

## A REVIEW ON CRACK RELIEF LAYER IN AIRPORT RUNWAY

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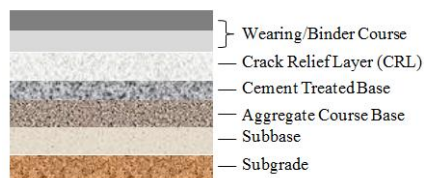
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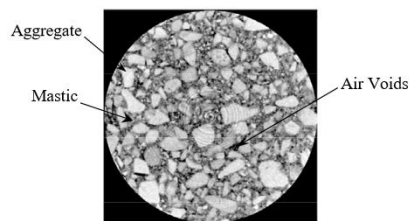
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### Graphical abstract



Placement of CRL in pavement strata



Air Voids Distribution in X-ray CT image

### Abstract

This article reviews the behaviour and function of the crack relief layer (CRL) in a pavement. The significance and effectiveness of implementing CRL into pavement layers to prevent reflective cracking are also included. Over the years, crack in pavement has been a major problem that causes obstacle to transportation system which has cost multi-millions of dollars. This is especially true in airport runway business industry where the traffic flow of aircrafts cannot be easily diverted or disturbed as it involve many parties and would jeopardize public safety. The characteristic of the CRL will be thoroughly investigated to achieve it desirable functional capability to act as the crack relieving agent. CRL is a layer made out of hot mixed asphalt that to the strata of the pavement with thickness of 100 to 150mm on top of base layer and under surface course. The significant of this hot mixed asphalt layer is in its capability to reduce reflective cracks development by separating bound and unbound layer and acting as buffer zone between those layers. Thus the layer designed to be semi-unbound layer to efficiently in creating the buffer zone for the crack transfer from the bottom to the top of the pavement. The layer also acts as the reducer by allowing cracks to develop on the layer thus the crack generate on top of the pavement surface would decrease in the process.

**Keywords:** Airport runway, Crack Relief Layer, pavement distress, pavement strata, reflective cracks

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## 1.0 INTRODUCTION

Airport is one of the major capital investments in the infrastructure of a country. It is also representing one of the most important sectors in economy and transportation of people and goods. Therefore, the sustainability of these investments in good condition is an essential requirement for government and strategic policy to be adopted. In this millennium era, air space means of transportation has becoming more crucial which then contributes to the aircraft traffic congestion. The increasing in aircraft traffic directly causes the declining of airport runway quality. This is a fact which has been taken into consideration in the airport development by shifting

the conventional focus from maintaining the pavement to prevent the deterioration in the pavement itself. Thus, it is necessary to study the factors in minimizing the deterioration of airport runway quality and to take essential measurements to counteract the problem. Previous studies in additional layer of pavement strata have introduced CRL as the crack relieving factor to the pavement design [1]. The weight of aircraft greatly differs from (or heavier than) the weight of land transportation that operates on paved platform, thus consideration of its load capacity is needed. The characteristics of CRL are essential to be determined in order to access the ability of the layer in term of its crack relieving strata in pavement layer.

## 2.0 REFLECTIVE CRACK

Reflective cracking in asphalt roads is one of the major concerns to many management institutes paved roads because this congestion significantly reduced the life of the pavement, as well as placing the annual budget constraint pavement sector. Reflective cracking mostly considered cosmetic in nature and do not necessarily reduce the smooth pavement or service if they are very small. However, if the cracks get wider, for instance, greater than 6 mm, they can lead to poor load transfer and increased pressure in the pavement structure, ultimately causing performance problems [2]. In addition, the ingress of water through the crack can exacerbate the failure of other difficulties associated with moisture damage [3].

When asphalt pavement overlays are placed over jointed and/or severely cracked rigid and/or flexible pavements, the cracks and joints in the existing pavement structure can reflect to the surface over time. If not properly maintained, these cracks can allow water to penetrate the underlying layers causing further damage to the bond between the existing pavement and overlay and causing moisture damage in the pavement layers. Reflective cracks have to be monitored and maintained to prevent increased roughness and possible further pavement distress.

Numerous studies have attempted to develop methods and materials to prevent reflective cracks from occurring within the design period. Most of the materials and methods in use today, however, only briefly delay or limit the severity of the reflective cracks. One possible reason for the shortened service life of overlays is that the rehabilitation strategy selected for a specific project is insufficient for the condition of the existing pavement, subgrade and drainage conditions.

