The Setting Time of Concrete as Effected by Various Types of Superplasticisers

Benjamin J. Kuchel

University of New South Wales at the Australian Defence Force Academy

The construction industry is characterised by a requirement to achieve a high standard of construction at the lowest possible cost in the shortest amount of time. A large emphasis is placed on the curing time and early strength development of concrete in order to reduce the time of construction. Another important consideration becoming more significant in recent years is sustainability. The use of superplasticisers in concrete to reduce the required water/cement ratio or achieve a high workability is common practice on construction sites. Developments in superplasticisers have resulted in more effective admixtures being developed in recent years. This project analyzed the effects of three commercially available superplasticisers on the setting time, and early strength development of two types of concrete. The results demonstrated an improvement in the setting time and early strength development of traditional concrete. With the introduction of the carbon tax and sustainability becoming a significant issue for the construction industry, HVFA concrete presents a viable option. The effectiveness of the superplasticisers was greatly reduced for HVFA concrete. In order to achieve a more realistic set of results, this project compared mix designs of the same workability adjusting the amount of superplasticiser to achieve the desired effect. This differs from previous studies, which compare mix designs containing superplasticisers to control mixtures of the same water/cement ratio, but do not achieve the desired effect.

Contents

I. Introduction 2
   A. Background 2
   B. Aim 3
   C. Objectives 3

II. Literature Review 3
   A. Superplasticisers 3
   B. High Volume Fly Ash Mix Designs 4
   C. Fresh Concrete Properties 5
   D. Hardened Concrete Properties 5

III. Approach 6
   A. Material Testing 6
   B. Mix Design 6
   C. Superplasticiser Dosage 7
   D. Batch Preparation 8
   E. Testing 8

IV. Results and Analysis 9
   A. Aggregate Testing 9
   B. Mix Design Testing 10
   C. Fresh Concrete Properties 11
   D. Compression Test Results 11
   E. Modulus of Elasticity Results 14
   F. Modulus of Rupture and Indirect Tensile Test Results 16

1 LT, School of Engineering & Information Technology. ZEIT4501
V. Discussion and Comparisons

VI. Recommendations
   A. Superplasticisers
   B. High Volume Fly Ash Mix Designs
   C. Methodology
   D. Testing

VII. Conclusions

Acknowledgements

References

APPENDICES
Appendix A. Mix Design Calculations
Appendix B. Mix Design Proportions
Appendix C. Sample Cylinder Dimensions
Appendix D. Project Timeline
Appendix E. Aggregate Sieve Analysis Results
Appendix F. Compressive Test Strength Results
Appendix G. Modulus of Elasticity Test Results
Appendix H. Modulus of Rupture Test Results
Appendix I. Indirect Tensile Test Results

Nomenclature

\[ \Delta \sigma = \text{change in stress (MPa).} \]
SNF = Sulphonated Naphthalene Formaldehyde condensates.
SMF = Sulphonated Melamine Formaldehyde condensates.
HWR = High-Range Water Reducing Admixture.
MWR = Mid-Range Water Reducing Admixture.
OPC = Ordinary Portland cement.
SSD = Surface Saturated Dry.
HVFA = High Volume Fly Ash.

B1A4.1 = Mix Designation:
The B identifies the producer of the mix.
The first number identifies the type of concrete;
1 = Traditional mix, or
2 = HVFA mix.
The second letter identifies the type of superplasticiser;
No letter = control mix,
A = ADVA 142,
B = CENTROX MWR, or
C = DARACEM.
The second number represents the mix design number.
The third and final number is the batch number for that mix design.

I. Introduction

A. Background
Superplasticisers are a special category of water reducing admixtures. They are defined as High Range Water Reducing Admixtures in international Standards (Brown and Hiznay 2004). Superplasticiser have been in use since the 1970s and have been further developed since, with the use of new formulas. There are four main categories of superplasticisers and they include sulphonated naphthalene formaldehyde condensates, sulphonated melamine formaldehyde condensates, modified lignosulphonates and others such as polyacrylate-based superplasticisers (Neville 1995; Whitney 2008). The sulphonated naphthalene formaldehyde condensates and sulphonated melamine formaldehyde condensates are the most widely used however they are not the most effective on the market. The main uses of superplasticisers include, achieving a high workability, reducing the water to cement ratio or reducing the amount of water and cement.
Superplasticisers have a number of effects on the properties of concrete mostly related to concrete in its fresh state. This is preferred as no admixture should adversely affect the long term hardened concrete properties. The properties that are being considered are those related to the setting of the concrete and its hardened strength. This is due to the problem of prolonged setting times on construction sites and waiting for important milestones to be met, before the following stages of construction can begin. The prolonged setting times lead directly to the project cost. Superplasticisers allow concrete to maintain a high workability and achieve higher strengths with lower water to cement ratios with shorter setting times. Superplasticisers do, however, have a significant financial cost that needs to be offset with the cost savings due to the benefits. The financial cost can range from $1400 per ton to $6000 per ton depending on the product (Grace 2006; AIAdditives 2012).

Limited testing has been conducted on how superplasticisers effect the setting time of concrete. A direct comparison, based on a fixed workability, between products in the market in the form of polycarboxylate ester formulas and the existing sulphonated naphthalene formaldehyde condensates has yet to be conducted. Throughout this testing two polycarboxylate ester superplasticisers will be used to demonstrate the differences that can be achieved within one of the main superplasticiser categories. Furthermore, a direct comparison between the effects that superplasticisers have on traditional mix designs and HVFA mix designs has yet to be conducted. HVFA concrete is characterized by a greater than 25% replacement of OPC and is associated with lengthy setting times making it uneconomical to use in the construction industry. A direct comparison using workability as a benchmark, between three different superplasticisers and two different types of concrete will fill the information gap on the effects of superplasticisers on concrete.

B. Aim
The aims of the project are as follows:

1. Design four traditional concrete mix designs and four HVFA mix designs including one control mix and three mixtures using different commercially available superplasticisers.

2. Conduct strength testing to determine the effects of the superplasticisers on the hardened concrete properties.

3. Conduct the cone penetration test; air entrained test and bleeding tests to determine the effects of the superplasticisers on the setting of concrete and any adverse effects to the concrete mixture.

C. Objectives
The report will allow for the direct comparison of three different superplasticisers including both old and new formulas as well as allow for a cross comparison between different types of concrete. Tests were conducted to ascertain the effect that the superplasticisers would have on the different strength properties and the setting time of concrete.

