

Behavior of Normal Concrete Beam with PCC During the Moisture Curing Period

Anggita Yuliana Lestari[1*] Chatarina Niken[2] Masdar Helmi[2] Hasti Riakara Husni[2]

1. School of Civil Engineering, University of Lampung, Jl. Sumantri Brojonegoro No 1 Bandar Lampung, Indonesia
2. Department of Civil Engineering, Faculty of Engineering, University of Lampung, Jl. Sumantri Brojonegoro No 1 Bandar Lampung, Indonesia

* E-mail of the corresponding author: anggitayuliana03@gmail.com

Abstract

The compressive strength of concrete depends on the treatment it undergoes. One way to preserve concrete is by curing it with moisture. During curing chemical reactions still occur which cause deformation. This behavior was studied using 3 concrete beam specimens with Portland composite cement (PCC) measuring 15 cm x 15 cm x 60 cm, with a concrete quality of 20.75 MPa. The test object is placed on two supports, and the EVWSG is located 5 cm from the end of the test object. Observations during the curing period are carried out over 24–48 hours, every 60 minutes; 3–8 days, every 2 hours. The results showed that changes in ambient temperature resulted in changes at the temperature of the soaking water. The temperature of the soaking water is similar to the temperature of the concrete and has a sinusoidal pattern. Concrete deformation occurs in the form of shrinkage and expansion in the same pattern as the temperature pattern in concrete. The rate and magnitude of expansion and shrinkage are the same, this shows that during the curing process, the concrete is elastic even though the soaking water temperature is 1–6.4 ºC, which is higher than the Indonesian standard. There is a close relationship between the temperature in the concrete and deformation, as well as between the temperature in the concrete and the temperature of the soaking water. Concrete deformation can be approximated as a straight line parallel to the horizontal axis and is constant.

Keywords: beam, concrete, curing, deformation, pcc

DOI: 10.7176/CER/15-3-05
Publication date: November 30th 2023

1. Introduction

Concrete is the most commonly used type of construction in the world, where reinforced concrete is more popular than steel (Kioumarsi *et al*. 2020). Concrete is an artificial stone with a cement binder. Currently, one type of cement that can easily be found on the market because of its increasing use in large projects is PCC (Portland Composite Cement). The tendency to use PCC-type cement continues to increase. The price of PCC-type cement is cheaper than OPC-type cement (Ordinary Portland Cement), easier to obtain, and more environmentally friendly because it reduces global warming. To obtain OPC-type cement, you have to make a special order because it is not distributed to the public. OPC cement does not contain pozzolanic material in it (Susanto *et al*. 2019). PCC is a cement product that contains less clinker, between 65%-95% compared to OPC of 95% (SNI 7064 2014).

One of the structural elements is a beam. The function of the beam is to receive the load from the plate and transfer it to the column. The strength to withstand compression is an advantage of concrete, but the reliability of a structure is not only its strength but also its ability to deform. Deformation occurs due to hydration reactions, environmental factors, and imposed loads. Natural deformation of concrete occurs in the form of shrinkage and expansion (Niken *et al*. 2019). Apart from that, there is a deformation called creep due to continuous loads. Creep cannot be separated from shrinkage because they occur together. Creep and shrinkage are different phenomena and are not interdependent. Creep can be measured from the beginning of the elastic strain until the inelastic strain occurs (David & Supartono 2023). Shrinkage and creep also occur in reinforced concrete-bore piles (Murison *et al*. 2022) and columns. One of the stability controls in column and beam structures is deformation (Niken *et al*. 2017; Alaydrus *et al*. 2016).

Concrete will be able to expand and contract without cracking if the particle bonds are strong and still elastic.