Reflective cracks in a flexible overlay of a pavement over an unstable base and/or subgrade layer. In an overlay, the cracks can occur directly over the underlying pavement joints and cracks. Reflective cracking can include cracks that occur away from an underlying joint or from any other type of base (e.g. reflective cracks due to subgrade shrinkage cracking or culverts or other utilities).

Movement of the concrete slab beneath the asphalt surface because of thermal and moisture changes, or shrinkage cracking in the subgrade and reflection up through the surface layers, or too thin of flexible pavement surface. Generally not load initiated, however loading can hasten deterioration.

Low severity cracks caused by reflective cracking can be repaired by using crack sealant to prevent entry of moisture into the subgrade through the cracks and further ravelling of the crack edges. In general, rigid pavement joints will eventually reflect through an overlay without proper surface preparation. As for medium severity cracks, use crack sealant to coat the exposed aggregate base layer in the crack, insert a flexible filler such as a backer rod

and then fill with crumb rubber flush with surface. May require partial depth repairs. And as for high severity cracks, may require partial depth repairs and/or removing and replacing the cracked pavement layer. This may include reclaiming, reshaping and repaving/new pavement surfacing

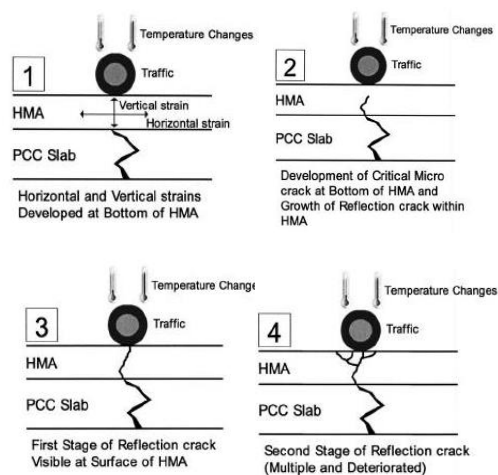
## 3.0 REFLECTIVE CRACKING MECHANISM

Cracking mechanism involves two processes reflect possible; opening and closing of cracks and joints or temperature variations that cause stress cracks heat and push start. Secondly, the traffic load and stress-related role in the second phase of crack propagation step. The most commonly accepted mechanism of crack reflects the result of the horizontal movement is concentrated at the joints in the existing pavement [4]. Horizontal movement is caused mainly by periodic, seasonal and daily temperature variations [4-7].

Water penetrated and trapped so the pavement is bound to accelerate other pressure mechanisms, especially with regard to the damage of moisture such as pot-holing, material durability, strength and weakness in the pavement. The importance of understanding the mechanisms that cause cracks in the asphalt wearing surface cracks may occur because variety of reasons, including poor coaching, failure of structures, asphalt-binder aging and cracking temperatures, among others [1].

The basic mechanisms that are normally assumed to cause reflection cracking are vertical and horizontal movements of the pavement. The vertical movement of the pavement is mainly caused by moving traffic. The vertical movement in the HMA overlay is generally induced by differential movements of the underlying pavement. The horizontal movement of cracks and joints is caused by temperature and/or moisture changes. The vertical movement in the overlay induces a shear stress in the HMA. The horizontal movement of cracked or jointed slabs causes high tensile stresses and strains at the bottom of the asphalt overlay and results in reflection 5 cracking. This happens because at low temperature, asphalt concrete is stiff, brittle and it cannot withstand large temperature-induced stresses. In addition to temperature changes in underlying cracked slabs, the total movement of the cracked slab is attributed to moisture changes, slab length, and stiffness properties of the overlaying material [2-3].

Figure 1 shows different stages in the development of reflection cracking in HMA overlays over a cracked concrete pavement. This process can be described in two modes. In Mode 1, the progress of reflection cracking is caused by horizontal movement of concrete slabs due to the change in temperature and/or moisture. In Mode 2, the vertical load from traffic causes the differential vertical movement of cracked concrete slabs and induces a large shear stress, and hence leads to shear failure.



**Figure 1** Different Stages in Development of Reflection Cracking on HMA Overlays [3]

### 3.1 Reflective Cracking in Cement Stabilized Bases

Various studies have confirmed that the development of reflective cracking as a result of shrinkage cracks and resulted in the loss of water catchment aggregate interlock on crack, separation layer, and local pavement declined. Cracks more than 6 mm of cement treated material is primarily due to drying shrinkage of hydration or temperature changes. As the movement of particle or crack formed in cement stabilized or treated base layer, the layer on top of this base layer would subjected to miniature movement which produce vibration that form cracks.

