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To cite this article: C Niken *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **857** 012028

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Deep-hair-cracks mechanism of rigid pavement in humid tropical weather

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Abstract. This research aims to find the cause of deep hair crack in the rigid pavement. This research was done by the observation on a real rigid pavement in Lampung, Indonesia. Rigid pavement length is 39.4 km with four lanes. The length was divided into segments, in which every segment is 5m × 4.6m. The total segments are 31520. The thickness of the rigid pavement is 30 cm with a flexural strength of 45 MPa. The base of the rigid pavement is lean concrete with 10 cm depth and f_c' of 10 MPa. The rigid pavement has contacted with the environment during the first 2 hours because of the made of grooving and cutting. The hair-cracks appear at 2 hours of age on 231 segments or 0.1% of all observed segments. Three core drills were done at the rigid pavement with hair-cracks at the age of 8 months. The depth of the cracks reached 77% of the rigid pavement depth. Hair-cracks appear on the surface because CH bond is not strong and elastic enough to withstand the tensile stress on the surface, the change of high rate expansion and high rate shrinkage due to Ca^{2+} .

Keywords: Concrete, cracks, pavement, rigid pavement, humid tropical weather

1. Introduction

Minor deformities or imperfections which are limited to the surface of concrete pavement are often referred to as surface defects. All of the surface defects can be affected by changing weather conditions, unique mix design characteristics, and de-icing/ anti-icing practice. These distresses typically do not significantly detract from the structural integrity of the pavement but can have an impact on its functional performance and its aesthetic appeal. These surface defects include the following: map cracking or crazing, plastic shrinkage, scaling, surface polishing, surface wear, and mortar flaking [1]. Concrete structures do not frequently fail due to lack of strength, but due to inadequate durability or due to improper maintenance technique. Despite excellent service history concrete pavement faces accelerated deterioration due to water and chemical ingress through the micro crack and surface void [2].

The quality of concrete floor or slab is highly dependent on achieving a hard and durable surface that is flat, relatively free of cracks, and at the proper grade and elevation. Properties of the surface are determined by the mixture proportions and the quality of the concreting and jointing operations, especially finishing, jointing, and curing is critical. Failure to address this issue can contribute to undesirable characteristics in the wearing surface such as cracking, low resistance to wear, dusting, scaling, high or low spots, poor drainage, and increasing the potential for curling. Concrete floor slabs



employing Portland cement, regardless of slump, will start to experience a reduction in volume as soon as they placed. This phenomenon will continue as long as any water, heat, or both is being released to the surrounding [3]. The hairline cracks occur more readily for the finer grade of sand than in the case of the coarser grade of sand [4].

Hair cracks type is random and the width is small. Map or random cracking is a network of cracks and fine fissures on the concrete surface that enclose small and irregularly shaped areas which size dimensions less than 2 in [5]. If larger cracks occur, are frequently oriented in the longitudinal direction of the pavement and are interconnected by finer transverse or random cracks. These cracks are shallow, often only 3 mm deep. Map cracking may be localized or may occur over the entire surface of the concrete slab. The number of occurrences and affected areas (in ft² or m²) is recorded. When an entire section is influenced, it is considered a single occurrence.

The most common cause of premature deterioration is attributed to the development of cracks. Cracking can occur in concrete pavements and structures for several reasons that can primarily load or environmental effects. Within the first few hours after placement, plastic shrinkage can occur at the surface of fresh concrete. Plastic cracks typically do not exceed 10mm wide but may pass through the full depth of the member. The mechanism leading to the formation of plastic shrinkage cracking does not explain full depth cracks. Plastic shrinkage cracking is a problem for large flat structures in which the exposed surface area is high relative to the volume of the placed concrete. The crack caused by plastic shrinkage can be quite wide on the upper surface 2 to 3 mm, but their width often decreases rapidly below the surface. It is probable that the subsequent events, including drying shrinkage and loading, can cause the plastic shrinkage cracks to propagate. Shrinkage is the main factor in the development of these cracks. Random, pattern, or map cracking were caused by plastic shrinkage and drying shrinkage. The time of appearance is 30 min to 6 hours and weeks to months, respectively. The environment has a significant influence on the properties of fresh and hardened concrete. Relative humidity, temperature, and wind show that the construction environment is a major concern when assessing the risk of this early age cracking [5].

