggregate from the RAP aggregates are supplemented with virgin aggregates to suit the requirements for 20mm DBM earlier suggested. ARRA (2001) in buttressing this cautioned that the addition of new aggregates should not be based on the gradation of the aggregate recovered from the RAP (RAP aggregates) alone, because coarse angular particles of conglomerated fines can be manufactured by cold milling that are not broken down by traffic. However, the addition of virgin aggregates can be beneficial and justified when excess binder is present or when it is deemed desirable to increase structural capacity of the mix. No value is given here for percentage addition of virgin aggregates to mix since each individual project merits individual treatment.

It is similarly important to determine the particle density and water absorption properties of both the RAP and virgin aggregates in order to make the appropriate decision with regard to bitumen emulsion content required for the mix.

4. Considerations for the choice of bitumen emulsion

Although there are a number of recycling agents which have been successfully used in cold recycling, this guideline focuses on bitumen emulsions. Factors to consider for choosing other recycling agents have been properly addressed by ARRA (2001), Wirtgen (2004) and Merrill et al. (2004).

The choice of suitable bitumen emulsion type i.e. cationic or anionic is determined by the aggregate type i.e. whether it is siliceous or calcareous. Cationic bitumen emulsion is appropriate for siliceous aggregates (granite for example), and anionic bitumen emulsion is considered appropriate for calcareous aggregates (e.g. limestone aggregates). This is important as it strongly affects the adhesion of the base bitumen in the emulsion to the surface of the aggregates. Medium to slow setting emulsions are considered appropriate for hot tropical conditions so as to guard against setting before compaction is carried out.

5. Estimation of pre-wetting water content and binder demand

Once a decision on the type of bitumen emulsion suitable for the project is taken, the determination of the quantity of bitumen emulsion required for the mix is next. Some important parameters are relevant here. These are pre-wetting water content, initial emulsion content (IEC), total fluid content (TFC) and the optimum bitumen emulsion content (OBEC) in the optimum total fluid content (OTFC).

1. The whole exercise starts by estimating the trial/initial emulsion content. The empirical formula suggested by Asphalt Institute method (MS-14, 1989) is considered appropriate for this thus:

$$P = (0.05A + 0.1B + 0.5C) \times (0.7) \quad (1)$$

where,

P= % by weight of binder demand by mass of total mixture

A= % of mineral aggregate >2.36mm

B=% of mineral aggregate <2.36 and > 0.075mm

C=% of mineral aggregate < 0.075mm

The bitumen content in the emulsion must be considered.

2. Apart from helping to activate the charges on the surface of aggregates which enhance attraction of emulsion to the aggregates, the addition of pre-wetting water enhances the compaction characteristics of the cold mix when optimal values are used. Pre-wetting water is determined with due regard to the natural moisture content of the aggregates (RAP or virgin) by determining both the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the mix using a range of moisture contents (say 0-12% at convenient intervals) for the moisture-density relationships. Though the gyratory compactor was found suitable for this exercise other convenient methods most especially as obtained in the modified proctor test can also be used. No specific value will be given here for these values (OMC and MDD) since each project should be given individual treatment.

3. Once the OMC is determined, the IEC value obtained in equation 1 is used to replace the same moisture proportion in the OMC to constitute the TFC. The difference between OMC and IEC is the pre-wetting water content. These are simply expressed as follows:

$$\text{TFC} = \text{Natural Moisture Content in Aggregates} + \text{IEC} + \text{Pre-wetting Water Content} \quad (2)$$

Further optimisation must be conducted to determine the optimum bitumen emulsion content (OBEC) to give the optimum total fluid content (OTFC) for the mix.

The OBEC in OTFC is determined in a similar fashion as is normally done for the determination of OMC and MDD but now by checking the indirect tensile strength (ITS using the Universal Testing Machine) and/or the indirect tensile stiffness modulus (ITSM using the Nottingham Asphalt Tester - NAT) of the mixtures in dry and wet conditions using a range of residual bitumen contents (RBC). The relationships generated in the process are the TFC – ITS and or TFC – ITSM relationships. Meanwhile, the OBEC must be chosen giving allowance for the absorption properties of the mix, and considering the fact that a significant portion of the moisture will evaporate upon curing. For example, while keeping the emulsion content constant at 'P%' by mass of the aggregate (as empirically determined in equation 1), the pre-wetting water content can be increased at intervals of 1.0% by mass of the aggregate starting from total fluid content equal in value to the OMC and ending at a convenient point, e.g. 10%. The procedure followed for preparing the specimens should be such that the pre-wetting water is first added to the dry batched mixture and then mixed using speed II on the Hobart Mixer for 60s. The required emulsion is subsequently added and the mixture mixed for another 60s. It is suggested that each batch of mixing should have sufficient materials for 4 specimens. The required materials are subsequently placed in 100mm diameter split moulds and then compacted applying the same compactive effort. These are left in the moulds for 24hrs (in a sealed condition) at the same ambient temperature before they are carefully extruded.