The most important hydration product for providing concrete strength is CSH. CSH and CH will grow at a high rate at the age of 1 to 7 days (Kurtis 2015). The growth of these hydration products causes high stress and strain. To be able to withstand the stress and strain that occurs, strong hydration product bonds are needed. If the bond is strong, then hairline cracks will not appear in the concrete, which is a manifestation of the bond breaking. CSH binding or hydration will be optimal if the ambient humidity is 85% (Sachan & Srivastava 2022). Therefore, it is very important to maintain high humidity in the concrete during this period, apart from preventing cracks, it is also important to achieve the targeted concrete compressive strength. Efficient and uninterrupted maintenance contributes to superior concrete quality (Challadattakarthik 2020). Curing moisture can be done by soaking it in plain water or seawater, covering it with plastic, covering it with a burlap sack, and watering it. Soaking with plain water produces the highest 28-day compressive strength compared to other moisture-curing methods (Patah *et al*. 2022; Tumpu *et al*. 2020). In addition to moisture curing, there is also evaporation curing (Wang *et al*. 2021). Due to advances in technology and chemistry, membrane-curing compounds, self-curing agents, encapsulated curing agents, accelerators, and waterproof compounds have been discovered (Pawar & Kate 2020). For locations where water is scarce and curing with water and evaporation is not possible, curing compound is the method that can be chosen. Curing compounds have shown good cooperation with concrete, which is described by their ability to withstand pressure and strain behavior (Kumar & Babu 2015).

Thus, there is a close relationship between curing, strength, and stretching behavior, which can be expressed as curing. Humidity significantly affects the quality, strength, and durability of the concrete that will be produced. Concrete moisture curing also functions to prevent water loss too quickly due to evaporation and helps create even conditions across the surface of the concrete, thereby reducing the risk of premature cracking. During the curing period, the hydration reaction, which is a chemical reaction, continues. This chemical reaction creates heat in the concrete. This heat can make the particles move, which will cause stress and deformation in the concrete, which can cause cracks in the concrete. Therefore, understanding the strain during the curing process is very valuable (Ahangari *et al*. 2013).

2. Materials and Method

This research was carried out experimentally in the Materials and Construction Laboratory, Civil Department, Faculty of Engineering, University of Lampung, Indonesia, using three concrete beam specimens with a fc' 20.75 MPa. Measuring 15 cm x 15 cm x 60 cm according to ASTM C 78-08, which is placed on two supports installed at 7.5 cm from the end of the test object.

2.1 Material

The material used in this research is PCC type with the Tiga Roda brand. Fine aggregate comes from the Gunung Sugih quarry, in Central Lampung, Indonesia. Coarse aggregate comes from PT. Batu Berkah, South Lampung, and the water used comes from the Materials and Construction Laboratory of the Civil Engineering Department, Faculty of Engineering, University of Lampung, Indonesia. The concrete used is normal concrete with a design compressive strength of 20.75 MPa and a slump value of 6–18 cm using the SNI 03-2834-2000 design mix (Table 1).

Table 1. Mix Design for Normal Concrete

Materials	Need
Cement (kg/m^3)	379.63
Fine Aggregate(kg/m^3)	741.63
Coarse Aggregate(kg/m^3)	1013.75
Water (kg/m^3)	205
w/c	0.54

2.2 Method

The strain is obtained from one EVWSG (Embedded Vibrating Wire Strain Gauge), which is installed on each test object. The length of the EVWSG is 153 mm. The EVWSG position is 5 cm from the end of the test object. The schematic can be seen in Figure 1 and Figure 2a.

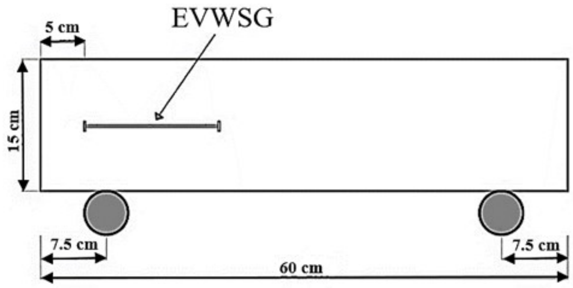

Figure 1. Schematic of beam specimens with EVWSG

EVWSG can detect strains up to 3000 με with an accuracy of about 0.025% and concrete temperatures between -80°C and 60°C with an accuracy of about 0.5%. The EVWSG used is the Geokon 4200 type. Immediately after casting, the test object is covered using styrofoam to minimize the evaporation of water from the concrete, the entry of outside air into the concrete, and the heat of the concrete without external influences (Figure 2b). After 24 hours, the mold on the test specimen was removed. Next, the object was soaked in a tub filled with fresh water for 7 days, according to SNI 6880 (2016). When soaking, the position of the test object was arranged horizontally, like the position of an actual concrete beam (Figure 2c). The water height in the soaking tank was kept the same as the height of the support (5 cm) made at the bottom of the test object (Figure 2d). Thus, it is hoped that there will be a balance between the tensile force acting upwards and the compressive force acting downwards on the concrete in the test specimen. The temperature of the soaking water is measured at the same time as the concrete strain is recorded.

