Experimental evaluation of concrete shrinkage deformation under the influence of foehn wind in vietnam

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Abstract. Foehn wind or foehn effect is a hot dry wind type blowing down from the mountains. It appears in the middle of Vietnam from early April to mid-September every year. The foehn effect has characteristic humidity drops deeply while the temperature rises. This has affected the concrete shrinkage deformation in the work construction. This paper presented an experimental study to evaluate the concrete shrinkage deformation under the influence of the Foehn wind in Vietnam. The experiment was performed in a simulated environment with temperatures high and humidity down, which is intended to simulate the phenomenon of foehn wind and climate change in the middle of Vietnam. The datasets obtained from this experiment were tested with previous results, it was highly accurate and reliable. The research obtained results have reflected that the concrete shrinkage deformation in foehn wind conditions has a significant effect compared to normal conditions in both the value and speed. In addition, this test also shows that the concrete shrinkage deformation with Ca(OH)2 added to in the mixture is smaller than concrete without Ca(OH)2.

1. Introduction

Concrete is a nonuniform material made of cement and its hydration products, aggregates, liquid and vaporized water, air, and maybe additional additives. It is widely recognized to show time-dependent deformation from autogenous and drying shrinkage [1]. Although the shrinkage phenomenon of concrete has been a subject of in-depth study, it is critical to further research each specific environmental condition. . Mateos, et al. [2] assessed the impact of the environmental condition on the shrinkage of concrete caused by moisture and its coefficient of thermal expansion.

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Du, et al. [3], Zhang, et al. [4], and Wang [5] investigated the effect of wind speed on the early shrinkage of concrete. Ziari, et al. [6] and Niu, et al. [7] studied the effect of temperature, relative humidity, and wind speed on concrete pavement and dam concrete, respectively. However, neither of the previous studies investigate the impact of the foehn wind on concrete shrinkage.

Recently, the effects of foehn wind have been studied with different aspects. Le Phuc, et al. [8] investigated the cooling island impact of urban lakes in heat waves under foehn and climate change. Sekuła, et al. [9] examed the impact of foehn wind on the urban boundary layer in complex terrain in Poland. Ma, et al. [10] modeled the relative roles of the foehn wind in the 2002 Beijing heat wave. The literature review demonstrated that a study related the concrete shrinkage due to the foehn wind in Vietnam has not yet been performed.

This study aims to investigate the impact of foehn winds in Vietnam on concrete shrinkage deformation. The concrete sample with grades of M150 and M200 are modeled under foehn wind conditions with different temperatures and humidity. The effect of Ca(OH)2 on concrete shrinkage was also considered.

2. Research significance

Foehn winds or foehn effect is a hot dry wind type blowing down from the mountains. It appears in the middle of Vietnam from early April to mid-September every year. The foehn effect has characteristic humidity drops deeply while the temperature rises. This has affected the concrete shrinkage deformation in the work construction.

From that fact, an experiment to evaluate the concrete shrinkage deformation under the influence of the Foehn winds in Vietnam was done. The experiment has been performed in a simulated environment with temperatures high and humidity down, which is intended to simulate the phenomenon of foehn wind and climate change in the middle of Vietnam.

The datasets obtained from this experiment were tested with previous results, it was highly accurate and reliable. The research obtained results have reflected that the concrete shrinkage deformation in foehn winds conditions has a significant effect compared to normal conditions in both the value and speed. In addition, this test also shows that the concrete shrinkage deformation with Ca(OH)2 added to the mixture is smaller than concrete without Ca(OH)2.