The response of materials depends on environmental conditions. The air temperature and relative humidity are changing time by time; therefore, its influence on the rigid pavement is not stable. The temperature effect is usually considered to be less important than relative humidity [6]. Although, it is less critical, at the early age ambient temperature is more dominant than humidity because of the ambient temperature in the form of gas with many particles with high-temperature moves quickly and penetrates the rigid pavement easily. Indonesia is the area with high rainfall. The crack observation is in Oslo [7]. The temperature range in Oslo is about -7-22°C, humidity 64-81%, and rainfall occur over a year. Pouring under hot weather even can lead to conditions that can contribute to rapid moisture loss and the development of plastic shrinkage cracking. Rapidly changing weather conditions can affect the quality of the curing. When it happens, the durability and strength of the concrete surface are also affected [8]. Highly evaporative conditions, e.g., windy conditions, and exposure to direct sunlight, contribute to rapid moisture loss from the surface, which can lead to the development of plastic shrinkage cracking in the concrete. This condition makes the mechanism of deep-hair-cracking different in the area with four seasons, and humid tropical weather, moreover, coupled with high rainfall conditions. By knowing the cause, preventive action can be done rightly.

2. Methods

The research was done by observed hair-crack of a rigid pavement (RP) in National road Bakauheni-Sidomulyo, Lampung Province, Indonesia. RP length observed is 39.4 km with four lanes. The closest distance to the highway to the beach is 10 km. The length was divided into segments. The measure of every segment is 5m × 4.6m. The total segments are 31520 pieces.

2.1. Materials

The RP was placed on 10 cm thick of lean-concrete (LC) with a compressive strength of 10 MPa. The cross-section layer of the RP can be shown in Figure 1.

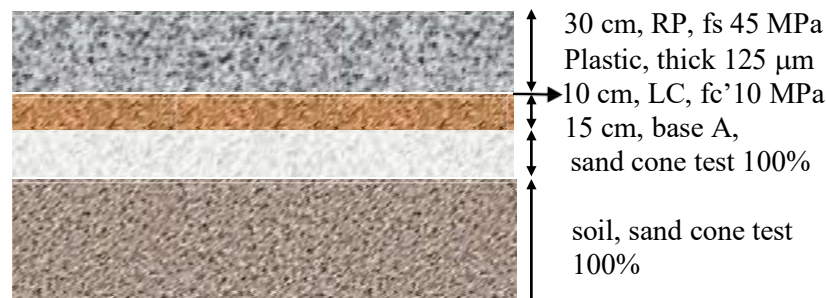


Figure 1. Cross-section layer of the rigid pavement

Pouring was begun at about 3 pm to decrease ambient temperature effect to the concrete. After pouring, RP does not cover the surface until groove making. Curing compounds should be done right after grooving to maintain internal moisture. It was done about a half-hour after grooving. Curing compound Type 2 according to [9] were used. The curing compound will disappear after about 5-8 hours. Right after the curing compound, RP was covered using non-woven geotextile. The geotextile can absorb water. Cutting was done in the age range of 12- 18 hours according to project specifications. For this purpose, the geotextile is opened as needed. Therefore, about the first 2 hours, the RP has direct contact with the environment. The amounts of pores are largest until 2 hours [10]. After this time, moisture curing was done for seven days. The moisture-curing method is to pour water over the geotextile three times daily for seven days.

2.2. Methods

The research method was done by observing defects per segment. Samples for bending and slump tests were taken from each concrete mixture from each dump truck. The slump test should be in the range of 0-5cm. Each segment condition was observed before the next step. Width and area of random defects, and also the first time the defects appear were noted. Three cores drill with 4" diameter done at the RP age about eight months. The core drill was done on the hair-crack area of the RP which was selected randomly. The depth of the cracks of every sample was measured. The depth of cracks determines the level of seriousness of the cracks for structural RP safety. The slump, grooving time, grooving period, curing compound quality, cutting period, surrounding weather condition are a parameter which was considered to analyze the cause of the random cracks. The parameters difference between no defect segment and segment with hair- cracks were studied. The early age behavior of the RP is assumed similar to [11] research. Based on the difference, and study literature, the cause of deep hair crack was analyzed.

3. Results and Discussion

In this section we discuss how to format the title, authors and affiliations. Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section, title so it should not be indented.

3.1. Results

Hair cracks in this RP were found in 231 segments at the age of 2 hours (figure 2). After the rain, hair-cracks appear clearer than before rain (fig. 2a and 2b). The width and depth of the hair-crack from core drill samples can be shown in fig. 2b and 2c. Slump at the segment with hair crack is closed to 5 cm (fig. 3).

Fine cracks appear on segments with high slumps. This causes grooving to be done later than the regular time so that the RP is longer exposed to the surrounding weather.

