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A REVIEW ON CRACK RELIEF LAYER (CRL) IN ROADS AND HIGHWAYS

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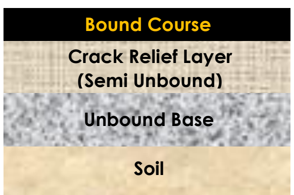
Graphical abstract



Abstract

Roads and highways are the most important mode of transportation systems for development of a nation. In order to fulfil this purpose, the pavement must be able to provide a safe and comfortable riding surface for the road users. However, pavement deterioration is a major obstacle that can prevent pavement from serving its main purposes. The most common type of pavement deterioration is reflective cracking which occurs when a crack in an overlay layer reflect the pattern of cracks and joints of the old pavement underneath it. Crack relief layer (CRL) is a layer that is placed between the new overlay and the old pavement in order to dissipate pavement movements before they create stress in a new overlay surface. CRL is an open-graded mix that had around 20 to 35% of air void which act as a cushion layer in order to dissipate cracks development in pavement layer. It has low bitumen content that normally around 3% in order for it to act as a semi-unbound layer in order to prevent horizontal and vertical movement of pavement strata. Previous implementation of CRL in airport and runways shows that CRL performance is promising for it to be used in roads and highways in order to overcome pavement distress. Further research is needed in order to ensure CRL implementation in pavements industry.

Keywords: Crack relief layer; reflective cracking; flexible pavement; roads and highways; deterioration

1.0 INTRODUCTION

Road infrastructure is crucial to improve the economy of a country and is one of the factors for increasing development of an area. Increasing socio-economic development is an important factor in the high demand of highway construction, new roads and upgrading existing roads to meet the needs of road users and the increasing traffic at present [1].

There are two type of pavement that commonly used in construction of roads and highways which are flexible pavement and rigid pavement. Mostly around the world, the roads are designed as flexible road pavement as it has a lot of benefits. Flexible pavement is designed for cater higher volume and heavier traffic compare to gravel and dirt roads. It consists of several layers that are subgrade, sub base, road base, and surface course. Flexible pavement design is based on the characteristic of the load distribution at each component layers [2, 3] where each component layer has various functions which need to be considered during the design process [4]. Proper design of pavement from choosing the materials and the process mixing are crucial for particular type of road to ensure design service life of the road, optimum cost of construction as well as uses green or sustainable road construction.

Construction of roads and highways consume huge amount of money in order to ensure road worthiness, safety and end user satisfaction [5]. This include the pavement maintenance and rehabilitation (major and minor) that incorporate all activities undertaken to provide and maintain serviceable roadways. However, pavement deterioration is a common phenomenon that occurs once it is opened for traffic. Pavement damages can cause discomfort and accidents for road users.

As it is widely known that pavement cracks is a major problems that can reduce the workability of pavement layers [6]. As today, there are many type of crack mitigation technique that have been introduced. In airport runways, they use Crack Relief Layer (CRL) as a method to minimize the crack propagation on the pavement. A CRL is typically a coarse, open-graded mix, produced from crushed material which is containing 20% to 35% interconnecting air voids. It is a stress and strain-absorbing membrane interlayer that placed between the old structure and the new overlay [7].

2.0 PAVEMENT DETERIORATION

Pavement deterioration is the process by which distress develop in the pavement under the combined effects of traffic loading and environmental conditions. It is very common in developing countries. Common pavement deterioration includes cracking, surface defects, deformation and structural failure when it was found to be experiencing serious damage or deformation behaviour [8]. Pavement deterioration can be hazardous to the road users if not being handled properly.

Crack is a major problem that occurs on the pavement. The major causes of crack are vehicle loading, temperature fluctuation and bitumen hardening [9-11]. The imposed load by vehicle can cause differential deflection if the load is on one side of the joint. This will cause the stresses in the interlayer above the joint until it reach to certain level and will damage the interlayer, resulted in cracks formation [12]. Fatigue crack is a main form of structural damage in flexible pavement that occurs under the action of repeated vehicular loading. Fatigue behaviour of the bituminous mixtures is characterized by the slope and the relative level of the stress or strain versus the number of load repetition to failure. The accumulation and growth of micro and macro cracks will cause deterioration of the asphalt materials in pavements to occur gradually [13].

