REPORT

D5 additive performance, review of the test results

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Dear Zarina and Matt

Thank you for engaging CBE Consultancy Ltd to undertake a review of the test results that were undertaken by Higgins Concrete and WSP Opus Central Laboratories, both New Zealand based firms. Higgins Concrete is a well-established readymixed concrete manufacturer operating primarily in the Lower North Island, as WSP Opus Central Laboratories is a specialist construction material research and testing firm, located in Lower Hutt.

The scope of the report is to provide an analysis of the D5 performance in comparison to Control and also a professional opinion on the efficiency of D5 additive on a number of different aspects of concrete characteristics.

There are 2 sets of test results: (a) conducted by Higgins Concrete (Wellington) and WSP Opus (Lower Hutt).

PRELIMINRY OBSERVATION

Testing at Higgins

The main objective was to establish the effect of D5 admixture on main characteristics of concrete, such as:

- Slump and slump loss,
- Air content
- Compressive strength at different ages
- Flexural strength
- Modulus of Elasticity
- Drying shrinkage
- Waterproofing (pore structure and sizing)
- Chloride ion permeability
- Water permeability

Some of the special tests, like waterproofing, chloride ion permeability and water permeability were also done on mixes with 2% D5 and SCM, presumably either fly ash or GGBS - Ground-granulated blast-furnace slag.

In total 12 trials, both laboratory (50 L) and full scale (1 m^3) were conducted.

The first 3 trials were direct comparison between Control, addition of 2% of D5 and addition of 3% of D5. The quantities of all the material were kept identical. The quantities of D5 were extra. No adjustments were made for D5 addition, so the mixes with D5 were slightly over yielded.

Testing at WSP Opus

The testing was aiming at evaluating the strength efficiency of D5 at 2 and 3% addition and its effect on drying shrinkage characteristics.

In total 6 trials were conducted:

- First 3 trials were aiming at establishing the water demand for the D5 containing mixes for the same, as control mix, slumps
- The other 3 mixes were for obtaining the testing specimens and conducting fresh concrete, compressive strength at different ages and drying shrinkage testing

The control mix designs used at Higgins Concrete and WSP Opus were using the same aggregates and cement and comparable proportions. No any other chemical admixtures were used.

REVIEW

Slump and Slump Retention

Testing at Higgins

With the same amount of total water and identical cement contents, the addition of D5 at 2% and 3% showed the slump increase by 155% and 209% respectively.

Slump loss:

	Original (mm)	In 1 hour	In 2 hours	In 3 hours
Control	110	100 (9%)	75 (32%)	50 (55%)
2% D5	170	130 (24%)	60 (65%)	30 (82%)
3% D5	230	210 (9%)	175 (24%)	90 (61%)

This slump rise caused by addition of D5 served as the base for the mix designs revision towards water reduction with the aim of achieving the same slump of concrete. Subsequently at Higgins a few trials were conducted with the slump and w/c equivalent to the Control mix.

Conclusion:

1. Direct addition of D5 to concrete increases slump by about 55% (2% of D5) and 110% (3% of D5)
2. D5 kept relatively high slump after 2 and 3 hours, but this is due to the higher original slump. The rate of slump loss was higher at D5 mixes.

Air Content

No significant deviations from entrained air contents were observed between Control, D5-2% and D5-3% at both Higgins and WSP Opus trials.

Conclusion:

1. D5 at any dosage (up to 3%) does not affect the air entrainment.

Strength at variety of ages

Flexural Strength

Testing at Higgins

Tested for Control and D5-2% mixes only, the flexural test results do not show much difference, however, D5-2% shows about 10% higher strength at 7 day.

Compressive Strength

Testing at Higgins

With the same amount of total water and identical cement contents, the addition of D5 at 2% and 3% showed the following strength results:

	Slump	1-day	3-day	7-day	28-day	56-day	90-day
Control	110	7.0	20.5	31.0	44.0	50.5	54.0
2% D5	170	12.5 (79%)	28.5 (39%)	40.5 (31%)	52.5 (19%)	54.0 (7%)	57.5 (6%)
3% D5	230	11.5 (64%)	24.0*	41.0 (32%)	51.5 (17%)	57.0 (13%)	60.0 (11%)

** – shear break, test is disregarded*

Testing at WSP Opus

Water reduction

Based on the tests conducted at WSP Opus, the water reductions for achieving the same initial slump were as the following:

- 2% of D5 addition – 14%
- 3% of D5 addition – 22%

With adjusted amount of water for achieving the same slump, the addition of D5 at 2% and 3% showed the following strength results:

	1-day	3-day	7-day	28-day	56-day
Control	9.0	22.5	31.5	43.5	48.5
2% D5	15.5 (72%)	27.5 (22%)	40.0 (27%)	54.0 (24%)	56.0 (16%)
3% D5	22.0 (144%)	37.0 (64%)	47.5 (51%)	58.5 (35%)	62.0 (28%)

Note. Percentages show strength increase in comparison to the strength of Control mix of the same age.

