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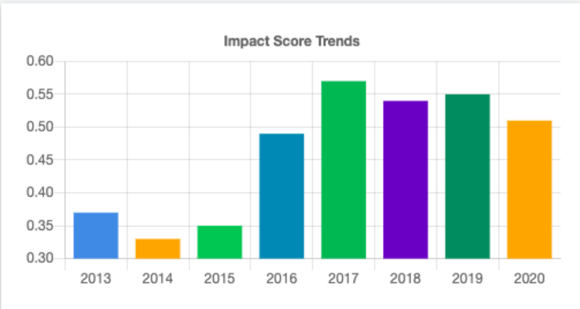

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Deformation of high performance concrete plate under humid tropical weather

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Abstract. This paper presents the relationship between surrounding relative humidity and temperature on deformation behavior of one sample concrete plate with compressive strength of 60MPa. This research was done in Indonesia that is in humid tropical weather. A specimens measuring 3000 mm×1600 mm × 150 mm were used. The behavior was obtained by using four embedded vibrating wire strain gauges (VWESG). As a result there is a very strong relationship between humidity and deformation at the age range of 7 until 21 days. The largest deformation occurs in the corner and the fluctuation of deformation in side position is larger than in the corner and in the middle. The peaks of surrounding relative humidity were fully followed by the deepest valley of deformation on time in the corner, while in another position the range delay time was 8 - 11 hours. There is a strong relationship between surrounding temperature and deformation at the range of 7 until 14 days. The influenced of surrounding relative humidity to concrete behavior is faster and longer than surrounding temperature. The influence of surrounding temperature in humid tropical weather was shorter than in non-humid tropical weather.

1. Introduction

Surrounding relative humidity (SRH) and temperature are never constant. The humidity and temperature penetrates to inside concrete through the concrete pores through the connected to the air surface. Element structure that has largest surface contacts to surrounding humidity and temperature is plate. Sarman, et al., 2015 observed concrete flat roof defects in equatorial climates [1]. Kim, et al., 2014 obtained finite element modeling of environmental effect on rigid pavement deformation [2].

To accommodate the need of increasing durability and load, many designers used high performance concrete (HPC). HPC is defined commonly as concrete with a minimum compressive strength of 60 MPa [3]. To obtain high strength concrete with good performance, more cement but less water is used in HPC than in normal concrete.

The response of materials depends on environmental conditions. The air temperature and relative humidity are changing time by time during 24 hours; therefore, its influence is not stable. The influence of the environmental to concrete depend is on concrete pores. The growth of product hydration changes the amount and size of pores.

Humid area is an area with high humidity. Humidity more than 40%, was mentioned less creep and shrinkage by ACI 209R, 1997 [4]. Although, high humidity is revealed less deformation, but high fluctuation of it, absolutely give a serious impact to concrete performance. Based on the observation of Niken et al, 2013, starting November 2009 until December 2011 in Jakarta as the representation humid tropical weather, the average humidity and temperature in Jakarta is 72% and 27°C respectively as shown in Fig. 1 and 2 [5]. Large deviation between maximum and minimum humidity occurs over the year (Fig.1).