In the rigid pavement, the crack mostly occurs as a result of the temperature and moisture variations [14]. Longitudinal reinforcement bars play a significant role in the development of horizontal cracking in rigid pavement. Concrete volume change due to the variations of temperature and moisture are restrained by the reinforcement, and results in vertical stress in concrete [15]. Significant tensile stress develops at concrete near longitudinal reinforcement because of the steel restraint. Horizontal cracking can occur in concrete near to the reinforcement bars due to the direction of principal stress that is nearly vertical [16]. The cracks initiate from the transverse crack and propagate along the longitudinal steel, which then induced a greater potential for horizontal cracks in rigid pavement [17].

Surface deformation is the result of weakness in one or more layers of the pavement that is experiencing movement after construction [18]. Surface deformation can cause discomfort to road users travelling on the road. This distress can occur when problems like subsoil erosion take place due to void formation and also ground movement that occur during construction and installation of utilities on the road and highways [19].

Disintegration is the progressive breaking up of the pavement into small, loose pieces. It can cause roughness and allow water ponding. It is a hazard to road users especially motorist. It is typically caused by localized consolidation or movement of the support layer beneath the surface courses due to instability [20].

Surface defect is a distress on the surface of the road. It can cause a pavement to lose the skid resistance and may as well end up with uneven pavement surface. These surface defects include ravelling, bleeding, polishing and delamination [21]. Bleeding is caused by high bitumen contents in the surface layer. This may occur in the presence of excessive tack coat that migrate into the surface layer or excessive bitumen used in producing the premix used for paving [22].

All the distresses in pavement need to be properly addressed by allowing preventive and maintenance works to be held more frequently in order to provide a comfortable ride for the road users. If not treated appropriately, such conditions will certainly be harmful which may triggers accidents to happen and risking the lives of all motorists and road users.

3.0 TOP-DOWN CRACKS

Top-down cracks in conventional pavement initiate at the pavement surface and propagate downward. It also sometimes throughout the entire depth of the pavement. This process involve three (3) stages. The first stage of a top-down cracks consists of a single short longitudinal crack appearing just outside the wheel path as shown in Figure 1. The second stage occurs when top-down cracks grows over time in which the longitudinal short cracks grow longer and sister cracks develop parallel to and within 0.3 to 1 m of the original crack as shown in Figure 2. The third stage occurs when the parallel longitudinal cracks are connected via short transverse top down cracks as shown in Figure 3 [23].

The main mechanism for top-down cracks is the tensile stresses and strains induced at the top of the pavement structure from the combination of traffic load, temperature, and aging of binder, which may cause shrinkage and differential stiffness between the pavement surface, levelling, and base courses. Studies also indicate that top-down cracking also may not necessarily initiate at the pavement surface only. It also may initiate at some distance down from the surface of the pavement [24].

Figure 1 First Stage of Top-down Cracking

Figure 2 Second Stage of Top-down Cracking

Figure 3 Third Stage of Top-down Cracking

In thick pavements, the cracks most likely initiate from the top in areas of high localized tensile stresses resulting from tire-pavement interaction and asphalt binder aging (top-down cracking). After repeated loading, the longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile [25]. Figure 4 shows top down crack propagation in pavement.

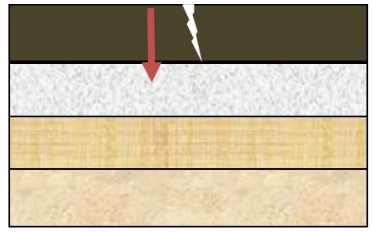


Figure 4 Top-down Crack Propagation in Pavement

4.0 REFLECTIVE CRACK

Reflective crack is a crack that occurs when a crack in an overlay reflect the pattern of cracks and joints of the old pavement underneath it. The movement of the underlying pavement structure is the cause of this crack to occur [26].

The mechanism of reflective cracking involves two possible processes, which is the load from the vehicle and temperature fluctuations. The vehicle load can creates stress concentration and causes reduction in bending stiffness of the pavement section. When these stresses exceed the new pavement's fracture resistance, the crack appears and spreads. Besides that, the opening and closing of the joint or crack and temperature variations will cause thermal stresses and induce cracking to initiates [27, 28]. Figure 5 shows the mechanism of reflective cracks propagation in pavement strata [29].

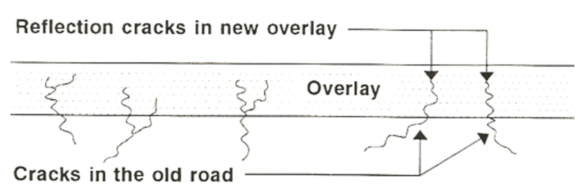


Figure 5 Reflective cracks propagation in pavement strata [29].

