University of Southern Queensland

Faculty of Engineering and Surveying

The Effect of Admixtures in Concrete Containing Manufactured Sand

A dissertation submitted by

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towards the degree of

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ABSTRACT

This project investigates the effects that varying water cement ratios and superplasticiser have on concrete containing manufactured sand as a complete replacement for natural sand. Due to current levels of construction in Australia there is an ever decreasing availability of natural sands suitable for use as a fine aggregate in concrete. Manufactured sands which are a by-product of rock crushing operations offer a viable solution to the declining availability of natural sands. However there are a number of drawbacks to the use of manufactured sand, particularly the poor workability and finish obtained. This is caused by the High fines content (<75 microns) and the irregular particle shape of the manufactured sand. For these reasons manufactured sand has a very poor reputation in the construction industry.

An experimental approach has been taken to study the effect of the varying water cement ratios and the effect of the superplasticiser. This has be done by making a number of concrete mixes each with either a different water cement ratio or amount of superplasticiser added to the mix. The properties of these concrete mixes have been assessed by measuring both the fresh and hardened state properties of the concrete mix.

The results of the tests have shown that a reasonable workability and a medium strength can be achieved with a high water cement ratio in a concrete mix. The addition of a superplasticiser to a concrete mix allows the mix to achieve a high strength while also having a good workability.

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Mark James Krinke
0011215007

Signature

Date

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Chapter 1
Introduction

1.1 Background Information

1.1.1 History of Concrete

Concrete has been around for many centuries, the first known use of a material resembling concrete was by the Minoan civilization around 2000 BC. During the early stages of the Roman Empire around 300 BC the Romans discovered that mixing a sandy volcanic ash with lime mortar created a hard water resistance substance which we now know as concrete. The predominant type of cement used in modern concrete is Portland cement, other types of cement available include; Blended cement, which is similar to Portland cement but may contain materials such as fly ash slag or silica fume; High early strength cements, which as the name suggests gains strength a lot quicker then Portland or blended cements; Low heat cements, used when limits are placed on the heat of hydration of the concrete; Shrinkage limited cements; Sulphate resisting cements; Coloured cements; Masonry cement.

Portland cement is made by mixing calcium carbonate commonly found in limestone or chalk and silica, alumina and iron oxide found in clay or shale. The two ingredients are ground and mixed together in either a dry or wet state depending on the characteristics of the rocks being used. The mix is then placed in a kiln at temperatures as high as 1400 degrees Celsius, at this temperature the two rocks fuse together to form clinker. The clinker is allowed to cool and gypsum is added at around 1 – 5 percent. The mix is then ground to the required fineness and distributed to concrete batch plants. Portland cement derives its name from the Portland limestone because of the close resemblance of the finished concrete to the Portland Limestone.

Concrete is one of the most popular materials for construction owing to the fact that it can be cast into just about any shape, it has good compressive strengths, is readily available just about anywhere and is relatively cheap in comparison to other materials available for construction, such as steel or fibre composites. Concrete is made from a mixture of cement powder coarse and fine aggregates, normally sand and crushed rock and water. It can be either mixed in a hand mixer or by a large batch plant

1.1.2 Aggregates

Aggregates were first considered to simply be a filler for concrete to reduce the amount of cement required. However it is now known that the type of Aggregate used for concrete can have considerable effects on the plastic and hardened state properties of concrete. Aggregates can form up to 80% of the concrete mix so there properties are crucial to the properties of the concrete. Aggregates can be broadly classified into four different categories, they are heavy weight, normal weight, light weight and ultra-light weight aggregates. However in most concrete practices only normal weight and light weight aggregates are used. The other types of aggregates are for specialist uses, such as nuclear radiation shielding for heavy weight concrete and thermal insulation for light weight concrete.

Types of aggregates commonly used include natural sands and gravels, crushed rocks and manufactured aggregates. Natural sands and gravels are normally sourced from stream beds, dunes, alluvial deposits or marine deposits. Crushed rocks have an advantage over other aggregates in that their size may be specified by using different size screens when the rocks are crushed. Rock types used for crushed aggregates include igneous rocks such as basalt, diorite and granite; Sedimentary rocks normally used as aggregates are lime stone but occasionally some sandstone is used; and metamorphic rocks are rarely used due to the highly variable nature of the mineral composition of these rocks.

1.1.3 Manufactured Sands

Due to the increased levels of construction expected in Australia in the forthcoming years it is expected that fine aggregate suitable for use in concrete will become scarce or uneconomical to produce. With the expected shortfall in natural sands manufactured sands offer a viable alternative to natural sand, if the problems associated with the use of manufactured sands can be resolved and its poor reputation in the industry overcome.

Manufactured sands are made by crushing aggregate to a size appropriate for use as a fine aggregate (<2.36mm). The crushing process however generates large amounts of materials <75microns as well as causing the manufactured sand to have an irregular particle shape. These fine particles and irregular shape of the aggregate have detrimental effects on the workability and finish of the concrete. These negative effects have given manufactured sands a poor reputation in the construction industry. However recent studies show that these fine particles may be able to be utilized to increase the compressive and flexural strengths of concrete.

1.2 Aims of this project

Manufactured sand offers a viable solution to the decreasing availability of natural sand. However, before manufactured sand can be widely used there are a few problems which need to be overcome. The first problem that needs to be overcome is the poor workability of manufactured sand. When this problem has been overcome then it will go along way to giving manufactured sand a better reputation in the construction industry. The aim of this project is to study the effects that varying amounts of admixtures have on concrete containing manufactured sand instead of natural sand. Hopefully the results of the project will show that a concrete mix containing manufactured sand and no natural sand can achieve a high strength and a good workability through the use of a superplasticiser.

The main aims of this project are:

1. Determine the workability, the overall strength, as well as the rate of strength gain for varying water cement ratios of concrete containing manufactured sand. Compare the results of the manufactured sand concrete to a conventional mix containing natural sand.

2. From the data collected in the previous objective choose a water cement ratio with poor workability and determine the required amount of superplasticiser to achieve a good workability. Also determine the overall strength, as well as the rate of strength gain of the concrete after the addition of a super-plasticiser

3. Conduct a cost analysis of all mixes and compare the costs of a mix containing manufactured sand to the cost of a control mix.

If time permits

4. Determine flexural strength and young's modulus of concrete containing manufactured sand, and compare to the flexural strength and young's modulus of a control mix
5. Determine the rate of strength gain for concrete containing a combination of manufactured sand and natural sand and the effect that the addition of a superplasticiser has on the workability.

1.3 Overview of this Dissertation

Chapter1: Provides some background information on manufactured sand and the use of admixtures in concrete, as well as the main objectives of this project.

Chapter 2: Reviews available literature on the use of manufactured sand and the different types of admixtures and how they work.

Chapter3: Discusses the adopted experimental procedures used in order to gain the required data.

Chapter 4: Analyses the results obtained from gathered data.

Chapter 5: Compares the cost of the different concrete mixes and any recommendations.

Chapter 6: Contains conclusions obtained from tests carried out, and any comments on any further work which may need to be done on manufactured sand concrete mixes.

Chapter 2

Literature Review

2.1 Manufactured Sands

Corrigan D'Sourza & Dumitru (n.d) reported that there are two major aspects that should be considered in the characterisation of manufactured sands:

- Manufactured sand has to be produced and engineered for the specific purpose of producing fine aggregate for concrete or asphalt industries, utilising technologies fit for the purpose.
- Research work has indicated that there is a possibility of utilizing a large proportion of 75-micron fines in the concrete if the fines are processed and applied in the correct fashion. Also recent work carried out in the USA by the International Centre for Aggregate Research show that in excess of 15% of 75 microns in the fine aggregate may be suitable in concrete, providing that the crushed fine aggregate is produced from a well known quarry source.

The Cement and Concrete Association of Australia's (CCAA) guide to Concrete Construction (2002), states that the shape and texture of aggregate particles has an important influence on the workability of freshly mixed concrete, and hence may effect the water demand and the water cement ratio.

The use of manufactured sands in concrete causes the concrete to have very poor workability. This is caused by the irregular particle shape of the manufactured sands. The water required for a given degree of workability (slump) is directly related to the void space in the aggregate. When the void space is high, the water requirement necessary for a given workability will also be high. And the strength of the concrete will also be low unless additional cement is added. The void content of manufactured sand is generally higher then that of natural sand (Hudson 1999).

The higher fines content of manufactured sand has significant effects on the workability and the strength of concrete. The CCAA's Guide to concrete construction states that aggregate combinations with excessive amounts of sand or excessively fine sands may produce uneconomical concretes because of the larger surface area of the finer particles. Hudson (1999) reported that "...Concrete manufactured with a high percentage of minus 75 micron material will yield a more cohesive mix then concrete made with typical natural sand. Hudson also reported that although the compressive strength and the workability may be superior to natural sand, the finish of the concrete containing manufactured sand is still a major draw back to its use.

In order to overcome the negative impacts that manufactured sand has on the workability plasticisers may be used to improve the workability and finish of concrete mixes. Corrigan D'Sourza & Dumitru's (n.d) report into the use of a New Generation Admixture for Improvement of Concrete with manufactured sands concluded that through the use of a medium-range water reducing admixtures, incorporating Polycarboxyate technology, a harsh concrete mix was made more workable, cohesive and easier to place and finish.

The manufactured sand to be used in this project has been sourced from Wagners and is made using the patented 'Great Divide' Sand Separator. This machine seen in figure 2.1 is designed to greatly reduce the amount of fines (< 75microns) present in the manufactured sand

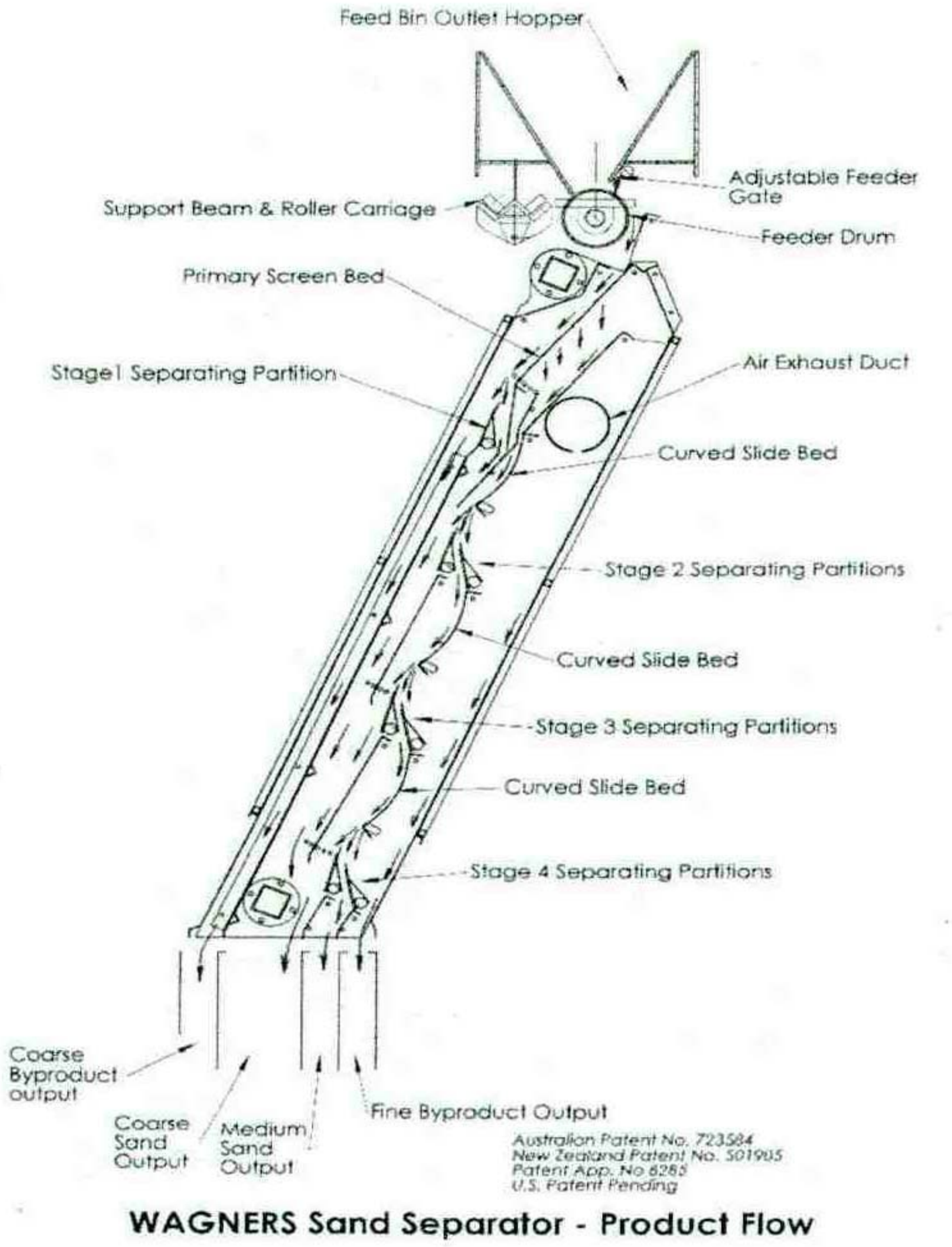

Figure 2.1: Schematic of the "Great Divide' Sand Separator showing the separation of fines in Manufactured Sand. Source: Wagners

2.2 Admixtures

Admixtures are substances which are added to the concrete mix to give it more desirable properties. Admixtures can be classified into a number of different categories. They are

- Air entraining Agents
- Accelerating Agents
- Retarders
- Water Reducing or Plasticisers
- Superplasticisers
- Bonding Admixtures
- Water Repelling Agents
- Pigments
- Porefillers
- Pozzolans

Each of these different admixtures has a different effect on the properties of fresh and hardened concrete. A superplasticiser will be used in this project because of its ability to dramatically increase the workability of fresh concrete with minimal effect on the overall strength of the concrete.