II. Literature Review

A. Superplasticisers
The introduction of sulphonated naphthalene formaldehyde condensates and sulphonated melamine formaldehyde condensates occurred in Japan and Germany respectively in the 1960s. The use of superplasticisers in concrete was not widely accepted until the 1970s (Rixom and Mailvaganam 1999). In the 1980s the development of polyacrylate and polycarboxylate based superplasticisers started to unravel some of the problems that occurred with the existing superplasticisers. These problems included the high rate of slump loss which affected many concrete mixes in which, naphthalene and melamine formulas were used. This forced users to add superplasticisers on site rather than at the mixing plant. The new polyacrylate-based superplasticisers were classified as extended-life superplasticisers and added a significant working life of up to two hours to the concrete mixes removing the requirement for onsite mixing in many cases (Neville 1995; Brown and Hiznay 2004).

Since the 1980s, construction product companies have been developing new superplasticisers to have a number of effects on the properties of fresh and hardened concrete. Superplasticisers can be used to achieve a high workability in fresh concrete without the need to add large amounts of water to increase flow. They can be used to achieve a high strength in concrete by lowering the water to cement ratio required but maintaining workability (Neville 1995; Ramezanianpour, Sivasundaram et al. 1995; Rixom and Mailvaganam 1999; Brown and Hiznay 2004; Kovler and Roussel 2011). Superplasticisers used in this way can decrease the required water by as much as 25-35% and increase the strength by as much as 50-75%, this is almost double the value of conventional water reducing admixtures (Neville 1995; Whitney 2008). Finally superplasticisers can be used to reduce the amount of
water and cement required for a concrete mix design. This causes a decrease in the temperature rise and amount of volume change during curing (Rixom and Mailvaganam 1999; Brown and Hiznay 2004).

A number of comparisons between superplasticisers have been conducted in the past, however; never with workability as the benchmark (Ramezanianpour, Sivasundaram et al. 1995; Zhang, Sisomphon et al. 2010). The use of superplasticisers at a fixed dosage without regards for the effects is not representative of the industry. The construction industry uses the minimum of superplasticisers to achieve the desired effect due to the high financial cost associated with their use. As such the findings that superplasticisers have a retarding effect on the setting time of concrete when used at the same W/C ratio is somewhat unrealistic as the workability for both mix designs will be substantially different. In order to achieve a fair test a control with the same or similar workability needs to be used.

Superplasticisers are water soluble polymers that are synthesized through a complex polymerisation process. This creates long chain molecules with a high molecular mass (Neville 1995). In the polymerisation process other chemicals can be added to achieve different effects in concrete. For example triethanolamine is added to counteract retardation of the concrete setting time and tributyl phosphate is added to reduce excessive air entrainment in concrete. Still other materials increase the retardation of concrete setting time in order to allow the mix to be kept in a workable condition for longer (Rixom and Mailvaganam 1999). There are four main categories of superplasticisers and they include sulphonated naphthalene formaldehyde condensates, sulphonated melamine formaldehyde condensates, modified lignosulphonates and others such as polyacrylate-based superplasticisers (Neville 1995; Whitney 2008). The basic chemical structures without the inclusions of the added materials can be seen in figure 1. Companies protect the chemical formulas of their products in confidence, as such accurate and detailed chemical analysis and comparison of their products can be difficult. It is recommended that products be compared based on cost to achieve a given effect rather than the mass required (Neville 1995).

Melamine and naphthalene molecules work by absorbing the non-polar section of the molecule onto the surface of the cement particle thus giving the particle a negative charge. This effect is known as electrostatic repulsion and causes the dispersion of the cement particles. The cement particles then repel each other preventing flocculation and segregation (Shaw 1983). Polycarboxylate molecules have the added effect of steric

Figure 1: Basic chemical structure of the categories of superplasticisers. (Rixom and Mailvaganam 1999)
repulsion, whereby the long side chains assist in physically separating the particles (Ramezanianpour, Sivasundaram et al. 1995; Brown and Hiznay 2004). These mechanisms result in a short term improvement to the workability of the concrete mix. Superplasticisers do not change the structure of concrete but simply ensure even distribution of the cement particles, leading to better hydration of the mix (Neville 1995). Superplasticisers only have a limited workable life once added to concrete this is accredited to small amounts of the superplasticiser molecules becoming trapped in the products of hydration as well as the shearing of cement particles creating a larger surface area during mixing (Neville 1995).

B. High Volume Fly Ash Mix Designs

It is common practice to use fly ash as a replacement for cement and fine aggregates in the production of concrete. HVFA mix designs are classified by more than 25% replacement of Portland cement. Around the world HVFA mix designs receive only limited use in structural concrete due to the retarding effect by the fly ash particles on the setting of concrete. This lengthens the curing process which greatly affects the rate at which a construction project can progress to the next stage of construction. This is especially important in multistory and prestressed structures. The key problems addressed by this project are the lengthy curing times of concrete in multistory and prestressed construction as well as the sustainable development of concrete structures. Studies have been conducted into the feasibility of using mix designs containing differing percentages of fly ash, up to 30% replacement, and the impact that the fly ash has on the pull out strength of concrete (Baweja, Marks et al. 2009). The findings were, once the minimum requirements for post tensioning were met, the fly ash had no effect on the pull out strength of the concrete (Baweja, Marks et al. 2009). This is significant as it leaves the prolonged curing time and the limited knowledge as the only problem preventing the widespread use of HVFA concrete. As it stands the main method to reduce the curing time of HVFA mix designs is to reduce the water to cement ratio (Bentz, Hansen et al. 2011).

HVFA mix designs also have significant environmental and cost savings associated with their use. As fly ash is a byproduct of coal production and its collection is mandatory for air quality reasons. As such there are no greenhouse gas emissions associated with the production of fly ash (O’Moore and O’Brien 2009; Bentz, Hansen et al. 2011). The production of OPC, as a comparison, produces between 700-900 kg of carbon dioxide equivalent greenhouse gas emissions per tonne of cement produced. Studies conducted show that the only significant emissions cost of fly ash is the transport cost to the concrete batching plant (O’Moore and O’Brien 2009). The financial cost of fly ash is also significantly less as it is a waste product which would otherwise be disposed of in landfill. The above cost savings for HVFA mix designs make them a far more sustainable option then OPC only mix designs for future use in the construction industry. As such greater consideration needs to be given to increasing the total percentage of fly ash allowed for use in structural concrete.

C. Fresh Concrete Properties

The properties of fresh concrete that this project has tested include the setting time, workability, bleeding of water and the amount of entrapped air (Brown and Hiznay 2004). Superplasticisers are known for the ability to reduce water and maintain workability, and not for the ability to act as an accelerating admixtures. Therefore its primary use is not to reduce the curing time of concrete. This has resulted in very limited research being conducted on the effect superplasticisers have on the setting time of concrete (Neville 1995). With new products being released by companies and more discoveries into the nature of superplasticisers being made, this project aims to assess improvements in the effect that superplasticisers have on the setting time and early strength development of concrete.