There are many researches that have been carried out in order to overcome the reflective cracking. One of it is the use of anti-reflective cracking system using geosynthetic in the interlayer zone. The geosynthetic layer was laid between the top layer and bottom layer test pieces which had a longitudinal groove to simulate an initial crack. It is then subjected to dynamic test that has been designed to simulate the passing of traffic loads on the road surface in order to ascertain its durability.

The test result shows that the system delayed the reflective crack from spreading. The system can also withstand between three to six times more cycles than the reference sample [30].

There is also project in Greater Peoria Regional Airport in United States where a hybrid reflective crack relief system was used. This system involves a combination of strain tolerant interlayer mixture used in conjunction with a fiberglass reinforcement grid applied in wide strips that was designed and installed in order to overcome the reflective crack on the taxiways of the airport [31]. The result is presented in Figure 6. It shows the percentage of cracking occurs was decreasing compared to untreated pavement.

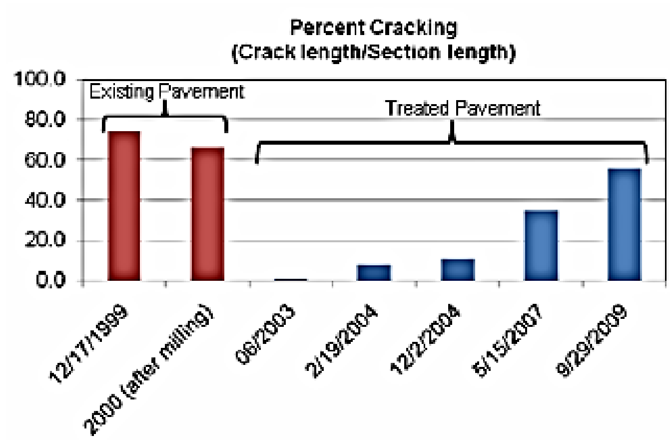


Figure 6 Percentage of cracking throughout treatment duration [31]

A study was held in in Shandong Province where a test road was constructed using different asphalt concrete overlay treatments. After 3 years of service, it is indicated that the coarse-aggregate asphalt mix interlayer worked exceptionally well in reflective crack control. A three-dimensional finite element analysis showed that the main stresses in the coarse-aggregate asphalt mix interlayer were lower than those in the normal asphalt concrete interlayer with the same thickness. It is believed that the large-size aggregates and high air voids in the mixture can block the paths of initial cracks to extend to the top of the interlayer [32].

There is also effort to use waste material in order to overcome reflective crack in pavement such as reusing the deconstructed tires as anti-reflective cracking mat systems in asphalt pavements. From this study it shows that the used of tire mat system reduced the crack damage suffered by the pavement and the appearance of cracks in the surface course is retarded. Furthermore, the use of this system allows the presence of thinner cracks that will enlarge the structural resistance of the pavement once they have appeared in the surface [33].

From previous study, it can be seen that various methods have been introduced to overcome the reflective cracks issue in a pavement. Test results are promising as these methods are effective in extending the serviceability of the pavement. With increasing serviceability of a pavement, the frequency of maintenance and rehabilitation works that need to be carried out on roads and highways can be reduced. Therefore, CRL can be seemingly being a potential method that can be used to overcome distress in road pavement.

5.0 CRACK RELIEF LAYER (CRL)

A CRL is needed because cracks in a pavement top layer will cause many problems, including water intrusion, pumping soil particles through a crack, and progressive degradation of the road structure near cracks. Several advantages of using CRL as a cushion layer are:

i. It insulates the existing layer, decreasing horizontal movements
ii. It reduces horizontal movements transferred from the existing layer 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 in existing pavement [34].

Pavement cracks normally occurs when there is horizontal movement at the bottom of the bound courses that will cause fatigue to occur and the vertical movement of the soil at the bottom of the pavement strata that will cause rutting[35]. By adding CRL layer between the bound course and the unbound courses it can prevent the horizontal movement of the layer. It also semi-unbound layers which make it able to prevent settlement from occurs due to the vertical movement of the pavement bottom layer as shown in Figure 7.