3. Foehn winds phenomenon in Vietnam

Foehn winds is a hot dry wind type blowing down from the mountains, also known as the foehn effect. This property greatly affects the shrinkage of concrete, especially during the initial forming stage. The winds forms from the gulf of Thailand, moving in a southwest-northeast direction through Cambodia and Laos. When approaching the Truong Son mountain (Vietnam), the wind accelerates, passes, and spills over the north-central and central-central regions of Vietnam as presented in Fig. 1 and Fig. 2. Localities such as Nghe An, Quang Binh, and Thua Thien Hue provinces have higher wind intensity and frequency than other areas. The wind usually appears from early April to mid-September, 8-9 AM to evening, and strongest from midday to late afternoon. Humidity drops to 30% while the temperature rises to 45°C. The properties and characteristics of foehn winds are:

- Cloud formation and precipitation result in moisture loss and heat gain as the air ascends.
- Alternatively, dry air sourced from higher up plunges down the lee slopes, becoming warm as it descends.
- Turbulence over the mountain transports heat into and moisture out of the low - level foehn winds.

- The dry, cloudless leeside conditions lead to further warming via solar radiation.

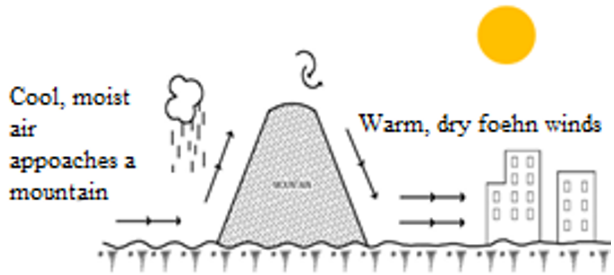

Figure 1. Formation of foehn winds

4. Testing concrete shrinkage at high temperature

Concrete shrinkage deformation is dependent on input parameters including internal factors, external factors, and factors showing the nature of aggregate and materials. Therefore, shrinkage deformation evaluation of concrete has been many prediction models such as ACI 209-2008, GL2000, RILEM - B3, EN 19921-1-1 2004, SABS 0100- 1; and MC -10 [11-15]. Besides, to accurately evaluate the concrete shrinkage deformation in a specific environmental condition, it is advisable to use the most accurate experiment.

In this work, an experimental program was organized to quantify shrinkage of concrete. The number of specimens, specimen dimension, concrete types, stress strength ratios, etc, were chosen as main parameters. Experiment was carried out to measure and evaluate the shrinkage deformation of concrete under foehn wind conditions, with an experimental period of 390 days.

This work presents an experimental test to investigate the effect of high temperatures on the Concrete shrinkage deformation. High temperature is a major feature of the foehn wind in Vietnam. In this regard, six parameters were selected: water-to-cement ratio (w/c), water content (w), maximum aggregate size (size), silica fume (SF), ground granulated blast furnace slag (GGBFS), and bulk volume of coarse aggregate (CA). A description of the material properties, concrete mixture design method, curing regime, and testing methods are presented in Khairallah [16] and Holt [17]. The experimental procedure is according to the guideline of Institute [18], Tran and Nguyen [19], Tran, et al. [20], Holt [17], and Omar, et al. [21]. Shrinkage experiments were performed with two grades of concrete M150 and M200 for 390 days, each of which consists of three samples labeled with the name “S”. Moreover, the purpose of this experiment also evaluates the influence of $Ca(OH)_2$ on concrete shrinkage, named “SC”. Table 1 presented ratio of Sand, Aggregate, Cement of M150 and M200 concrete.

The sample size is 100×100×400 mm (width×height×length). The concrete shrinkage was performed at the laboratory of Vinh University, from March 2021 to April 2022 (390 days), under 40 ^oC and 40 - 80% of humidity. It is shown in Fig. 3-4.