The cone penetration test forms the primary testing for this project; however, as this is also a comparison of different formulas of superplasticisers the other properties of concrete also require testing to lay the ground work for future research using the new products available. The workability of the mix designs will be constant for the purpose of comparison with the total amount of superplasticiser required to reach a slump of between 150 mm and 200 mm changing according to product. The two properties that relate to quality are the amount of entrapped air in the concrete and the amount of water bleeding from the mix. These two properties are significant as they relate to defects in the final product. The amount of entrapped air can result in weak spots in the mix where pockets of air form, these can result in defects like honeycombing and weak points for cracks to propagate from (Brown and Hiznay 2004). The final property of the concrete to be tested in its fresh state will be the amount of bleeding that occurs from the sample as this can affect the amount of water available for hydration of the mix and the total final strength that can be obtained.

The properties of fresh concrete influence cost in the construction industry in a number of ways. The workability of concrete affects its potential uses as free flowing concrete, pump-ability and setting time retardation. The setting time determines how fast a project can progress in the initial stages of construction. The
quality of the concrete determines whether the final product will be acceptable or require restoration work. The previously mentioned properties are all influenced by various types of superplasticiser.

D. Hardened Concrete Properties

Superplasticisers can positively impact the final product, not by changing the structure of the concrete, but by ensuring a more even distribution of cementitious material. An important point is that there is no long term degradation of the strength of the concrete from use of superplasticisers (Neville 1995; Rixom and Mailvaganam 1999). Superplasticisers can however influence the following hardened concrete properties including compressive strength, modulus of elasticity and tensile strength, bond to reinforcement, temperature increase, durability, shrinkage and creep (Brown and Hiznay 2004).

The tests relating to strength are important for determining the impact superplasticisers have on setting time. The primary focus of these tests is to determine how soon the concrete will be ready for the next phase of construction after placement. The compressive strength and tensile strength are important for comparison between mixes, to determine if more time is required for the concrete to set. They also give an indication of the quality by ensuring that the mixes meet the required strength for the concrete. These tests relate to the inclusion of prestressed reinforcement, and at what point the concrete will be strong enough to resist the forces that occur from the steel. Following the above strength tests are the modulus tests. These tests will include the modulus of elasticity test and the modulus of rupture testing. The modulus of rupture test determines the tensile force in the lowest fiber of the concrete (Neville 1995). The strength of the final samples dictates whether the mix will be able to hold the forces being applied during construction. Other factors which are essential for concrete suitability are temperature, shrinkage and creep. These factors will not be tested for as part of this project and can be considered in future research.

III. Approach

A. Material Testing

Prior to the commencement of testing the mix designs and available materials had to be characterised. The tests that were conducted involved four aggregate sieve analysis tests and water absorption tests. Samples were collected as specified in AS1141.3.1, all sieve analysis tests were conducted in accordance with AS1141.11, fine aggregate water absorption tests were conducted in accordance with AS1141.5 and the coarse aggregate water absorption test were conducted in accordance with AS1141.6.1. These tests were completed to determine the grading of aggregate sizes, densities of the aggregates and the percentage of water required for each aggregate to reach the SSD condition. The materials available were aggregates from Mugga Quarry by BORAL Resources PTY LTD and included fines and aggregates of maximum sizes 7 mm, 10 mm and 14 mm.

B. Mix Design

The mix design was calculated using a modified version of the British Method suggested by Professor O. Kayali. The modification was suggested to reduce the amount of inefficiency in the final mix proportions. The modification involved reducing the water and cement in the design by 15% from the original method. The mix design was calculated with the following parameters:

1. Coarse graded aggregate max size–20 mm with a surface saturated dry density of 2640 kg/m³.
2. Type A General Purpose Portland Cement of density 3170 kg/m³.
3. Fineness modulus of 1.88 calculated from the available materials.
4. Inclusion of 25% and 47.5% fly ash to replace cement.
5. High slump ranging from 150-200 mm.

The above parameters were selected to give a mix design which is readily transferable to the construction site. The calculated standard traditional mix design had an approximate density of 2320 kg/m³ whilst the HVFA
mix design had an approximate density of 2280 kg/m$^3$. For more details on the calculations used refer to appendix A. Table 1 below shows the approximate measurements of the basic components of the mix designs.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Traditional- Control Mix (kg/m$^3$)</th>
<th>Traditional HVFA-Control Mix (kg/m$^3$)</th>
<th>HVFA Mix (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>341.2</td>
<td>208.4</td>
<td>208.4</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>113.8</td>
<td>191.6</td>
<td>191.6</td>
</tr>
<tr>
<td>Total Water</td>
<td>247.6</td>
<td>220.9</td>
<td>182.1</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>852.0</td>
<td>884.7</td>
<td>935.0</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>695.0</td>
<td>721.3</td>
<td>762.3</td>
</tr>
</tbody>
</table>

Table 1: Material proportions of the mix designs.

In table 1 the differences between the mix designs can be seen. There is a 20% reduction in the amount of free water or water used in hydration, in the mixes containing superplasticisers. This affects the mass of the aggregate in the mix design and changes the compressive strength. The mass of the total cementitious material however did not change between the control and superplasticiser mixes. Between the two types of concrete, aside from the difference in the percentage of cement replacement with fly ash there is also a reduction of the total cementitious material in the HVFA mix designs. This occurred in order to increase the efficiency of the HVFA mix designs which were expected to achieve a higher workability than the traditional mix designs. It did however also cause a significant decrease in the final strength. For the full proportions of all of the mix designs used refer to appendix B.

C. Superplasticiser Dosage

The types of superplasticisers that were compared throughout this project included the commercial products DARACEM, ADVA 142 and CENTROX MWR. DARACEM is a modified sulphonated naphthalene formaldehyde condensate, manufactured by Grace Construction Products. Modified in this case refers to the additional materials added to the molecular structure of the superplasticiser to achieve or enhance the desired properties in the fresh and hardened states of concrete. This product according to the commercial data available is ideally designed for the purpose of reducing the water to cement ratio whilst still maintaining a degree of workability (Grace 2006). DARACEM is best suited to prestressed or precast situations. DARACEM is classified as a high range water reducing admixture under AS 1478.1 – 2000 and has a specific gravity of 1.17. The cost of DARACEM quoted by Grace construction products was $3.44 per L for bulk orders in excess of 5000 L.

ADVA 142 is a polycarboxylate ester and is also manufacture by Grace Construction Products. This superplasticiser is a third generation superplasticiser. According to commercial data available, it is best suited to achieving high slump with a lower rate of slump loss. The comparison of this with CENTROX MWR will assist in determining the additional materials which allow for the various desired properties to be achieved. ADVA 142 is classified as a high range water reducing admixture under AS 1478.1 – 2000 and has a specific gravity of 1.09. The cost of ADVA 142 quoted by Grace construction products was $6.00 per L for bulk orders in excess of 5000 L.