There are several factors that contribute to cracking and crack spacing in cement treated bases which include the characteristics of material, construction procedures, traffic load, and the restraint imposed on the basis of the subgrade [5-7]. Stage drying shrinkage is influenced by soil type, degree of compaction, curing time, cement content, and temperature and humidity changes.

Design of lime-stabilized mixtures is usually based on laboratory analysis of desired engineering properties. Several approaches to mix design currently exist. In addition to engineering design criteria, users must consider whether the laboratory procedures used adequately simulate field conditions and long-term performance. Aspects of these procedures are likely to be superseded as the American Association of State Highway and Transportation Officials (AASHTO) shifts to a mechanistic-empirical approach.

Laboratory testing procedures include determining optimum lime requirements and moisture content, preparing samples, and curing the samples under simulated field conditions. Curing is important for chemically stabilized soils and aggregates—particularly lime-stabilized soils—because lime-soil reactions are time and

temperature dependent and continue for long periods of time (even years). Pozzolanic reactions are slower than cement-hydration reactions and can result in construction and performance benefits, such as extended mixing times in heavy clays (more intimate mixing) and autogenously healing of moderately damaged layers, even after years of service. On the other hand, longer reactions may mean that traffic delays are associated with using the pavement. In addition, protocols for lime-soil mixture design must address the impact of moisture on performance.

Lime stabilization construction is relatively straightforward. In-place mixing (to the appropriate depth) is usually employed to add the proper amount of lime to a soil, mixed to an appropriate depth. Pulverization and mixing are used to combine the lime and soil thoroughly. For heavy clays, preliminary mixing may be followed by 24 to 48 hours (or more) of moist curing prior to final mixing. This ability to “mellow” the soil for extended periods and then remix is unique to lime. During this process, a more intimate mixing of the lime and the heavy clay occurs, resulting in more complete stabilization. For maximum development of strength and durability, proper compaction is necessary; proper curing is also important. Other methods of lime stabilization include in-plant mixing and pressure injection.

### 3.2 Dense Bituminous Macadam

Dense bituminous macadam (DBM) is dense graded material structure that is being used as binder course for heavy-duty pavement that designated with heavy traffic [5-10]. Since DBM is a close-graded course material, it is water impermeable and the air void percentage of DBM is evidently low. The aggregate used for this design is in even smaller size in such a way that it is consistent, unlike conventional mix asphalt that consist of variety aggregate size in the structure. Thus, DBM characteristic slightly varies than the conventional asphaltic layer attribution. The function of DBM is to act as load carrier, which is entirely different from CRL as CRL's mechanism is in term of its crack relieving factor rather than loads distributor or carrier [11-14].

Bituminous macadam (BM) shall consist of mineral aggregate and appropriate binder, mixed in a hot mix plant and laid with a mechanized paver. It is an open graded mixture suitable for base course. It is laid in a single course or in a multiple layers on a previously prepared base. Thickness of the single layer shall be 50 mm to 100 mm.

Since the bituminous macadam is an open-graded mixture there is a potential that it may trap water or moisture vapour within the pavement system. Therefore, providing proper drainage outlet to the BM layer should be considered to prevent moisture-induced damage to the BM and adjacent bituminous layers.

### 3.3 Cement Treated Base (CTB)

A common layer that was used in airport runway is Cement Treated Base (CTB). It was used because of its strong properties which consist of soil, gravels, or manufactured blended with prescribed quantities of cement and water. The material inside this layer is the important factor which provides CTB with a strong base for a concrete or asphalt pavement wearing surface. [21].

During the construction, a bituminous or Portland cement concrete wearing course is placed on the CTB to complete the pavement structure. Cement-treated base is widely used as a pavement base for highways, roads, streets, parking areas, airports, and materials handling and storage areas.

