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Communication

Correlation between 28-day and 6-hour compressive strengths

P.J. Tumidajski[a,*], B. Gong[b], D. Baker[b]

[a]St. Lawrence Cement, 3300 Highway 7, 6th Floor, Concord, Ontario, Canada L4K 4M3
[b]Dufferin Concrete, Concord, Ontario, Canada L4K 4M3

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Abstract

Using commercially batched ready-mix concrete, a linear relationship was established for compressive strengths at 28 days (wet-cured) and 6 h (microwave-cured), $\log f_{28\text{-day}} = 1.31 + 0.35 \log f_{6\text{ h}}$. The relationship is important because the impact of concrete mix adjustments is quickly appreciated, reducing the frequency and financial severity of rework or litigation.

Keywords: Microwave processing; Compressive strength; Portland cement; Granulated blast furnace slag; Concrete

1. Introduction

The acceptance of concrete at the construction job site is typically required sooner than 3 or 7 days. A quick response to strength changes in the concrete reduces the frequency and financial severity of rework or litigation. There are several methods to determine the 28-day strength of concrete by accelerated methods (ASTM C684). The techniques to accelerate curing use a complicated and expensive high-temperature and high-pressure apparatus that is not available at commercial ready-mix concrete plants.

It has been reported that a quick microwave cure is a simple and inexpensive tool to track concrete strength [1–3]. However, the technique has not been applied in a commercial operation. Therefore, it is the purpose of this study to establish whether compressive strength developed after a short microwave cure is related to the 28-day wet-cured compressive strength for commercially produced ready-mix concrete.

2. Background

Consider the generic Abrams equation for strength,

$$\log f_{28\text{-day}} = \log A_{28\text{-day}} - B_{28\text{-day}}\left(\frac{w}{c}\right) \quad (1)$$

where $f_{28\text{-day}}$ is the compressive strength at 28 days, $A_{28\text{-day}}$ and $B_{28\text{-day}}$ are constants, and (w/c) is the water-to-total cement ratio. For an accelerated curing strength test, the corresponding Abrams formula will be,

$$\log f_{\text{accelerated}} = \log A_{\text{accelerated}} - B_{\text{accelerated}}\left(\frac{w}{c}\right) \quad (2)$$

where the symbols have the same meaning as in Eq. (1). When concrete samples are taken from the same batch, then w/c is the same. Accordingly, Eqs. (1) and (2) can be rearranged and solved for w/c as,

$$\left(\frac{w}{c}\right) = \frac{\log A_{28\text{-day}} - \log f_{28\text{-day}}}{B_{28\text{-day}}} = \frac{\log A_{\text{accelerated}} - \log f_{\text{accelerated}}}{B_{\text{accelerated}}} \quad (3)$$

Eq. (3) can be simplified to obtain the relationship between the 28-day and accelerated strengths.

$$f_{28\text{-day}} = \alpha f_{\text{accelerated}}^{\beta} \quad (4a)$$

or,

$$\log f_{28\text{-day}} = \log\alpha + \beta \log f_{\text{accelerated}} \quad (4b)$$

* Corresponding author. Tel.: +1-905-761-7100x203; fax: +1-905-761-7200.
E-mail address: ptumidajski@stlawrencecement.com (P.J. Tumidajski).

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Table 1
Experimental data

Sample	Cement (kg)	Grancem (kg)	Water (kg)	Compressive strength (MPa)		Air content (%)
				28-day cure	6-h cure	
1	405	130	160	55.4	17.8	5.4
2	265	110	150	46.2	10.3	6.6
3	245	80	155	41.0	7.3	7.4
4	265	110	150	46.9	11.2	6.6
5	185	60	165	37.5	5.7	Not measured
6	270	85	145	44.8	9.2	5.4
7	240	80	155	43.2	8.4	5.8
8	270	90	155	46.4	10.1	5.8
9	200	65	165	37.0	5.3	Not measured
10	210	70	159	42.7	8.8	Not measured
11	240	80	155	42.5	8.4	5.8
12	365	0	150	45.8	10.6	7.6
13	355	0	155	48.7	11.5	5.7
14	255	85	150	44.1	8.7	7.4
15	245	80	155	41.5	7.3	7.4
16	285	90	150	40.7	7.2	7.2
17	285	90	150	46.2	9.8	4.7
18	165	55	165	28.0	2.5	Not measured
19	240	80	155	43.8	8.4	5.8
20	285	90	150	51.7	12.8	6
21	185	60	165	35.4	5.3	Not measured
22	270	85	155	43.9	7.6	6.8
23	270	85	145	44.8	8.8	5.4
24	185	60	165	36.6	5.6	Not measured
25	270	85	155	43.9	8.1	6.2
26	420	0	155	50.5	14.2	5.6
27	255	85	150	41.3	7.7	7
28	255	85	150	39.1	6.2	8.6
29	270	85	155	44.3	8.6	7.9
30	265	110	150	46.3	9.8	6.4

Therefore, for samples from the same batch with the same w/c, then the plot of $\log f_{28\text{-day}}$ versus $\log f_{\text{accelerated}}$ will be a straight line with a slope of β and ($\log \alpha$) intercept.