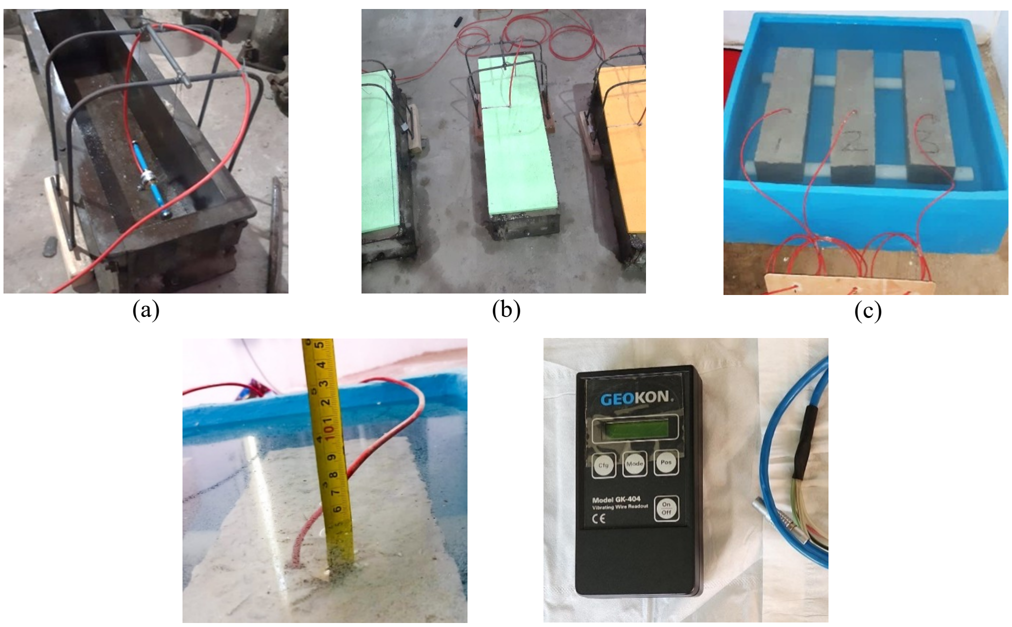

Figure 2. (a) EVWSG installation; (b) Styrofoam installation; (c) Placing the beam in the pool
(d) Measuring the pool water level; (e) Reading with a readout

Recording of strains and temperatures in concrete during curing is carried out every 60 minutes when the concrete is 24–48 hours old, every 2 hours at 3–8 days old, as well as recording the temperature and relative humidity and soaking water temperature.

This research includes observations of the deformation of the three concrete samples tested. Data from the three samples were analyzed using the Dixon criterion method, which is used to select or discard data that is likely to be an outlier. Dixon's criterion equation for 3–7 samples with$X_1 \leq X_2 \leq ... \leq X_n$ is as follows:

Dixon's criteria for the smallest data : $D_{3\text{-}7} = (X_2 – X_1) / (X_n – X_1)$ (1)

Dixon's criteria for the largest data : $D_{3\text{-}7} = (X_n – X_{n\text{-}1}) / (X_n – X_1)$ (2)

Equations 1 and 2 are used to select the largest or smallest data from the three samples at a certain age. In this research, observations were made during the curing period (2–8 days). After that, the three samples were combined into one final dataset and then compared with the temperature and RH data around the concrete.

3. Results and Discussions

3.1. Result

The results of research on behavior in concrete during the curing period can be seen in Figure 3.

