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A Comprehensive Review on Reflective Cracking: Concept, Mechanism, and Laboratory Performance Tests

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Abstract— *Asphalt overlay is one the common rehabilitation alternative to mitigate a deteriorated flexible or rigid pavement. In such case, the cracks from existing pavement rapidly propagate through the asphalt concrete overlay, which makes this solution as a less durable alternative for rehabilitation purpose. The appearance of existing cracks or joint from underlying pavement through the surface of new overlayed bituminous surface is commonly referred as reflective cracking. This cracking usually appears in the early age of overlay serviceability. There are two main roots of reflecting presences cracks though new surface: traffic and environmental loading. Many studies have been done to understand the mechanism of each loading and its contribution to the reflective cracking initiating and propagation process. There is not a complete solution for preventing of such cracks in AC overlay yet, while many types of research concentrated on the retardation of reflective cracking in the AC overlay. In this review, the significant factors involved in initiating and propagation process of reflective cracking were reviewed and discussed, and then the mechanism of two primary external loading was explained. The finding showed that incorporation of an interlayer effectivity enhances the reflective cracking resistance. And also, modification of used asphalt mixture, overlay thickness, using stress relieving interlayer and incorporation of stress absorbing interlayer have an effective influence on retardation of reflective cracking in AC overlay.*

Keyword— ***Composite pavement, Asphalt overlay, Reflecting cracking, asphalt pavement.***

I. INTRODUCTION

Asphalt mixture is one of the widespread construction material used in many countries (Mallick and El-Korchi, 2009), recently different researchers, because of the environmental issues, are paying attention to the impacts and environmental side effects of producing asphalt and concrete materials (Daghighi et al., 2017; Nahvi et al., 2018; Haghiri et al., 2018). Over time concrete overlay are deteriorated by external entities such as de-icing salt during winter, which although application of new technologies can minimized the negative effects on the concrete overlay but it is not always applicable and need relatively huge capital cost (Habibzadeh-Bigdarvish et al.,2019). Because of viscoelastic behavior of asphalt binder through asphalt concrete composition, many phenomena will happen though service life of pavement which leads it most prone for a wide array of distresses(Notani&Mokhtarnejad, 2018; Daghighi and Nahvi, 2014).There is a growing concerns regarding the deterioration of infrastructure, and the condition assessment is always a challenge (MalekMohammadi et al., 2019;MalekMohammadi et al., 2019). However, one the most common mitigation treatment for rehabilitation purpose of a deteriorated pavement is pacing an asphalt concrete overlay, which it is a quick and cost-effective alternative to enhance the structural and functional conditions of an existing roadway. When HMA overlays are placed over jointed or harshly decayed rigid or flexible pavements, the existing cracks and joints in the underlying pavement system can reflect through the surface of the newly placed HMA overlay is called as reflective cracking. Mallick and El-korchi(2009) described the reflective cracking as exhibited cracks in AC overlay, which its source can be addressed in the underlying pavement structural and functional conditions. Penman and Hook (2008) defined it as an accelerate crack propagation process from the bottom layer of the composite pavement, with a different progressive rate, upward the new pavement surface which its rate highly depends on the environmental and traffic loading.Shalaby and Frenchette(2000) named it the unanticipated occurrence of cracks on overlays at locations and orientations that

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matches to positions of cracks in lower pavement layers. In summary, reflective cracking can be defined as the appearance of underlying pavement cracks and joints through placed AC overlay in the early age of overlay. In such type of distress, the crack initiation and propagation process are the major elements of the appearance of the underlying cracks to the surface of the composite pavement. However, study the impact of independent and non-independent parameters on an element or outcome can provide valuable information (Emamjomeh et al., 2019).Fig.*1* shows a simple schematic of a composite pavement indicating a reflective cracking configuration in the overlay, whicheither placed on Portland cement concrete or asphalt concrete.