Since the mixtures produced in the process are still very fragile even after 24hrs curing in the mould, the produced specimens must be further cured in a forced draft oven. Curing at 60^0C for 96hrs is considered appropriate here for the specimens that are tested dry to represent typical hot tropical conditions. Wet vacuum saturated specimens at a pressure of 140mbar should be further conditioned in water for 24hrs at 30^0C (average maximum ambient temperature in the tropics) and followed subsequently by further conditioning at 20^0C (average minimum ambient temperature in the tropics) before the ITS and ITSM tests are conducted at 20^0C. This procedure should fully account for the recovery potentials of the mixture after exposure to severe conditions. Testing for ITS and ITSM at 20^0C ranks CBEMs better than testing at 30^0C which is the more appropriate temperature for hot tropical conditions. The results are used to generate TFC-ITS/ITSR, and TFC-ITSR/ITSMR relationships where the optimum total fluid content (OTFC) is determined.

In order to determine the OBEC in the OTFC, further optimisation must be conducted just as explained above but now keeping the OTFC constant. Ideally, and if possible the best way of establishing this is by varying the bitumen/water ratio in the emulsion, but since most emulsions are proprietary, varying the emulsion/ pre-wetting water content ratio should be adopted.

4. Now that the OTFC is known, it is important to ensure that the appropriate mixing time for the mixture is ascertained. 2-4 minutes using the sun and planet mixer is considered adequate and similarly in a suitable Hobart mixer. For example, in a 4-minute mixing time, the first 2minutes is used for the pre-wetting water addition/mixing, while the remaining 2minutes is used for the bitumen emulsion addition/mixing.

5. Further investigations must be conducted on the designed (fully optimised) mix to ascertain its mechanical performance. The results of such will be useful for the structural design of the layer. Of importance are the ITSM and fatigue tests. If possible, permanent deformation and resilient modulus

tests can be conducted although not always practical. The more the traffic volume anticipated, the more important it is to conduct these tests. With low-medium volume roads, ITSM and fatigue tests should suffice. The durability (ageing and water susceptibility) of the mixture must also be considered. All these will give an indication on the performance of the mixture in service. Figure 2 and Table 2 are summarised procedures for the cold mix design.

6. Structural design of cold recycled bituminous emulsion mix layers

A number of methods are available for pavement structural design. These include, catalogue design methods, structural number method, deflection based methods and the mechanistic methods (Wirtgen, 2004). Wirtgen (2004) stated that the use of a mechanistic pavement design method for rehabilitation works is the most fundamentally sound approach since the method is based on engineering principles, using the performance data developed through research on different materials.