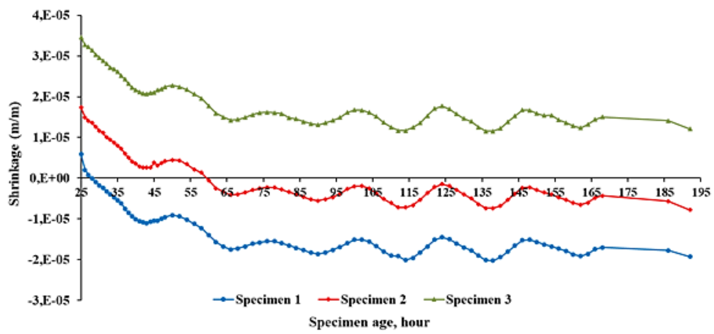

Figure 3. Concrete behavior during curing

The results of research on three samples show that all three have similar shrinkage graphic patterns, which indicates that the samples have the same material composition or soaking conditions. In the age range of 25–43 hours, concrete continues to expand due to the high relative humidity conditions around it. Furthermore, in the range of 43–50 hours, the concrete shrinks, this occurs during the day when the relative humidity is low. In the 50–65-hour range, there is significant development, along with an increase in the relative humidity value around the concrete and a decrease in the air temperature and the temperature inside the concrete. Then, when the concrete is 65–192 hours old, it continues to experience shrinkage and expansion, which are relatively equal in magnitude and stable. Data from the three samples, as presented in Figure 3, were processed using ASTM E 178-02. The data assessed is data at the age of 2–8 days because, during that period, the concrete is cured for 7 days (SNI 2847 2019). The data selected to be processed using Dixon's criteria is all the data at peaks and valleys in Figure 3. The results of data processing can be seen in Figure 4.

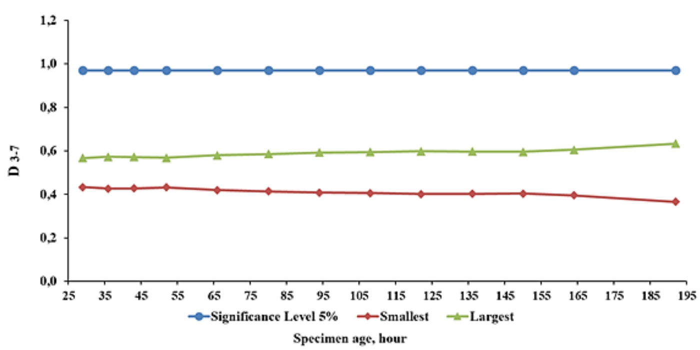

Figure 4. Results of strain data processing for the largest and smallest values for the three samples

In the most extreme data processing, both the largest and smallest of the three concrete samples during the curing period are smaller at the significance level limit value of 5%, so all data is accepted. The strain is taken from the average strain of the three samples and is presented in Figure 5.

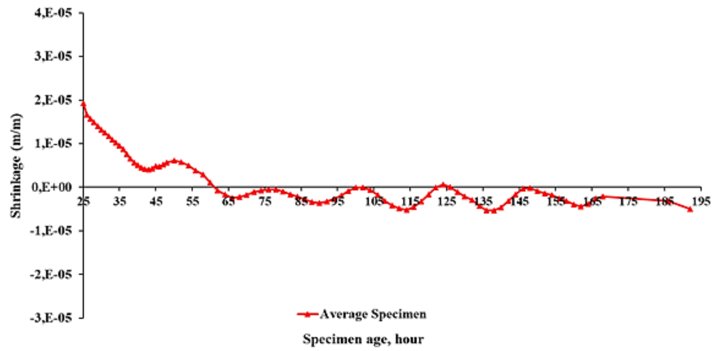

Figure 5. Strain in concrete during curing

The internal temperature of the concrete in the three samples was processed in the same way. The average temperature in the concrete, soaking water temperature, and surrounding temperature can be seen in Figure 6.