Water reducing plasticiser has a detergent like property which is referred to as a surface active agent. These substances carry an unbalanced charge of electricity and when put into water will migrate towards the surface of the water with the electrically charged end sticking into the water whilst the tale is out of the water.

The Cement and Admixtures Association, (1977) reported that two things will happen when a surface active agent is placed into a suspension of cement particles.

1. The surface active agents 'tail' is absorbed on the surface of the cement particle with the negative charge protruding into the water. As a result the cement particles do not collect together and therefore more surface area is available for reaction with the water. At the same time water that may be trapped inside a cement particle floc is released. The combined effects improve the workability of the cement mix; this can be seen graphically in figure 2.1
2. Entrapped air is also more readily removed since orientation of the surface active agents prevents the air bubble from attaching to cement particles, seen in figure 2.2

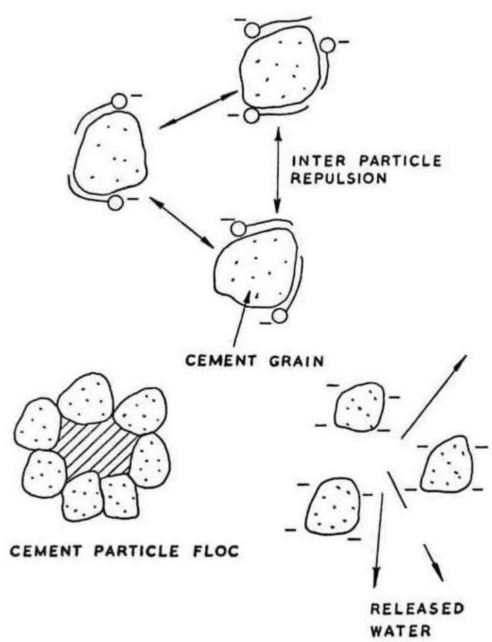

Figure 2.1: Effect of surface active agent on cement particle floc, Source: Cement Admixtures Association

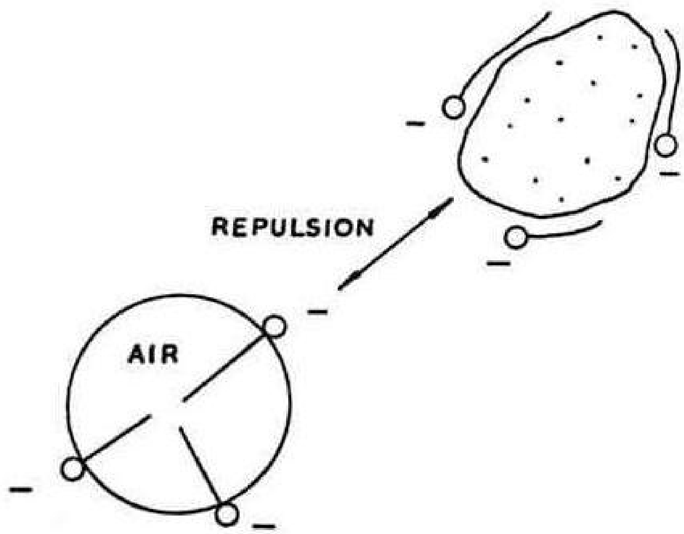

Figure 2.2: Repulsion of air bubble by surface Active Agent, Source: Cement Admixtures Association

Chapter 3

Experimental Methodology

In order to effectively analyse the effects that the manufactured sand has on the fresh and hardened properties of concrete, a number of different trial mixes have been made. These trial mixes are varied in water cement ratios and the percentages of plasticiser added to the concrete mix. The plasticiser chosen for this project was superplasticiser manufactured by Chemical House; this plasticiser was chosen for us in this project for its ability to dramatically increase the workability of the fresh concrete mix. The recommend dosages for the superplasticiser was a range of 0.4 to 1.5 percent for conventional concrete mixes, however it was expected that for this project larger dosages of plasticiser would be required to achieve a suitable workability. The main objectives of the trial batches were to:

- Determine if a suitable workability and strength can be achieved in concrete containing manufactured sand as a complete replacement for natural sand;
- Determine what percentage of superplasticiser is required to achieve a suitable workability for concrete containing manufactured sand;
- Determine the impact that the superplasticiser has on the strength of the concrete;
- Determine the rate of strength gain for the concrete containing manufactured sand with and without superplasticiser;

3.1 Aggregates

To ensure consistency of aggregates all of the aggregates have been sourced from Wagners in Toowoomba. To ensure a consistent quality and grading so that alterations were not required for the mix, enough manufactured sand to complete all of the mixes was sourced at the beginning of the testing phase. The manufactured sand used came from Wagners Malloo quarry, where the manufactured sand is produced from the by product of blue metal crushing operations.

In order to design the concrete mix the aggregates properties had to be analysed. In order to do this a number of tests were carried out on the concrete, they were; sieve analysis, bulk density, dry density and moisture content. All of the aggregate tests were done in accordance with AS 1141.

Due to the increased surface area of the fines, increased amounts of water and cement will be required to achieve target workability's and strengths. The higher amounts of fines and the irregular particle shape of the manufactured sand can also be seen in figure 3.1. The irregular particle shape also has a negative impact on the workability of the concrete due to the increased amount of voids created in the concrete. However an irregular particle shape may produce a stronger concrete mix then a mix made with rounded particles as the aggregate will interlock better with the other aggregate and the cement paste.

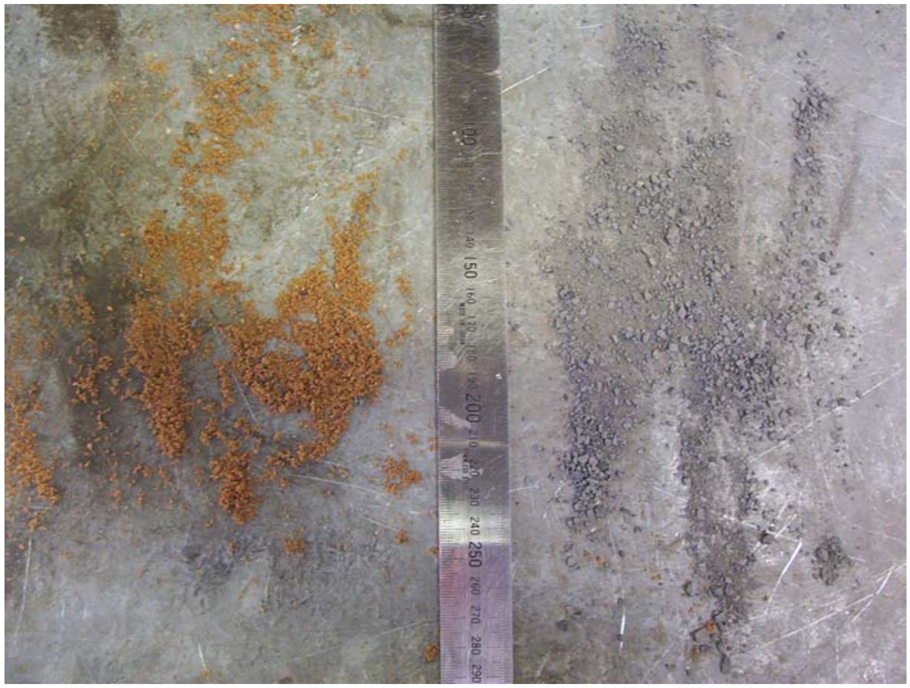

Figure 3.1 Comparison of Manufactured Sand (right) and Natural sand (left)

3.2 Concrete Mix Design

A number of different trial mixes were decided to be assessed; firstly the water cement ratio of the trial mixes were altered to assess the properties of the concrete containing 100 percent manufactured sand and no plasticiser. Initially it was decided to try and achieve a medium strength concrete mix around 25 Mpa. From the study guide this gave a target strength of around 32 Mpa. This target strength corresponded to a water cement ratio of 0.65. After trialling this mix it was discovered that the mix achieved a reasonable workability without the use of a superplasticiser. In the next mix it was decided to try and reduce the workability by reducing the water cement ratio to 0.5. This mix had a much reduced workability than previous but further reduction of the workability was necessary before the superplasticiser. The next mix trialled had a water cement ratio of 0.4 and exhibited very poor workability. This mix was adopted as the mix which would be used for the addition of superplasticiser. This was also adopted as the water cement ratio of the natural sand control mix.

The target grading adopted for the aggregate was chosen from a previous study done by a research student, on manufactured sand so that some comparisons might be drawn between the two different studies. The adopted target grading is seen in table 3.2. The aggregate blend was developed using Rothfuchs methods for two or more aggregates for the mixes with manufactured sand and for the natural sand mix. This blend was later checked using a spreadsheet program which showed that the actual mix quantities provided a grading very close the target grading.

Table 3.2: Target Grading

Sieve Size (mm)	Percentage Passing
26.5	100
19	99
13.2	80
9.5	65
6.7	52
4.75	48
2.36	42
1.18	35
0.6	22
0.3	10
0.15	3
0.075	2

The aggregate cement ratios were selected by using the tables provided in (chapter 3 pp3.10-3.11) of the concrete technology study book. The different trial mixes are summarised in table 3.3, trial mix 7 was the natural sand control mix. Each trial mix required 15 small concrete cylinders, (100mm diameter 200mm high) for measuring the compressive strength of the concrete and 2 large cylinders (150 mm diameter 300mm high) for the indirect tensile test

Table 3.3: Summary of Trial Mixes

Mix Number	WC ratio	AC ratio	% plasticiser
1	0.65	5.2	0
2	0.5	4.1	0
3	0.4	3.3	0
4	0.4	3.3	0.88
5	0.4	3.3	1.77
6	0.4	3.3	2.36
7	0.4	3.3	0

3.3 Fresh Concrete Properties

In order to determine the properties of the fresh concrete a number of tests have been carried out on the concrete, they include Slump, Compacting factor, and Vebe tests. The different tests are carried out to get a better indication of the workability of the concrete. The slump test is the most common test carried out on fresh concrete and gives a good indication to the workability of the concrete; the slump test is carried by filling a standard conical mould with the fresh concrete, then removing the cone and measuring how much the concrete subsides; however when the concrete has a very high or very low slump its results may not be accurate. Because of this the compacting factor and the Vebe tests are carried out as well. The Vebe test is done using a Vebe consistometer, this apparatus consists of vibrating plate with a metal cylinder mounted on the plate, a slump cone is then placed inside the metal cylinder, the slump cone is then filled the same as it was done for the slump test and the cone is removed. The vibrating plate is then turned on and the time taken for the concrete to completely subside is recorded. The compacting factor test is considered to be a very good indicator of the workability of concrete and can be used on concrete mixes which have minimal slump. The compacting factor is measured using an apparatus which consist of two hoppers mounted one above the other and a metal cylinder under the bottom hopper, seen in figure 3.3. The compacting factor is measured by filling the top hopper and then releasing the trap door so the concrete falls into the second hopper, the trap door is then released on the second hopper and the concrete then falls into the metal cylinder, the cylinder is then weighed; this is the partially compacted concrete mass. The cylinder is then refilled and fully compacted, this is the fully compacted mass, and the compacting factor is measured by dividing the partially compacted mass by the fully compacted mass.

Figure 3.2: Slump Test

Figure 3.3: Compacting Factor Apparatus

3.4 Hardened Concrete Properties

3.4.1 Compressive Strength

The compressive strength of the concrete was determined by testing concrete cylinders 100mm in diameter and 200 mm high, these cylinders were tested in accordance with AS 1012.8. All specimens were weighed and measured to determine the area of the cylinder and the density of the concrete. Tests were carried out on the concrete at ages 3, 7, 14, 21 and 28 days to determine the rate of strength gain of the concrete. Before testing of the concrete all cylinders were inspected for defects in the concrete to ensure consistent results and then rubber caped before being loaded at a constant rate of 240Kn/minute, in the testing apparatus at the USQ concrete laboratory. At each age three specimens were tested to ensure accurate results were obtained.

Figure 3.3: Compression cylinder capped and ready to be tested

The compressive strength of the concrete is determined from the following formulae

$$f = \frac{P}{A}$$

Where:

f Is the compressive strength of the concrete;

P Is the maximum force measured during testing;

A Is the area of the cylinder being tested.

3.4.2 Tensile Properties

To gain an indication of the tensile strength of the concrete it was decided to do the indirect tensile or Brazil splitting test. More flexural strength tests were not done at this stage as the main focus of this project is on the workability of the concrete and on the rate of strength gain of the concrete. Also in order to effectively analyse the rate of strength gain the concrete mixes were required to be quite large and making concrete beams to determine the flexural strength as would have required considerably larger mixes to be made, as well as taking up more time in the already busy schedule of the concrete laboratory.

The Indirect tensile strength is calculated from testing a concrete cylinder with a diameter of 150mm and a height of 300 mm. The specimen is placed length ways between two metal plates, and is then loaded until the specimen splits down its vertical diameter.