In cement-treated base construction the objective is to obtain a thorough mixture of an aggregate/granular material with the correct quantity of Portland cement and enough water to permit maximum compaction. The completed CTB must be adequately cured to both let the cement hydrate and to harden the cement-aggregate mixture. The fundamental control factors for quality CTB are:

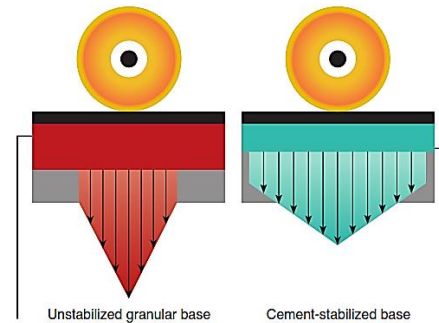
- i. Proper cement content
- ii. Adequate moisture content
- iii. Thorough mixing
- iv. Adequate compaction
- v. Proper curing

The aggregate/granular material, cement, and water are typically mixed in a central mixing plant. Central plants can either be continuous-flow or batch-type pugmill mixers. CTB can also be mixed-in-place using transverse-shaft pulver mixers or traveling mixing machines.

The thickness of Cement-treated Bases is less than that required for granular bases carrying the same traffic because CTB is a cemented, rigid material that distributes the load over a large area. Its slab-like characteristics and beam strength are unmatched by granular bases that can fail when interlock is lost. This happens when wet subgrade soil is forced up into the base by traffic loads. Hard, rigid CTB is practically impervious. It resists cyclic freezing, rain, and spring-weather damage. Cement-treated base continues to gain strength with age even under traffic. This reserve strength accounts in part for CTB's excellent performance.

Compare to other granular bases, CTB had less thickness than normally that been used on normal pavement strata that carry the same traffic as shown in Figure 2. The advantage of CTB is compare to other bases:

- i. It can distribute load to a larger area
- ii. It can reduce the stress on subgrade
- iii. It can act as the load carry element of a flexible pavement or a subbase for concrete.



**Figure 2** Comparison of thickness between normal granular base and CTB [22]

CTB also can reduce the deflection through its rigid layer which had a slab like characteristic. It can help the layer from failing, which is different from granular bases that can fail when aggregate interlock is lost [22]. There are many benefits from use of CTB such as of CTB in the construction of pavement. Such as:

- i. Lower costs thru use of local or marginal aggregates
- ii. Eliminates subgrade infiltration into base
- iii. Fast construction
- iv. Reduced moisture susceptibility
- v. Reduces work stoppages due to rain (open base sheds water)
- vi. Frost-resistant
- vii. Spans weak subgrades

By these reasons, it shows why CTB was a suitable layer that was used during the construction of CRL layer.

### 4.0 CRL MIX DESIGN

The importance of all asphalt mixture design procedures is the laboratory compaction method in producing substantially the same internal structure that affects the properties of the asphalt mixture. Thus, the selection of the laboratory compaction method has at least as much effect on mix performance as aggregate type, binder type, fines content, or air void content [15-18].

The main point of CRL characteristic is its function in relieving cracks that are greatly contributed by high percentage of air voids present in transmitting the vibration through the layer. It is agreed that vibration transmitted through a solid surface is faster than in liquid and gas medium, thus CRL uses this logic physics to achieve the required properties of its crack relieving property. These properties prevent the reflective cracking from forming either from above or below the layer from developing. The air voids act as a buffer zone of the layer from transmitting cracks thus controlling the crack development from continuing to penetrate through the pavement layers. The suggested air void in CRL is around 20% where the air



void percentage is comparable to porous asphalt [17].

As CRL suppress the development of crack, certainly it will bear the consequences by allowing crack to form in the layer itself, thus, relieving the crack development of other structural layers. To enable CRL to develop crack, the bitumen percentage in the layer has to be designed at low bitumen content which is ought to be around 3%. This is very much different from porous asphalt and any other normal asphaltic pavement [19]. The normal asphaltic pavement uses around 4 to 6% of bitumen content for which the main reason is to hold the layer intact and solidified the layer [20]. The low bitumen content of the layer permits the crack development by the fragile bond of the layer yet remains firm to regard as a layer known as CRL. Figure 3 shows the CRL arrangement in pavement strata.

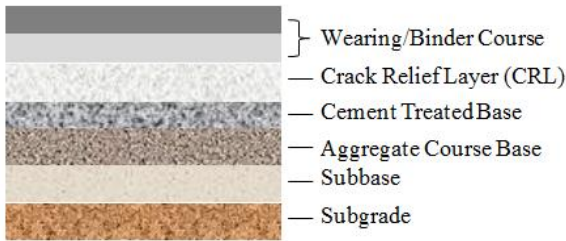


Figure 3 Placement of CRL in pavement strata [18]

The used of crack relief layer is widely used by the construction of airport runway to decrease the need of maintenance work frequency. A good example is the upgrading of airport Al Jouf, Saudi Arabia that operate for 20 years and need to be upgraded. The airport runway upgraded to a more preventative method since the design need to cater heavier load compare to its precedence design 20 years back and as the problem solving method been chosen is adding an additional layer which is CRL as the cushion layer.