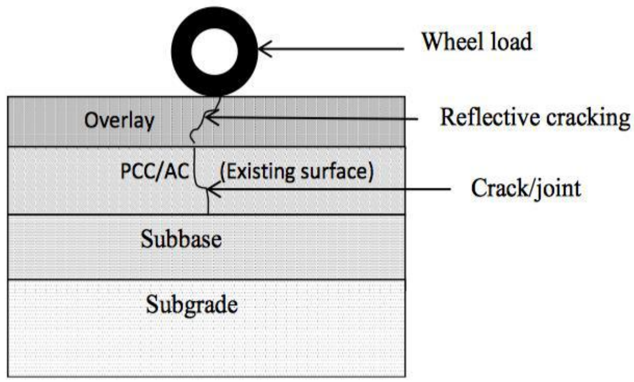

Fig.1: A schematic of reflective cracking in composite pavement(Shalaby and Frechette, 2000)

Reflective cracking is mainly produced by traffic loading and thermal fluctuation in the existing pavement (Ogundipe, 2012). Moreover, considering heat transfer process and studying thermal behavior of solids, the thermal cycling influence on the horizontal and vertical movement of the underlying concrete pavement can be perceive and realized that, it is one of the principal components of starting reflective cracking on AC overlay(Roberts et al., 1991; Sterpi et al., 2018; Sterpi et al., 2018; Gonzalez-Torre et al., 2015).This crack commonly happens in the early service life of the asphalt overlay compared to other distresses observed in such composite pavement. After initiating of reflective cracking trough body of the overlay, it propagation rate will be increased by moisture infiltration (Roberts et al., 1991). Presence of reflective cracking on AC overlay typically results in discomfort to road users and increased preservation and maintenance cost; in some cases, the pavement may have to be rebuilt from the basis.

The main mechanism of the reflective cracking

The vertical and horizontal movement in the underlying rigid pavement are the primary roots of the differential movement of the composite pavement system. The traffic load mainly causes the vertical movement in the edge of crack and joint in the underlying pavement(Baek and Al-Qadi, 2009). Figure 2 shows thistype of mechanism. This type of action causes shear stress in the AC overlay.

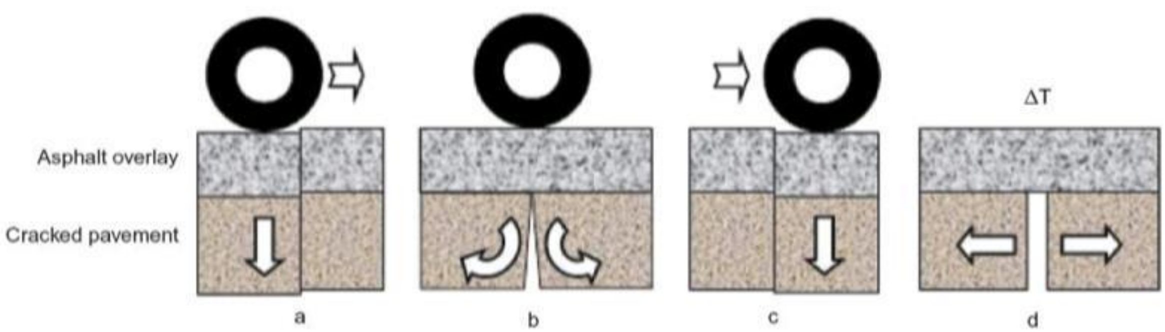

Fig.2: Displacement in pavement cracks and joins (Baek and Al-Qadi, 2009)

The horizontal displacement is produced by thermal and or moisture change in the underlying pavement. Consequently, because of interface strength, substantial tensile stress and strain will have happened at the bottom of the HMA overlay and then, if it surpasses the tolerable tensile stress of the overlay, the reflective cracking will initiate and propagate to reach the surface (Francken et al., 1997). It should be noted that, at low temperature, asphalt material is stiff and brittle, and this feature intensifies the propagation of reflective cracking. Sherman and some other researchers indicated that the variation of moisture in the underlying slab, slab length, and HMA material characteristics have an undeniable influence on the reflective cracking (Von Quintus et al., 2007; Sherman, 1982).