Finally CENTROX MWR is a polycarboxylate ester manufactured by Australian Industry Additives. CENTROX MWR is classified as a mid-range water reducing admixture under AS 1478.1 – 2000 with specific gravity of 1.03. Centrox is a relatively new product on the market and has only just been introduced for testing at the university of New South Wales campus at the Australian Defence Force Academy. This combination of commercial products will allow for a direct comparison between products that are both new and old in the high range classification and with two products of a similar molecular makeup. The cost of CENTROX MWR quoted by Australian Industry Additives was $1.40 per L for bulk orders in excess of 5000 L.

Each superplasticiser was added to a set mix design within the recommended dosages and in the prescribed manner in order to achieve the maximum possible slump. For the control mix the water to cement ratio was adjusted until a slump of 100–150 mm could be achieved. Although this was not consistent with the mix designs for the superplasticisers, it was necessary to avoid excessive bleeding and segregation. The target initial slump for each mix incorporating a superplasticiser was between 150–200 mm. Through preliminary test mixes it was determined that the dosages, outlined in table 2, for the superplasticisers would be used to achieve the required slump.
The aim to achieve a 20% reduction in water, with an initial slump of 150–200 mm allowed for variations in the dosages of the superplasticiser. DARACEM was used at its maximum dosage in accordance with grace constructions and as such could not achieve a higher slump with the 20% reduction in water. Rather than modify the mix design it was decided that the lower slump would be accepted. Similarly despite the reduced effectiveness of the superplasticisers on the HVFA mix it was decided that the Dosage would remain the same.

D. Batch Preparation

All mixes were produced in accordance with AS1012.2 with a number of adjustments outlined in the following procedure:

1. The quantities of materials were weighed in order to achieve the required volume of concrete with an additional 20% to ensure enough concrete was produced.
2. The aggregates were placed into the mixer, the water required to achieve SSD condition from the ‘AS IS’ condition was added whilst the aggregates were mixed for a period of 1–2 min.
3. The quantity of fly ash and 10% of the free water were added and mixed for 2 min. The addition of the 10% water is not specified in the standard however as no air intake was installed to extract excess dust it was deemed necessary to add the water to prevent dust from spreading throughout the laboratory.
4. The portion of cement was added and mixed for 2 min. During the first minute of mixing the remaining free water was added to the batch. The required amount of DARACEM was added at this point dissolved in the remaining free water.
5. The batch was allowed to rest for 2 min before a further 2 min of mixing. The required amounts of ADVA 142 and CENTROX MWR were added on the recommencement of mixing.
6. Following this a slump test was conducted in accordance with AS1012.3.1 to ensure the required consistency was reached.
7. The mix was placed into molds for the required testing and vibrated.
8. All samples were allowed to rest for a period of greater than 18 hours before being removed from the molds and placed into a curing room at constant temperature 23 degrees and 100% humidity.

Superplasticisers as previously mentioned were added at the time when they would achieve the greatest effect. For CENTROX MWR and ADVA 142 this was during mixing immediately after the batch had been allowed to rest for 2 min in step 5. This is due to polycarboxylic ether polymers being much more effective when the majority of the free water is being used by the hydration process. DARACEM however was dissolved with the 90% free water portion and added before the rest period, this allowed it sufficient time to take effect before the initial slump test.

E. Testing

The testing of the properties of concrete occurred in accordance with the standards listed in table 3 below and at the nominated time after mixing. The standards were followed where ever possible, however; on occasion the procedure could not be followed. For example not all cylinders used for testing fitted the minimum dimensions outlined in the tests below. The complete list of test specimens can be found in appendix C with all dimensions not within the minimum range highlighted in red. AS 1478 specifies that compression tests are to be conducted at 1, 3, 7 and 28 days for mixtures containing HWR superplasticisers. The compressive tests as per table 3 were not conducted in this order with the 24 hour test conducted after 40 hours. This allowed for the samples to strengthen sufficiently to grind the ends and also allowed for better management of time between

---

<table>
<thead>
<tr>
<th>Mix Description</th>
<th>Mix Designation</th>
<th>Superplasticiser Dosage (ml/100 kg of Cementitious Material)</th>
<th>Water/Cement Ratio</th>
<th>Total cementitious material per m³ of concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Traditional Mix</td>
<td>B12</td>
<td>0</td>
<td>0.5</td>
<td>445</td>
</tr>
<tr>
<td>ADVA Traditional Mix</td>
<td>B1A4</td>
<td>1100</td>
<td>0.4</td>
<td>445</td>
</tr>
<tr>
<td>CENTROX Traditional Mix</td>
<td>B1B4</td>
<td>800</td>
<td>0.4</td>
<td>445</td>
</tr>
<tr>
<td>DARACEM Traditional Mix</td>
<td>B1C4</td>
<td>1500</td>
<td>0.4</td>
<td>445</td>
</tr>
<tr>
<td>Control HVFA Mix</td>
<td>B22</td>
<td>0</td>
<td>0.5</td>
<td>400</td>
</tr>
<tr>
<td>ADVA HVFA Mix</td>
<td>B2A2</td>
<td>1100</td>
<td>0.4</td>
<td>400</td>
</tr>
<tr>
<td>CENTROX HVFA Mix</td>
<td>B2B2</td>
<td>800</td>
<td>0.4</td>
<td>400</td>
</tr>
<tr>
<td>DARACEM HVFA Mix</td>
<td>B2C2</td>
<td>1500</td>
<td>0.4</td>
<td>400</td>
</tr>
</tbody>
</table>

Table 2: Superplasticiser dosages and mix design proportions.
mixing and testing samples. Table 3 below shows the number of each kind of test conducted for each mix design at the designated time. For further information on the project timeline refer to appendix D.

The testing for this project allowed for a detailed comparison of the early stage strength development of the concrete. Testing at 28 days allowed for the comparison of results between the different types of concrete. The 28 day test results are not significant when used to compare mix designs. This is due to the changes in the mix designs that are outlined above, to ensure that the mixes being tested are more closely aligned to industry practice rather than for laboratory convenience. The adjustments that prevent any significant conclusions being made from a direct comparison of 28 day test results include the change of the water to cement ratio between the control and the mix designs in order to achieve a comparable workability and the reduced cementitious material between the HVFA mix designs and the traditional mix designs. These changes represent substantial differences in the mix designs and demonstrated significant effects on the 28 day strength test results.

<table>
<thead>
<tr>
<th>Time of Testing (Days after mixing)</th>
<th>0</th>
<th>2</th>
<th>3</th>
<th>7</th>
<th>28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump Test</td>
<td>AS 1012.3.1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penetration Resistance Test</td>
<td>AS 1012.18</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement of Bleeding</td>
<td>AS 1012.6</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement of Entrained Air</td>
<td>AS 1012.4.1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive Strength Test</td>
<td>AS 1012.8.1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5-8</td>
</tr>
<tr>
<td>Indirect Tensile Strength Test</td>
<td>AS 1012.8.1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>AS 1012.17</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulus of Rupture</td>
<td>AS 1012.11</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Testing of Concrete Samples.