A. Jakarta B. New York

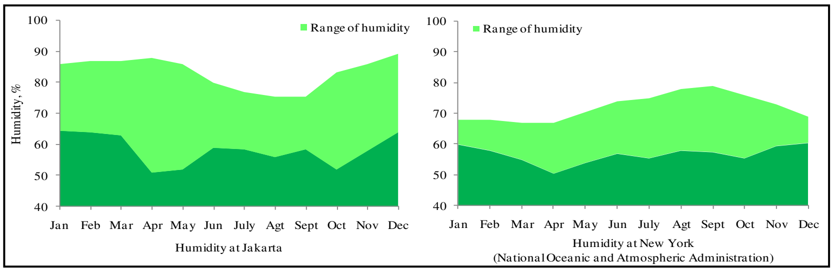

Figure 1. Humidity in Jakarta and New York

A. Jakarta B. New York

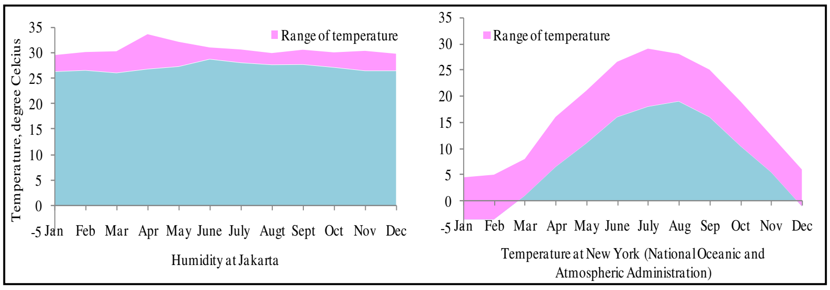

Figure 2. Temperature range in Jakarta and New York

Temperature effect is usually considered to be less important than relative humidity. Although, it is less important, at the temperature of 50°C, creep strain is approximately two to three times than creep strain in the temperature less than 19 - 24 °C [4].

Surrounding humidity and temperature influence internal humidity and concrete deformation. The influence of internal humidity to concrete has already learned [6]. Various studies of the influence of temperature on concrete behavior have been published among others [7, 2, 8, and 9]. As a guide, ACI 209 R, 1997 has accommodated the influence of humidity and temperature on concrete shrinkage and creep by giving a factor [4].

Researchers as mentioned above, consider the influence of humidity on concrete is separated with the influence of temperature, even though there is a relationship between humidity and temperature by Dew point temperature [10]. Researchers who had studied about the influence of humidity and temperature together on concrete are Xu, et al., 2016 and Saha & Eckelman, 2014 [11,12]. They obtained degradation of material due to moisture and temperature.

2. Methodology/Experimental

The research was conducted in Jakarta, Indonesia, with humid tropical weather. This research was performed experimentally using one specimen of 3000 mm×1600 mm × 150 mm, with four embedded vibrating wire strain gauges (EVWSG) as shown in Fig. 3.

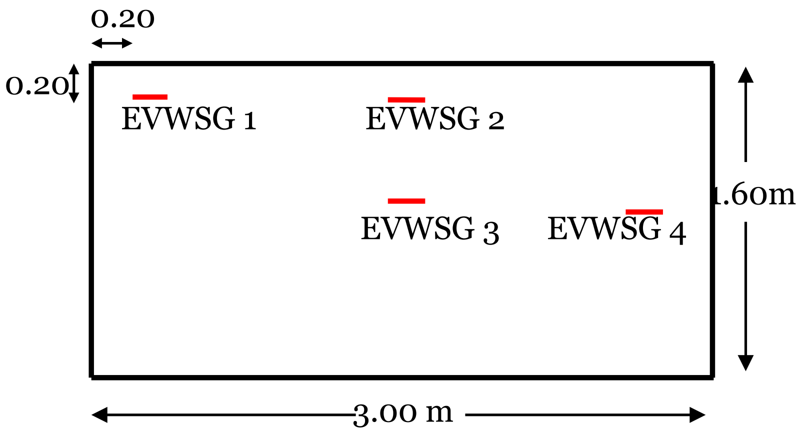

Figure 3. The scheme of plate and the placement of vibrating wire strain gauges

HPC with target compressive strength of 60 MPa and slump flow diameter of 35 ± 2 cm was applied. The plate was cast at 22.10 pm with surrounding temperature of 25.4°C and relative humidity of 94%.

2.1. Materials

The mix design was conducted in compliance with ACI 211.4R, 1993 [13], with a limit of 500 kg/m^3 cement content to meet the shrinkage factor closest to 1 [4]. Ordinary Portland Cement (OPC) produced by Indocement Ltd was used. Condition of the aggregate was saturated surface dry (SSD). Fine aggregate in the form of river sand was brought from Sungai Liat (Bangka, Sumatra, Indonesia); specific gravity (SSD) was 2.605; and absorption was 0.4%. The sand had been filtered and cleaned using a mixture of standard graphs obtained from the mid-gradation, according to ASTM C.33/C.33M-08 [14]. Coarse aggregate in the form of volcanic rock fragments was obtained from Banten, West Java, Indonesia. Composition of the coarse aggregate used was 70% size of 13 - 19mm; specific gravity (SSD) was 2.563; absorption was 1.543%; and 30% size of 6 - 12mm; specific gravity was 2.636; and absorption was 2.26%.