Molenaar(1993) categorized the reflective cracking into three modes: in the first mode, the crack occurs due to tensile stress created by a reduction in temperature or flexural bending under traffic loading. In the second mode, reflective cracking initiating by the caused shear stress applied to the overlay from passing a loaded wheel from one side of presented crack or joint of underlying pavement to another side. In addition, the third mode referred to as the tearing mode, which this mode is less often in the launching and propagation process of reflective cracking. Figure 3 shows all of the three ways of initialing of reflective cracking which authenticated by Molenaar.

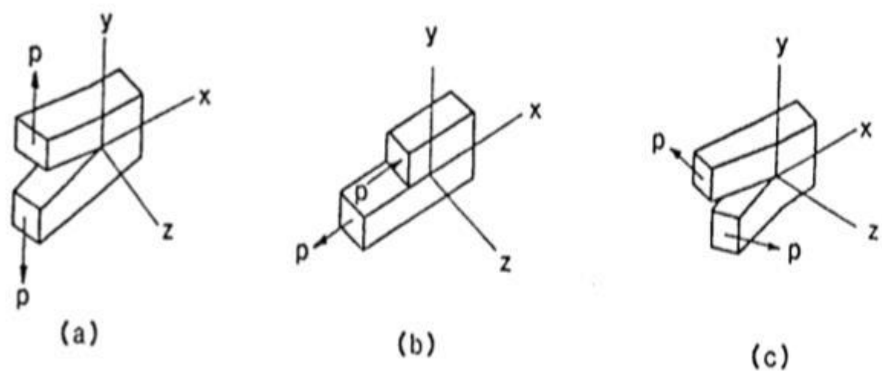

Fig.3: hree modes of initiating reflective cracking

Recent solution for mitigating reflective cracking

Because of the complexity of behavior and interaction between a set of variables, usually, there is not any perfect solution for addressing the problems and the methods for advanced statistical prediction such as Artificial Neural Networks (ANN), Genetic Programming (GP), and Monte Carlo Simulation (MCS) are being used but they might have a huge computational cost (Gheytaspour and Habibzadeh Bigdarvish, 2018; Asgari-Motlagh et al., 2019; Daghighi, 2017). For the case of preventing cracks in AC overlays since there is no certain solution, hence, retarding of the crack propagation and progress is known as the best option for mitigating reflective cracking in AC overlays so far. Many attempts have been made to minimize the propagation of an existing crack upward to AC overlay. For instance, installation of a transition interlayer, sawing, and sealing, etc. It has proved that increasing overlay thickness, retard the reflective cracking appearance of the surface of AC overlay (Notani et al., 2018). Given this orientation, several transition interlayer system has been latterly introduced. This layer mainly delays reflection of cracks from the underlying pavement by two mechanisms: retarding reflective cracking by using reinforcement systems, using a stress absorption layer like a low modulus material (Notani et al., 2019). The approaches have been examined so far can be reviewed as follows:

1) Use a reinforcement layer like geogrid or steel
2) Apply treatment on the underlying pavement such as crack sealing
3) Put stress absorption membrane as an interlayer
4) Modifying asphalt binder with polymers
5) Increasing HMA overlay thickness
6) Utilizing porous friction course and rubblization of existing concrete

Different types of interlayer material have been used in composite pavement system to retard reflective cracking. Such interlayers classified into two major categories: stress relieving interlayers or stress-absorbing and reinforced interlayers (Notani et al., 2019). Asphaltic materials, modified asphalt binder commonly form stress relieving interlayers, and fibers panels with asphalt binder and binder instilled geotextiles (National Asphalt Pavement

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Association, 1999; Han et al., 2013). On the other hand, reinforced interlayers should have a high stiffness to allow the AC overlay to support greater bonding stress for a given asphalt mixture strength.