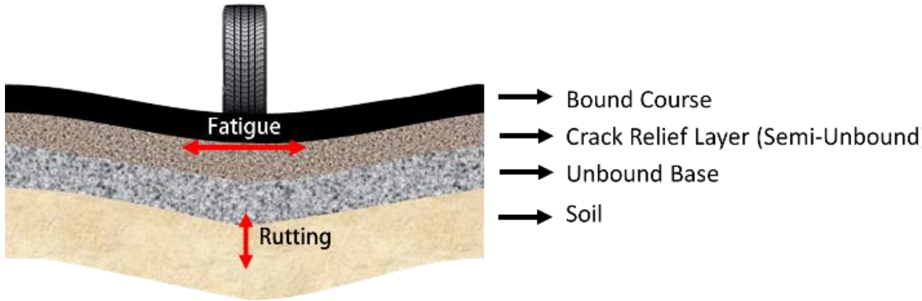


Figure 7 Crack Relief Layer cracks preventive mechanism

CRL layer is a semi rigid layer due to its low bitumen content and high resilient modulus. It also had a large amount of air void content that act as a buffer layer in order to reduce the vibration from transmitted to the pavement strata. This is very much different function from porous asphalt which had almost the same amount of air void as CRL [36]. This characteristic makes CRL able to absorb the stress and supress the development of cracks in pavement layers.

CRL is an open-graded mix due to its large size of aggregate in order for it to had large amount of air void. The aggregate come is varies of sizes as used in Kuala Lumpur International Airport (KLIA) runway [37]. The grading of aggregate used are 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%)

CRL had been used in many of construction of runways project around the world. A project in Al Jouf Airport in Saudi Arabia had implemented CRL in the pavement upgrading works. The design consultant for the project is Netherland Airport Consultants. The pavement for runway and taxiway of the project were badly cracked with typical block cracks in the 20 years of 130 mm thickness [38].

In 1998, an existing Portland cement concrete apron of approximately 45,000m^3 of concrete was overlaid at Cairo International Airport, Egypt as shown in Figure 8. The pavement is regularly monitored. The performance by far is excellent since special measures were taken at expansion joints.

Polymer Modified Asphalt	**120mm**
Crack Relief Layer	**100mm**
Existing PCC pavement	**30 years old**

Figure 8 Pavement Cross Section of Cairo International Airport, Egypt [32]

In project of Kuala Lumpur International Airport in Malaysia which was opened in 1998, CRL was part of the preventive measure in the project. The airport consists of 2 main runways (4000 x 45m), 4 parallel taxiways and various other link taxiways. The layer of pavement is shown in Figure 9.

After the success of Al Jouf Airport in Saudi Arabia, NACO had also involved in other projects that used CRL in the pavement. There were projects in 1999 that involved the construction of new pavement and rehabilitation in Manado International Airport, Indonesia as well as rehabilitation of runway and parallel taxiway at Luxor Airport, Egypt [38].

From these records of CRL used in pavement rehabilitation, it can be seen that CRL is a suitable method to overcome distress in pavement. This method can also be extended to use in roads and highways pavement because of the high demand from road user for smoother rides when using roads and highways.

Polymer Modified Asphalt	**150mm**
Crack Relief Layer	**100mm**
Cement Treated Base (pre-cracked)	**450mm**

Figure 9 Pavement Cross Section of Kuala Lumpur International Airport, Malaysia [38]

6.0 ADDITIONAL LAYERS

CRL worked as a crack reliever in a pavement system. Although it works as a layer that absorb and reduce the cracks propagation, it need a layer underneath it to work as a support. This is because CRL layer is quite fragile layer due to its low percentage of binder. The layers that normally used underneath of CRL layer to work as a support is Dense Bituminous Macadam (DBM) and Cement Treated Base (CTB). The layers also act as a base course in order to provide a flat surface to laid CRL layer

6.1 Dense Bituminous Macadam

Macadam defined as broken stone of even size used in successively compacted layers for surfacing roads and paths, and typically bound with tar or bitumen. Dense Bituminous Macadam (DBM) is closely graded which contain higher percentage of finer fraction sizes. The percentage of air void in DBM is around 3% to 6% which reduces its permeability [39]. This make DBM resisted to water and required filler such as Hydrated Lime or Cement if the mix fails to meet the water sensitivity requirement. The high percentage of higher fraction size also increase the internal friction and resistance to internal movement of a bound mixture. Thus this make DBM rigid and suitable to be used as a binder course for pavements subjected to heavy traffic [40].