Added material used was silicafume of 8% cement weight produced by Sika Indonesia Ltd. To achieve the desired high strength with low water to cementitious material ratio and good workability, polycarboxylic superplasticizer under the commercial name Visco Crete 10 from Sika Indonesia Ltd was added to the concrete mix as the high range water reducer (HRWR). The dose of HRWR of 1.4% cement weight was added according to that generally used in Indonesia. Local water was supplied by the Structure and Material Laboratory of Universitas Indonesia. An electrical scale was used especially for cementitious materials, HRWR and water to obtain the accurate water to cementitious material ratio. The mix composition is OPC 500 kg/m^3, silica fume 40 kg/m^3, water 142.6 kg/m^3, sand 800 kg/m^3, coarse aggregate 935 kg/m^3, and HRWR 7.6 kg/m^3.

During the concrete mix design stage, all of the aggregate were assumed to be under saturated surface-dry condition. A tilting drum mixture of 0.3m^3 capacity was used. The mixing started with all cementitious material in dry condition, followed with 50% fine aggregate. Subsequently, 50% water was added to the revolving mixture. Then these materials were mixed for approximately 1.5 minutes. Next, 50% water was slowly poured in, which was mixed with HRWR homogenously. Thereafter, 100% coarse and 50% fine aggregate were added. With all the materials placed according to its order into the mixer, the concrete was mixed for approximately 3 minutes. The slump flow of the mixture was measured before pouring by using Abram's cone upside down.

2.2. *Methods*

Shrinkage was measured as strain change against time by installing four embedded vibrating wire strain gauge (EVWSG) in the specimen (Fig. 3). The EVWSG has abilities to detect the strain up to 3000 με with accuracy of about .025% and concrete temperature between -80°C and 60°C with about .5% accuracy. Surrounding relative humidity and temperature were obtained by using room humidity and thermometer.

Right after casting specimens were covered with plastic membrane to eliminate water evaporation. The specimens were cured after de-molding (one day after casting) by covering wet sacks over the specimens to the age of 7 days. After this treatment, specimen was allowed to intersect with surrounding relative humidity and temperature but with protection again raindrops. Observation was performed right after pouring as follows: 0 - 24 hours, every 15 minutes; 24 - 48 hours, every 60 minutes; days 3 - 10, every 2 hours; days 10 - 14, one time a day using a read out. Two beams of 3000 mm×600 mm × 200 mm were cast on the plate at the plate age of 14 days; therefore, on the plate occurs creep. Fifteen days is selected because load generally applied on the rigid pavement or slab. Observation was done right after applied load as follows: days (specimen age) 14 - 16, every 15 minutes; days 16 - 17, every 60 minutes and days 17 - 21, every 2 hours.

Data were analysis in the age range of 7 until 21 days. The deformation of every position is sought for the cause of its behavior difference by literature study and the properties of water and heat movement.

3. Result and Discussion

3.1. Result

The observation results of all deformation were shown in Fig. 4.