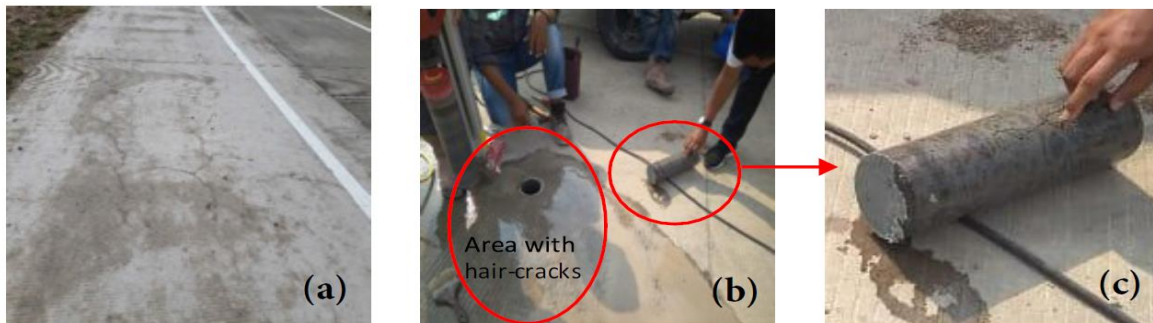


Figure 2. a. Hair-cracks after rainy, b. Hair-cracks before rain and core drilling RP with the hair crack, c. Sample 1 hair crack depth: 20 cm

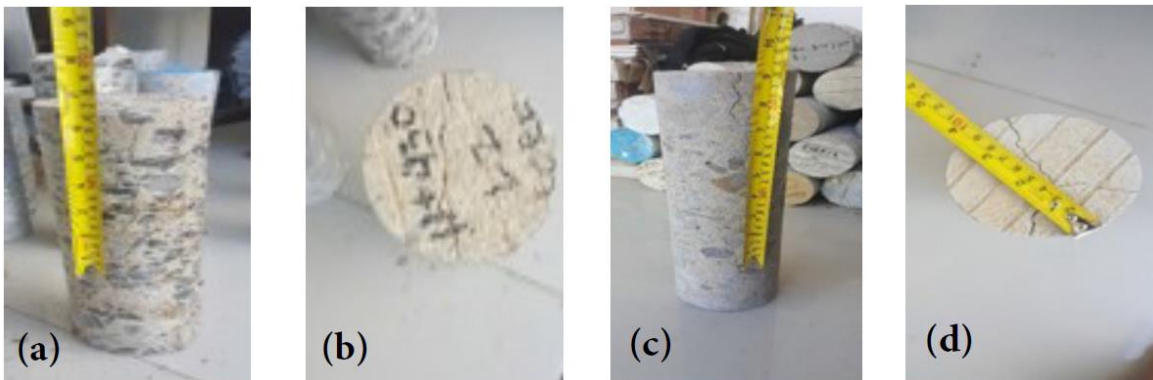


Figure 3. Sample 2 with hair-crack depth of 21 cm(a); hair-crack width of about 3mm (b, sample 3 with hair-crack depth of 23 cm (c), and hair-crack width of about 3mm

3.2. Discussion

From observations and data obtained that the ratio between segments with hair-cracks and total segments is about 0.1%. Although it was small, another defects-type can be triggered by these cracks. These cracks influence surface defects index (SDI) value [12]. The crack depth ratio to the thickness of RP is in the range of 67-77%. Pouring concrete was done afternoon. High slump makes the setting time RP longer so that the waiting time for grooving is longer. This condition causes temperature, wind, and humidity to affect the moving out of inner water and makes RP surface more sensitive to cracks.

3.2.1. Hydration

Portland cement consisted of C_3S (alite), C_3A , and C_4AF (gypsum). C_3S reaction is very fast resulted in CSH and CH. The expansion was caused by ettringite (Figure 4a) and Ca^{2+} (Figure 4c). The C_4AF was reacted to the CSH, and the product of this reaction is ettringite (Equation 1). The ettringite gels attach on the surface of cement grains until the concrete age of 18 hours [8] as displayed in Figure 4a.



At the age of 0-2 hours (hair cracks appear), ettringite or $C_6AS_3H_{32}$ (Figure 4a) and CH (Figure 4b) grow with a high rate for the first time, after that no growth of them both until the age of 6 hours [10]. The expansion of ettringite was offset by shrinkage because of CH. Because of this mechanism, the analysis of deep hair cracks mechanism was emphasized on Ca^{2+} (Figure 4c). Portland cement contains 50%-80% of alite [13]; therefore, its product hydration dominates the behavior of concrete.

One of the product hydrations of alite is Ca^{2+} . Until the age of 1 hour, Ca^{2+} growth at a high rate. The maximum number of alite was formed at the age of one hour. After that, in the range age of 1-1.5 hours, the number of Ca^{2+} decreases with a high rate [14]. Thus, there are two mechanisms during the first 2 hours, expansion and shrinkage. CH occupies about 15% of the volume of normal cement paste. It forms as crystals with a wide range of shapes and sizes, depending primarily on the amount of room available for growth [15].