Geu(1993) used geo-grid-reinforced overlay in a real overlay rehabilitation and then, it was indicated that inclusion of glass-fiber at the interface of overlay by existing pavement, limiting the reflective cracking which used to appear near the interface and also, enhance the of bending strength and extending the fatigue life of overlay. Fujio (1993) studied the effect of overlay reinforced with geogrid on reflective cracking potentiality. It has proved that using the reinforced layer decreases surface deflection and in the meantime, using two layers of geogrid in the body of overlay result more efficient than using a single layer. In another study, Kim (1999) implemented a field test using a modified asphalt mixture and glass grid for construction of AC overlay on a PCC pavement. It was showed that the interaction of modified overlay material and reinforced layer in the body of the overlay, significantly enhance the fatigue life of AC overlay.

Evaluating method

A considerable number of evaluations of reflecting cracking have been studied using a wide array of methods or approaches including numerical models, mechanistic models, and laboratory and field investigations. In this regard, several studies have been attempted to address crack width and crack propagation.

Laboratory investigation

Several laboratory apparatuses have been designed for simulating the field condition for assessing reflective cracking of AC overlays. In this orientation, one of the most practiced tests in this area has developed in the Autun laboratory in France. In this path, Texas overlay tester developed by Texas DOT is another commonly used laboratory device in the investigation of reflective cracking life of HMA overlays. Lee and coworkers introduced two set-ups test for the lab investigation of reflective cracking to simulate the reflective cracking mechanism (Lee et al., 2007). Figure 4 shows the test configurations for two modes of reflective cracking mechanisms.

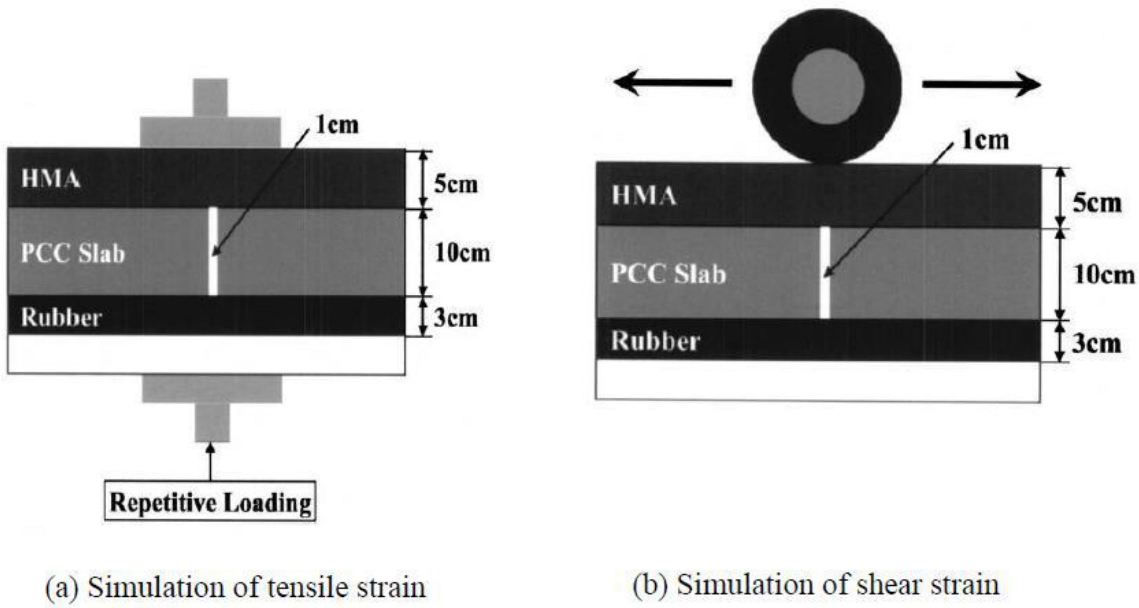

Fig.4: to main test set-ups for evaluating reflective cracking in laboratory scale

Figure 4a shows the set up for simulating applying tensile stress at the bottom of the overlay. Figure 4b shows the set up for creating movement in a vertical direction to create shear stress in on the HMA overlay.