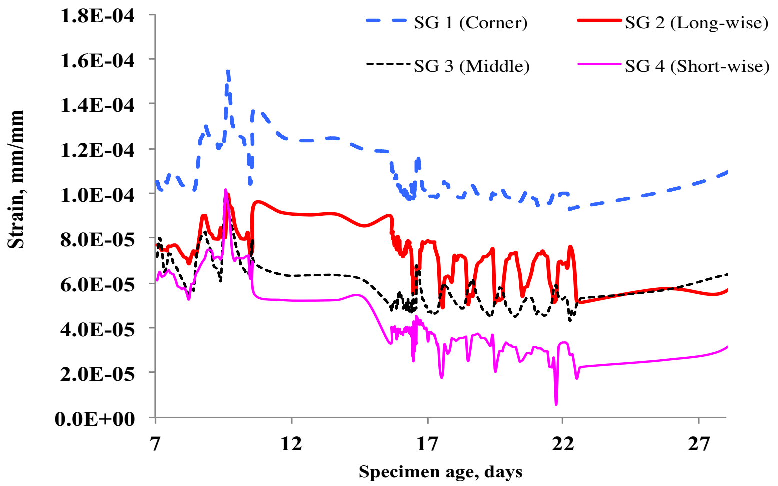

Figure 4. Plate deformation of all vibrating wire strain gauges

Observation results of surrounding humidity, temperature and concrete temperature were shown in Figure 5. Concrete temperature is lower than surrounding temperature since 17 days age as shown in Fig.5.

The lowest SRH for every fluctuation happen at the time range of 10.00 am to 04.00 pm. Only 30% the lowest of SRH occur at the time range of 10 am until 11.00 pm.