Other reference is Egypt Air, Apron Cairo, where the existing Portland Cement Concrete (PCC) pavement is stack on by crack relief layer and polymer mixture asphalt layers. Figure 4 shows the pavement layer arrangement of the airport runway.

Polymer modified	120mm
Crack Relief Layer	100mm
Existing Portland Concrete Cement (PCC)	30 Years

Figure 4 Apron Cairo, Egypt runway structure [1]

From the specification used for Kuala Lumpur International Airport (KLIA) runway, Malaysia, the CRL aggregate material comes with a few variation of sizes with definite reason [21]. The materials used consisted of various aggregate size as the CRL design needs approximately 20% air voids. Thus the margin of the size has been suggested to be far apart so voids will form in the layer. For example the aggregate gradation in KLIA runway is as below (percentage by weight):

- i. 37.5mm nominal size aggregate (45%)
- ii. 20.0mm nominal size aggregate (33%)
- iii. 10.0mm nominal size aggregate (14%)

Based on this specification, an illustration KLIA runway pavement layer is illustrated in Figure 5.

Polymer modified	150mm
Crack Relief Layer	100mm
Cement Treated Base (Pre-cracked)	450mm

Figure 5 Kuala Lumpur International Airport runways structure [1]

#### 4.1 CRL Advantages

This treatment method is defined as layers greater than 75 mm in thickness that provides structural support to the cracked pavement and separates the base layer and dense-graded HMA overlay. Cushion layers consist of crack relief layers (defined as open-graded HMA mixtures with large aggregate) and unbound aggregate or crushed stone base materials. Several advantages of using a cushion layer are listed below [25].

- i. It insulates the existing PCC slab, decreasing horizontal movements and curling at the joints and cracks.
- ii. It reduces horizontal movements transferred from the existing slab to the overlay by breaking or reducing the bond between the overlay and existing pavement.
- iii. It absorbs or distributes some of the differential deflection at joints and cracks because of the increased layer thickness and lower modulus material of the cushion layer.

Theoretically, this treatment method should mitigate reflective cracks. A disadvantage with using this method is that the cushion layer can hold water because it is permeable. This trapped water can lead to deterioration of the overlay and pavement structure.

## 5.0 MARSHALL MIX DESIGN FOR CRL

The Marshall Method for the design of asphalt mixtures was developed at the Mississippi Highway Department by Bruce Marshall in year 1939. Marshall Mix design is the procedure of designing and evaluating bituminous paving mixes and common test activities for the paving works.

The principle of Marshall Method was to determine the binder control required by a given blend and grading of aggregates. Marshall Design was divided into two levels of laboratory works which were sample preparation and testing.

Marshall Mix Design for CRL had been used in the KLIA Design. It used the same method that been used to normal mix design of hot mix asphalt. The design method involves the selection of the asphalt binder content with a suitable density which satisfies minimum stability and range of flow values. Marshall's Stability is the term used to measure the strength of the asphalt mixes. In ASTM D6927-06. (2006) specification, Marshall's Stability is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. In this test compressive loading was applied on the specimen at the rate of 50.8 mm/min till it was broken. The temperature 60°C represents the weakest condition for a bituminous pavement.

The flow value is the terms represent the measure of flexibility which is measured by the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. During the loading, an attached dial gauge measures the specimen's deformation due to the loading. The associated plastic flow of specimen at material failure is called flow value. In order to obtain optimum quality of the mixes, the job mix formula for each type of mix has to be prepared on the basis of testing several laboratory design mix aggregate gradations within the limits at an appropriate range of bitumen content. Each combination of laboratory design mix aggregate gradation and bitumen content should be subject to the Marshall test procedure and volumetric analysis as follows (JKR, 2008);

- i. Preparation of laboratory specimens for the standard stability and flow test in accordance with ASTM D 6926 using 75-blow/face compaction standard,
- ii. Determination of the bulk specific gravity of the specimens in accordance with ASTM D 2726,
- iii. Determination of the stability and flow values in accordance with ASTM D 6927,
- iv. Analysis of the specific gravity and air voids parameters to determine the percentage air voids in the compacted aggregate, the percentage air voids in the compacted aggregate filled with bitumen and the percentage air voids in the compacted mix.