Conclusion:

1. Addition of D5 shows very high early age strength gain from between 70 and 140% increase in 1 day, 20-60% - in 3 days and 30-50% - in 7 days
2. The 28-day strength increased by about 25% and 35% with 2% and 3% of D5 respectively. This is based on the test results from WSP Opus as more controlled and reliable.
3. Flexural strength can be slightly higher at early age, due to higher strength shown in compressive strength testing. However, the ultimate, 28-day strength does not show any significant difference.

Based on the above test results it can concluded that the estimated cement content reduction to achieve the same 28-day strength could be as high as 12-16% and 22-27% for 2% and 3% of D5 addition.

Drying shrinkage

Shrinkage was tested on specimens prepared by Higgins (tested at WSP Opus) and at WSP Opus (tested at WSP Opus). At Higgins only Control and D5-2% were tested, as at WSP Opus all three, i.e. Control, D5-2% and D5-3%, mixes were tested.

In general, drying shrinkage final result (measure at 56th day) of Control and D5-2% were about 10% lower for specimens made by Higgins from their samples of concrete. As far as drying shrinkage testing accuracy is concerned this cannot be considered as significant difference, however the actual mix composition plays significant role in shrinkage characteristics.

Testing at WSP Opus

	7-day	14-day	21-day	28-day	56-day
Control	420	590	730	850	980
2% D5	500 (19%)	650 (10%)	780 (7%)	860 (1%)	1020 (4%)
3% D5	510 (21%)	730 (24%)	810 (11%)	890 (5%)	1060 (8%)

As it can be seen from the above table, the drying shrinkage characteristic is slightly higher for D5-2% and D5-3% compared with Control. But as it was mentioned before 7-8% difference is not significant. However, the trend is quite consistent: higher shrinkage at higher dosage of D5. This was not expected as much less water was used for D5-2% and D5-3% than for Control.

The more interesting was the rate of shrinkage – percentage difference at each week of testing:

	7-day	14-day	21-day	28-day	56-day
Control	0%	41%	24%	16%	15%
2% D5	0%	30%	20%	10%	19%
3% D5	0%	43%	11%	10%	19%

Since the main problem associated with drying shrinkage is the risk of cracking, which is a balance between the rate of shrinkage (or growth of the tensile stresses in concrete) and its (tensile) strength, the higher the strength gain rate compared with the rate of shrinkage, the lesser the risk of cracking.

Conclusion:

1. Drying shrinkage of D5-2% and D5-3% in general is slightly higher than of Control,
2. The rates of shrinkage of D5-2% and D5-3% is in general lower than of Control,
3. The risk of cracking, especially at early age, due to drying is less in concretes containing D5 admixture

Special (durability) testing

Special tests, like waterproofing, chloride ion permeability and water permeability were conducted on specimens prepared by Higgins Concrete at Cement Australia and BORAL (Australia) specialised laboratories.
The tests were conducted on Control, D5-2% and D5-2%+SCM (@24%, presumably either fly ash or GGBS - Ground-granulated blast-furnace slag). Total cement reduction in D5-2% was 20% compared with Control. The total cementitious content of the D5-2%+SCM was the same as in D5-2%, however cement only content was reduced by about 40% compared with Control.

Since the purpose of this report is to focus entirely on D5 admixture performance, the data for D5-2%+SCM is not considered in this analysis.

In general, based on the Waterproofing test (BET Surface Area, Cumulative Volume of Pores, Average Pore Diameter), Chloride Ion Permeability and Depth of water penetration test results, D5 at 2% shows noticeable improvement. This is mainly contributed by lower water content and subsequently lower

water-to-cement ratio (w/c). Since 3% addition of D5 demonstrated even further water reduction and further reduced w/c it would be only logical to assume that all the above durability characteristics will be improved when 3% of D5 is used.

Conclusion:

1. Addition of D5 improves durability as far as water and chloride ion permeability are concerned. The higher the dose rate of D5 (up to 3%), the better the durability characteristics.
2. This is contributed by lower w/c of concrete containing D5 compared with Control mixes.

Theoretical assumption for the Heat of Hydration reduction

Based on the above-mentioned strength test results, it is assumed that in order to maintain the same compressive strength, the theoretical cement reduction could be:

- about 15% when 2% of D5 is used, and
- about 25% when 3% of D5 is used

Based on this, it would be possible to estimate the reduction of the core temperature and the temperature differential due to heat of hydration (all other environmental and construction conditions are equal) using CIRIA C660 modelling tool:

	Reduction of core temperature	Reduction of temperature differential
Control	0.0%	0.0%
2% D5	12%	14%
3% D5	19%	21%

Conclusion:

1. When aiming for the same compressive strength results, addition of D5 can substantially reduce both the ultimate core temperature and the temperature differential, hence
2. Addition of D5 reduces potential risk of cracking due to reduction in heat of hydration.

Kind regards

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