IV. Results and Analysis

A. Aggregate Testing

These tests were conducted to determine the grading of aggregate sizes, densities of the aggregates and the percentages of water required for each aggregate to reach the SSD condition. The materials available characterised through sieve analysis tests, included crushed aggregates of maximum sizes 7 mm, 10 mm and 14 mm. A summary of the results for the water absorption tests are in table 4. The results are typical of the values expected of aggregates in the construction industry.

<table>
<thead>
<tr>
<th>Sample Designation</th>
<th>Apparent Particle Density (kg/m³)</th>
<th>SSD Particle Density (kg/m³)</th>
<th>Dry Particle Density (kg/m³)</th>
<th>Water Adsorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJK01</td>
<td>2670</td>
<td>2630</td>
<td>2610</td>
<td>0.88</td>
</tr>
<tr>
<td>BJK02</td>
<td>2720</td>
<td>2680</td>
<td>2650</td>
<td>1.01</td>
</tr>
<tr>
<td>BJK03</td>
<td>2680</td>
<td>2600</td>
<td>2560</td>
<td>1.78</td>
</tr>
<tr>
<td>BJK04</td>
<td>2600</td>
<td>2540</td>
<td>2510</td>
<td>1.50</td>
</tr>
<tr>
<td>Graded Aggregate</td>
<td>2690</td>
<td>2640</td>
<td>2610</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Table 4: Aggregate densities and required SSD water absorption percentages.

The sieve analysis testing results concluded that all the materials were defined as one size aggregates in accordance with the definition in AS1141.11-2009, as below.
‘An aggregate of which at least 60% of the mass of the total material passes a sieve, selected from the set 75.0 mm, 37.5 mm, 26.5 mm, 19.0 mm, 13.2 mm, 9.50 mm, 6.70 mm, 4.75 mm and 3.35 mm, which is immediately less than the nominal size of the aggregate and is retained on the sieve immediately following the selected sieve in this series.’

A nominal size aggregate is defined for convenience where by ‘the nominal size is expressed as a whole number above the smallest sieve aperture size through which at least 90% of the aggregate passes’. In order to achieve a graded aggregate mix design two aggregate mixes were tested in the traditional control mixture to determine the design suitability. The first mix design consisted of 35% fine aggregate and 65% coarse aggregate. The coarse aggregate could be further broken down into 35% of 14 mm aggregate, 20% of 10 mm aggregate and 15% of 7 mm aggregate. When tested as part of the traditional control mix design it was determined through visual observation that the batch was too coarse. This adversely affected the slump results of the test mix and lead to a higher degree of air entrainment in the batch. The second aggregate mix design tested included 45% fine aggregate and 55% coarse aggregate. The coarse aggregate mix design was further broken down into 20% of 7 mm aggregate, 20% of 10 mm aggregate and 15% of 14 mm aggregate. The reduction in the amount of coarse aggregates reduced the strength of the concrete however it improved the slump result of the mix and improved the workability of the mix design. The graded aggregate densities and water absorption percentages shown in table 4 are those of the second, accepted mix design. The sieve analysis results for the 4 available aggregates are shown below in figures 4 to 7. All Aggregate sieve analysis data can be found in appendix E.

B. Mix Designs
Prior to the batching of concrete several preliminary tests were conducted to determine the proportions for the mixtures that would be used. The results demonstrated that of the three superplasticisers CENTROX MWR was the most effective at increasing slump as shown in table 5 below. There is a significant difference in the
effect of the superplasticisers on the traditional mix designs and the HVFA mix designs. The effect of the superplasticiser on the slump achieved is nearly halved in the HVFA mix designs. There is no decrease between the two control mixes despite the lower total cementitious material in the HVFA control mix as shown in table 5. This would also have resulted in a decrease in the slump of the superplasticiser mix designs but not on such a large scale. It is documented in industry practice notes that fly ash increases the workability of concrete as it acts as a filler and has pozzolanic properties (CIA 2003; S. Srinivasan, S. Barbhuiya et al. 2010).

This leads to a number of possible hypotheses the first being that sulphonated naphthalene formaldehyde and polycarboxylate ester superplasticisers do not directly affect the fly ash particles. This is supported by the results in table 5 and the results of the hardened concrete tests which were conducted later. The controls of both mix designs achieved the same slump within an expected margin of error as per AS1012.3.1 being ± 10 mm. The mix designs containing superplasticisers, however, demonstrated a slump roughly half that of the traditional mix designs even though all the superplasticisers were used near to their maximum allowable dosage. The second possible hypothesis is that the superplasticisers were less effective on the fly ash due to the smaller nature of the fly ash particles and the much larger surface area for the relative replacement of cement.

<table>
<thead>
<tr>
<th>Mix Designation</th>
<th>Superplasticiser Dosage (ml/100 kg of Cementitious Material)</th>
<th>Avg. Slump Achieved (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12</td>
<td>0</td>
<td>130</td>
</tr>
<tr>
<td>B1A4</td>
<td>1100</td>
<td>180</td>
</tr>
<tr>
<td>B1B4</td>
<td>800</td>
<td>170</td>
</tr>
<tr>
<td>B1C4</td>
<td>1500</td>
<td>95</td>
</tr>
<tr>
<td>B22</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>B2A2</td>
<td>1100</td>
<td>90</td>
</tr>
<tr>
<td>B2B2</td>
<td>800</td>
<td>85</td>
</tr>
<tr>
<td>B2C2</td>
<td>1500</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 5: Superplasticiser dosages and mix design workability.

The results in table 6 also demonstrates which of the HWR admixtures is the most efficient and cost effective. During the preliminary testing of the superplasticisers on the traditional mix designs all HWR admixtures were tested for slump at the maximum recommended range. They achieved the slump results shown below. Despite being classified as a MWR admixture CENTROX MWR was the most effective. The slump achieved of 270 mm is characteristic of self-compacting concrete and could be used in such applications. Such a high slump could also be used to achieve high strength concrete by further reducing the water to cement ratio from 0.4. More importantly though is the significant advances in concrete technology that have been made in the newer generation of admixtures demonstrated by the significant difference in slump of the 2 types of superplasticiser.

<table>
<thead>
<tr>
<th>Mix Designation</th>
<th>Max. Superplasticiser Dosage (ml/100 kg of Cementitious Material)</th>
<th>Avg. Slump Achieved (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12</td>
<td>0</td>
<td>130</td>
</tr>
<tr>
<td>B1A4</td>
<td>1200</td>
<td>220</td>
</tr>
<tr>
<td>B1B4</td>
<td>1000</td>
<td>270</td>
</tr>
<tr>
<td>B1C4</td>
<td>1500</td>
<td>95</td>
</tr>
</tbody>
</table>

Table 6: Maximum recommended superplasticiser dosages and mix design workability.