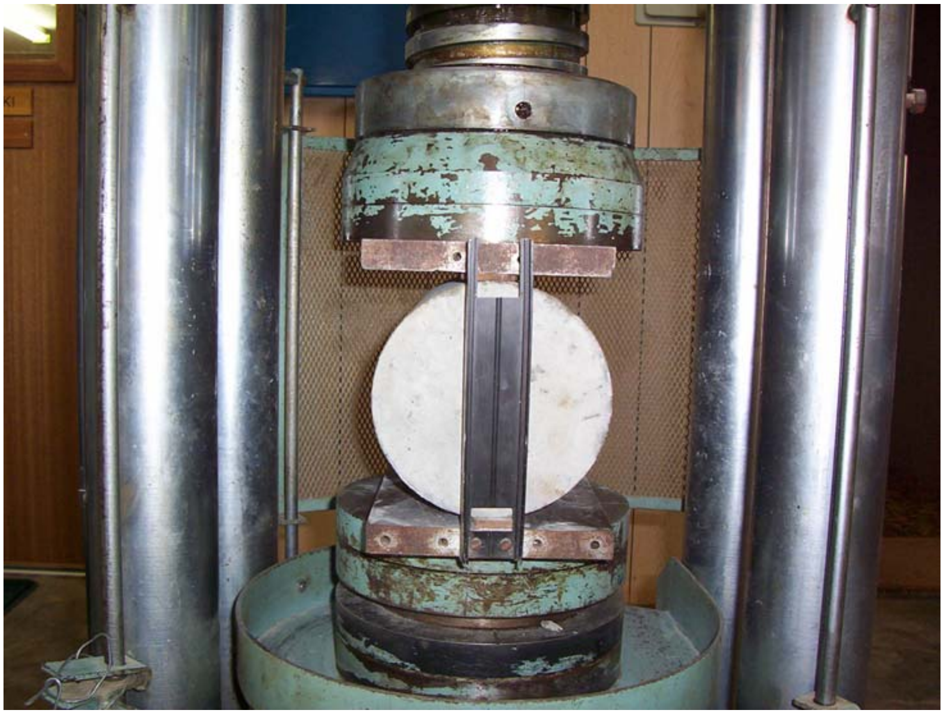

Figure 3.4: Indirect Tensile Test

The Indirect tensile strength is determined from the following formulae

$$f_{ct} = 2000P / \pi LD$$

Where

f_{ct} Is the indirect tensile strength of the concrete;

P Is the maximum force measured by the testing machine;

L Is the length of the specimen being tested;

D Is the diameter of the specimen being tested.

Chapter 4

Results Analysis

As discussed earlier in chapter 3 the main objectives of this project were to

- Determine if a suitable workability and strength can be achieved in concrete containing manufactured sand as a complete replacement for natural sand;
- Determine what percentage of superplasticiser is required to achieve a suitable workability for concrete containing manufactured sand;
- Determine the impact that the superplasticiser has on the strength of the concrete;
- Determine the rate of strength gain for the concrete containing manufactured sand with and without superplasticiser.

4.1 Aggregate Analysis

The results of the sieve analysis as expected showed that manufactured sand has considerably larger amount of fine material then the natural sand. The grading of the natural sand and the manufactured sand are extremely dissimilar and for this reason the aggregate blend for the natural sand mix will be different to the aggregate blend for the manufactured sand mix. The results from the sieve analysis for all of the aggregates used in the concrete mixes for this project can be seen in table 4.1.

Table 4.1: Summary Sieve Analysis

Sieve size	20mm	10mm	7mm	Manufactured Sand	Natural sand
26.5 mm	100.0	100.0	-	-	-
19 mm	100.0	100.0	-	-	-
13.2 mm	65.9	100.0	-	-	-
9.5 mm	16.8	92.6	100.0	-	-
4.75 mm	1.2	4.8	23.7	100.0	100.0
2.36 mm	0.5	2.6	3.2	96.7	99.8
1.18 mm	0.3	1.7	1.9	71.4	98.4
600 µm	-	0.0	0.0	50.8	90.4
300 µm	-	-	-	36.6	55.2
150 µm	-	-	-	25.5	17.6
75 µm	-	-	-	12.1	4.7

4.2 Fresh Concrete Properties

The results of the slump tests carried out on the fresh concrete gave a good indication of the workability of the concrete; however the slump test is limited in its applications. A better indication of the workability is given from the Compacting Factor tests and from the Vebe tests. A summary of the fresh concrete tests can be seen in table 4.2.

Table 4.2: Summary of Fresh Concrete Properties

Mix Number	WC ratio	% plasticiser	Slump	Compacting Factor	Vebe
1	0.65	0	160	0.992	1:23
2	0.5	0	70	0.967	1.81
3	0.4	0	22	0.890	5.19
4	0.4	0.88	46	0.969	2.92
5	0.4	1.77	104	0.978	1.4
6	0.4	2.36	174	0.993	1.29
7	0.4	0	185	0.993	0.64

The results obtained from the slump tests shows that as the water cement ratio or the percentage of plasticiser was increased the slump of the concrete also increased. This was to be expected. However the slump that was obtained was considerably less then what would have been expected from a comparable mix which contained no manufactured sand and only natural sand. The results from the slump tests can be seen graphically in figure 4.1; these graphs clearly show that as the water cement ratio is increased the slump of the concrete is also increased. The first trial mix tested had a water cement ratio of 0.65 and a target strength of 33 Mpa. This mix was able to achieve a good workability and also achieved its target strength of 33 Mpa. In the following mix the water cement ratio was reduced to 0.5 to decrease the workability of the mix and to achieve a higher strength, this mix again achieved a reasonable workability. Although not a great workability was achieved it was suitable enough that the addition of a superplasticiser did not appear necessary. The third mix had the water cement ratio reduced even more to 0.4. This caused a very poor workability; the concrete mix was very difficult to place and took a long period of time to finish off. This concrete mix also exhibited some honeycombing of the concrete cylinders; as a result of this a number of cylinders appeared unsuitable for testing. This honeycombing was caused by a number of factors including a lack of vibration of the concrete cylinders. This mix with a water cement ratio of 0.4 was adopted as the mix to trial different percentages of superplasticiser.

The recommended dosage of superplasticiser given by the manufacturer is a range of 0.4 to 1.5 percent; it was clear after the first trial with manufactured sand that larger amounts of plasticiser may be required. To achieve a high slump, additional superplasticiser was added until the concrete reached a workability which appeared to be easy to place and finish. The amount of plasticiser added was well outside of the maximum recommended dosage of 1.5 percent. The effect that the different percentages of superplasticiser had on the workability of the concrete can be seen graphically in figure 4.2.

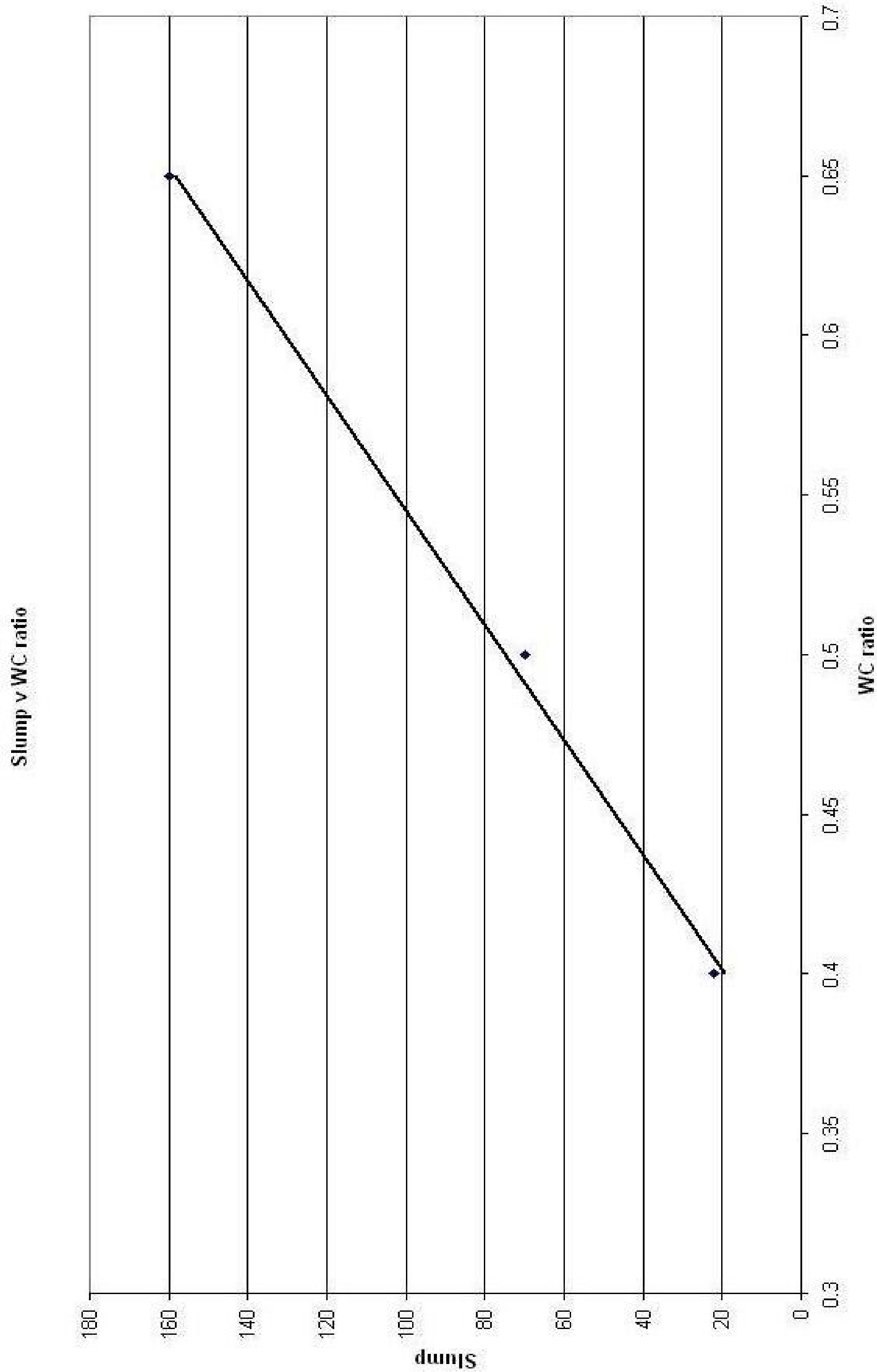

Figure 4.1: Effect of Water Cement Ratio on Slump

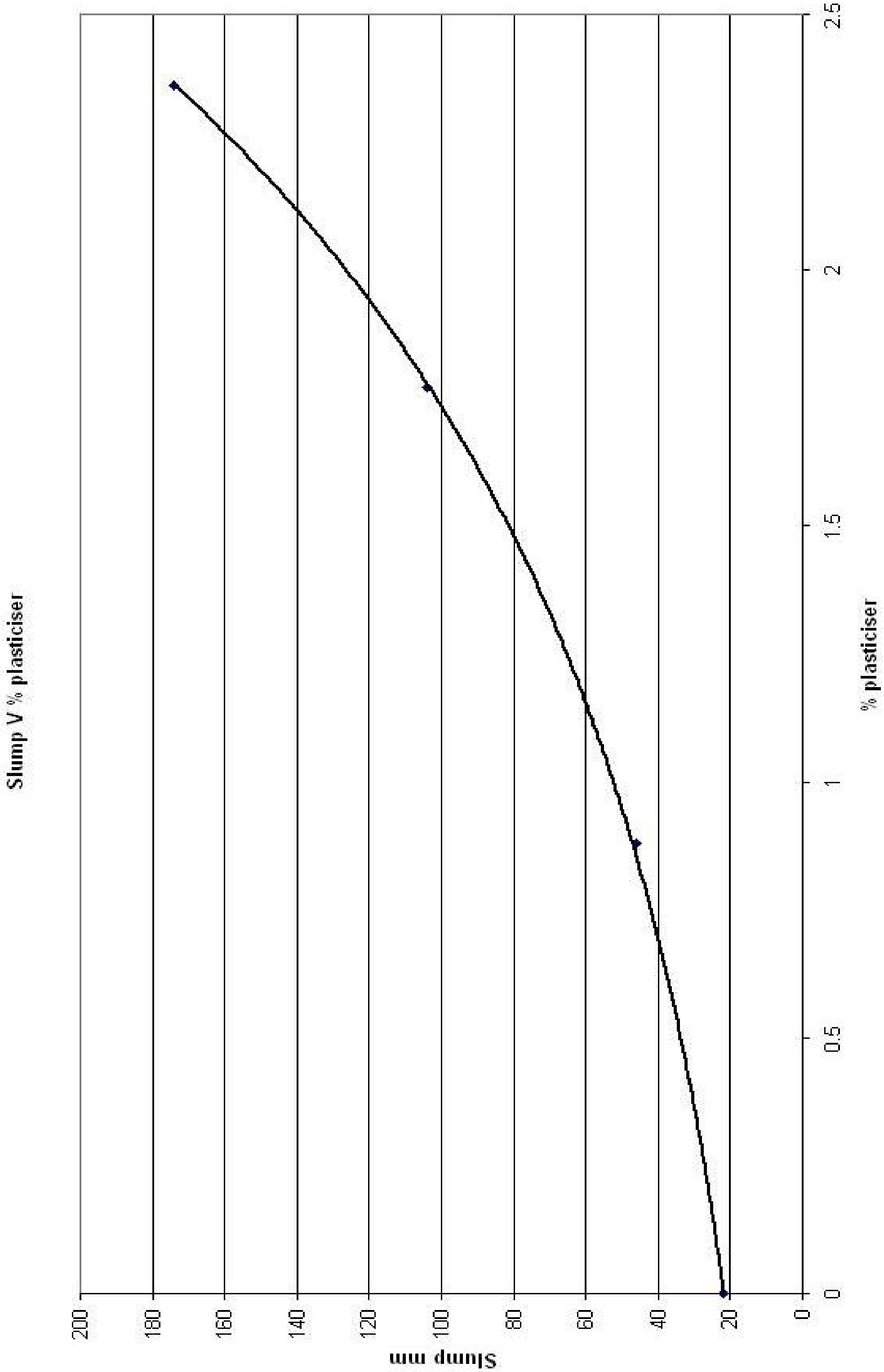

Figure 4.2: Effect of Superplasticiser on Slump

The trial mixes which had manufactured sand were also a lot more difficult to finish and a lot more time was required to trowel the mixes to achieve a decent surface finish. Even with the addition of a superplasticiser, it still required a large amount of trowelling to achieve an acceptable surface finish. The difficulty in achieving a smooth finish with the manufactured sand can be attributed to the irregular particle shape of the manufactured sands. The difference in the surface finish obtained with a manufactured sand (left) mix and a natural sand (right) mix can be seen in figure 4.3

Figure 4.3 Comparison of surface finishes

The results of these slump tests appear to show that a good workability is achieved with a water cement ratio of 0.65, however although the slump was high the concrete was still quite sticky and was not as easy to place as a concrete with a slump in that region should be. This difficulty is caused by the higher fines content of the manufactured sand. A better indication of the workability of the concrete mixes can be gained from the Vebe tests. This test shows that although the slumps were reasonably similar for mixes 1, 6 and 7(control Mix) the time taken on the Vebe consistometer for the manufactured sand mixes is almost twice as long as the time taken for the natural sand control mix. The results from the Vebe tests can be seen in figure 4.4 for the different water cement ratios, and in figure 4.5 for the varying percentages of manufactured sands.