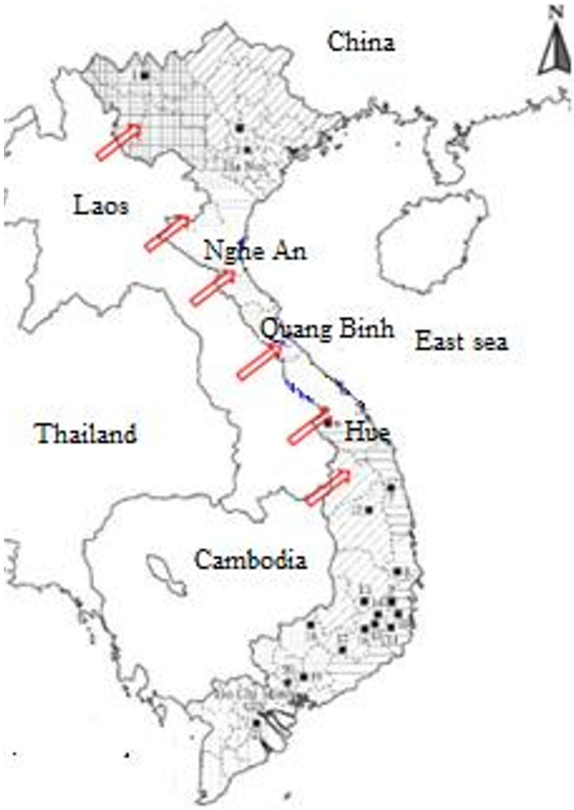

Figure 2. Zones of influence of foehn winds

Figure 3. Samples for concrete shrinkage eveluation

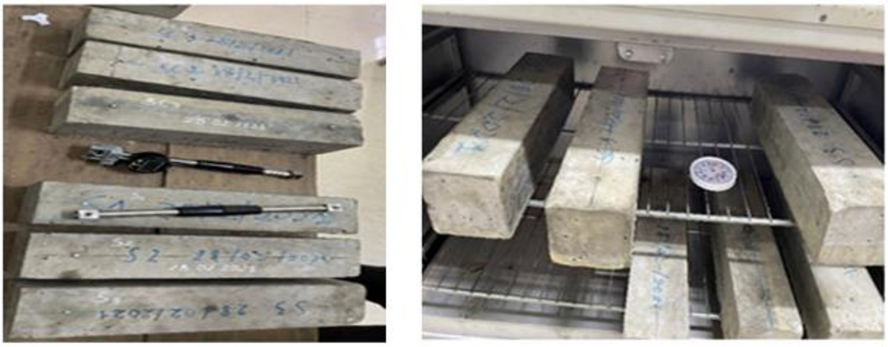

Figure 3. Samples at the step of shrinkage measurement

Table 1. Ratio of sand, aggregate, cement of M150 and M200 concrete

Grades of concrete	C (kg)	S (kg)	a (kg)	W (L)
M150	243.8	674.9	1231.1	195.0
M200	292.5	648.3	1216.3	195.0

5. Results and discussions

The experimental results are shown in Table 2 and Table 3. Fig. 5 and Fig. 6 present the early-age shrinkage of the concrete M150 and M200. In the beginning, within seven days of curing, the degree of the concrete shrinkage is fast. However, the degree of the shrinkage decreases gradually after seven days. The value of shrinkage deformation obtained in the experiment is quite large compared to the value measured under standard conditions (temperature 27 ± 20 ºC, humidity 80 ± 5%). The effect of $Ca(OH)_2$ is also illustrated in Fig. 5 and Fig. 6. The level of shrinkage of “SC” is lower up to about 20% compared to that of “S”.

Table 2. Experimental results of the shrinkage of concrete grade M150

Date	Template (oC)	Humidity (%)	Number of days	Dataset on Shrinkage of concrete grade M150					
				S1	S2	S3	SC1	SC2	SC3
3/7/2021	25	71		0.082	0.069	0	0	0.067	0.064
	30	60	1	0.068	0.081	0.071	0.071	0.075	0.065
3/8/2021	24.5	81		0.076	0.071	0.062	0.055	0.064	0.043
	30	58	2	0.064	0.061	0.058	0.047	0.057	0.045
3/9/2021	25	78		0.063	0.068	0.061	0.048	0.048	0.041
	40	44	3	0.091	0.073	0.08	0.076	0.082	0.068
3/10/2021	28	78		0.058	0.049	0.048	0.046	0.046	0.036
	40	44	4	0.095	0.079	0.094	0.068	0.078	0.068
3/11/2021	27	73		0.06	0.044	0.057	0.04	0.045	0.037
	42	42	5	0.086	0.074	0.085	0.07	0.07	0.071
3/12/2021	28	72		0.057	0.04	0.051	0.032	0.035	0.035
	40	46	6	0.083	0.067	0.085	0.066	0.066	0.078
3/13/2021	28.5	74		0.038	0.025	0.039	0.017	0.025	0.02
	40	45	7	0.069	0.043	0.065	0.05	0.048	0.049