DBM known as a close graded which consist crushed course aggregate retained on 2.36mm sieve and shall be crushed, slag crushed gravel(shingles) and shall consist of angular fragments, clean, tough and durable rock free from disintegrated pieces and organic or deleterious matter and adherent coatings. Preferably the aggregate shall be hydrophobic and low porosity. Meanwhile the type of bitumen normally use if bitumen grade 60-70 with amount of bitumen content within 4% to 6%. During the laying process the temperature should not exceed 160^{0}C and should not be less than 120^{0}C. DBM layer should not be laid on damp or wet surface base course and normally when the temperature in the shade is 15^{0}C or less [41]. This quality measure must be done properly on order to produce a strong and durable DBM layer that can fulfill its function.

DBM also can be used as a base course due to its well-shaped surface that suitable to laid CRL layer on top of it. Due to its stone content of the material, it provide a surface texture and it has low permeability when it is compacted. This will prevent water from passing thought it, which will increase the strength of the pavement layer. [42]. This advantage is very important in the design of pavement layer due to water that act as common enemy in a pavement layer that can cause deterioration. Due to this characteristic, DBM was used as a base course for CRL layer in order to strengthen the pavement structure.

6.2 Cement Treated Base (CTB)

Cement Treated Base (CTB) is a common layer that is used in the airport runway because of its strong properties. CTB consisted of soil, gravels, or manufactured blended with prescribed quantities of cement and water which make it a strong base for a concrete or asphalt pavement wearing surface [43].

In CTB construction, it is very important to obtain a thorough mixture of an aggregate or granular material with the correct quantity of Portland cement and enough water to permit maximum compaction. Proper curing must be done for CTB to both let the cement hydrate and to harden the cement-aggregate mixture. The fundamental control factors for quality CTB are proper cement content, adequate moisture content, thorough mixing, adequate compaction, and proper curing. If this factors is reached, it will provide this a CTB layer that is very strong and durable [44].

CTB materials such as the aggregate, 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 pulvermixers or traveling mixing machines [45].

CTB had less thickness than normally required for granular bases that carry the same traffic. It can distribute load to a larger area, reducing the stress on subgrade and act as the load carry element of a flexible pavement or a sub base for concrete. Figure 10 show the mechanism of load transfer between unstabilized granular base with cement stabilized base [46].

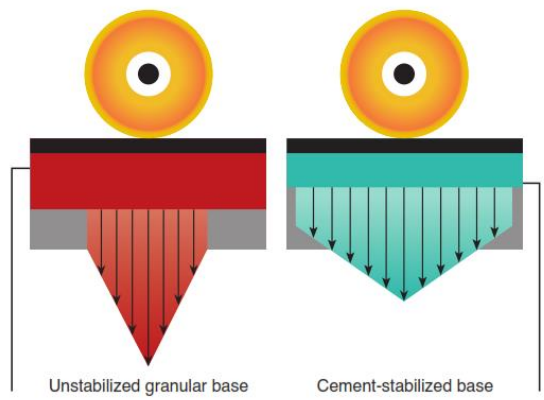


Figure 10 Comparison between unstabilized granular base with cement stabilized base. [46]

CTB is a rigid layer that had a slab like characteristic that reduce deflection, unlike granular bases that can fail when aggregate interlock is lost. This happens when wet subgrade soil is forced up into the base by traffic loads. CTB is a hard, rigid and practically impervious. It resists cyclic freezing, rain, and spring-weather damage. Even when under traffic, CTB continues to gain strength with age. This reserve strength is a part contribute for CTB's excellent performance [47,48].

There are many benefit from use of CTB such as of CTB in the construction of pavement. In term of construction, it is lower costs thru use of local or marginal aggregates and can be construct fast. It also can reduce work stoppages due to rain due to its open base sheds water. This will prevent water ponding and can make construction work done more efficiently. Meanwhile in term of functionality, CTB can reduced moisture susceptibility, frost resistant and spans weak subgrades due to its strong and low permeability properties. By this reasons, it shows why CTB was a suitable layer that was use during the construction of CRL layer [49].

7.0 CONCLUDING REMARKS AND RECOMMENDATIONS

From this paper, it shows that CRL has potentials to act as solution to reflective cracks that occur on pavement. It can be seen that CRL had been used in many construction of airport runways around the world. However, the implementation of CRL layer is not widely published. The understanding about CRL layer is very low as the specification of this layer was kept secret within people in airport runway industry. So, the technical guidance for this layer is hardly accessible. Further research need to be done in order to evaluate the effectiveness of the CRL in mitigating reflective crack development thus for it to be considered in the design of roads and highways.

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