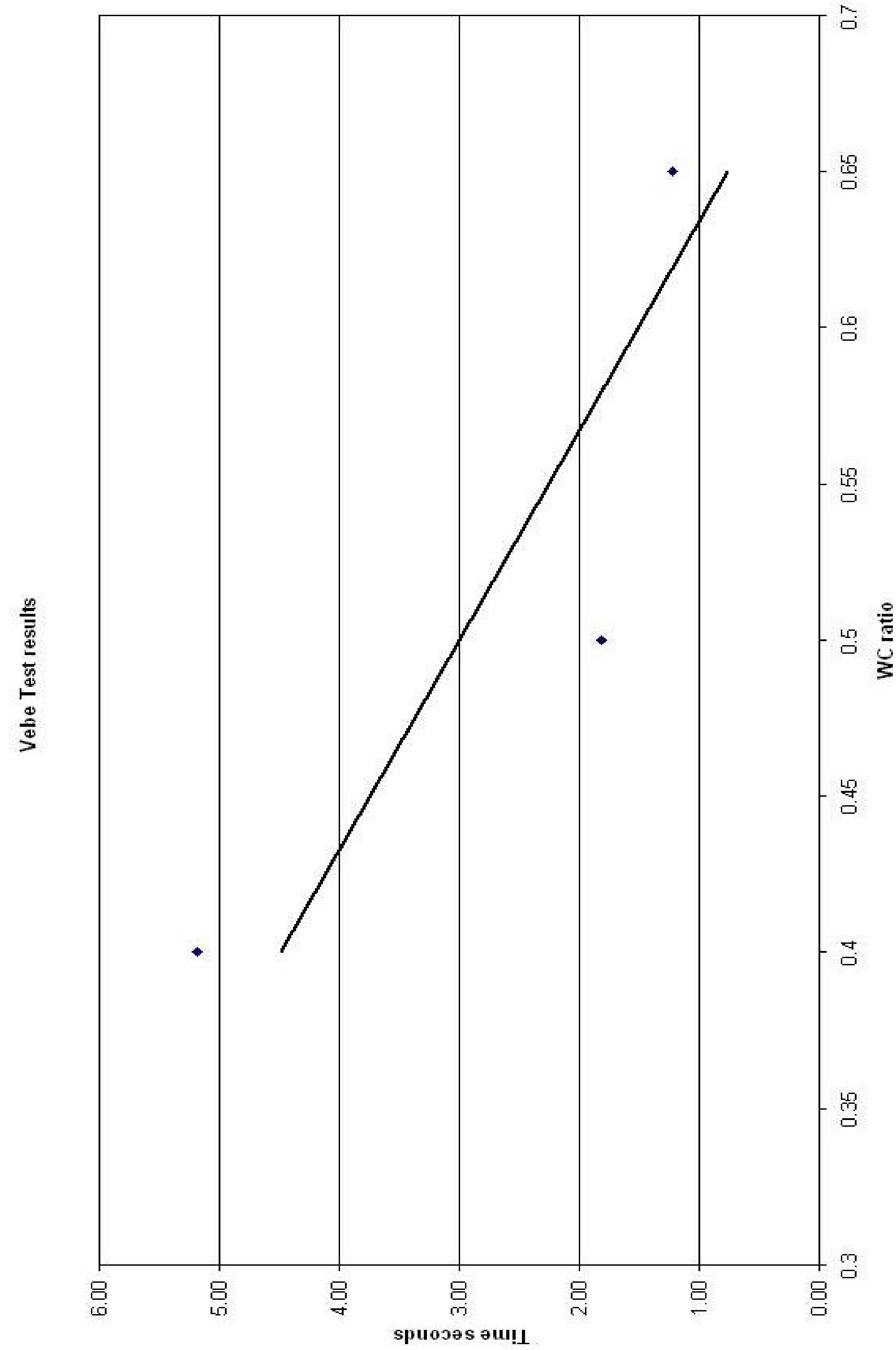

Figure 4.4: Effect of Water Cement Ratio on Vebe test results

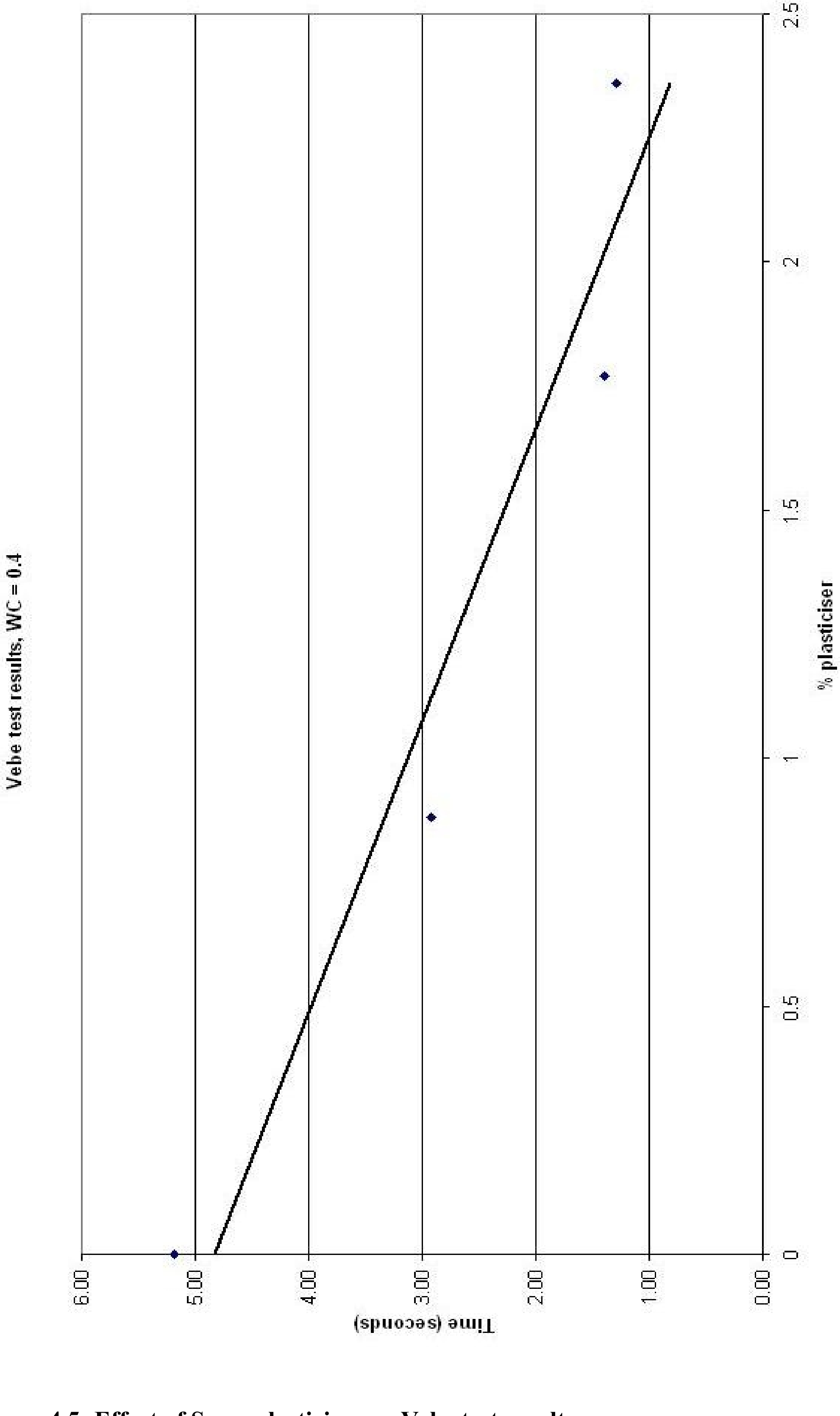

Figure 4.5: Effect of Superplasticiser on Vebe test results

4.3 Hardened Properties

4.3.1 Compressive test results

The hardened properties of the concrete have been measured at ages 3, 7, 14, 21 and 28 days, this has been done to determine the rate of strength gain of the concrete. The compression tests are summarised in table 4.3 below. Due to restrictions on the availability of mixing equipment in the USQ concrete lab a number of mixes had to be tested at 2 and 4 days instead of 3 days of age.

Table 4.3: Summary of Compression Tests

Mix Number	WC ratio	% plasticiser	AGE				
			3	7	14	21	28
1	0.65	0	16*	25	30	33	35
2	0.5	0	29	39	44	46	48
3	0.4	0	32*	45	48	48	48
4	0.4	0.88	42**	43	47	51	54
5	0.4	1.77	37	47	53	56	60
6	0.4	2.36	31*	51	59	62	63
7	0.4	0	29	43	47	48	49

Note: * indicates the specimen was tested at 2 days of age instead of 3 days of age

** indicates the specimen was tested at 4 days of age instead of 3 days of age

The results from the compression tests as expected showed that as the water cement ratio was increased the strength of the concrete declined; The difference in strength with time for the first three mixes in which the water cement ratio was varied and the natural sand control mix can be seen in figure 4.6. These graphs clearly show that the higher the water cement ratio the lower the compressive strength. Comparing mixes three and seven shows that a manufactured sand mix with no plasticiser is capable of a similar strength of a natural sand mix. But the manufactured sand mix was able to reach its maximum strength a lot faster then the natural sand mix was able to. This discovery could have significant implications on the uses of manufactured sands in the construction industry. A comparison of the rate of strength gain of the different trial mixes without superplasticiser can be seen in figure 4.7.