Date	Template (oC)	Humidity (%)	Number of days	Dataset on Shrinkage of concrete grade M150					
				S1	S2	S3	SC1	SC2	SC3
3/22/2021	25	70		0.015	0.011	0.018	0.013	0.003	0.004
	40	40	14	0.035	0.004	0.042	0.008	0.012	0.019
5/4/2021	29	74		0.003	0.020	0.032	0.029	0.010	0.02
	40	48	30	0.042	0.016	0.04	0.006	0.026	0.02
4/5/2021	28	75		0.03	0.052	0.015	0.057	0.041	0.038
	40	45	60	0.008	0.035	0.025	0.037	0.016	0.022
5/6/2021	30	80		0	0.010	0.04	0.09	0.07	0.06
	40	45	90	0.05	0.080	0.02	0.07	0.06	0.05
5/7/2021	32	75		0	0.115	0.126	0.01	0.093	0.083
	42	50	120	0.058	0.094	0.104	0.09	0.072	0.062
6/8/2021	30	75		0.085	0.121	0.13	0.119	0.095	0.09
	41	55	150	0.075	0.117	0.123	0.107	0.09	0.078
17/9/2021	32	80	180	0.065	0.101	0.111	0.097	0.065	0.066
6/12/2021	31	70	240	0.052	0.094	0.098	0.081	0.063	0.077
7/4/2022	33	80	360	0.057	0.089	0.096	0.075	0.053	0.068

Table 3. Experimental results of the shrinkage of concrete grade M200

Date	Template (oC)	Humidity (%)	Number of days	Dataset on shrinkage of concrete grade M200					
				S1	S2	S3	SC1	SC2	SC3
3/13/2021	40	46	1	0.103	0.099	0.096	0.099	0.104	0.091
	28.5	74		0.055	0.054	0.051	0.051	0.052	0.048
	40	45		0.049	0.051	0.049	0.038	0.04	0.032
3/14/2021	29	72	2	0.045	0.051	0.047	0.053	0.064	0.051
	40	42		0.09	0.084	0.08	0.08	0.083	0.073
3/15/2021	30	68	3	0.04	0.048	0.035	0.031	0.036	0.031
	42	40		0.088	0.08	0.074	0.078	0.082	0.072
3/16/2021	28	74	4	0.027	0.028	0.023	0.024	0.033	0.024
	42	42		0.073	0.074	0.067	0.073	0.078	0.069
3/17/2021	31	70	5	0.024	0.026	0.019	0.021	0.027	0.018
	39	50		0.062	0.057	0.044	0.05	0.055	0.045
3/18/2021	31	77	6	0.016	0.018	0.01	0.021	0.028	0.02
	40	46		0.058	0.048	0.043	0.045	0.049	0.041
3/19/2021	35	70	7	0.02	0.022	0.015	0.016	0.025	0.018
	40	48		0.061	0.059	0.054	0.05	0.069	0.049
3/26/2021	23	78	14	0.01	0.01	0.013	0.02	0.01	0.01
	40	44		0.042	0.04	0.032	0.06	0.041	0.035