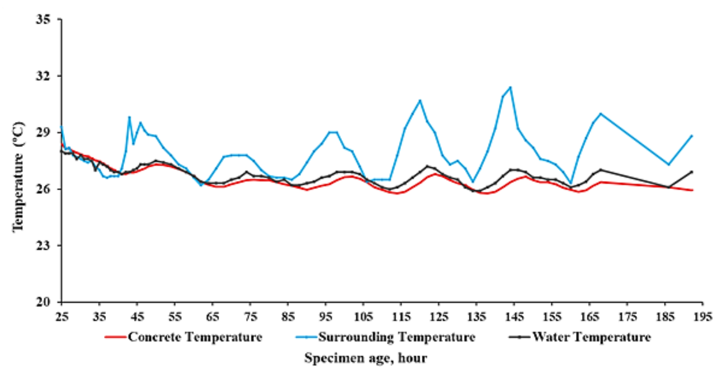

Figure 6. Average temperature in concrete, surrounding temperature, and soaking water temperature

The results of observations of relative humidity and surrounding temperature are presented in Figure 7.

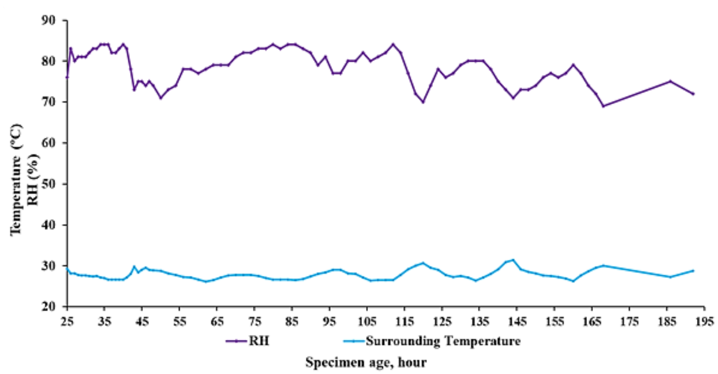

Figure 7. Relative humidity and surrounding temperature

3.2. Discussion

According to SNI 2493 (1991), there are special requirements for the temperature of the soaking water for test objects. This standard requires that the room temperature for storing test objects be in the range of 20–30 ºC, and the water temperature when immersing the test objects must be in the range of 23 ± 2 ºC (SNI 2493 1991).

However, in this study, the average water temperature used for immersing the test objects was 26.8 ºC. The cause of the water temperature being higher than recommended is due to the air temperature around the concrete during the concrete curing process, which is also quite high, ranging from 26–31.4 ºC. This information is based on data provided by the Meteorology, Climatology, and Geophysics Agency (BMKG) for the Bandar Lampung area in June 2023, which recorded an average temperature of around 28.3 ºC.

3.2.1. Relationship between surrounding, soaking water temperature and concrete temperature

There is the same temperature fluctuation pattern between the surrounding temperature, the soaking water temperature, and the temperature inside the concrete (Figure 6). An increase in the surrounding temperature will result in a change in the temperature of the soaking water (Table 2).

Table 2. Relationship between surrounding, soaking and concrete temperature

Temperature						**Different temperatures**			
Surrounding		**Soaking water**		**Concrete**		**Surrounding & soaking water**		**Soaking water & concrete**	
Peak (ºC)	**Time (hour)**	**Peak (ºC)**	**Time (hour)**	**Peak (ºC)**	**Time (hour)**	**Peak (ºC)**	**Time (hour)**	**Peak (ºC)**	**Time (hour)**
29.5	46	27.5	50	27.3	50	2.0	4	0.2	0
27.8	70	26.9	74	26.5	74	0.9	4	0.4	0
29.0	96	26.9	98	26.7	102	2.1	2	0.2	4
30.7	120	27.2	122	26.8	124	3.5	2	0.4	2
31.4	144	27.0	144	26.7	148	4.4	0	0.3	4
30.0	168	27.0	168	26.4	168	3.0	0	0.6	0

During 7 days of soaking, the concrete temperature and ambient temperature showed similarities to a sinusoidal graph. During this period, there were 6 waves, meaning 6 temperature peaks in both the soaking water and the concrete temperature. The lowest temperature of soaking water is 25.9 ºC, the highest temperature is 27.5 ºC. Meanwhile the highest ambient temperature is 31.4 ºC and the lowest is 26.5 ºC (Figure 6). Thus, the surrounding temperature can raise the soaking water ±4 ºC, but a decrease in the surrounding temperature does not necessarily reduce the temperature of the soaking water to the same as the surrounding temperature because the water does not immediately release heat. There was a delay in the peak temperature of the soaking water relative to the peak surrounding temperature in 4 waves. Delays decreased until the last 2 waves occurred simultaneously (Table 2). The delay is due to the need for time to warm up the water at the beginning because the water is taken from the source, while at a later time, the delay decreases because the water is already hot.

