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Effect of Improper Curing on Concrete Performance

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ABSTRACT

In a drive to reduce the carbon footprint of construction, the cement industry increasingly uses supplementary cementitious materials, such as pulverised fuel ash (PFA). However, such binder hydrates more slowly and may require longer curing times. This project has looked at the impact of improper curing as a function of concrete mix design; (CEM I 52.5N) vs. CEM I plus 30%PFA replacement, workability (10 to 30 and 60 to 180 mm slump) and target mean strength (20, 50 and 80MPa). Samples were cured in fog room at 20^0 C or under ambient conditions 20^0 C and 42% RH.
The degree of saturation (DOS) of concrete affects the measured strength. Performing strength testing at constant degree of saturation is of interest to know the effect of improper curing. Therefore, in this study subsequent to curing, the specimens will be dried in oven at 40^0 C to constant weight, unconfined compressive strength will be determined at various degrees of saturation while changes in weight will be measured also. The result of compressive strength against time will be plotted and there the effects due to DOS will be obtained with the effect due to degree of hydration. The impact of each of the mix design variables mentioned above on improper curing and the DOS will be studied.

1. INTRODUCTION

Concrete is, by far, the most popular global construction material; with global production approaching 20×10^{12} kg per annum [1] . The use increases annually at several percentage points as large developing nations upgrade and install infrastructure.

Portland cement is the most commonly used material in producing concrete [2]. However, the production of one ton of Portland cement releases ~900kg of carbon dioxide, such that that vast amount of new concrete is responsible for ~7% of global anthropogenic greenhouse gas emissions. The global cement industry therefore has a significant role to play in the transition to a low carbon economy [4-7].

One approach to reducing emissions has been the use of supplementary cementitious materials (SCMs). Fly ash, blast furnace slag, silica fume and metakaolin are common SCMs, which may improve concrete durability, reduce the risk of thermal cracking in mass concrete and are less energy- and CO_2 -intensive than cement [9].

Pulverised fuel ash (PFA) is a by-product of coal combustion in the generation of electricity. Most PFA particles are spherical and amorphous; ranging in size from 10 to 100µm. Fly ash is an important pozzolan, which offers a number of benefits to Portland cement concrete; including reduced heat of hydration, improved long term strength and reduced permeability.

However, the use of PFA slows the rate of hydration, and may require longer curing times, thus assisting the hydration of cement and enabling the pozzolanic reaction. Curing of concrete is very essential for strength gain and durability [13], both of which may be compromised by improper curing practices, particularly at the surface of the concrete. This is particularly significant as it constitutes the cover zone for most reinforced concrete construction [14].

Several investigations have reported that the strength development and durability of concrete mixtures containing SCMs is related to the extent and degree of curing [16,17]. For water cement ratios (w/c) greater than approximately 0.42, there is sufficient water in the mixture such that complete hydration of the cement can be achieved theoretically without supplying additional water to the cement paste.

A problem may arise however if SCM levels are increased, necessitating longer curing times, without any change in site practice. Thus, the impact of improper curing on low-carbon concrete deserves more attention.

There are further complications in that the degree of saturation (DOS) can affect strength. Concrete cured under non-ideal conditions will exhibit an artificially high strength due to drying. Therefore studies of the effect of improper curing need to be coupled with studies on the effect of sample drying.

This project will investigate the impact of improper curing on the performance of low-carbon concrete, while also ensuring that measurements are made at a constant degree of saturation.

2. EXPERIMENTAL

Concrete specimens were cast using CEM I 52.5N. The PFA used was from Drax power station and complied with BS EN 450-1:2012. The chemical compositions of the PFA as obtained from XRF are 0.90% Na_2O, 1.63% MgO, 25.49% Al_2O_3, 50.73% SiO_2 , 0.20% P_2O_5 , 0.41% SO_3 , 3.46% K_2O, 2.28% CaO, 1.04% TiO_2, 0.05% V_2O_5, 0.02% Cr_2O_3, 0.10% Mn_3O_4, 10.05% Fe_2O_3, 0.03% ZnO, 0.04% SrO, 0.09% Y_2O_3, 0.09% ZrO_2, 0.11% BaO. The aggregates used meet the requirements for particle size distribution set out in BS EN 196-1: 2005. 10 mm diameter uncrushed coarse aggregate and quartz sand of diameter 150 µm to 5mm was used. The aggregates were oven dried before use. Potable mains water, as permitted by BS EN 196-1: 2005 was used.