Low-temperature cracking is one of the critical constituent contributing to begin reflective cracking in asphalt overlay. In this case, the tensile stress endurance of overlay material is essential. For evaluating the tensile stress of HMA material, there are several test methods like indirect tensile test and thermal cracking tests. The thermal cracking test specifies the tolerable tensile strength and the temperature at fracture of asphalt material by measuring the tensile load in a specimen which is tempered at a constant rate of conditioning (Notani et al., 2019).However, in all steps of the

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thermal experiment or project, it should be noted that experimental data are highly important to study the performance of the system and also can be utilized for validation of numerical models (Sterpi et al., 2017). Measuring AC overlay tolerable tensile strain is also important to find what the tolerable tensile stress is before initiating and preparation of the crack at the bottom of AC overlays. Recently, the semi-circular bend (SCB) test has been practiced to characterize the tensile strength of HMA material. Arabani and Ferdowsi (2007) used the SCB test in the reflective cracking study to evaluate the mixture tensile strengths.

Caltabiano has done a study on the effect of the interlayer and modified mixture on reflective crack propagation process. In this way, the beam testing was used to simulate loading to the beam amples by a servo-hydraulic device (Figure 5).

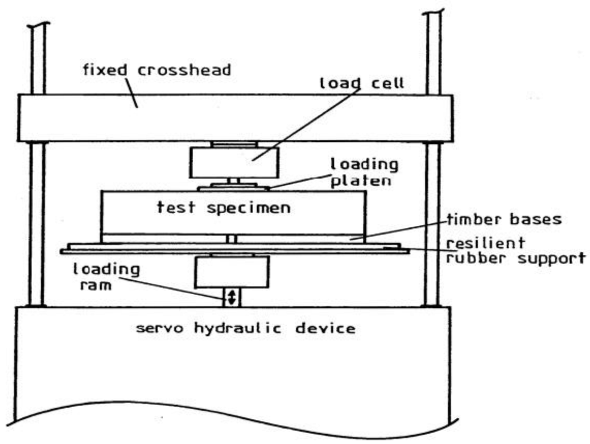

Fig.5: Test setup for evaluation reflective cracking (Arabani and Ferdowsi,2007)

In this study, three different scenarios were chosen which scenario one has 100 mm thickness, and two others have a 75 mm thickness. From the loading point, an 810-kPa load pressure was used in the first and second scenarios and for the last one, 555kPa load pressure was selected. For fabricating interlayer, polymer modified binder, geotextile and geogrid interlayer were used. Moreover, to have a better understanding, wheel track test was applied on the slab samples w/o interlayers. The result of this study indicated that incorporation of geogrid interlayer presents the higher enhancement compared to modified binder and geotextiles. In addition, increasing overlay thickness by 25%, significantly increase the reflective cracking resistance (Wang et al., 2005; Caltabiano, 1990). Khodaii(2008) and coworkers have investigated the effect of location of the geogrid in the overlay on reflective cracking evaluation. Figure 6 shows the specimen fabrication and test set up.

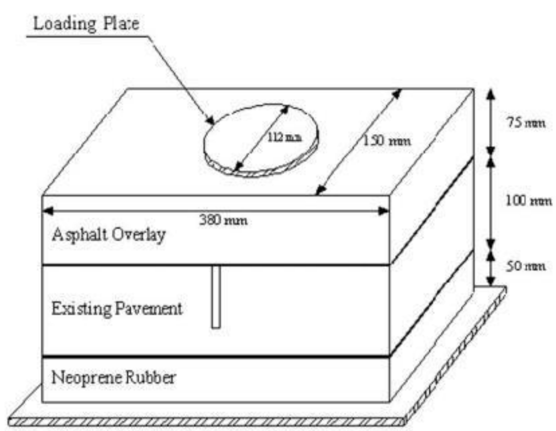

Fig.6: Test set up for evaluating crack initiating and propagation

The finding of this study proved that installing the geogrid at one-third height in the overlay exhibits a much better performance, although it asks the contractor to implement the overlay in two lifts resulting in an additional charge. Moreover, the effectiveness of geogrid at the low temperature is higher than high temperature.