The temperature in the concrete can be said to coincide with the temperature of the soaking water. The peak concrete temperature in the first wave was the same, namely 27.3 °C, with a peak soaking water temperature of 27.5 °C, and occurred simultaneously (Figure 6). The peak temperature of the concrete in the next wave is lower than the peak temperature of the soaking water and is slower. At the beginning of curing, the number of pores is still very large, so the influence of the temperature of the soaking water directly affects the temperature in the concrete, while in the next wave, the number and size of the pores decrease. The number and size of pores are reduced by the growth of hydration products, so that the temperature of the soaking water takes longer to reach the peak temperature of the concrete, and as a result, the peak temperature of the concrete is lower than the temperature of the soaking water (Table 2). The lowest concrete temperature and soaking water temperature, respectively, are ±25.8 ºC and 26ºC (Figure 6). If both are considered the same, then the average of the concrete temperature (Tc) and soaking water temperature (Tsw) is Tc = Tsw = ±27.75ºC.

3.2.2. Relationship between deformation and temperature in concrete

Temperature in concrete arises from chemical reactions. The maximum concrete temperature during curing is 28.4 ºC, this also occurs at the beginning of curing. The maximum temperature during the first 24 hours was 31.2 ºC. The average concrete temperature is 26.6 ºC and the average air temperature is 27.9 ºC. Thus, the heat of hydration does not need to be taken into account during curing, especially as a relationship has been found between the temperature of the concrete and the temperature of the soaking water. The environment influences the internal temperature of concrete more than heat due to hydration reactions.

The deformation during curing is below the 0 line, so at the beginning of curing, the concrete expands. Furthermore, the deformation has a sinusoidal shape. Concrete expands and contracts regularly, with a maximum expansion value of 5E-06. Concrete also can shrink at the same value and rate (Figure 5). This means that swelling and shrinkage during curing are reversible, or the concrete is in an elastic condition, even though the soaking water temperature is higher than 1–6.4 °C against Indonesian standard requirements.

This deformation during curing can be approximated as a straight line, which is the average of shrinkage and expansion, namely ε_{curing} = 2.5 E-06 (Figure 5).

The peak of deformation occurs at the same time as the peak of temperature in the concrete (Figure 8).