3. Experimental

The concrete mix designs, representing commercial deliveries, are presented in Table 1. For each load, 10 l of concrete was sampled (ASTM C172). Cylinders of dimension 75 mm (diameter) × 150 mm (height) were cast (ASTM C31). Three cylinders were immediately placed in a 100% relative humidity curing room. At 28 days, these cylinders were capped (ASTM C617) and tested for compressive strength (ASTM C39).

The cylinders for the microwave treatment were air cured for 60 min. Subsequently, the cylinders were heated for 60 min at 10% power in the microwave oven (General Electric model JE1550GWC). Then, the cylinders dwelled for 30 min with the power off, followed by a further heating cycle of 30 min at 20% power. Finally, the cylinders were allowed to cool for 3 h inside the microwave oven with the power off. The total curing time was 6 h. At this time, the cylinders were capped (ASTM C617) and tested for compressive strength (ASTM C39). For the 28-day wet cure and for the microwave cure, reported compressive strength data represents the average of at least three cylinders.

4. Results and discussion

Data are summarized in Table 1. All concrete was air entrained with Euclid Air XL or Air Extra depending on slump requirements. The cementitious material for 27 batches was Portland cement and up to 30% by weight of Grancem which is a proprietary ground granulated blast furnace slag. The remaining three batches used Portland cement.

The 28-day, wet-cured compressive strengths have been plotted against the 6-h accelerated microwave compressive

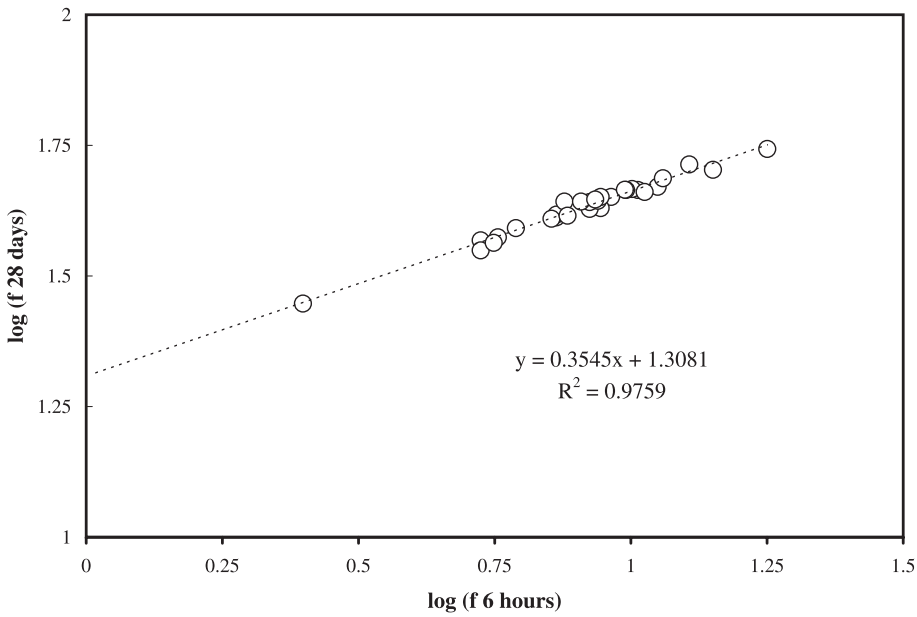

Fig. 1. Twenty-eight-day compressive strength versus 6-h microwave cured compressive strength as in Eq. (5a).

Table 2
Statistical summary output for linear regression

Regression statistics	
Multiple R	.987881835
R^2	.975910519
Adjusted R^2	.97505018
Standard error	.008868515
Observations	30.

ANOVA

	df	SS	MS	*F*	Significance *F*	
Regression	1	0.089215924	0.0892159	1134.3331	3.34971E − 24	
Residual	28	0.002202216	7.865E − 05			
Total	29	0.09141814				
	Coefficients	Standard error	*t* Statistics	*P* value	Lower 95%	Upper 95%
Intercept	1.308123419	0.009791575	133.59684	8.002E − 41	1.288066266	1.328180573
log $f_{6\text{-h}}$	0.354457458	0.010524315	33.679861	3.35E − 24	0.332899353	0.376015564

strengths in Fig. 1. The statistical analysis is given in Table 2. It can be seen that there is a linear relationship and Eq. (4b) is valid in the form,

$$\log f_{28\text{-day}} = 1.31 + 0.35 \log f_{6\text{-h}} \quad (5a)$$

or

$$f_{28\text{-day}} = 20.3 f_{6\text{-h}}^{0.35} \quad (5b)$$

Therefore, Eqs. (5a) and (5b) and 6-h microwave-cured compressive strengths will predict 28-day wet-cured compressive strengths.

5. Conclusions

Accelerated microwave curing of concrete is a fast and inexpensive quality control tool. The technique allows a rapid prediction of 28-day compressive strengths from specimens cured for 6 h.

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