C. Fresh Concrete Properties
Testing for the fresh concrete properties including the cone penetration test and the bleeding test could not be included as part of this project report due to material shortages outside the control of those involved. The cone penetration test would have given more insight into the behavior of the concrete within the first 6 hours of setting. The test is planned to be conducted for the final project deliverable, as part of the test, the bleeding of the mixtures used will also be measured.

D. Compression Test Results
The hardened concrete testing was concerned with the properties of the concrete after 40 hours. The hardened concrete testing was conducted in compliance with the relevant methodology in the concrete standard AS 1012 as per table 3. The averaged results for the compressive tests can be seen below in figure 8. For all compression test results refer to appendix F. The first series of mix designs denoted by the solid lines in figure 8 are the compressive strength test results of the traditional concrete mix designs. The control traditional mix and the traditional mixes containing CENTROX MWR and DARACEM displayed typical curves expected of the
concrete. The mix B1A4.1 containing ADVA displayed a much greater increase from 40 hours to 7 days following mixing and a reduced gradient leading to 28 days. This suggests that the mix was subject to retardation and bleeding. The samples were covered after they were placed into the molds to prevent evaporation of bleed water, however; the molds contained join cracks which allowed small amounts of bleed water to escape from the sample. The retardation would have resulted in the low early strength followed by the greater 7 day strength. The reduced water to cement ratio due to bleeding would have resulted in a lesser long term strength. This can be seen in table 7 and figure 9, where B1A4.1 and B2A2.1 demonstrated an increased change in strength between the tests conducted at the 72 hr and 7 day tests, in comparison to the other superplasticisers used.

Figure 8: Compressive strength test results.

The initial differences in the 40 hour compressive test strength results are due to a combination of factors. The first being the difference in proportions of the water, cementitious material and aggregates due to the changed water to cement ratio between the control mix and the mixes containing superplasticisers. The second is the effects of the superplasticisers themselves. The first factor can be seen in the difference between the control mix and the three mixes containing superplasticisers. This contributes a total difference of between 7–12 MPa which can be considered to be nearly double the 40 hour compressive strength of the control mix when the individual effects of the superplasticisers are considered. The second factor can be seen by the differences between the 40 hrs compressive strength of the three mixes containing superplasticisers. The difference caused by the three superplasticisers was a smaller 4 MPa in the traditional mixtures. The differences in the effects of the superplasticisers can be more effectively quantified as percentages of the 28 day strength as seen in figure 9.
The difference in the superplasticisers mix strength at 28 days is attributed to the better distribution of cementitious materials by the superplasticisers (Neville 1995). This is best demonstrated by the percentages shown above in figure 9. The controls of both the HVFA and the traditional mixes had a much lower early strength as a percentage of the 28 day strength than the three superplasticisers of the same mix type for all tests within the first 7 days. Observing the changes in strength between the tests conducted we can see the effects the superplasticisers contribute to the concrete. The following table 7 shows the changes in strengths and percentages between the four compressive tests conducted.

<table>
<thead>
<tr>
<th>Mix Designation</th>
<th>0-40 hrs</th>
<th>40-72 hrs</th>
<th>3-7 days</th>
<th>7-28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12.1</td>
<td>8.75</td>
<td>6.96</td>
<td>8.16</td>
<td>14.80</td>
</tr>
<tr>
<td>B1A4.1</td>
<td>16.01</td>
<td>9.87</td>
<td>12.31</td>
<td>16.21</td>
</tr>
<tr>
<td>B1B4.1</td>
<td>20.47</td>
<td>7.72</td>
<td>9.51</td>
<td>16.28</td>
</tr>
<tr>
<td>B1C4.1</td>
<td>19.20</td>
<td>6.49</td>
<td>7.87</td>
<td>16.58</td>
</tr>
<tr>
<td>B22.1</td>
<td>4.27</td>
<td>2.29</td>
<td>5.26</td>
<td>11.65</td>
</tr>
<tr>
<td>B2A2.1</td>
<td>7.39</td>
<td>4.83</td>
<td>6.96</td>
<td>15.78</td>
</tr>
<tr>
<td>B2B2.1</td>
<td>9.91</td>
<td>4.10</td>
<td>5.98</td>
<td>14.44</td>
</tr>
<tr>
<td>B2C2.1</td>
<td>9.97</td>
<td>3.32</td>
<td>6.61</td>
<td>15.61</td>
</tr>
</tbody>
</table>

Table 7: Difference in compressive strength between tests.
almost negligible with the exception of ADVA which maintained a slight improvement of the strength development.

The fly ash as shown in previous studies had a set retarding effect on the mix design used (Neville 1995). The superplasticisers had a more consistent effect on the HVFA mix designs as shown by the very similar 28 day compressive strength with all three values falling between 33–35 MPa in figure 10 below. The retardation effect of the HVFA mixtures acts in opposition to the superplasticisers this can be seen by the concrete gaining the majority of its strength in the 7–28 days period. The superplasticisers were less effective in the HVFA mix designs when compared with the traditional mix designs in all the early strength tests. The HVFA mix designs containing CENTROX MWR and DARACEM again obtained roughly a 60% improvement in strength in comparison to the control. The two mixes achieved 28% of the final strength in the first 40 hours; this is less than the traditional mix designs and is almost proportional to the differences between the control mix designs. The difference in the effectiveness indicated only a slight decrease in the effect of the superplasticiser on the early strength development of the HVFA mix designs.

The difference in the 28 day test results indicates that the superplasticisers have a reduced effect on the HVFA mix designs. The range of the superplasticiser traditional mix compressive strengths at 28 days was 4 MPa whilst the range of the HVFA mixtures compressive strengths at 28 days is 1.5 MPa. The difference is not proportional to the results and points to a definite decrease in the difference of the effects of the superplasticisers. This is not in agreement with current industry practice notes which stipulates that the inclusion of fly ash results in little to no difference or a slightly improved performance of superplasticisers, but only for percentages under 25% replacement (CIA 2003). This further supports both the hypothesis that superplasticisers of the categories sulphonated naphthalene formaldehyde and polycarboxylate esters do not directly affect fly ash particles or have a reduced effectiveness due to the increased surface area.

E. Modulus of Elasticity Test Results

The modulus of elasticity test results were very much as expected as can be seen in figure 11. Past studies have found that the inclusion of fly ash lowers the final modulus of the concrete (Babu and Rao 1993). The modulus of elasticity tests found very similar results whereby the modulus was greater in the traditional mix designs, due to fly ash not acting as a binder but as a filler. This means that the setting of the cement is still retarded by the use of the superplasticiser. This is the same for the initial testing of all the superplasticiser mix designs where they still have an initial but reduced effect. This supports both hypothesis whereby the reduced effectiveness cannot be attributed to the increase in the percentage of fly ash or the different types of superplasticiser.
designs as opposed to the HVFA mix designs; this can be seen in figure 11 below. The modulus of elasticity test results can be found in appendix G.