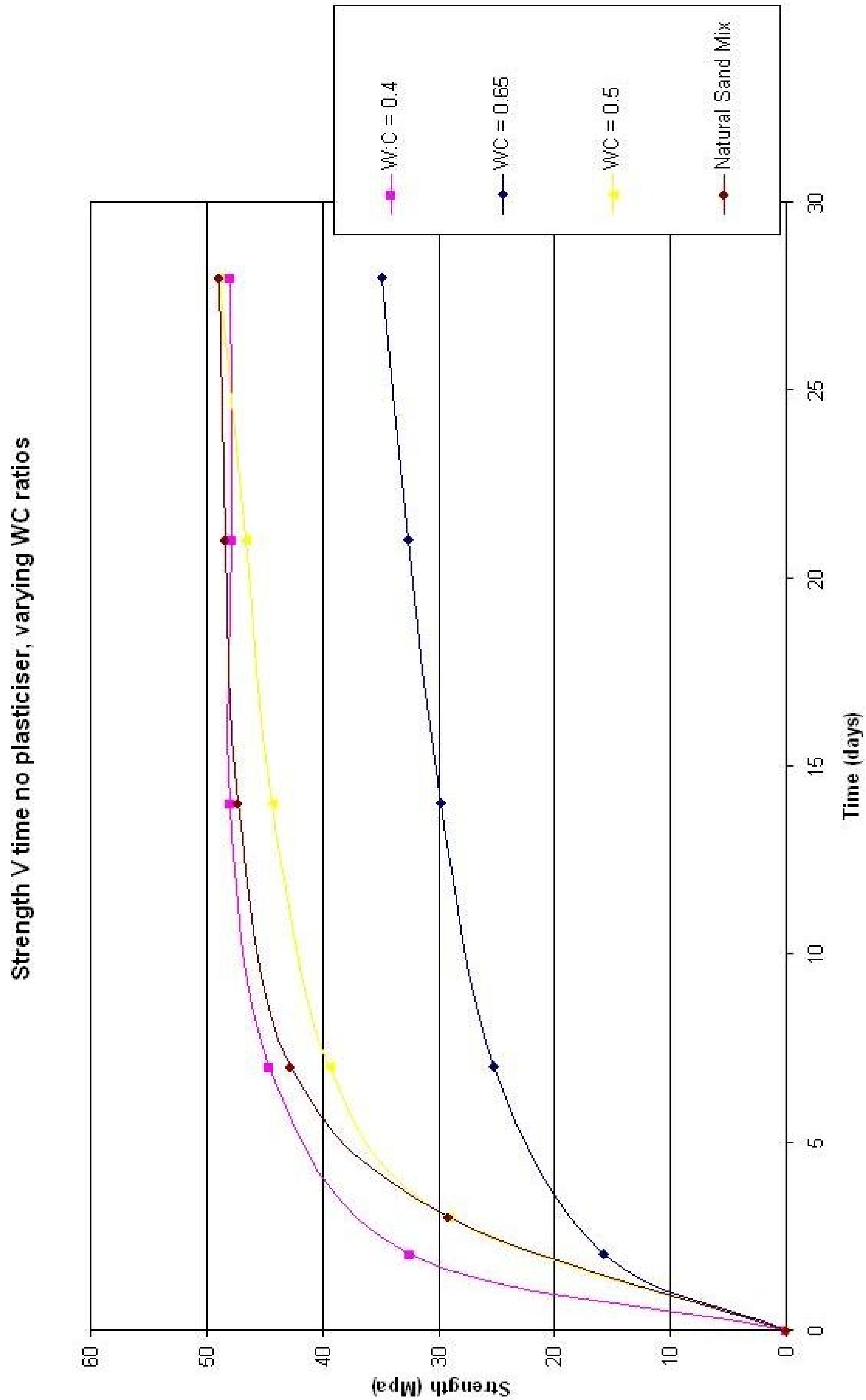

Figure 4.6: Comparison of Strength verse Time for Varying Water Cement Ratios

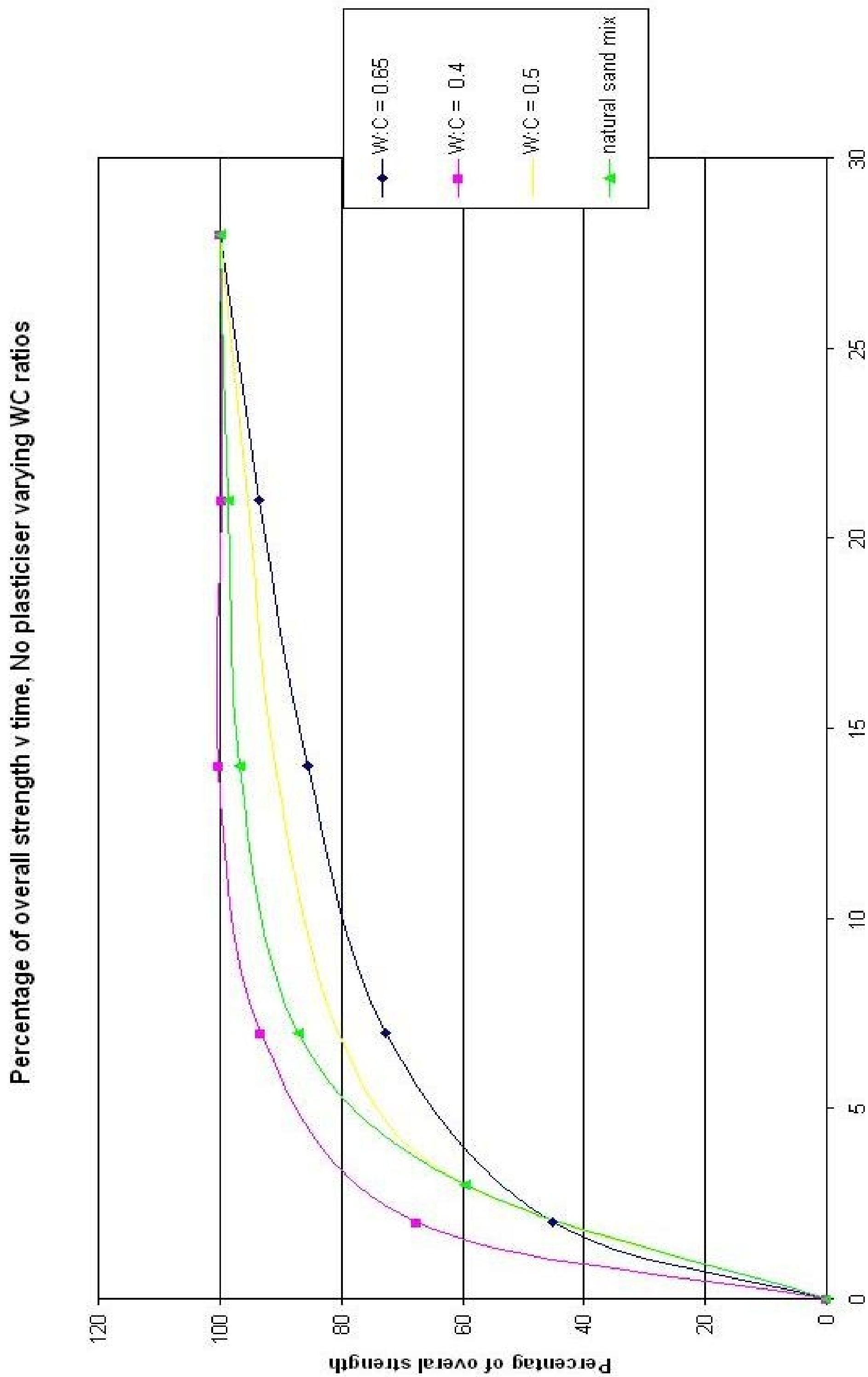

Figure 4.7: Comparison of percentage strength gained verse time for varying water cement ratios.

The addition of the superplasticiser had a very distinct effect on not only the workability of the concrete but also on the compressive strength of the concrete. In the case when 2.36 percent superplasticiser was added to the concrete mix the compressive strength of the concrete improved by around 30 percent. This dramatic improvement in the compressive strength of the concrete can be attributed to the increased compaction that was available from the increased workability of the concrete mix. Compacting factor test results and average 28 day compressive strength are summarised in table 4.4. The increase in compressive strength as a result of the increased compaction can be seen in figure 4.8

Table 4.4: Summary Compacting Factor Results and Compressive Strengths

Mix Number	WC ratio	% plasticiser	Compacting Factor	28 Day Compressive Strength
3	0.4	0	0.89	48
4	0.4	0.88	0.969	54
5	0.4	1.77	0.978	60
6	0.4	2.36	0.993	63

The improved compressive strength of the concrete mixes with a superplasticiser can be seen graphically in figure 4.9. This graph clearly shows the increase in strength that was achieved through the use of the superplasticiser.

The addition of the superplasticiser gave increased compressive strengths. The difference in strengths of the concrete mixes as it cured can be seen in figure 4.10. Although the mixes containing superplasticiser achieved a higher strength, the rate of strength gain of these concrete mixes were slower then the rate of strength gain of the natural sand mix, and considerably less then the manufactured sand mix which contained no superplasticiser. This delay in the percentage strength gain is believed to be a side effect from the addition of the superplasticiser. The rates of strength gain of the concrete mixes are shown in figure 4.11