Twelve different mixes were prepared; with 2 binders at 3 strengths and 2 workabilities. The binders were CEMI or CEM I with 30% replacement by PFA. Target strengths were 20, 50 and 80 Mpa. Target slumps were 10 to 30 and 60 to 180 mm, defined hereafter as “dry” and “wet”.

Each mix was cured under three conditions. One in the fog room at 99% RH, the second one under ambient conditions (ca. 20^{0}C, 42 % RH), and the last one will be using a minimum moist curing time as specified in BS EN 13670:2009 based on the ratio of the mean compressive strengths at 2 and 28 days followed by continued curing under ambient conditions (f_2 /f_{28} +ambient).

100 X 100 X 100 mm cubes were cast in steel moulds. The specimens were covered with plastic sheets while in the moulds. After 24 hours specimens were stripped from their moulds and placed either in the fog room or under ambient conditions.

To study the impact of the degree of saturation samples were cured at 99% RH and then dried to constant weight in an oven at 40^{o}C on concrete strength. Samples were weighed regularly and tested for unconfined compressive strength.

3. RESULTS

The compressive strength data for each mix are shown in Tables 1-4, and figures 1-4. At one and two days there were no clear differences depending upon curing conditions, but some differences became evident with longer curing times, as the samples cured under ambient conditions started to dry out.

Considering first the wet, i.e. workable mixes, curing conditions did not appear to have a significant effect on performance. However, the resilience of the dry, i.e. stiff mixes to non-ideal curing appeared to depend upon the binder composition. The dry CEM I mixes cured under ambient conditions were often stronger than those cured under ideal conditions. As the cement hydrates water is consumed such that those samples cured under ambient conditions are no longer saturated and thus their strength increased, i.e. the degree of saturation gives a false impression of performance. (see below and Figure 5).

However, the dry mixes containing 30% PFA when cured under ambient conditions exhibited lower strengths. This is despite the increase in strength which would have come about from the reduction in the degree of saturation. In this instance, the lack of water brought about by the stiffness of the mix, combined with the drying under ambient conditions.

Table 1. UCS for CEM I dry mixes cured at 99% RH or under ambient conditions.

Age (days)	20MPa 99%RH	50MPa 99%RH	80MPa 99%RH
1	10.29	37.45	52.79
2	16.59	47.17	57.27
7	26.15	58.12	60.92
28	32.35	62.53	63.51
56	35.04	65.21	70.26

Age (days)	20MPa Ambient	50MPa Ambient	80MPa Ambient
1	10.45	37.45	52.79
2	16.26	47.94	58.02
7	25.94	58.38	64.78
28	30.83	68.52	70.59
56	32.81	68.74	69.58

Table 2. UCS for CEM I wet mixes cured at 99% RH or under ambient conditions.

Age (days)	20MPa 99%RH	50MPa 99% RH	80MPa 99% RH
1	14.24	33.34	44.52
2	20.04	39.85	50.33
7	31.39	49.28	52.35
28	38.54	57.12	63.45
56	42.90	61.03	63.93

Age (days)	20MPa Ambient	50MPa Ambient	80MPa Ambient
1	14.24	33.34	44.52
2	18.72	44.05	48.14
7	29.80	51.57	54.96
28	36.22	56.97	63.45
56	35.30	56.98	63.45

Table 3. UCS for 30% PFA dry mixes cured at 99% RH or under ambient conditions.

Age (days)	20MPa 99%RH	50MPa 99% RH	80MPa 99% RH
1	9.19	22.47	31.02
2	15.26	31.04	37.89
7	25.72	45.79	46.69
28	32.77	53.94	54.35
56	35.93	56.20	62.09

Age (days)	20MPa Ambient	50MPa Ambient	80MPa Ambient
1	8.39	22.14	30.63
2	15.23	32.66	39.73
7	23.39	43.86	47.89
28	28.54	50.09	52.69
56	29.21	50.59	60.14

Table 4. UCS for 30% PFA wet mixes cured at 99% RH or under ambient conditions

Age (days)	20MPa 99%RH	50MPa 99% RH	80MPa 99% RH
1	10.70	20.65	29.78
2	15.29	29.53	34.29
7	22.21	37.16	44.82
28	29.72	49.97	51.62
56	36.27	55.47	60.29

Age (days)	20MPa Ambient	50MPa Ambient	80MPa Ambient
1	10.38	23.06	31.12
2	15.77	30.41	36.00
7	23.70	40.73	45.32
28	28.54	48.03	53.95
56	32.92	48.95	57.87

Figure 1: Strength development of the dry CEM I mixes.