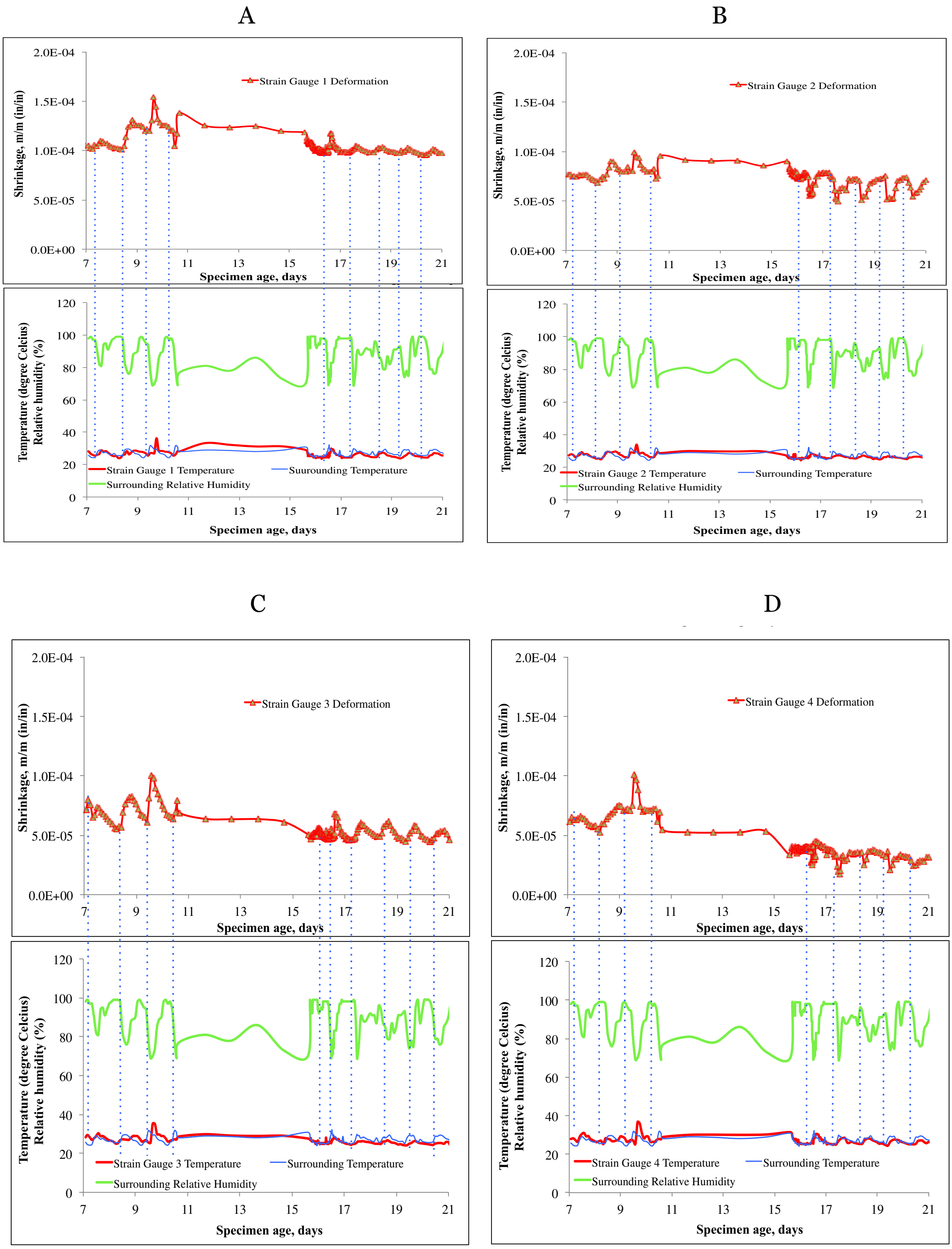

Figure 5. Relationship between concrete deformation, concrete temperature, surrounding relative humidity and surrounding temperature (7 - 21 days), (A) Strain gauge 1 (corner), (B) Strain gauge 2 (longwise), (C) Strain gauge 3 (middle), (D) Strain gauge 4 (short wise).

3.2 Discussion

Deformation in all position shows similar type (Fig.4). The largest deformation occurs in the corner position and the smallest is in the short-wise position. Although, the plate is placed on the soil, corner deformation is larger than deformation in another position (Fig.4). The difference was mentioned by Huang, 2003 [15].

At this age of 7 – 21 days, hydration is a major process in concrete. Cement becomes a bond material in concrete formation through the hydration process. Deformation caused by hydration process, and the process was determined especially by water. Cement it-self, is very sensitive to the water even water content in the air. By ensnaring the water in air, cement grains forms a bond itself. At humid tropical weather there are a lot of water vapor available in the air together with high temperature over the year (Fig. 1A and 2A); therefore, the hydration process occurs under this situation. High humidity condition makes the growth of silica bridges as a bond becomes optimum [16]. Because in humid weather area the high humidity is occur over the year, hydration rate or the form of bond to be faster than in non-humid area.

There are two types deformation: shrinking and swelling as displayed in Fig. 5 and 6. The growth of product hydration causes volume shrinks as a consequence of the smaller concrete paste ingredients volume at mature time than at mixing time. Swelling is caused the available of Ca^{2+} as a product of the reaction [17] and capillary pore tension. Pores were formed because during concrete manufacture, some air was trapped. When the concrete formed at the beginning, it is many and large size. Hard cement paste, has enormous areas of internal pores that is about $500m^2/cm^3$ [18]. The amount and size of pores are decreases according to concrete age [19]. The pores become entrance and exit of air water vapor and air temperature. In plate, environment moisture and heat enters the concrete from the top surface, and other than that, at longwise and short wise position the moisture and heat enter also from one side of the plate, and for the corner position enters through two plate sides that are perpendicular to each other.

Moisture that enters from one side will accelerate moisture movement from top surface; therefore, the deformation becomes more fluctuate according to SRH fluctuation (Fig. 5B and 5D) at the age of 15 – 21 days. While in the corner, moisture also enters through two sides (perpendicular to each other) leads the moisture to more spread sideways and make the mode of fluctuation smoother (Fig. 5A and 5C). This matter will change internal moisture of the concrete. The first change of internal moisture occurs in the position directly contact with surrounding environment; and then distribute to the deeper part of concrete. If the water moves in and out from the micro-pores, macro-diffusion will occur. The infiltration and distribution of air water vapor depend on the number and size of pores, and will be accelerated by the surrounding air pressure. This infiltration water will increase internal moisture and then lead the increase of hydration process rate.

The several of water that infiltrates, will stay in pores. The characters of this water depend on the pores size and humidity [20, 21]. The pores size was distributed over a wide range. Pores with diameters of 10 - 20 nm are related to pores space of C-S-H hydrat cluster, and pores with diameters of 1 - 2 nm is related to internal porosity of hydrat [22]. Pores with a diameter of 10 nm are often formed in the normal concrete [20].