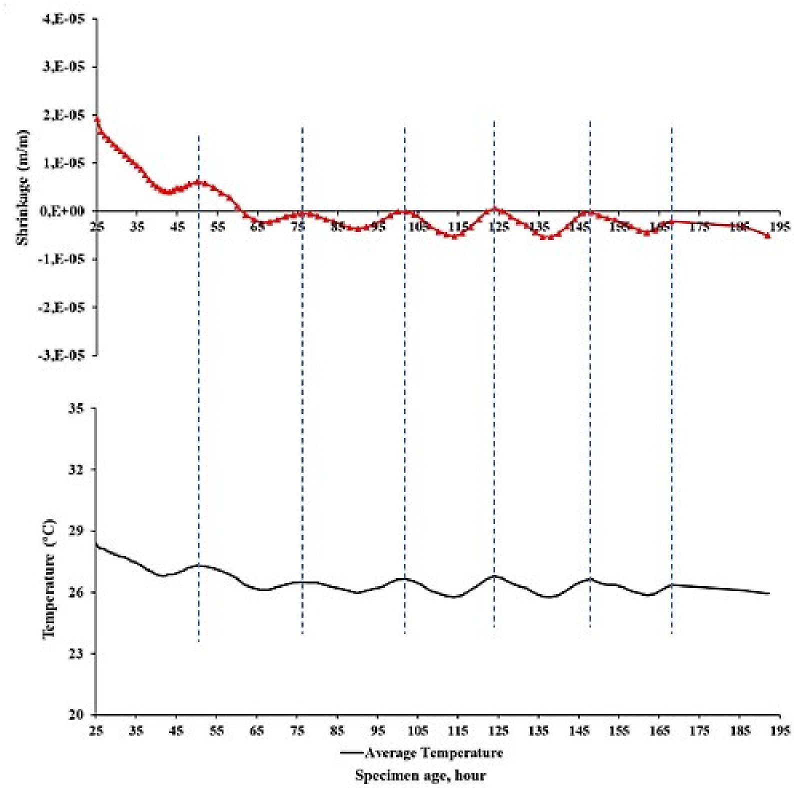

Figure 8. Relationship between concrete temperature and shrinkage

Thus, there is a very close relationship between concrete temperature and deformation, or soaking water temperature and deformation. It can be said that the soaking water temperature of 27.75 °C causes shrinkage during curing 2.5E-06.

3.2.3. The relationship between deformation and air humidity

From the observations, the temperature and relative humidity of the surroundings are obtained. These results are presented in Figure 7. The relative humidity graph does not appear to be regular, especially at 35–95 hours, but only appears to have a pattern at 95 hours, or the end of the curing period. At 55-115 hours, relative humidity can be approached at a constant value of ±80%. Meanwhile, the air temperature has a sinusoidal pattern, starting with a small initial wave until the middle of the curing period, and then increasing until the end of the curing period (Figure 7). Due to the irregularity of the surrounding relative humidity pattern, no conclusion can be drawn on the relationship between temperature and surrounding relative humidity, so there is no relationship between deformation during curing and surrounding humidity.

4. Conclusion

Deformation and temperature in concrete during curing with a soaking system have been studied. From the discussion above, the following can be concluded:

1. The soaking water temperature pattern follows the surrounding temperature pattern; the temperature pattern in concrete follows the temperature pattern of the soaking water. This type of pattern is sinusoidal.
2. There is a delay in the peak temperature of the concrete relative to the peak temperature of the soaking water due to the reduction in the number and size of pores due to the growth of hydration products in the

concrete.

3. There is a decrease in the peak temperature of the concrete relative to the peak temperature of the soaking water.
4. Changes in the surrounding temperature result in changes in the temperature of the soaking water. An ambient temperature of 31.4 °C can raise the temperature of the soaking water to ±4 °C. Soaking water temperature is higher by 1-6.4 °C than the Indonesian standard.
5. Concrete deformation during the curing period appears to be swelling and shrinking with almost the same magnitude and rate, therefore during curing the concrete is elastic.
6. Concrete deformation during curing for normal concrete can be approximated by a constant value that is not a function of time.
7. The temperature pattern in concrete is the same as the deformation pattern, so both have a very close relationship. Concrete temperature of 27.75 °C results in deformation of 2.5E-06.

References

Ahangari, K., Najafi, Z., Zakariaee, S.J.S., & Arab, A. (2013). Estimating strain changes in concrete during curing using regression and artificial neural network. *Journal of Concreting Engineering*. 2013 ID 380693. https://doi.org/10.1155/2013/380693

Alaydrus, M., Nurlina, S., & Remayanti, C. N. (2016). Analisis deformasi struktur balok beton bertulang dengan lubang hollow core pada tengah balok. *Jurnal Teknik Sipil Universitas Brawijaya*. https://media.neliti.com/media/publications/111762-ID-analisis-deformasi-struktur-balok-beton.pdf

ASTM C 78-08. (2008). *Standard test method for flexural strength of concrete (using simple beam with third-point loading)*. American Society for Testing and Materials, 1-4. New York.

ASTM E 178-02. (2002). *Standard practice for dealing with outlying observation*. American Society for Testing and Materials, 1-18. New York.

Badan Standarisasi Nasional. (2019). SNI 2847: *Persyaratan beton structural untuk bangunan gedung dan penjelasannya*. Jakarta.

Badan Standarisasi Nasional. (2014). SNI 15-7064: *Semen portland komposit*. Jakarta.

Badan Standarisasi Nasional. (2011). SNI 2493: *Tata cara pembuatan dan perawatan benda uji beton di laboratorium*. Jakarta.

Badan Standarisasi Nasional. (1991). SNI 2493: *Metoda Pembuatan dan Perawatan Benda Uji Beton di Laboratorium*. Bandung.