The superplasticisers again had a very clear effect on the early development of the modulus after 72 hours of setting time. The difference in the development of the modulus of elasticity of the mixes containing superplasticisers was between 15–20% greater than that of the control mix of the traditional mix designs. This is almost identical to the difference in the compressive strengths at 72 hours for the traditional mix designs. This suggests that the early moduli could also be as much as 60% higher for the batches containing superplasticisers at the 40 hr tests. The early strength development of the HVFA batches moduli is almost negligible with a difference of less than 5% between the control mix and the superplasticisers.

The effects of the superplasticisers were again greatly reduced in the HVFA mix designs where a much smaller range of results can be seen across the three mixes containing superplasticisers. This is consistent with the results of the compression tests where the final compression strength range of the different mixtures was also greatly reduced. The effectiveness of the superplasticisers is shown through the 72 hour modulus results as a percentage of the 28 day modulus. The percentage of the 28 day modulus was substantially higher in the traditional mix designs than the HVFA mix designs. Table 8 shows the 72 hour modulus as a percentage of the 28 day modulus for all the mix designations. As can be seen the early age moduli of the traditional mix designs were significantly higher than those of the HVFA mix designs. Furthermore the control mix designs maintained an equal rate of growth at the 72 hour test.

![Figure 11: Summary of modulus of elasticity test results.](image)

### Table 8: 72 hour modulus of elasticity development.

<table>
<thead>
<tr>
<th>Mix Designation</th>
<th>72 hrs Modulus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B12.1</td>
<td>67.0</td>
</tr>
<tr>
<td>B1A4.1</td>
<td>77.4</td>
</tr>
<tr>
<td>B1B4.1</td>
<td>80.5</td>
</tr>
<tr>
<td>B1C4.1</td>
<td>77.0</td>
</tr>
<tr>
<td>B22.1</td>
<td>66.5</td>
</tr>
<tr>
<td>B2A2.1</td>
<td>71.0</td>
</tr>
<tr>
<td>B2B2.1</td>
<td>70.1</td>
</tr>
<tr>
<td>B2C2.1</td>
<td>68.2</td>
</tr>
</tbody>
</table>
F. Modulus of Rupture and Indirect Tensile Test Results

The modulus of rupture tests had very different results in terms of the effect of the superplasticisers shown in figure 12. The modulus of rupture testing demonstrated that superplasticisers had a very limited effect. The differences in the values for the traditional mix designs can be attributed to the differences in the final compressive strength as well as the concrete mixes containing the higher superplasticiser dosages demonstrating more ductile properties. This can be seen by the reversal of results from the compression tests. Interestingly the HVFA mix designs all had a higher flexural strength than the traditional mix designs. This is attributed to the silica contained in the fly ash giving the concrete more ductile properties. The full set of modulus of rupture test results are in appendix H.

The indirect tensile tests appeared to be directly proportional to both the modulus of rupture and the compressive test results. This appears to be the case as the results fit neither the strength nor flexural properties of the 2 other tests as shown in figure 13. Where a sample has done poor in one of the tests in comparison to the other samples it has a lower indirect tensile strength. For example B1C4.1 had the lowest compressive strength and the highest flexural strength and yet had the greatest indirect tensile strength. The HVFA samples had a considerably lower indirect tensile strength despite having such high flexural strengths and lower compressive strengths. The indirect tensile test or splitting test is viewed as only partially demonstrating the ductility of a sample. This is because the sample is under compression but the bonds within the sample are under tension. The full set of indirect tensile strength test results are in appendix I.

![Figure 12: Summary of modulus of rupture test results.](image1)

![Figure 13: Summary of indirect tensile strength test results.](image2)

V. Discussion and Comparisons

The results above have yielded a number of possible outcomes the most significant being the reduced effect of the superplasticisers on the HVFA mix designs. This is significant as HVFA mix designs address the problem of sustainable construction and reduced emissions. HVFA mix designs gain further importance with the introduction of the carbon tax in July 2012 as a method to reduce costs in the construction industry. The three superplasticisers demonstrated a number of significant advantages in early strength development when considered in order to achieve the desired affect rather than simply adding a fixed dosage as has been done through studies in the past. Polycarboxylate ester superplasticisers proved to be the more efficient of the two categories tested. Differences do exist between formulas, which this project did not address as mentioned in the literature review. These differences in the molecular structure of the superplasticisers had the effects of retarding the setting time as was observed by the ADVA 142 results, increasing the effectiveness of the superplasticisers as observed through the different dosage amounts required to achieve very similar effects in the polycarboxylate.
As previously mentioned, superplasticisers have not been observed to fundamentally change the structure of concrete and as such any benefits to setting time or strength development can be attributed to the better dispersion of the cementitious material resulting in a more homogeneous material. This can also be witnessed through the low standard deviation values achieved in the samples for each test taken. This can be observed through the standard deviation of 28 day compressive test results shown in Table 9 below. This makes the results very reliable and the small differences can be attributed to differences in the mix designs for example the type of superplasticiser rather than the uncertainty normally associated with concrete batching. That said to remove any uncertainty the tests would have to be repeated for at least one of the mix designs for each of the types of concrete to ensure that the results are reproducible and accurate.

<table>
<thead>
<tr>
<th>Mix Designation</th>
<th>B12.1</th>
<th>B1A4.1</th>
<th>B1B4.1</th>
<th>B1C4.1</th>
<th>B22.1</th>
<th>B2A2.1</th>
<th>B2B2.1</th>
<th>B2C2.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (MPa)</td>
<td>2.67</td>
<td>1.37</td>
<td>4.17</td>
<td>2.96</td>
<td>2.19</td>
<td>1.16</td>
<td>1.63</td>
<td>2.06</td>
</tr>
<tr>
<td>Standard Deviation (MPa)</td>
<td>1.02</td>
<td>0.46</td>
<td>1.31</td>
<td>0.98</td>
<td>0.73</td>
<td>0.47</td>
<td>0.56</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Table 9: 28 day compressive test results standard deviation and range.

There is a clear advantage to using superplasticisers for early strength development in both mix designs. Whether this holds true for HVFA mix designs with cement replacement in excess of 50% still needs to be determined.

From the results above two likely hypotheses were outlined to explain the difference in the effectiveness of the superplasticisers on the traditional and HVFA concrete. The results above support both hypotheses, however, through research of testing conducted on superplasticisers and blended cementitious mix designs the first hypothesis has, in the past, been ruled out as highly unlikely. The first hypothesis, that superplasticisers do not directly affect fly ash is indeed less likely due to the similar nature of fly ash and cement. Fly ash and OPC have very similar surface charges as demonstrated by the increased workability of blended mixes containing fly ash (CIA 2003; Bentz, Hansen et al. 2011). This is also supported by testing conducted on the charges of different cement suspensions (S. Srinivasan, S. Barbhuiya et al. 2010).