The use of low water to cement ratio or silica fume (nano particles materials) in high performance concrete and high strength concrete (HSC) makes the pores condition as mention above becomes change, big capillary pores decrease, medium capillary pores (diameter of 50 -10nm) and little gel pores (diameter of 10 - 2.5nm) increase. If low cement to water ratio was used together with silica fume, the size of pores getting smaller again, because silica fume is a nano material [23]. Big capillary pores have no menisci; thus, no capillary tension force; while medium capillary pores and little gel pores have strong menisci [20]. This condition makes capillary tension force in HPC and HSC higher than in normal concrete. More over, water in medium capillary pores and small gel pores can evaporate even in high relative humidity situation; on the other hand, the concrete also can shrink in the similar condition [20].

The peaks of surrounding relative humidity were fully followed by the deepest valley of deformation (Fig. 5). Delay times between peak of surrounding relative humidity and deepest valley of deformation means infiltration of moisture and temperature meet some barriers. In the longwise deformation, largest fluctuation occurs (Fig. 5B). The fluctuation type was similar to deformation in the short-wise position (Fig.5D).
The peaks of surrounding temperature were also followed by the peaks of deformation (Fig.5). Delay times between the both were also occurs. The delay time can be seen in Fig. 6.

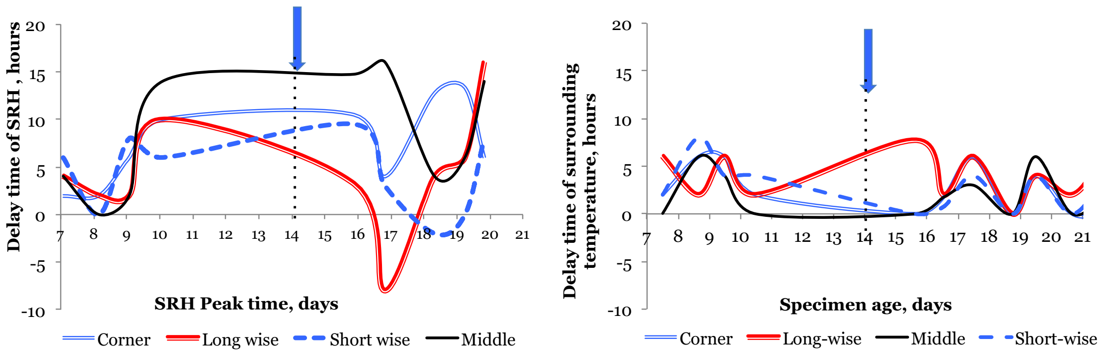

Figure 6. Delay time of (A). Peak of surrounding relative humidity and deepest deformation; (B). The peak of surrounding temperature and the peak of deformation

Delay time between peak of deformation and peak of surrounding temperature is about half delay-time correspondent to surrounding relative humidity (Fig.6A and Fig.6B); thus, surrounding temperature is easier to penetrate the concrete than surrounding relative humidity. This result shows that surrounding temperature meets significant barriers that are the available of pores water and product hydration. Because the barrier has a fluctuation in the form of sinusoidal type according to surrounding relative humidity; therefore, the delay time is also has a similar fluctuation too (Fig. 6B). The long delay time means that surrounding relative humidity meet strong barrier. The strong barrier caused by same cause of surrounding temperature and the movement of particles as a consequence of the ease of surrounding temperature infiltration.

Temperature in Jakarta is more than 24°C and occurs over the year (Figure 2); thus, the heats energy level is also high. The highest temperature was reached at 9.7 days with 36.7°C (Fig. 5). This temperature is 12.7°C exceeded normal range temperature of ACI 209R, 1997 [4]. It can be meant 1.5 – 2 times than creep strain in the temperature less than 19 - 24 °C, if linear interpolation was used. High temperature infiltration makes atoms and molecules move rapidly. The move was depends on its strength barrier. The barriers are pores water and silica bridges which growth rapidly. If the barriers become strong and increase in number, surrounding temperature more difficult to penetrate and its influence to concrete deformation decrease.