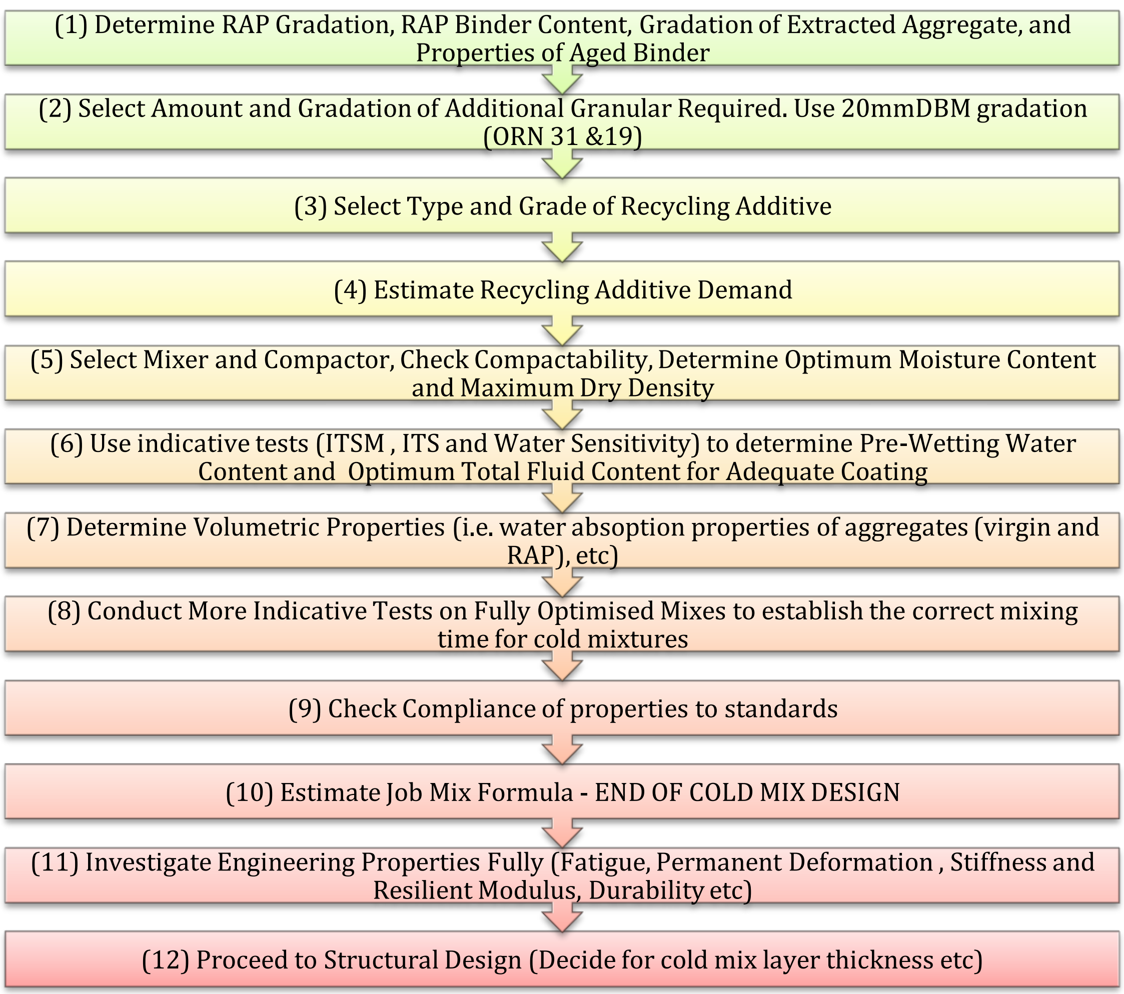

Figure 2. Flow Chart for Cold Recycled Bituminous Emulsion Mix Design

Table 2. Step by Step Approach to Cold Recycled Bituminous Emulsion Mix Specimens Preparation

1.Materials for Cold Bituminous Emulsion Mixture (CBEM)		
RAP and Virgin Aggregates	Characterise RAP (check residual bitumen content and properties and the gradation of extracted aggregate). Determine quantity and sizes of virgin aggregates required to fill deficiencies. Use 20dmm DBM gradation	
Optimum Total Fluid Content	Start by estimating trial emulsion content. Determine the pre-wetting water content using moisture-density relationships.	Determine OTFC using TFC – ITS and or TFC –ITSM relationships.
Batching	Each batch contains enough materials for 4 cores at 910g per sample	
2. Mixing		
Material Conditioning prior to mixing	- Materials (aggregate mix, bitumen emulsion in air tight container and demineralised water) preconditioned over night at the desired mixing and compaction temperatures (32^{0}C) - Set Sun and Planet Mixer also to the desired temperature over night (or 3hrs to the time of mixing) - Precondition prepared moulds at the required temperature	
Fluid Addition and Mixing Technique	- Add the prescribed amount of pre-wetting water to mix in the mixing basin. - Mix continuously for 60s and stop the mixer. Stir mix manually using a spatula. Mix again for 60s - Add the prescribed bitumen emulsion content to water pre-wetted mix - Mix for 60s and stop the mixer. Also stir manually to obtain homogeneous mix. Complete operation by mixing for 60s more. Place loose CBEM in moulds and subsequently condition for 30minutes	
3. Compaction		
Moulds	- Prepare 100mm diameter moulds and precondition overnight - Upon mixing, place 900g of CBEMs in each mould - Condition for about 30minutes	
Compaction Information	- Set angle of gyration to 1.25^{0} - Compaction pressure to 600kPa - Target 200gyros for good compaction - Target 100gyros for mild compaction	
Specimen Size	- Diameter = 100±1mm - Height = 50±2mm (requires no cutting)	
4. Curing		
Stage 1 of Curing	First 24Hrs after compaction - Keep in mould (sealed) condition for 24hrs at ambient condition (temperature of about 20^{0}) - De-mould or extrude specimens carefully after 24hrs - Check mass	
Stage 2 of Curing	Curing in the Forced Draft Oven After 24Hrs of Stage 1 Curing - Cure @ 40^{0}C over 12hrs (Early Life) - Cure @ 40^{0}C over 72hrs (Intermediate Life) - Cure @ 60^{0}C over 96hrs (Fully Cured Condition)	
5. Handling of Specimens After Curing		
Storage After Curing	If specimens are not tested immediately after curing, store in the cold store at 5^{0}C until needed for testing	
Conditioning Prior to Test	- Prior to any dry test (i.e. ITSM), place specimens in the conditioning cabinet at the desired test temperature for about 8hrs (preferably overnight) - Specimens for wet tests (for water sensitivity) should be conditioned for 2hrs in water at the desired test temperature before testing	