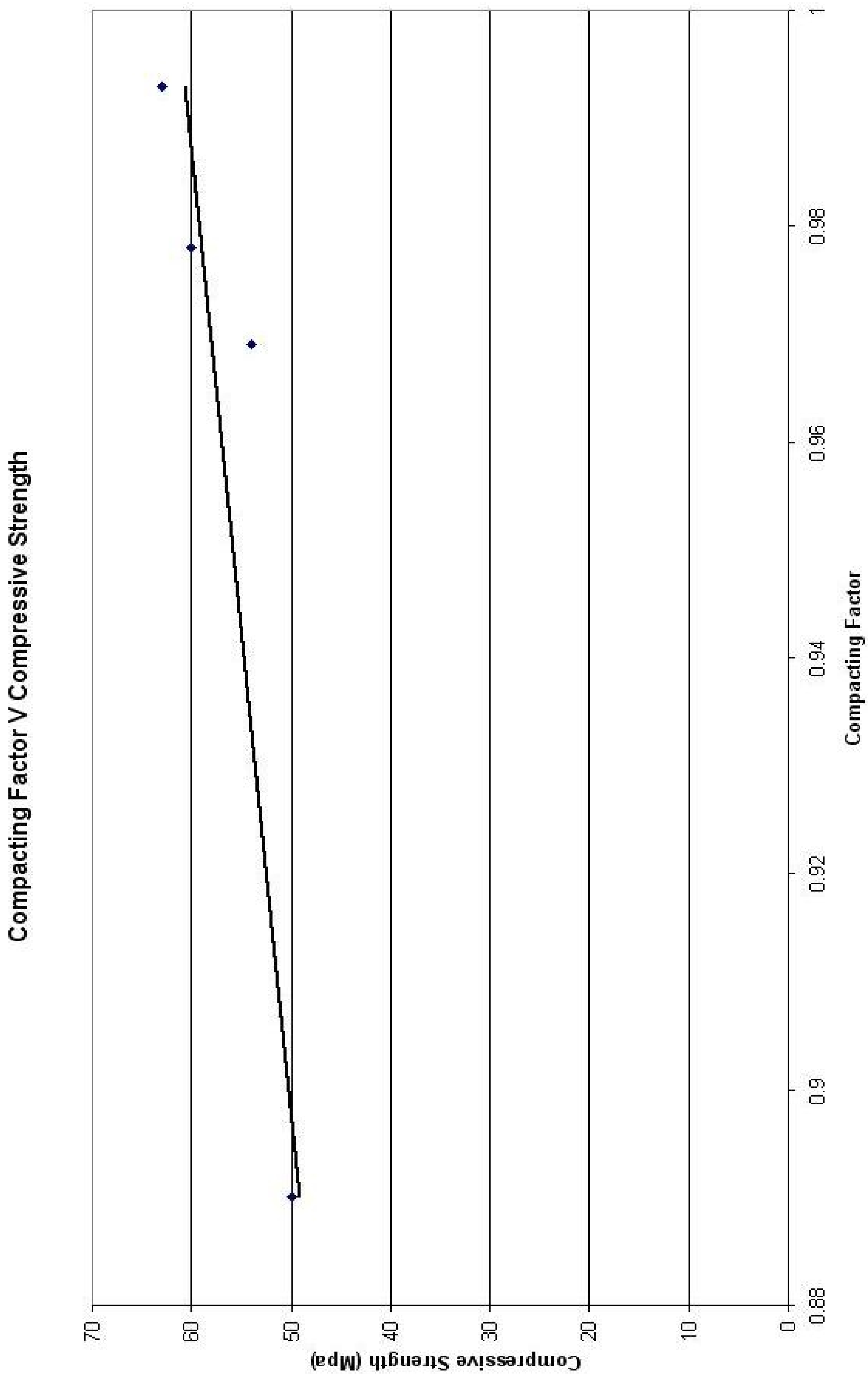

Figure 4.8: Compressive Strength verse's Compacting Factor

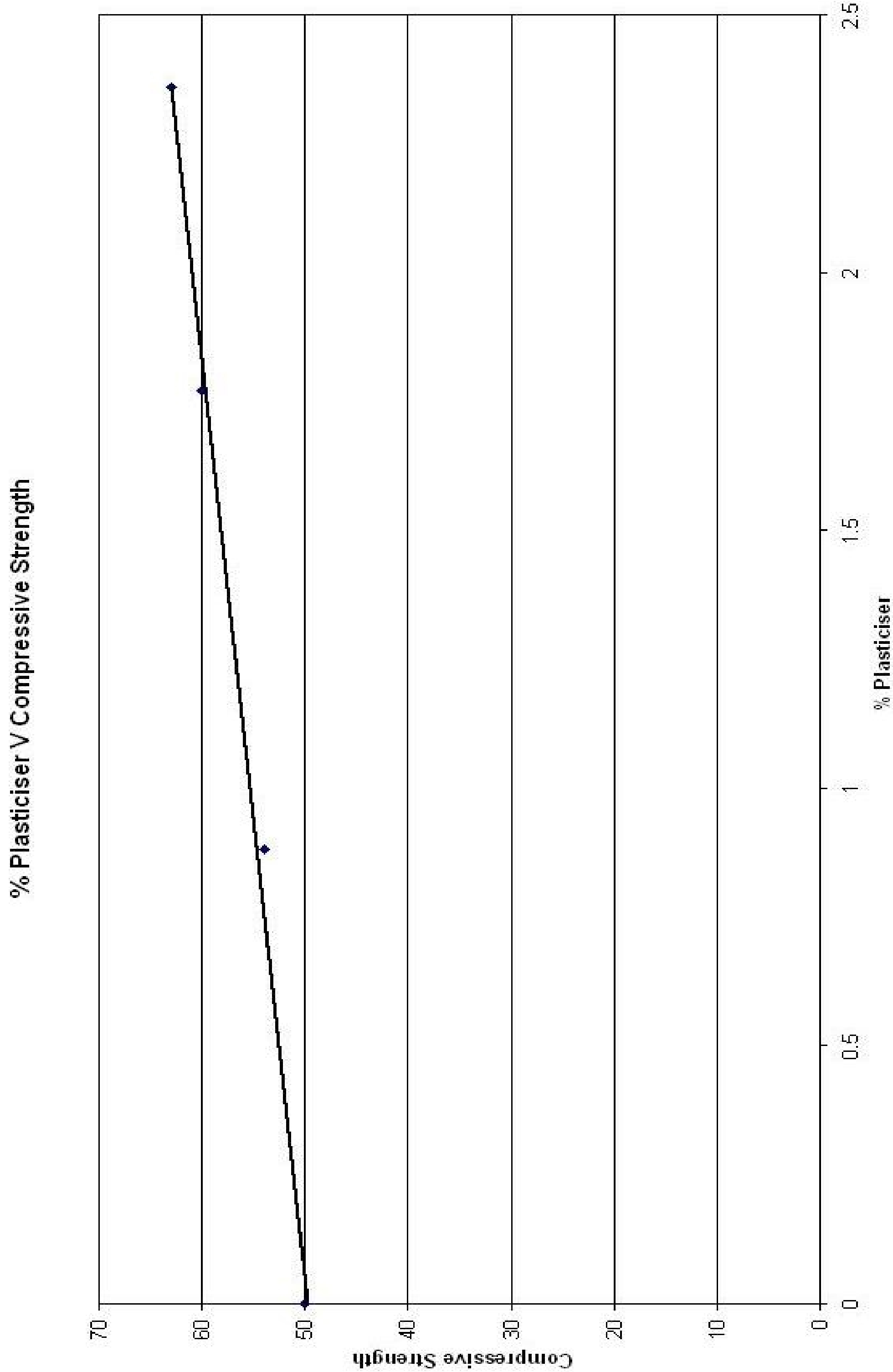

Figure 4.9: Effect of superplasticiser on compressive strength

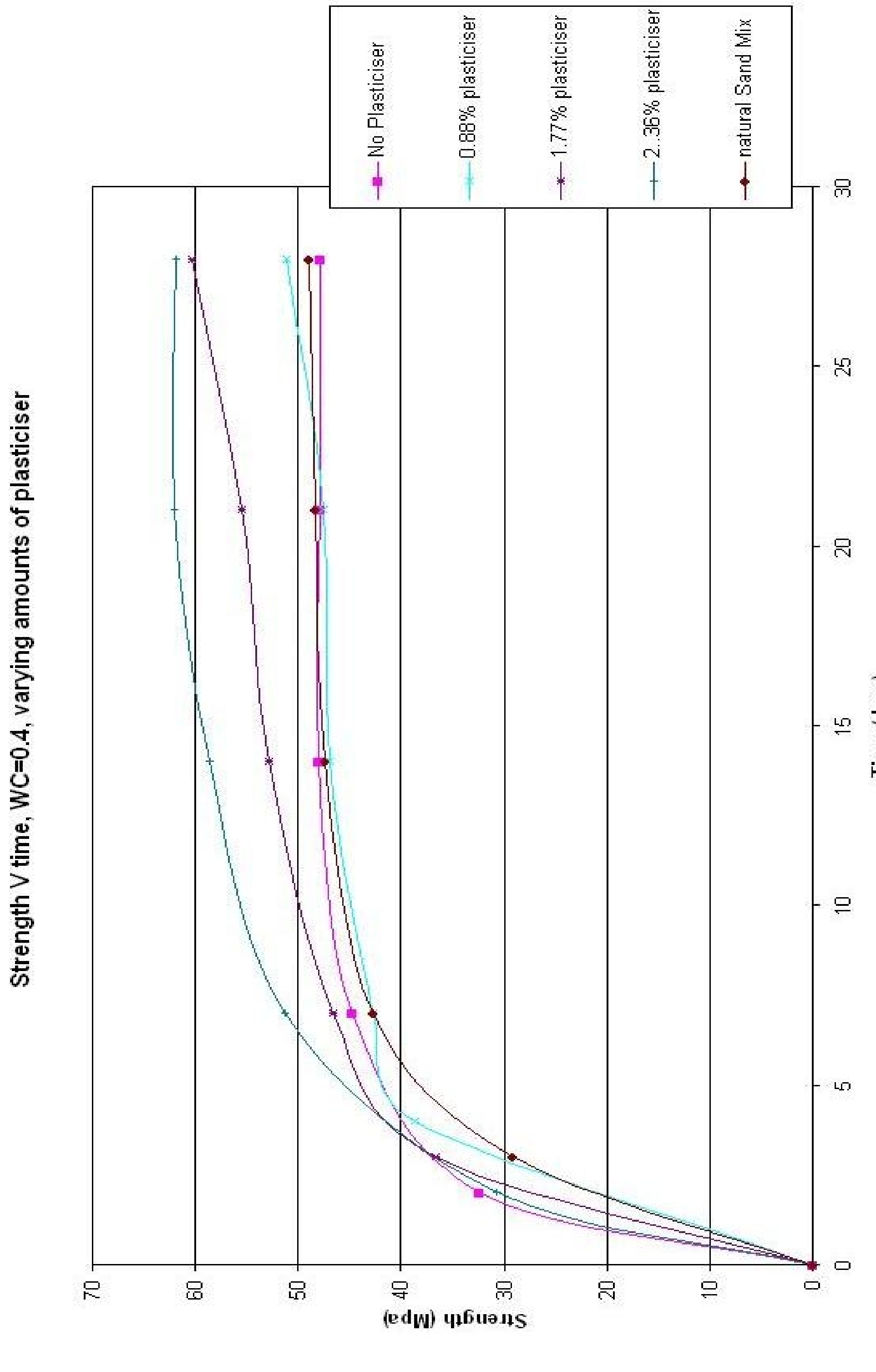

Figure 4.10: Comparison of Strength Verse Time for Varying Percentages of Superplasticiser

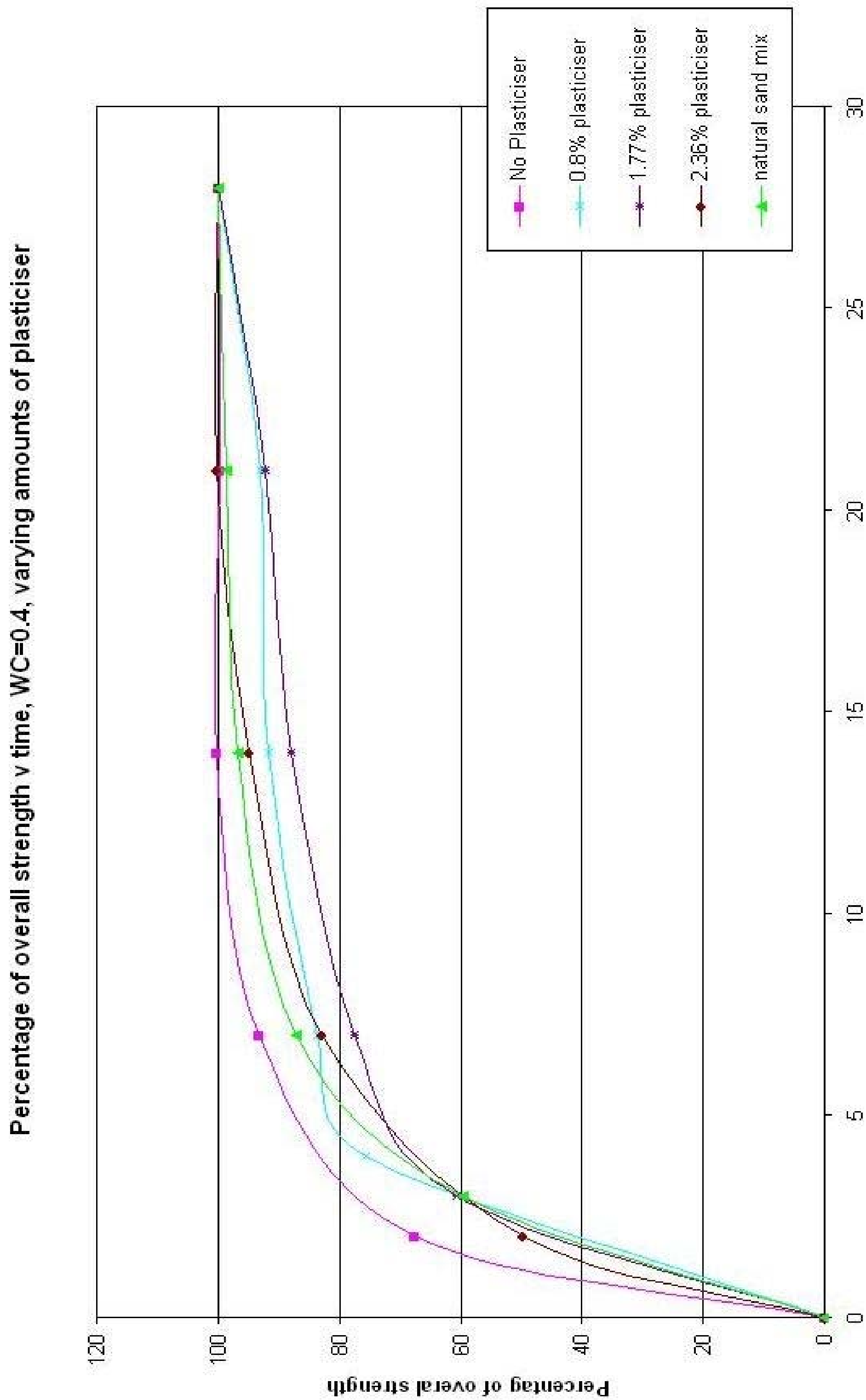

Figure 4.11: Summary of Rate of Strength Gain for Mixes Containing Superplasticiser

4.3.2 Tensile Properties

The tensile strength of the concrete has been measured using the indirect tensile strength or the Brazil splitting test. This test was chosen for its ease of operation and because it did not require the construction of concrete beams. The tensile tests carried out are summarised in table 4.5.

Table 4.5: Summary of Indirect Tensile Strength Tests

Mix Number	WC ratio	% plasticiser	Indirect Tensile stength
1	0.65	0	2.34
2	0.5	0	3.7
3	0.4	0	4.63
4	0.4	0.88	4.27
5	0.4	1.77	4.5
6	0.4	2.36	3.89
7	0.4	0	3.937

As was the same case with the compressive strength tests, as the water cement ratio was decreased the tensile strength of the concrete increased. This can be seen graphically in figure 4.12. The tests showed that for the same water cement ratio the manufactured sand mix was capable of achieving a higher tensile strength then the natural sand control mix. However once the superplasticiser was added to the mix the concrete appeared to loose some of its tensile strength. When large amounts of superplasticiser were used the tensile strength of the concrete mix was lower than the tensile strength of the natural sand control mix. The results from the indirect tensile tests on the concrete mixes with plasticiser can be seen in figure 4.13.