BMKG. Badan Meteorologi, Klimatologi, dan Geofisika. (2023). BMKG Provinsi Lampung. [Online] Available:https://lampung.bmkg.go.id/info/?ase=vivideoklim&r=iklim# [Accessed 5 Sept. 2023]

Challadattakarthik, Ruthvik,U., & Sivavignan. (2020). Study on the Influence of the methods of curing on the strength properties pf concrete. *Journal on Structural Engineering*, 9(1), 7 pages. https://doi.org/10.26634/jste.9.1.17006

David, W., & Supartono, F. X. (2023). Analisis pengaruh construction stage terhadap deformasi dan gaya dalam struktur gedung bertingkat dengan dinding geser. *JMTS: Jurnal Mitra Teknik Sipil*,6(1), 109-122. https://journal.untar.ac.id/index.php/jmts/article/download/17043/13736

Kioumarsi, M., Azarhomayun, F., Haji, M., & Shekarci, M. (2020). Effect of Shrinkage Reducing Admixture on Drying Shrinkage of Concrete with Difference w/c Ratios. Materials, 13, 5721. https://doi.org/10.3390/ma13245721

Kate, S.R., & Pawar, Y. (2020). Curing of concrete: A Review. *International Research Journal of Engineering and Technology*, 7 (8), 5 pages. https://dx.doi.org/10.13140/RG.2.2.32095.07848

Kumar, A.S., & Babu, T.S. (2015). Effect of self-curing compound on strength and durability of M25 mix concrete. *International Journal of New Technology and Research*, 1, 01-04. https://media.neliti.com/media/publications/263677-effect-of-self-curing-compound-on-streng-0ac202b1.pdf

Kurtis. (2015). Portland cement hydration. School of Civil Engineering, Georgia Institute of Technology, Atlanta, Georgia. https://media.neliti.com/media/publications/111762-ID-analisis-deformasi-struktur-balok- beton.pdf

Murison, R., Jacobsz, S., Silva, T., Gaspar, T., & Osman, A. (2022). Monitoring bending moment distributions in large-scale laterally loaded piles using fibre Bragg gratings and vibrating wire strain gauges. *Korean Geotechnical Society (KGS).* https://www.researchgate.net/publication/363885413

Niken, C. (2019). One day high-performance concrete mechanism of plate, beam, and column. *IOP Conf. Series: Materials Science and Engineering*, 669 012012. doi:10.1088/1757-899X/669/1/012012

Niken, C., Elly, T., & Supartono, F. X. (2017). Long-term deformation of beam and column of high performance concrete. *International Journal of Technology*, 8(5), 811-819. https://doi.org/10.14716/ijtech.v8i5.863

Patah, D., Dasar, A., & Indrayani, P. (2022). Pengaruh perbedaan metode terhadap kuat tekan beton. *Journal of Civil Engineering*, 4 (1). https://doi.org/10.31605/bjce.v4i1.1536

Sachan, K., & Srivastava, S. (2022). A comprehensive study of self-curing concrete. *AIP Conf. Proc.* 2413, 030015. https://doi.org/10.1063/5.0091324

Smith, J. (1999). One of Volvo's core values. [Online] Available: https://www.volvo.com/environment/index.htm (July 7, 1999)

Susanto, D., Djauhari, Z., & Olivia, M. (2019). Karakteristik beton Portland composite cement (PCC) dan silica fume untuk aplikasi struktur di daerah Laut. *Jurnal Rekayasa Sipil*, 15 (1), 1-11. https://doi.org/10.25077/jrs.15.1.1-11.2019

Tumpu, T., Irianto., & Parung, H. (2020). The effect of curing methods on compressive strength of concrete. *IOP Conf. Series:Earth and Enviromental Science*. https://doi.org/10.1088/1755-1315/921/1/012007

Wang, P., Fu, H., Guo, T., Zuo, W., Zhao, H., Tian, L., & Chen, C. (2021). Volume deformation of steam-cured concrete with fly ash during and after steam curing. *Construction and Building Material*, 306. https://doi.org/10.1016/j.conbuildmat.2021.124854