From the work done by Oke (2010), it is important to consider the non-linear elastic behaviour of the Cold Recycled Bituminous Emulsion Mixtures (CRBEM). This informs that the resilient modulus test results are required in this regard for the input parameters in the mechanistic analyses. The KENLAYER computer software developed by Huang (2004) which is commonly available is considered appropriate in this regard for analysing the response of the non-linear layer to load. The desired outputs from the analyses are:

- Horizontal tensile strain at the bottom of the HMA (surface layer)
- Vertical strain on top of the subgrade

A range of layer combination and thicknesses for surfacing layer (HMA), road base layer (CRBEM), sub-base layer (unbound granular materials- lateritic gravel) and subgrade layer must be tried until the desired layer combination is found that satisfactorily meets the requirements for the desired pavement design life. This must be economically viable compared to when the conventional pavement is used. Experience shows that with a well designed CRBEM road base layer, and good sub base and subgrade layers, a surfacing layer (HMA) thickness of 20mm – 50mm is achievable.

For the prediction of Equivalent Standard Axle Load applications, transfer functions are required for realistic values. It is advised that transfer functions or shift factors for critical conditions for fatigue and permanent deformation are used for such estimations as follows:

Fatigue;

Values obtained when the horizontal strains from multi-layer analysis have been substituted in fatigue life equations obtained from fatigue tests should be multiplied by 77

Permanent Deformation;

$$N_{cr} = fr\left(\frac{7.6\ x\ 10^8}{\varepsilon_z^{3.7}}\right) \qquad (3)$$

where:

- N_{cr} = life to critical condition (10mm rut)
- Fr = a rut factor to account for the hot mixture type- 1.56 for dense bitumen mixtures

Such shift factors are to be used with caution for the CBEMs (cold mixtures) since they were developed for HMA. At present, no such values are available for cold mixtures. The adopted factor of 77 may be too low to describe total pavement life. Considering the fact that cold mixtures are not as good as HMA as observed by Oke (2010), it is believed that the appropriate value for life to failure should be somewhere in between 77 and 440 for critical and failure conditions respectively. These shift factors are based on the Nottingham Asphalt Design method for hot mixtures.

For the construction of pavements which contain cold recycled bituminous emulsion mixture (CRBEM) layers, the guidelines for such given by ARRA (2001), Wirtgen (2004) and Merrill et al. (2004) are relevant. However, it is advised that such constructions should be done in the harmattan (dry) season in hot tropical countries such as Nigeria, and where very thick layers of road base CBEMs are considered i.e. from 200mm to say 300mm in order to minimise the thickness of the HMA surfacing, such a CBEM layer should not be laid in one lift but in layers (of say 100mm thick) to allow for adequate curing. This can be done at intervals of 12hrs for good performance in a typical hot tropical climate considering the stiffness values observed by Oke (2010). It follows therefore that 12hrs after being laid such CBEM layers can be opened to vehicular traffic. This is believed to give room for consolidation of the CBEM layers before they are sealed with a HMA surfacing layer.

7. Conclusion

This paper has given a short and concise set of guidelines for producing and using cold bituminous emulsion mixtures (CBEM) containing severely aged reclaimed asphalt pavement (RAP) in hot tropical climates which for a while has been lacking. The formulation of the guidelines was preceded by an extensive laboratory investigation on the production of bitumen emulsion stabilised RAPs for roads in the tropics. The guidelines cover mix design of RAP CBEMs and structural design of pavements containing such non linear materials. The guidelines are applicable mainly to cold recycling *ex situ* (in-plant) and should facilitate the integration of recycling into road maintenance/rehabilitation in developing countries with hot tropical climates. Cold recycled RAP CBEMs are suitable as road base layers and should be sealed with hot mix for good results. The 20mm DBM gradation as suggested in ORN 31 and 19, which is suitable for excessive axle loads is recommended.

Recycling of RAP promotes sustainable road development and also helps in stretching funds available for road which in recent times have been dwindling in many developing countries of the world.

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