



Stronger, Superior Concrete

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1. Introduction

Concrete is a composite material composed of cement, aggregates, admixtures and water and is the most popular construction material used due to its strength and durability. One interesting property used in design is the compressive strength which is primarily a function of the water / cement ratio and increases over time. Conventional mix designs have water/cement ratios as high as 0.45 and provide strengths in the range of 10-40 MPa at 28 days.

High performance concrete (HPC) is concrete that provides strengths as high as 150 MPa at 28 days using water to cement ratios as low as 0.20. Key characteristics of HPC include the use of supplementary cementitious materials (SCMs) and chemical admixtures. SCMs provide higher concrete strength due to the fact that they are much finer in size than cement particles and therefore are able to fill voids in hardened concrete which would have otherwise been left as air voids. In addition, SCMs also react with Ca(OH)_2 in the presence of water to produce strength gaining compounds with properties similar to the compounds produced from cement reacting with water, hence further increasing the strength of the concrete.

Chemical admixtures, such as superplasticizer, give the concrete mix adequate workability at low water / cement ratio. SCMs are very sustainable as they are bioproducts of industrial process.

Research of the most economical mix design with a target strength of 100 MPa at various dosages of SCMs and w/c ratio is carried out.

2. Methodology

Three cylinders of mix designs (MD) I, II and III were batched and cured at atmospheric pressure, room temperature and minimum moisture control. The proposed mix designs were calculated in reference to empirical and historical data regarding HPC.



Figure #1 – Mix design materials, from left to right: Coarse aggregates, Slag / Fly Ash binder, Cement, Fine Aggregate, Water and Superplasticizer.

Table #1 – Tested mix designs

Materials	MD I	MD II	MD III	Cost ($\frac{\$}{m^3}$)
Water (kg/m ³)	137.5	130	132	2.35
Super plasticizer (kg/m ³)	40	30	22	1180.00
Blended Cement (kg/m ³)	307.5	224	171.2	424.39
Silica Fume (kg/m ³)	26.75	19.6	14.8	1781.06
Slag (kg/m ³)	170.75	199.6	301.6	361.95
Fly Ash (kg/m ³)	84.25	98.4	148.6	185.19
Coarse Aggregates (kg/m ³)	1220	1046	1060	54.01
Fine Aggregates (kg/m ³)	750	738	676	37.95
Other Properties				
w/c	0.30	0.30	0.24	-
% Slag	29 %	37 %	47 %	-
% Fly Ash	14 %	18 %	23 %	-
% Silica Fume	5 %	4 %	3 %	-
Total SCM (%)	48 %	59 %	73 %	-

3. Results

Table #2 – Strength test results

	7 Day Strength (MPa)	14 Day Strength (MPa)	28 Day Strength (MPa)	Cost of MD ($\frac{\$}{m^3}$)
MD I	31.50	44.88	56.67	168
MD II	35.10	41.92	30.5*	141
MD III	42.13	57.89	53.44*	137

* Result are possible outliers. Strength increases over time and should not decrease as dramatically as these data points suggest.

The investigated mix designs yielded high performance concrete of 28 day strength in the range of 53 – 56 MPa, more formally known as Class I HPC.

However, these results are not satisfactory as HPC of strength in the region of 100 MPa (Class III) was targeted.

After testing, the data suggests that mix designs with higher dosage of supplementary cementitious materials provide higher early strength development at 7 days but stagnate the strength development at 14 and 28 days. This is the case with mix designs I and II which only differed in the dosage of supplementary cementitious materials.

Mix design I contained less slag and fly ash but a slightly higher dosage of silica fume than mix design II. At 7 days, mix design II had an 11% increase of strength than mix design I. However, at 14 days, mix design II had a strength reduction of 6.6% over mix design I. Furthermore, the 1 % incremental increase in silica fume between MD I and II could have increased the strength of MD I at 14 and 28 days.

Mix design I which contained the least amount of SCMs had the largest 28 day strength of 56.67 MPa. Mix design III which contained the largest amount of SCMs and the lowest w/c ratio demonstrated the second largest 28 day strength of 53.44* MPa. The low w/c ratio used (0.24) also made mix design III the densest of all three mix designs.

4. Conclusion

The investigated mix designs only yielded Class I HPC. It was observed that as the dosage of Slag/Fly Ash increased, test cylinders exhibited early strength development but slower strength development after 7 days. In addition, as the w/c ratio decreased, strength significantly increased.

To provide the most economical and strongest concrete, then lower w/c ratios are to be used with higher dosages of SCMs consisting mostly of slag and fly ash since they are the cheapest SCMs.

Future investigation should investigate mix designs at w/c ratios as low as 0.20 and SCM dosage as high as 70 % to achieve cheap HPC Class III concrete.

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6. References

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