Cement and fly ash mixtures form what is called a colloidal dispersion with the particles working to repulse one another. Superplasticisers work in the suspension using electrostatic repulsion by attaching a lyophobic part or anchor onto the surface of cement particles as outlined in the section on superplasticisers above (Brown and Hizmay 2004). This works in the case of cement particles due to their size, fly ash on the other hand can have a much finer particle distribution then cement. This is supported by a study conducted on the effects of the particle size distributions of the OPC and fly ash. The study observed the effects of optimized blended cement mixtures on the setting time and early strength development of concrete. The study found that if an appropriate particle size distribution was found for blended cement mixtures it would reduce the demand for HWR admixtures (Bentz, Hansen et al. 2011). This, however; was not supported by the results as no superplasticiser was used in cement blends with 65% replacement of cement with fly ash and an inversely proportional amount of superplasticiser was used to the percentage of fly ash.

Furthermore additional testing on how to characterise the interaction between cement and superplasticisers using zeta potential measurements has been conducted in Ireland (S. Srinivasan, S. Barbhuiya et al. 2010). The findings from these tests demonstrated that, for two control mix designs, one of OPC and the other of a blended mix using cement and fly ash, the electrostatic repulsion was greater in the blended mix. With the inclusion of different superplasticisers the tests found that the PPC mix designs maintained the higher zeta potential for longer periods of time which indicates that the excess superplasticiser remains in suspension and does not react with the fly ash (S. Srinivasan, S. Barbhuiya et al. 2010).

If the finding of the study, with regards to the effects of particle size distribution on the effectiveness of superplasticisers proves true, then the second hypothesis would be confirmed. The causes of the reduced effectiveness of the superplasticisers would then be attributed to the increased surface area of the portion of fly ash as well as the increased surface charge of the fly ash particles demonstrated through the zeta potential testing (Bentz, Hansen et al. 2011). This would mean that if the superplasticisers did affect the fly ash the same dosage would have to act over a larger surface area having a reduced effect. The higher repulsive charge that already exists between the fly ash particles would mean any gains in the dispersive nature of the suspension would also prove to be less effective.
The results of this project demonstrate a definite trend towards the reduced effectiveness of the superplasticisers on the setting time, workability and strength development of HVFA mix designs. The reasons for this trend, however, remain unclear with two different hypotheses and several possible causes. To confirm the results, further tests need to be conducted to determine the surface chemistry of the fly ash in suspension with the superplasticisers present. Furthermore, testing to further determine the effects of the other categories of superplasticisers should be conducted. This is supported by the zeta potential study which found that sulphonated melamine formaldehyde condensates had a much higher charge in the blended cement suspension than the control.

VI. Recommendations

A. Superplasticisers

It is recommended that superplasticisers be used to decrease the setting times and enhance the early strength development of mix designs. The testing conducted has demonstrated that there is an estimated 50-60% increase in the compressive strength of the concrete at 40 hours of curing and up to an additional 20% improvement in the modulus at 72 hours for mix designs of the same workability.

B. HVFA Mix Designs

It is recommended that further studies into the use of HVFA mix designs be conducted. As it stands, the maximum percentage of cement replacement by fly ash in structural concrete is 25%. This is a limited percentage and does not allow for the full environmental or cost benefit of using fly ash in concrete.

C. Methodology

It is recommended that a similar method of testing be adopted in the future, whereby superplasticisers are used in proportion to the effect desired as well as the control mix. Whilst this is different to previous research in the past it is representative of industry practice whereby efficiency is key to achieving the effect of the admixtures, due to the high cost associated with their use.

D. Testing

It is recommended that further testing be conducted on the particles size distribution of the cement and fly ash used. Surface chemistry testing should also be conducted to determine the way in which each of the superplasticisers react with the cement and fly ash particles. Further testing into the effects of superplasticisers on HVFA mix designs should be conducted to determine the reaction of superplasticisers with fly ash. Testing should be aimed at determining whether, it is a reduced effect due to surface area and greater magnitude of particle surface charge or an indirect effect through its interaction with the cement particles.

VII. Conclusions

The following conclusions have been reached after conducting hardened property testing on the eight mix designs used throughout this project.

a. Sulphonated naphthalene formaldehyde and polycarboxylate ester superplasticisers improve the early strength development of traditional concrete but lose any benefit after 7 days. This includes the compressive strength and modulus of elasticity results. It is hypothesised that this is due to the better distribution of cementitious materials resulting in a more homogeneous suspension and better strength development.

b. Sulphonated naphthalene formaldehyde and polycarboxylate ester superplasticisers had a reduced effect on the HVFA concrete. It is hypothesised that this was caused by either, reduced effectiveness, due to the higher charge of the fly ash particles and the increased surface area due to the smaller fly ash particles; or due to the above mentioned superplasticisers not directly affecting fly ash particles as the conditions were not correct for the surface chemistry reaction.

c. HVFA mix designs have a greater flexural strength than traditional mix designs. This is attributed to the silica content in fly ash which has the effect of increasing ductility.

d. Further testing on the fresh properties and the surface chemistry interaction of the particles will need to be conducted to confirm or disprove the hypotheses above.

These tests involved only two of the four categories of superplasticisers. With two of the admixtures coming from the same category showing vastly different results further testing will need to be conducted in order to
HVFA concrete represents a very sustainable type of concrete, however; further studies on increasing its early strength development need to occur before it will be accepted as a viable replacement for the mix designs being used today. Further fresh concrete testing will occur as part of this project but could not be included in this report due to material shortages outside the control of those involved.

Acknowledgements

I would like to thank my supervisor Dr. Obada Kayali who greatly assisted with his technical experience and understanding throughout this project. This topic was of my own choosing and Dr. Kayali was very supportive in making the testing possible and suggesting ways in which I could expand the project. I would also like to thank the lecturers who were very understanding and flexible with my submission dates for other course work due to my taking on an additional course for the semester and the involved nature of this project. Your patience over the year has been greatly appreciated. Thanks also to the lab technicians in the Civil Engineering Lab, Jimmy Baxter, Matt Barrett and Dave Sharp. They provided unlimited technical support at all hours and were extremely flexible and helpful. I would like to thank my beautiful wife Hannah for her unwavering support and love, despite the late nights working and the house cleaning not done. This was your project to complete as well. I would like to thank Ryan Puth for his constant questions as to the method of testing and always asking the question of is that significant. Finally I would like to thank Sam Baker who was a genuine friend, shown through the countless hours that he dedicated to assisting me with batching concrete and cleaning with no expectation of a reward or payment. Sam made the number of tests possible, in the timeframe with the number of other external pressures present.

References


25. AS 1141.5-2000 : Methods for sampling and testing aggregates - Particle density and water absorption of fine aggregate. ISBN 0-7337-3448-0.