The stability and flow value of each test specimen then determined in accordance with ASTM D 6927. After the completion of the stability and flow test,

specific gravity and voids analysis then carried out for each test specimen to determine the percentage air voids in the compacted aggregate filled with bitumen (VFB) and the percentage air voids in the compacted mix (VIM). The average values of bulk specific gravity, stability, flow, VFB and VIM obtained should be plotted separately against the bitumen content and a smooth curve drawn through the plotted values. The mean optimum bitumen content shall be determined by averaging five optimum bitumen contents so determined as follows (JKR, 2008);

- i. Peak of curve taken from the stability graph.
- ii. Peak of curve taken from the bulk specific gravity graph.
- iii. VFB equals to 75% for wearing course and 70% for binder course from the VFB graph.
- iv. VIM equals to 4.0% for wearing course and 5.0% for binder course from the VIM graph.

Although it Marshall Mix Design Method had been successfully used in creating CRL sample, this method had been observed not to simulate the field conditions. Present study attempts to simulate the field compaction in the laboratory.

## 6.0 SUPERPAVE GYRATORY

The laboratory testing of asphalt mixture design and performance is influenced by the method of compaction. For performance testing to produce reliable mechanical properties, it is necessary to ensure that laboratory specimens produced in such a way that adequately simulates field compaction. The simulation is based on the distribution of aggregates and air voids inside the mixture, which is referred to in this study as the internal structure [22].

The objective of laboratory specimen compaction has always been to fabricate specimens that, as closely as possible, resemble field conditions, and consequently, yields reliable engineering properties. If the laboratory compaction technique does not simulate the field condition, the sensitivity of the test method and equipment is of little use in evaluating its performance [23-25]. The comparison between laboratory and field compaction procedures was generally based on the mechanical properties of asphalt specimens obtained using laboratory testing and field trials [26].

This method was developed to identify unstable mixes with the help of Superpave gyratory data. The basis of this method is that the primary difference in behaviour of a stable mix and an unstable mix is that a stable mix gains in strength with densification and retains it through further compaction and ultimately resists lowering of voids below a particular value, whereas an unstable mix initially gains in strength but loses it beyond a certain densification point and becomes susceptible to shear failure [27-31].

Based on the above statement it is clearly stated that gyratory is suitable to be conducted on unstable specimen which is CRL. Rather than Marshall Test,

gyratory test is also fit for CRL laboratory testing. As CRL is not the conventional type of pavement layer which varies in term of its aggregate size with large margin of sizes, low bitumen content, and high air void, due to these Marshall Test is out of question. Therefore, gyratory test should be used. Figure 6 shows the internal structure of the specimen using Superpave gyratory compaction technique to achieve the desired air voids content.

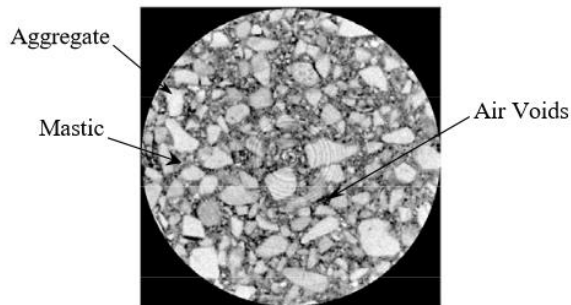


Figure 6 Air Voids Distribution in X-ray CT image [22]

## 7.0 RECOMMENDATION

Airport runway deterioration caused by crack formation is critical for pavement industry sector because of the high cost of reconstruction and the tremendous disadvantages come with the disturbance to the air traffic is unbearable. Engineers are well aware of this problem and have proposed several solutions in which one of it is CRL application. Thus to have a better understanding to this subject, it is suggested to study the CRL on this path:

- i. The application of CRL on highway and road for emergency consideration if in future there is a need for aircraft to depart on highway or road.
- ii. Reflective cracking between the layers which consider the CRL additional factor to pavement strata.
- iii. Study on the optimum CRL thickness for its respective load carried by the transportation.
- iv. Differentiate dense bituminous macadam (DBM) and CRL based on its function and workability.
- v. The compaction method of the specimen using Turamesin® that greatly resembles the field condition for a simulation of field result.

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