Relative humidity in Jakarta is more than 40%, therefore shrinkage factor by relative humidity is more than 1. Water vapor that enter in concrete is more difficult to exit than inner temperature, because the barriers growth; therefore, several water still stay in the pores. Generally, pores water temperature is lower than surrounding temperature because no direct connection. This condition together with decreasing hydration heat, and water vapor that still stay in the concrete will make concrete temperature to be lower than surrounding temperature. This condition makes concrete temperature become lower than surrounding temperature. This phenomenon occurs at the age more than 16 days (Fig. 5).

High heat energy occurs together with high surrounding relative humidity. High heat energy makes the particles move rapidly, and high surrounding relative humidity leads product hydration growth rapidly. Product hydration would be a barrier for particles to move; thus, the influence of temperature to concrete deformation can shorter than in non-humid weather. The particles movement meets strong barrier at the age of 14 days because inner C-S-H were formed [20].

We also note that there is different phenomenon of the environment during night and day. At noon, temperature and relative humidity fluctuations are influenced by direct sunrays radiation. While during the night, the temperature and relative humidity are mainly influenced by output energy of the earth's surface [24]. From this observation, the lowest surrounding relative humidity occurs in day time, in between 10 am to 04.00 pm. This condition makes high fluctuation of surrounding relative humidity at noon and smooth fluctuation at night (Fig. 5 and 6). To avoid, the influence of high surrounding temperature at the beginning hydration process, concrete was casting in night.

4. Conclusion

The conclusions of this research are:

1. Deformation in all position shows similar type.
2. The largest deformation occurs in the corner position and the smallest is in the short-wise position.
3. Moisture that enters from one side will accelerate moisture movement from top surface and the deformation becomes more fluctuate according to surrounding relative humidity fluctuation
4. Moisture enters through two sides (perpendicular to each other) leads the moisture to more spread sideways and make the mode of fluctuation smoother
5. The peaks of surrounding relative humidity were followed by the deepest valley of deformation
6. The peaks of surrounding temperature were followed by the peaks of deformation
7. Delay times between peak of surrounding relative humidity and deepest valley of deformation means infiltration of moisture and temperature meet some barriers
8. Delay time between peak of deformation and peak of surrounding temperature is about half delay-time correspondent to surrounding relative humidity
9. Delay time correspond to temperature has a sinusoidal fluctuation
10. Concrete temperature is lower than surrounding temperature at the age more than 16 days
11. The influence of temperature to concrete deformation is shorter than in non-humid weather

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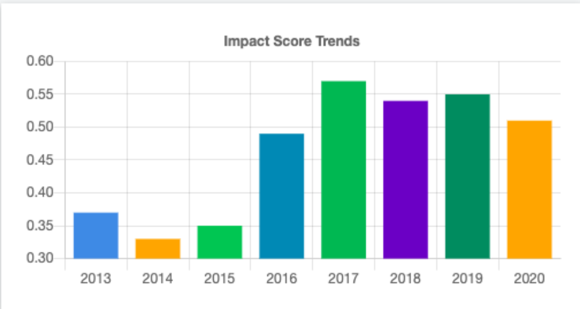

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Deformation of high performance concrete plate under humid tropical weather

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References

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Abstract

This paper presents the relationship between surrounding relative humidity and temperature on deformation behavior of one sample concrete plate with compressive strength of 60MPa. This research was done in Indonesia that is in humid tropical weather. A specimens measuring 3000 mm × 1600 mm × 150 mm were used. The behavior was obtained by using four embedded vibrating wire strain gauges (VWESG). As a result there is a very strong relationship between humidity and deformation at the age range of 7 until 21 days. The largest deformation occurs in the corner and the fluctuation of deformation in side position is larger than in the corner and in the middle. The peaks of surrounding relative humidity were fully followed by the deepest valley of deformation on time in the corner, while in another position the range delay time was 8 - 11 hours. There is a strong relationship between surrounding temperature and deformation at the range of 7 until 14 days. The influenced of surrounding relative humidity to concrete behavior is faster and longer than surrounding temperature. The influence of surrounding temperature in humid tropical weather was shorter than in non-humid tropical weather.

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