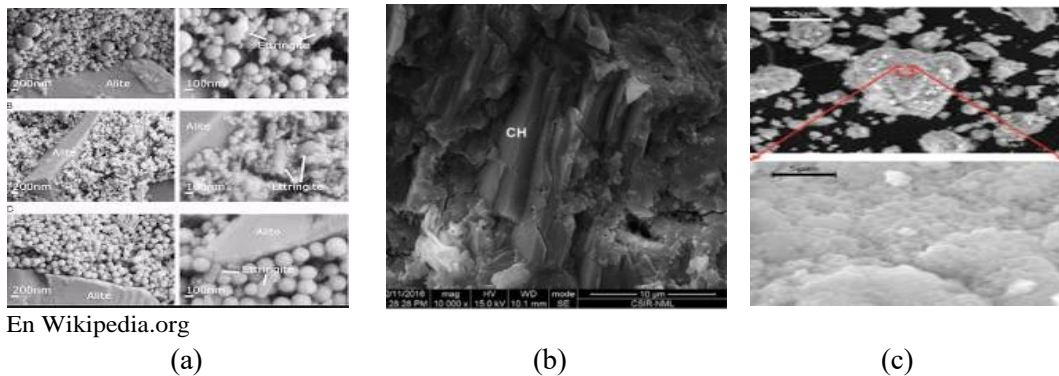


Figure 4. a. Ettringite, b. CH (Portlandite), c. Ca^{2+}

3.2.2. Environmental Effects

The effect of temperature, ambient humidity, and rain on the appearance of hair cracks and deep hair crack is outlined as follow:

- *Hair cracks*

Exposure to the environment makes the concrete more sensitive [16]. During the first 2 hours, this RP has directly contacted with surrounding weather. Ambient temperature is 27.3-28.7°C and humidity in the afternoon is 79-84%, respectively [11]. The autogenous concrete temperature in the age of 0-2 hours is between 27.6°C-29.1°C [11]. The difference of concrete temperature and ambient temperature is small (0.6°C); therefore, it can be assumed that no influences of ambient temperature to the concrete.

A chemical reaction makes the concrete hot. A large amount of pore in the first 2 hours, makes surrounding relative humidity penetrate to the concrete. This condition makes CSH bonds were quicker formed.

Because internal water was moving out caused by direct contact with the environment, hydration occurs with limited water. Water for hydration was obtained from pores water; therefore, on the surface, the tensile force occurs. Expansion and shrinkage due to Ca^{2+} occur at a high rate. The change between expansion and decreasing volume needs bond strength and plastic. Both mechanisms happen together with moving out of internal water because of open conditions, lead tensile stress to be more. The high tensile stress breaks the weak bonds. The breaks make hair-cracks on the surface of RP. Beside CSH, the hydration was also produced CH. CH is the most soluble of the hydration products, and this is a weak link in cement and concrete [17].

- *Deep hair cracks*

Deep hair-cracks were found from the core drill test at 8 months old. At the age, the hydration process is almost over. It is difficult to clearly distinguish between CH and CSH since the latter contains a significant proportion of Ca-OH bonds. CH contributes slightly to the strength and impermeability of the paste because it reduces the total pore volume by converting some of the liquid water into a solid form. Calcium hydroxide is believed to play

a role in limiting the amount of shrinkage that occurs when a cement paste is dried. As water is removed from the pore system, the CSH gel phase collapses, causing an overall shrinkage, while other crystalline phases such as CH are unaffected. As the CSH starts to shrink the CH that is in contact with it acts as a restraint so that the overall shrinkage is less than it would be if the CH were not present.

Blended cement pastes have little or no CH, as the CH that forms from cement hydration are consumed along with the mineral admixtures to form additional CSH gel. This condition has beneficial effects on the strength and permeability but tends to increase the tendency for drying shrinkage for the reasons mentioned above [15]. Freshwater from the surrounding (e.g. rainfall or dew) penetrates to the concrete from the hair-cracks. The freshwater, makes the CH leach out, increasing the porosity and makes the hair-cracks deeper and deeper. The phenomenon was making the paste more vulnerable to further leaching and chemical attack.

4. Conclusion

Tensile strength on the surface occurs because of removing water from the surface pores during two hours after casting. High rate expansion due to Ca^{2+} makes the tensile force to be more. The shrinkage with a high rate occurs after that need strong and elastic chemical bonds. Removing water make CSH bonds which were still in weak condition collapse and can't handle the change from expansion to shrinkage and break. The breaks appear as hair-cracks. Penetration of freshwater (e.g. rainfall or dew) to the RP from the hair-cracks, removes the CH. With no CH in the concrete, the ability of concrete to handle deformation is decreasing This mechanism makes the increase of porosity, makes the cracks wider and deeper. It is very important to cover the rigid pavement right after pouring.

Acknowledgment

I would like to thanks Pembangunan Perumahan Ltd which was supported data, and equipment for this research. Our appreciation is for Universitas Lampung for supporting the research.

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