Date	Template (oC)	Humidity (%)	Number of days	Dataset on shrinkage of concrete grade M200					
				S1	S2	S3	SC1	SC2	SC3
9/4/2021	28	78	21	0.02	0.02	0.029	0.02	0.01	0.02
	40	48		0.046	0.015	0.014	0.05	0.026	0.014
10/5/2021	30	75	30	0.05	0.05	0.052	0.02	0.04	0.05
	40	47		0.04	0.04	0.044	0.058	0.03	0.04
7/6/2021	40	75	90	0.09	0.09	0.096	0.03	0.08	0.09
	39	70		0.08	0.07	0.082	0.06	0.06	0.07
	38	70		0.11	0.11	0.119	0.02	0.1	0.11
6/8/2021	40	68	150	0.1	0.1	0.111	0.05	0.09	0.1
17/9/2021	33	75	180	0.09	0.09	0.097	0.03	0.07	0.08
6/12/2021	32	80	360	0.07	0.08	0.085	0.04	0.07	0.07
7/4/2022	33	75	390	0.06	0.07	0.078	0.03	0.05	0.06

Tables 2-3 and Figs. (5-6) show that high temperature and low humidity occur during foehn winds. Specially, temperature is as high as 42 degrees celsius then humidity is down to approximately 30%. These are the two basic factors that have affected the concrete shrinkage deformation.

Figs. (5-6) show that the concrete shrinkage deformation increases very strongly in the period in the first 3-5 days. This proves that foehn wind is a strong influence on concrete shrinkage deformation.

Concrete shrinkage deformation occurring on the surface of the concrete specimen was very strong, parallel to the rapid water evaporation rate during strong foehn wind. On the surface of the concrete sample, small cracks were found, which proves that the concrete shrinkage strain has developed rapidly.

The impact of Ca(OH)2 on the concrete shrinkage deformation is considerable. The concrete shrinkage deformation with $Ca(OH)_2$ admixture is smaller than concrete without $Ca(OH)_2$

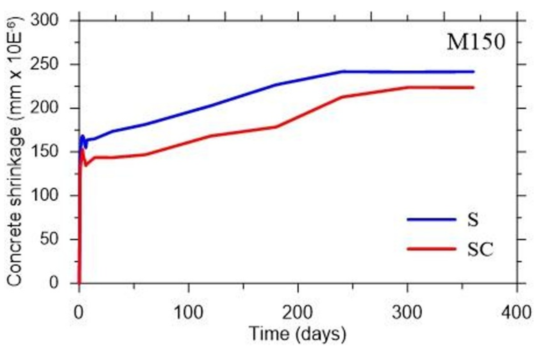

Figure 4. Time-shrinkage deformation of concrete M150

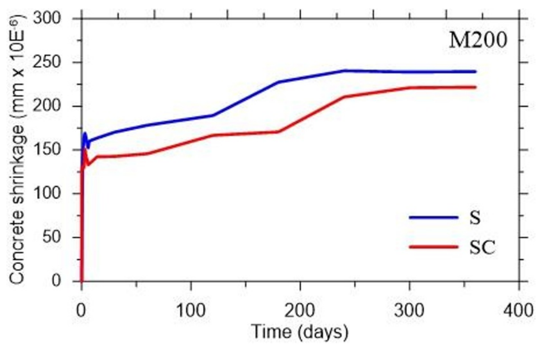

Figure 5. Time-shrinkage deformation of concrete M200

6. Conclusions

This study were performs a series of experiments to the concrete shrinkage deformation evaluate under the fohn win in Vietnam. The concrete with the grade of M150 and M200 were used. The normal and $Ca(OH)_2$ admixture concrete is also considered. The following conclusions are withdrawn.

The experiment has obtained the results of the temperature and humidity in the environment in the foehn wind, which is much different from the normal environment. High ambient temperature due to wind effect can be up to 42-45 degrees, low humidity sometimes reaches approximately 30%. It is for this reason that it is necessary to have a suitable model for predicting concrete shrinkage in the foehn wind temperature condition.

The new proposal for a concrete shrinkage prediction model that needs to take into account the factors of the foehn wind speed, the rate of change in humidity and temperature caused by the foehn wind.

The presence of $Ca(OH)_2$ in the concrete mixture reduced the rate of water evaporation, thereby reducing the rate of increase of concrete shrinkage strain. In conditions foehn wind, it is essential to add $Ca(OH)_2$ with a reasonable ratio to the concrete mix.

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