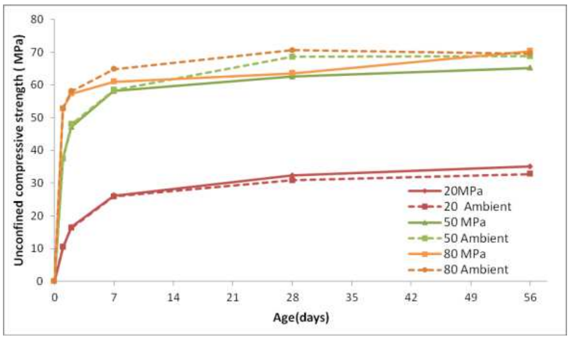


Figure 2: Strength development of the wet CEM I mixes.

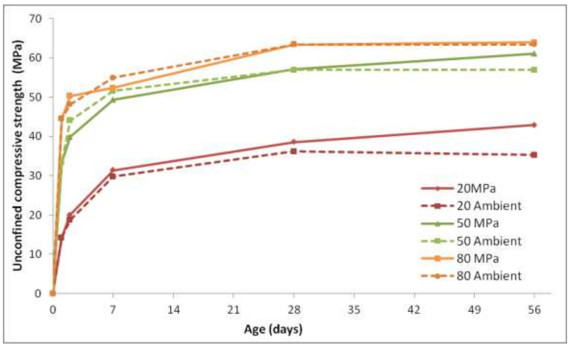


Figure 3: Strength development of the dry 30% PFA mixes.

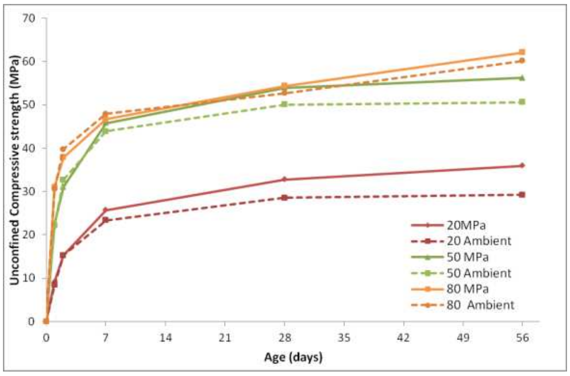
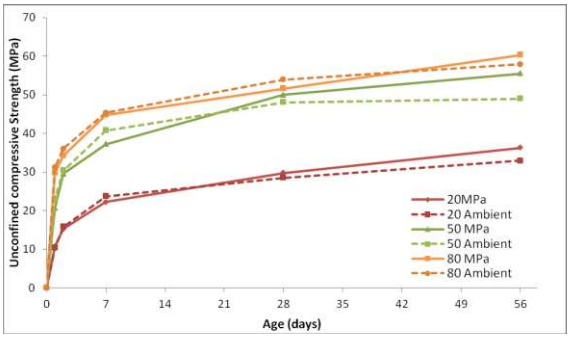
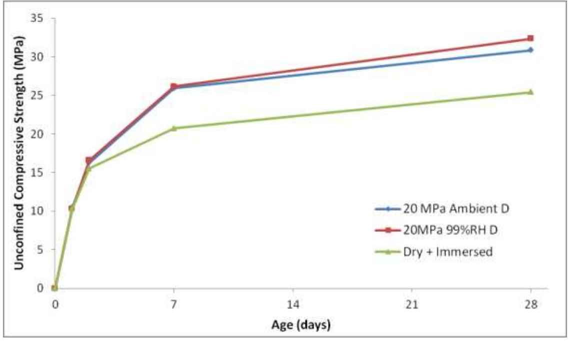


Figure 4: Strength development of the wet 30% PFA mixes.