One equal significant factor in the appearance of reflective cracking is the shear strength of AC overlay material. Several laboratory test methods have been offered for evaluating reflective cracking resistance of AC overlay. In this regard, the Superpave shear tester (SST) is one of the well-known devices for evaluating shear strength. Wang and coworkers in a study related to reflective cracking evaluation adopted a triaxle device to determine the shear properties of HMA material (Wang et al., 2005). National Cooperative Highway Research Program recently developed a simple SST test acknowledged as the filed shear tester (FST) because the SST is expensive and it requires a skilled operator to operate the test (Li et al., 2006). Compatible with the shear failure at the top of the joint or cracks, fatigue resistance of the AC overlay can be counted as an essential factor contributing the reflective cracking as well.

Field studies

Typically, reflective cracking started from the underside of the asphalt overlay and grows toward to the overlay surface, while if there is a high-temperature variation, top-down cracking in reflective cracking will have occurred. Figure 7 shows that the top down reflective cracking mechanism in a composite pavement. As it can be seen, the presence of curling and warping in the underlying layer, cause tensile stress in the top section of AC overlay (Notani et al., 2019). Lee (2007) showed that the reflective cracking appears by the interaction of traffic load and temperature load in which at the beginning the crack is initiated by horizontal movement and then, traffic load applies high shear stress which leads the overlay to shear failure.

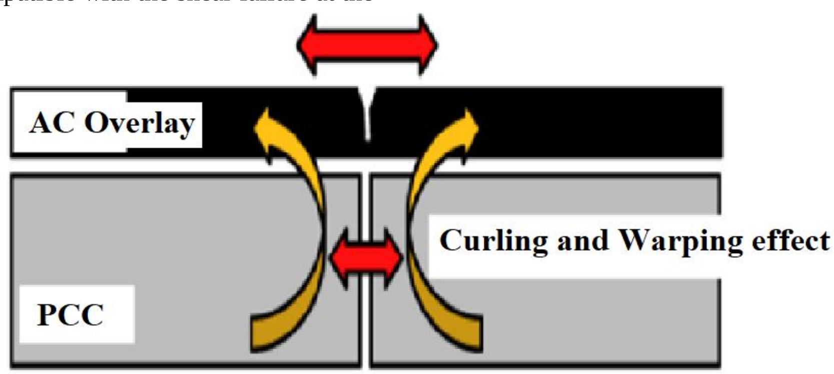

Fig.7:/ Curling and Warping impact in initiating crack at the top of the overlay

Theoretical evaluation method of reflective cracking

Since most of the researches in reflective cracking have been studied based on the laboratory results and empirical prescription, the demand for a theoretical understanding of reflective cracking has been bolded. In this way, using the fracture mechanism theory is employed to understand the fundamental behavior of reflecting cracking in a pavement system. At first, Molenaar (1993) evaluated the reflective cracking using finite element model.

Dave and Buttlar (2010) studied the thermal reflective cracking using cohesive fracture model. In this approach, the fracture energy concept was used to explain the required amount of energy by the AC overlay to form a unit-fractured surface. The result of this modeling showed that increasing slab length increases the probability of reflective cracking due to the presence of more great curling near the joint. Besides, it was stated that PCC rubblisation is better to perform before overlay construction to reduce of risk of reflective cracking in the early age of AC overlay (Al-Qadi et al., 2008).

II. CONCLUSION

Overlay is one the option to mitigate the roadway functional and structural condition by providing a smooth surface for road users. In general, overlay placed on a deteriorated either rigid or flexible pavement. From another side, the crack and joints in the existing pavement can reflect through the overlay surface in the early age of overlay. The leading causes of happening the reflective cracking are traffic and environmental loads. Because of the sophisticated interaction and behavior of this cracking, there is not a perfect solution to preventing of the reflective cracking. Many types of research have been executed to find out the primary mechanism of initiating and propagation of reflective cracking through AC overlay. It was indicated that incorporation of relieving or stress absorbing interlayer could significantly delay the time of happening or reduce the progressing rate of the cracks. Moreover, it has proved that the modification of HMA and using reinforcement interlayer can also enhance the retardation time of reflective cracking as well as increasing the overlay thickness can also enhance the overlay reflective cracking resistance significantly.

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