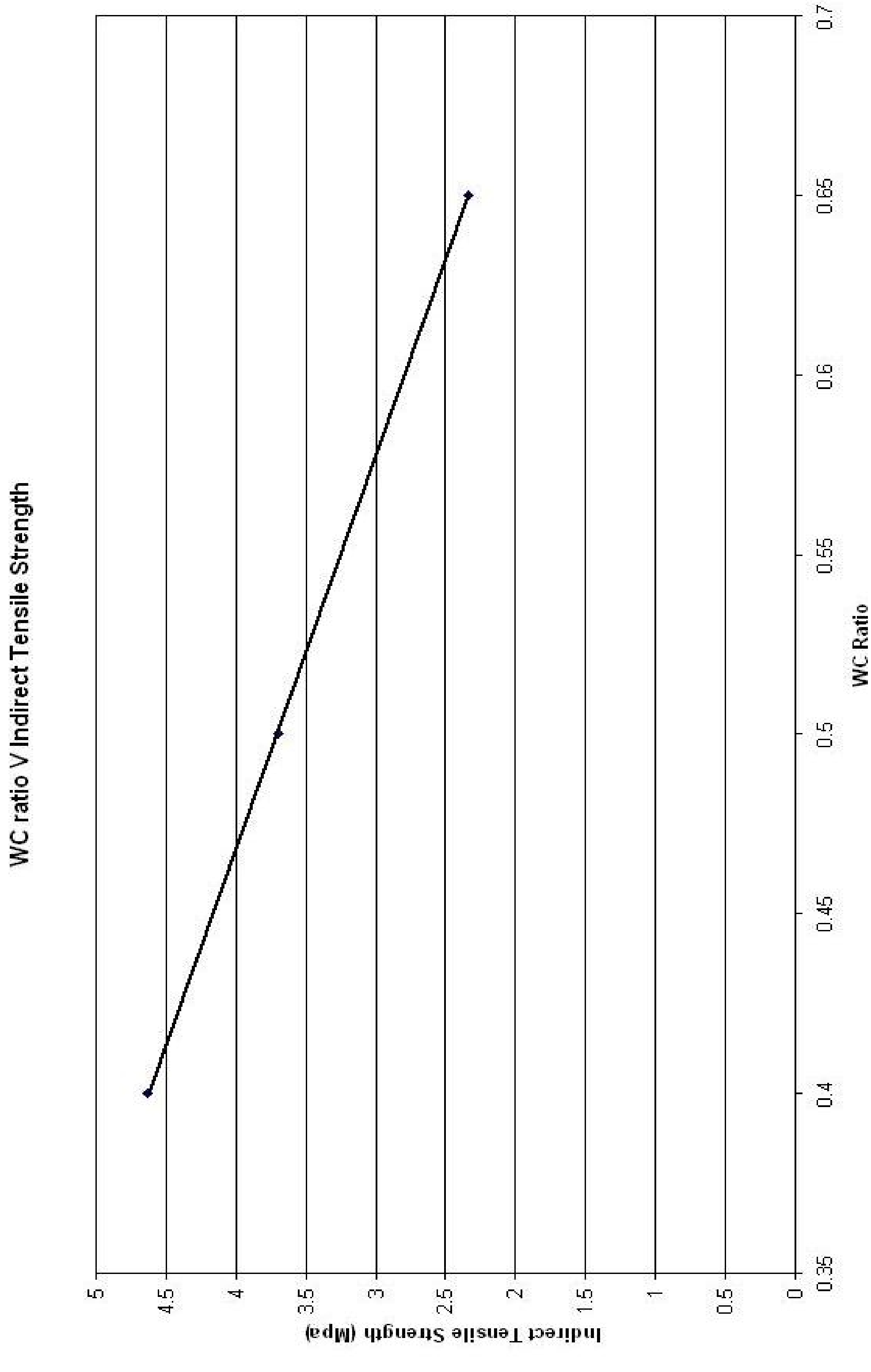

Figure 4.12: Effect of water Cement ratio on Indirect Tensile Strength

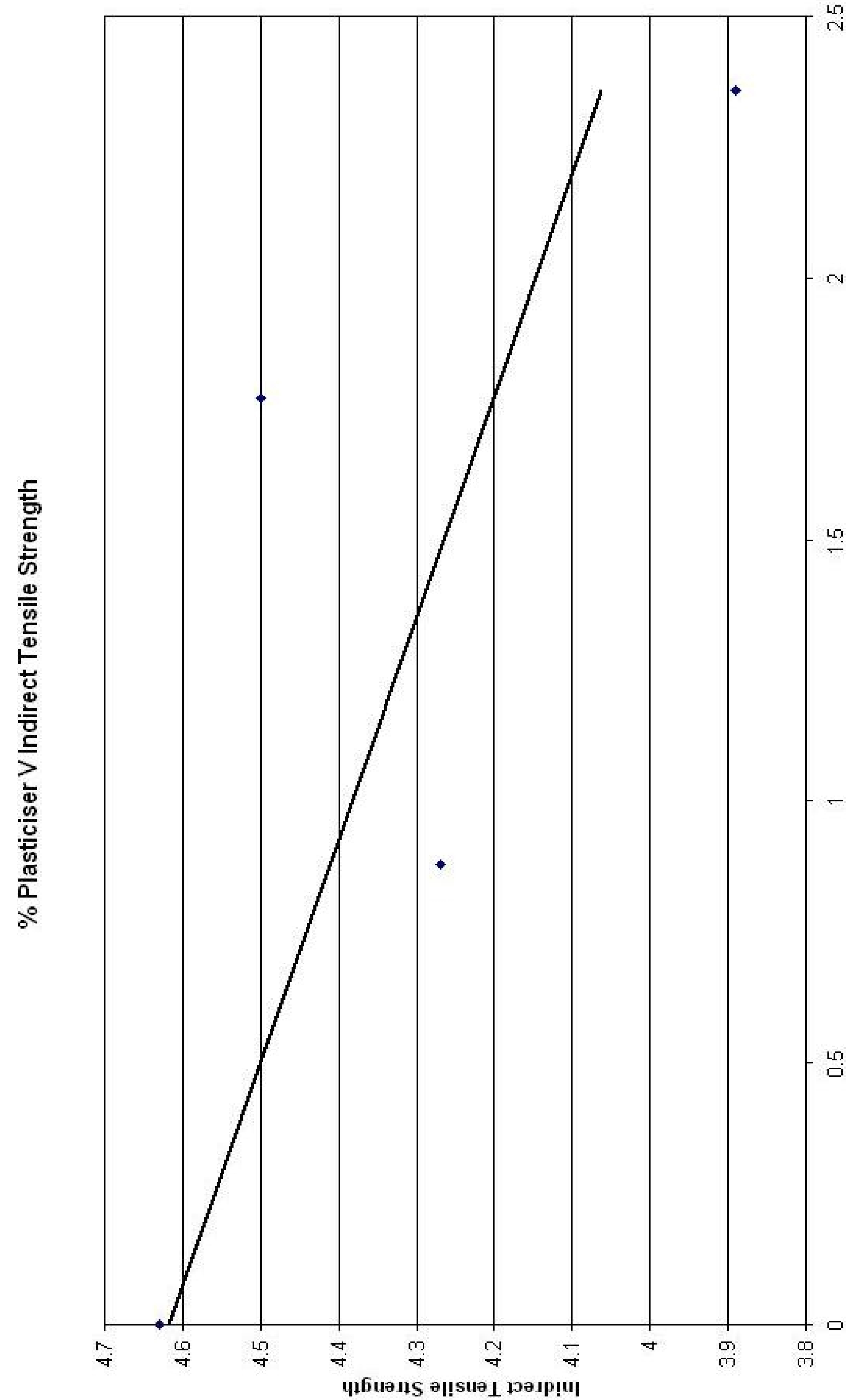

Figure 4.13: Effect of superplasticiser on indirect tensile strength.

Chapter 5

Economic Analysis and Recommendations

5.1 Economic Analysis

The costs of the aggregates for this mix were obtained from Wagners and were current as at the 14th of September 2004. The cost of the materials are summarised in table 5.1. The cost shown for the natural sand is an approximation used for analysing the cost of each concrete mix, as the actual cost of the natural sand varies from around \$25 to \$40.

Table 5.1: Summary of Costs for Materials Used

Material	Cement \$/KG	20mm \$/tonne	10mm \$/tonne	7mm \$/tonne	Manufactured Sand \$/tonne	Natural Sand \$/tonne	Plasticiser \$/L
Cost	0.27	17	19	17	20	35	12

By using Wagners manufactured sand instead of natural sand without the addition of a superplasticiser in a concrete mix can expect a saving in the order of around 30 dollars per cubic metre, which is quite a significant saving. However this concrete mix is unsuitable for use due to its extremely poor workability. The addition of the superplasticiser makes this same concrete mix suitable for use; however the addition of the superplasticiser significantly increases the cost of the concrete mix. Trial mixes five and six which both contained manufactured sand and high dosages of superplasticiser both had a higher cost than the natural sand mix. This can be seen in figure 5.1. In order for a manufactured sand mix containing the superplasticiser to be more economical then the natural sand control mix the maximum dosage of superplasticiser would be 1.5 percent.

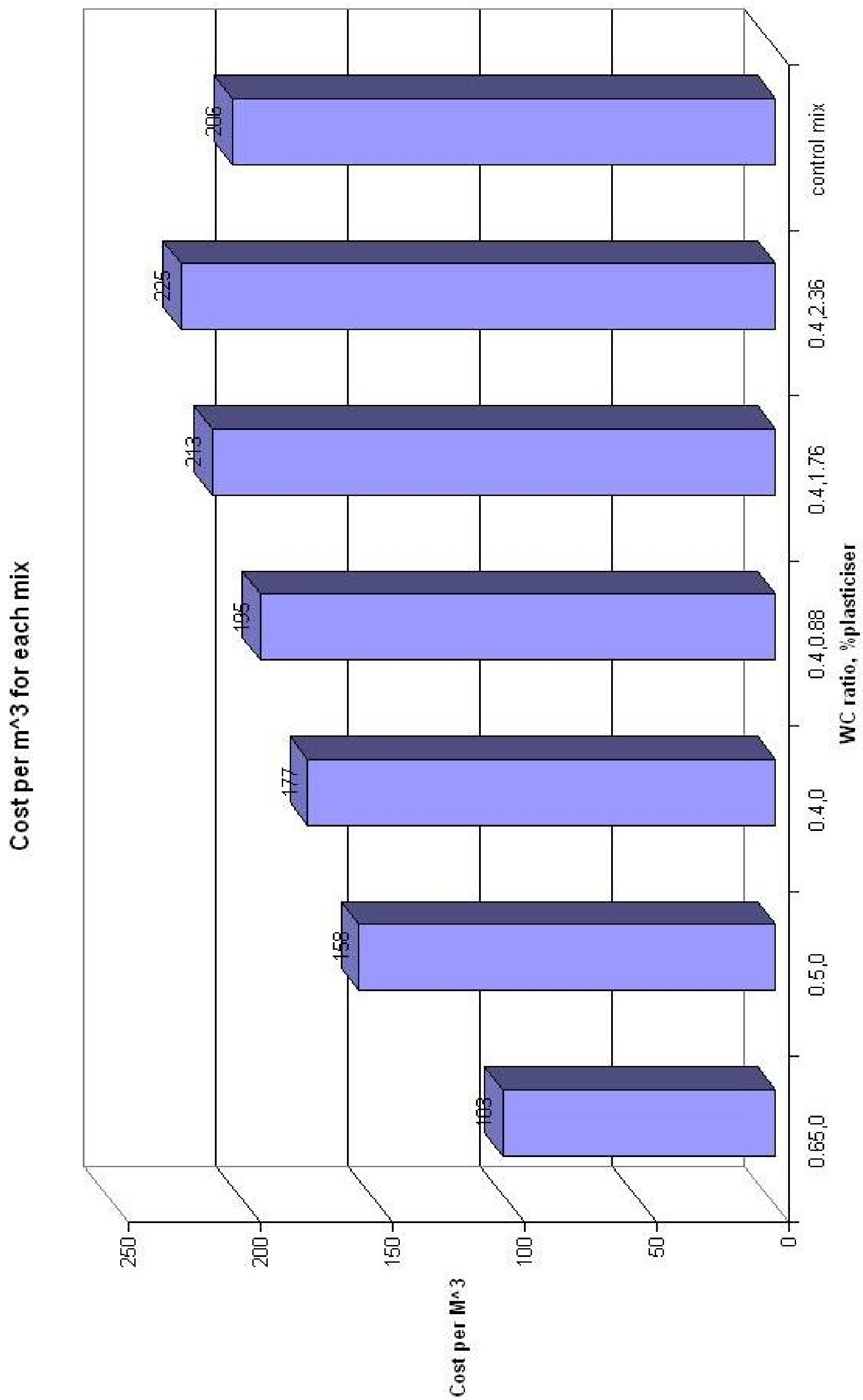

Figure 5.1: Comparison of Cost for Each Trial Mix

5.2 Recommendations

Using manufactured sand in concrete mixes is a viable alternative to the use of natural sand, however a number of factors must be considered before using the manufactured sand mixes. If you are targeting a medium strength concrete mix then using a high water cement ratio with manufactured sand should achieve a reasonable strength and workability, however the operator will have to take special care to ensure that the concrete mix achieves a suitable finish. If a high strength concrete mix is required then this can be achieved by lowering the water cement ratio of the concrete mix and using a superplasticiser to achieve a suitable workability. The amount of superplasticiser added will depend on the workability that is required, however it should be noted that using large amounts of a superplasticiser may cause the concrete mix to be more expensive then a natural sand mix. In order for the manufactured sand mix to remain cheaper then the natural sand concrete mix, the amount of superplasticiser added should not exceed 1.5 percent. Interpolation from figure 4.9 shows that a mix which would contain 1.5 percent superplasticiser would be expected to have a slump of around 80mm. This would be acceptable for most concreting jobs, however it is expected that this mix would still be quite difficult to finish and would probably require a large amount of trowelling to achieve a suitable finish.

Chapter 6

Conclusions

6.1 Conclusions from Analysis

At the beginning of this project a number of goals were set out to achieve, these goals were to:

- Determine if a suitable workability and strength can be achieved in concrete containing manufactured sand as a complete replacement for natural sand;
- Determine what percentage of superplasticiser is required to achieve a suitable workability for concrete containing manufactured sand;
- Determine the impact that the superplasticiser has on the strength of the concrete;
- Determine the rate of strength gain for the concrete containing manufactured sand with and without superplasticiser;

After the completion of testing and analysing, there are a number of conclusions which are able to be made.

- By using large amounts of water in the concrete mix manufactured sands are capable of achieving a suitable workability and also achieving the target strength. However the amount of time required for achieving a suitable finish on the concrete is still a major drawback to its use in the construction industry.

- With the addition of a superplasticiser a concrete mix containing manufactured sand is capable of not only achieving a workability similar to that of natural sand, however to achieve this workability, dosages as high as 2.36 percent were required. The additional cost of these large amounts of superplasticiser in the concrete mix makes the manufactured sand concrete mix less economical to produce then a natural sand control mix. However with the declining availability of natural sands suitable for use in concrete, the use of concrete mixes containing 100 percent manufactured sand or high percentages of manufactured sands in the aggregate blend may become a lot more common.

- The addition of superplasticiser into a concrete mix not only improves the workability of the concrete mix but also the strength of the concrete mix. When large amounts of plasticiser were added the strength improved by around 30 percent on the mix without plasticiser, however the rate of strength gain of the concrete mix is lowered considerably when the plasticiser is added

6.2 Further Research

Further research is needed on manufactured sand to determine;

- The flexural strength of manufactured sand concrete mixes;
- The young's modulus of the concrete;
- The impact that a superplasticiser will have on a concrete mix containing a blend of manufactured sand and natural sand, which has a high percentage of manufactured sand.

Appendix A

Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Mark James Krinke BENG (civil)**

TOPIC: THE EFFECTS OF ADMIXTURES IN CONCRETE CONTAINING MANUFACTURED SAND

SUPERVISORS: Dr. Thiru Aravinthian

SPONSORSHIP: Faculty of Engineering and surveying

PROJECT AIM: The aim of this project is to study the effects that varying amounts admixtures have on concrete containing manufactured sand instead of natural sand.

PROGRAMME: **Issue A march 2004**

1. Research the background of manufactured sand and admixtures in concrete
2. Carry out Particle Shape, Water Absorption and Grading tests on aggregates to be used in the concrete mixes.
3. Develop a number of different trial mixes for testing using varying water cement ratios and varying amounts of admixtures.
4. For each trial Mix perform Slump, Vebe and Compacting Factor Apparatus tests on the fresh concrete.
5. Perform compression tests on the hardened concrete at 3, 7, 21 and 28 days for each trial mix.
6. Perform indirect tensile strength test at 28 days for each trial mix.
7. Evaluate results of tests comparing strengths at different ages of different trial mixes.

as time permits

8. Develop trial mixes with different amounts of manufactured sand and natural sand with admixtures, and perform similar tests carried out on previous trial mixes.

AGREED:

…………… …….. (student) ……………………………………………(supervisors)

Date: …../…../…..