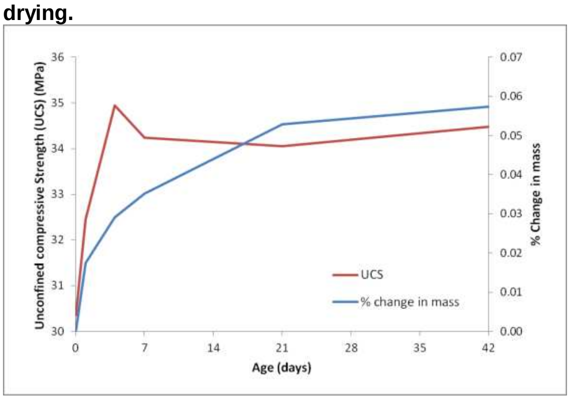
As mentioned above, changes in the degree of saturation gave a false impression of the strength of the dry CEM I mix. Whilst samples cured under ideal and ambient conditions showed similar compressive strengths, the samples cured under ambient conditions and then immersed in water for three hours to ensure saturation showed considerably lower strengths. Figure 5 shows the results obtained from the dry 20MPa mix cured under ideal or ambient conditions, (as shown in figure 1), plus the data for the samples cured under ambient conditions and then saturated. Saturating the samples reduced their compressive strengths by almost 30%.

Figure 5: the effect of curing conditions and degree of saturation on UCS development of a dry 20MPa mix.



The effect of sample drying was investigated by drying samples to constant weight at 40oC with regular strength testing. The impact of gradual sample surface drying is shown in figuer 6. Here it can be seen that, as the sample dries, strength increases.

Figure 6: Change in weight and UCS upon sample drying.



3. CONCLUSIONS

Based on the discussion above, the following conclusions can be made. Improper curing affects the degree of hydration in cement mixes. However, this may not be noticed when testing samples of different degrees of saturation. Samples cured under ambient conditions, but then saturated before strength testing, showed considerably lower strengths, reflecting the impact of sample drying during improper curing conditions.

Work is ongoing to investigate the extent of sample drying upon strength as a function of mix design. Further work will investigate the effect of improper curing on the degree of hydration.

REFERENCES

1. Purnell, P. and L. Black, Embodied carbon dioxide in concrete: Variation with common mix design parameters. Cement and Concrete Research, 2012. **42**(6): p. 874-877.
2. Naik, T.R., Sustainability of concrete construction. Practice Periodical on Structural Design and Construction, 2008. **13**(2): p. 98-103.
3. Kumar, B.S.C., V.K. Varanasi, and P. Saha, Sustainable Development Using Supplementary Cementitious Materials and Recycled Aggregate. 2012: p. 165- 171.
4. Chandler David L Paving the way to greenhouse gas reductions. 2011.
5. Damtoft, J., et al., Sustainable development and climate change initiatives. Cement and concrete research, 2008. **38**(2): p. 115-127.
6. Meyer, C., The greening of the concrete industry. Cement and Concrete Composites, 2009. **31**(8): p. 601-605.
7. Mehta, P.K., Reducing the environmental impact of concrete. Concrete international, 2001. **23**(10): p. 61-66.
8. Sabir, B., S. Wild, and J. Bai, Metakaolin and calcined clays as pozzolans for concrete: a review. Cement and Concrete Composites, 2001. **23**(6): p. 441-454.
9. Berndt, M., Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. Construction and Building Materials, 2009. **23**(7): p. 2606-2613.
10. Siddique, R. and M.I. Khan, Supplementary cementing materials. Vol. 37. 2011: Springer.
11. Shi, X., et al., Durability of steel reinforced concrete in chloride environments: An overview. Construction and Building Materials, 2012. **30**: p. 125-138.
12. Neville A.M , B.J.J., Concrete Technology. Second Edition ed. 2010, England: Pearson Education Limited.
13. Al-Gahtani, A., Effect of curing methods on the properties of plain and blended cement concretes. Construction and Building Materials, 2010. **24**(3): p. 308-314.
14. Gowripalan, N., et al., Effect of curing on durability. Concrete International, 1990. **12**(2): p. 47-54.
15. Punmia, B., A.K. Jain, and A.K. Jain, Basic Civil Engineering. 2003: Firewall Media.
16. Haque, M., Some concretes need 7 days initial curing. Concrete International, 1990. **12**(2): p. 42-46.
17. Bentz, D.P. and P.E. Stutzman, Curing, hydration, and microstructure of cement paste. ACI materials journal, 2006. **103**(5): p. 348.