Appendix B

Test Results

Table B.1: Summary of Tested Fresh Properties

Mix number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Slump (mm)	160	70	22	46	104	174	185
Compacting Factor							
Partiall compacted mass	26220	26410	23.57	25570	25880	26220	25840
Fully compacted mass	26420	25555	26.4	26380	26440	26400	26020
Compacting Factor	0.99243	1.033457	0.892803	0.969295	0.97882	0.993182	0.993082
Vebe (seconds)	1.23	1.81	5.19	2.92	1.06	1.29	0.64

Table B.2: Summary of Compression Cylinders tested, Trial Mix 1

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	2	100.35	100.35	200.05	4019.9	7905.0	1581404	2542.0	126	16		
2	2	100.2	99.9	200.1	3986.6	7857.9	1572356	2535.4	122	16	16	45
3	7	100.1	100.3	201.25	3921	7881.4	1586138	2472.0	192	24		
4	7	101.4	101	200.25	4159	8039.5	1609916	2583.4	211	26	25	73
5	14	100	99.9	201	3971	7842.2	1576273	2519.2	242	31		
6	14	102	101.5	200	4108	8127.2	1625431	2527.3	235	29		
7	14	100.1	100.4	199	3953	7889.3	1569971	2517.9	235	30	30	86
8	21	101.5	101.5	201	3926.7	8087.3	1625541	2415.6	240	30		
9	21	101.1	101.9	201.5	4012.4	8087.3	1629584	2462.2	275	34		
10	21	102	102.05	201	3987.6	8171.1	1642400	2427.9	267	33	32	92
11	28	101.2	101.5	201	3913	8063.4	1620740	2414.3	302.5	38		
12	28	102.2	101	202	3973	8103.2	1636848	2427.2	272	34		
13	28	101.4	101.2	202	3970	8055.4	1627196	2439.8	270	34	35	100

Table B.3: Summary of Compression Cylinders Tested, Trial Mix 2

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	3	100.1	100.1	200	3976	7865.7	1573142	2527.4	262	33		
2	3	100	100	201	3923	7850.0	1577850	2486.3	235	30		
3	3	99.58	99.9	200.5	3955	7809.2	1565751	2525.9	190	24	29	60
4	7	100.15	100.2	200	3978	7877.5	1575500	2524.9	325	41		
5	7	100.15	100.13	200	3952	7872.0	1574399	2510.2	325	41		
6	7	100.13	100.15	200	3957	7872.0	1574399	2513.3	310	39	41	83
7	14	101.1	101.1	201	4020	8023.6	1612754	2492.6	320	40		
8	14	101.5	101.2	200.5	3980	8063.4	1616708	2461.8	315	39		
9	14	101.6	101.4	202	4016	8087.3	1633628	2458.3	325	40	40	81
10	21	102.1	102.1	200.5	4000	8183.2	1640724	2437.9	362	44		
11	21	102.2	102.1	200	4005	8191.2	1638236	2444.7	370	45		
12	21	101.6	101.5	200	3982	8095.2	1619047	2459.5	385	48	46	93
13	28	101.4	101.7	200	3998	8095.2	1619047	2469.4	422	52		
14	28	101.6	101.65	200	3976	8107.2	1621440	2452.1	377	47		
15	28	101.7	101.7	199	3950	8119.2	1615715	2444.7	390	48	49	100

Table B.4: Summary of Compression Cylinders Tested, Mix 3

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	2	100.1	100.2	202	3963	7873.6	1590461	2491.7	256	33		
2	2	100.7	100.9	201	3976	7976.1	1603197	2480.0	258	32	32	64
3	7	100.2	100.5	201	3917	7905.0	1588914	2465.2	352	45		
4	7	100.2	100	202	3931	7865.7	1588873	2474.1	345	44		
5	7	100.3	100.2	206	3923	7889.3	1625196	2413.9	360	46	45	89
6	14	101.9	101.5	201	3929.2	8119.2	1631953	2407.7	387	48		
7	14	101.1	101.3	202	3941.2	8039.5	1623985	2426.9	362	45		
8	14	101.3	101.2	201	3920.8	8047.5	1617543	2423.9	413	51	48	95
9	21	101	101	201	3891	8007.8	1609565	2417.4	400	50		
10	21	101.6	102.3	202	3976	8159.1	1648145	2412.4	375	46		
11	21	101.4	100.7	200	3883	8015.7	1603143	2422.1	355	44		
12	21	101.8	101.6	200	3945	8119.2	1623834	2429.4	415	51	48	95
13	28	101	101.2	201	3926	8023.6	1612754	2434.3	415	52		
14	28	101.8	102	202	3972	8151.1	1646529	2412.3	390	48		
15	28	101.4	100.7	201	3927	8015.7	1611159	2437.4	420	52		
16	28	101.2	101.2	201	3901	8039.5	1615946	2414.1	400	50	50	100

Table B.5: Summary of Compression Cylinders Tested, Mix 4

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	4	102.1	102	201	4037	8175.1	1643205	2456.8	341	42		
2	4	101.5	101.3	200	3998	8071.3	1614268	2476.7	350	43		
3	4	101.3	101.2	200	3972	8047.5	1609495	2467.9	325	40	42	77
4	7	101.3	101.5	200.5	3911	8071.3	1618303	2416.7	350	43		
5	7	101.9	102.3	200	4046	8183.2	1636632	2472.1	355	43		
6	7	101.5	101.2	201.5	3991	8063.4	1624771	2456.3	335	42	43	79
7	14	100.9	101.3	200	3993	8023.6	1604730	2488.3	380	47		
8	14	101.7	101.6	200	4062	8111.2	1622237	2503.9	425	52		
9	14	101.2	101.5	200	3987	8063.4	1612676	2472.3	330	41	47	87
10	21	101.6	101.7	200	4016.8	8111.2	1622237	2476.1	390	48		
11	21	101.6	101.6	202	4070.2	8103.2	1636848	2486.6	355	44		
12	21	101.6	102.2	200	4057	8151.1	1630227	2488.6	415	51	48	
13	28	101.35	101.9	200	4043.6	8107.2	1621440	2493.8	400	49		
14	28	101.7	102.4	200	4082.9	8175.1	1635030	2497.1	440	54		
15	28	101.8	101.2	200	4019	8087.3	1617453	2484.8	475	59	54	100

Table B.6: Summary of Compression Cylinders Tested, Mix 5

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	3	101.4	101.5	201.5	4025	8079.3	1627979	2472.4	325	40		
2	3	101.2	101.1	200	3965	8031.6	1606318	2468.4	275	34		
3	3	101.6	101.3	203	4040	8079.3	1640098	2463.3	285	35	37	61
4	7	102.1	102.1	201	4069	8183.2	1644816	2473.8	380	46		
5	7	101.6	101.9	200	4029	8127.2	1625431	2478.7	375	46		
6	7	101.6	101.9	201	4056	8127.2	1633558	2482.9	385	47	47	77
7	14	101.6	101.4	201	4008.7	8087.3	1625541	2466.1	455	56		
8	14	101.2	101.2	201	3995.4	8039.5	1615946	2472.5	415	52		
9	14	101.4	101.3	201	4030.3	8063.4	1620740	2486.7	410	51	53	88
10	21	101.9	102	202	4088.7	8159.1	1648145	2480.8	440	54		
11	21	101.8	101.6	201	4038.2	8119.2	1631953	2474.5	440	54		
12	21	101.6	101.7	200	4022	8111.2	1622237	2479.3	475	59	56	92
13	28	101.6	101.9	201	4034.6	8127.2	1633558	2469.8	490	60		
14	28	101.7	102.1	201	4059.7	8151.1	1638378	2477.9	495	61		
15	28	102.2	102.2	201	4070.3	8199.2	1648039	2469.8	490	60	60	100

Table B.7: Summary of Compression Cylinders Tested, Mix 6

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	2	101.5	101.4	199	3975	8079.3	1607781	2472.4	250	31		
2	2	101.8	101.9	200.5	3975	8143.1	1632699	2434.6	265	33		
3	2	102	102.2	200	4045	8183.2	1636632	2471.5	235	29	31	50
4	7	101.7	101.9	199	4001	8135.1	1618894	2471.4	420	52		
5	7	101.4	101.3	200	3966	8063.4	1612676	2459.3	410	51		
6	7	102.1	102	201	4052	8175.1	1643205	2465.9	420	51	51	83
7	14	101.6	101.8	200	4001.8	8119.2	1623834	2464.4	435	54		
8	14	102.1	102.1	198	4035.7	8183.2	1620266	2490.8	435	53		
9	14	101.6	101	199	3971.4	8055.4	1603030	2477.4	448	56	54	87
10	21	101.4	101.4	200	4014	8071.3	1614268	2486.6	505	63		
11	21	101.4	101.2	200	3984.2	8055.4	1611085	2473.0	495	61		
12	21	101.7	102.1	200	4005	8151.1	1630227	2456.7	505	62	62	100
13	28	101.3	101.2	200	3994.1	8047.5	1609495	2481.6	495	62		
14	28	101.7	101.4	200	3997.7	8095.2	1619047	2469.2	530	65		
15	28	101.6	101.6	200	4029.6	8103.2	1620642	2486.4	475	59	62	100

Table B.8: Summary of Compression Cylinders Tested, Mix 7

Test Number	Age (days)	Diameter (mm)		Height (mm)	Weight (g)	Area (mm^2)	Volume (mm^3)	Density (Kg/m^3)	Measured Force (Kn)	Strength (Mpa)	Average (Mpa)	% of overall strength gained
1	3	102.2	102	198	3853	8183.2	1620266	2378.0	245	30		
2	3	101.5	101	200	3794	8047.5	1609495	2357.3	240	30		
3	3	101.4	101.6	200	3799	8087.3	1617453	2348.8	225	28	29	59
4	7	101.5	101.4	200	3844.5	8079.3	1615860	2379.2	350	43		
5	7	101.5	101.2	199	3812.9	8063.4	1604613	2376.2	342	42		
6	7	101.8	101.9	200	3842.1	8143.1	1628627	2359.1	345	42	43	86
7	14	101.6	101.8	199	3840.8	8119.2	1615715	2377.2	356	44		
8	14	101.4	101.4	200	3788.6	8071.3	1614268	2346.9	402	50		
9	14	101.4	101.2	200	3818.6	8055.4	1611085	2370.2	390	48	47	96
10	21	101.4	101.2	198	3777.4	8055.4	1594974	2368.3	400	50		
11	21	101.5	101.5	199	3831.3	8087.3	1609366	2380.6	400	49		
12	21	101.4	101.2	200	3787.3	8055.4	1611085	2350.8	370	46	48	98
13	28	101.4	101.35	198	3817	8067.4	1597337	2389.6	400	50		
14	28	102	101.9	199	3871.2	8159.1	1623668	2384.2	400	49		
15	28	101.4	101.5	199	3848.3	8079.3	1607781	2393.5	405	50	50	100

Table B.10: Summary from Indirect Tensile Strength tests

Mix Number	Age	Diameter		Average Diameter	Height	Weight	Area	Volume	Density	Measured Force	Strength	Average Strength
1	28	150.7	149.8	150.25	299	13183	17721	5298706	2488.0	165	2.34	2.34
2	28	150.65	150.1	150.65	301	13459	17751	5343028	2519.0	255	3.58	
2	28	150.1	149.7	150.1	300	13392	17639	5291687	2530.8	270	3.82	3.70
3	28	150.3	150.3	150.3	302	13383	17733	5355433	2499.0	330	4.63	
3	28	151.3	151.3	151.3	304	13619	17970	5462873	2493.0	335	4.64	4.63
4	28	150.15	150	150.15	301	13534	17680	5321730	2543.1	295	4.16	
4	28	149.7	151	149.7	304	13564	17745	5394486	2514.4	315	4.41	4.28
5	28	150.1	151	150.1	302.5	13573	17792	5382159	2521.9	270	4	
5	28	152.45	152.2	152.45	306.5	14267	18214	5582677	2555.5	375	5	4
6	28	150.8	150.2	150.8	300.5	13531	17780	5343024	2532.5	270	3.79	
6	28	152.4	152.1	152.4	304.5	14086	18196	5540788	2542.2	290	3.98	3.89
7	28	150.5	150.2	150.5	298	12839	17745	5288016	2427.9	280	3.978	
7	28	150.5	150.1	150.5	299	12856	17733	5302233	2424.6	275	3.896	3.937

Table B.11: Results from 20 mm Aggregate Sieve Analysis.

Sieve Size	Mass Retained	% Mass Retained	Cumulitive Percentage Retained	Percent Passing
26.5	0.0	0.0	0.0	**100.0**
19	0.0	0.0	0.0	**100.0**
13.2	3048.4	34.1	34.1	**65.9**
9.5	4394.7	49.1	83.2	**16.8**
4.75	1394.7	15.6	98.8	**1.2**
2.36	58.9	0.7	99.5	**0.5**
1.18	23.5	0.3	99.7	**0.3**
Pan	23.0	0.3	100.0	**0.0**
	8943.2	100.0		

Table B.12: Results from 10 mm Aggregate Sieve Analysis.

Sieve Size	Mass Retained	% Mass Retained	Cumulitive Percentage Retained	Percent Passing
13.2	0.0	0.0	0.0	**100.0**
9.5	193.4	7.4	7.4	**92.6**
4.75	2281.2	87.7	95.2	**4.8**
2.36	59.2	2.3	97.4	**2.6**
1.18	23.0	0.9	98.3	**1.7**
Pan	43.5	1.7	100.0	**0.0**
	2600.3	100.0		

Table B.13: Results from 7 mm Aggregate Sieve Analysis.

Sieve Size	Mass Retained	% Mass Retained	Cumulitive Percentage Retained	Percent Passing
9.5	0.0	0.0	0.0	**100.0**
4.75	280.9	76.3	76.3	**23.7**
2.36	75.5	20.5	96.8	**3.2**
1.18	4.8	1.3	98.1	**1.9**
Pan	7.1	1.9	100.0	**0.0**
	368.3	100.0		

Table B.14: Results from Manufactured Sand Aggregate Sieve Analysis.

Sieve Size	Mass Retained	% Mass Retained	Cumulitive Percentage Retained	Percent Passing
2.36 mm	4	3.3	3.3	**96.7**
1.18 mm	31.2	25.4	28.6	**71.4**
600 µm	25.3	20.6	49.2	**50.8**
300 µm	17.4	14.2	63.4	**36.6**
150 µm	13.6	11.1	74.5	**25.5**
75 µm	16.5	13.4	87.9	**12.1**
Pan	14.9	12.1	100.0	**0.0**
	122.9	100.0		

Table B.15: Results from Natural Sand Aggregate Sieve Analysis.

Sieve Size	Mass Retained	% Mass Retained	Cumulitive Percentage Retained	Percent Passing
2.36 mm	1	0.2	0.2	**99.8**
1.18 mm	8.7	1.4	1.6	**98.4**
600 µm	49.5	8.1	9.6	**90.4**
300 µm	215.8	35.2	44.8	**55.2**
150 µm	231.1	37.6	82.4	**17.6**
75 µm	79.1	12.9	95.3	**4.7**
Pan	28.7	4.7	100.0	**0.0**
	613.9	100		

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