University of Southern Queensland

Bachelor of Engineering

Experimental Investigation on the Alkali Silica Reaction Effect on Concrete Strength Degradation

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October 2014

Abstract

Alkali Silica Reaction (ASR) is a significant cause of premature concrete deterioration. This internal reaction is a result of alkali hydroxides in pore solution that reacts with reactive silica found in certain aggregates. Once the silica is released from the aggregate an alkali-silica rich gel forms. ASR has been analysed for approximately 80 years, and has been a concern for the mechanical capacity of the affected structures.

Under natural environment, the ASR reaction usually does take a few years to appear and show damage; Since the project time frame has been set as 8 months, the ASR reaction has to be accelerated to suit the time frame by using highly reactive aggregate, adding chemicals and placing the sample in hot water or oven.

The Queensland Department of Transport and Main Roads has concerns that some of concrete bridges been affected by ASR. They are interested on the strengths (compressive and tensile) reduction cause by the reaction. In addition, they desire to know possible methods and remedies to minimise or even stop the reaction into the structure.

The aggregate was first tested for reactivity using American Society for Testing and Materials (ASTM C 1260) – Standard test method for potential alkali reactivity of aggregates (mortar bar method); mortar bar (200 mm x 50 mm x 50 mm) and cylinder (200 mm x 50 mm) were casted. Regular expansion measurements were taken. Flexural strength test were conducted on the mortar bars at 155 days.

Tests planned methodology: eighteen concrete cylinders (200 mm x 100 mm) were casted. Nine samples were casted according to Australian Standards and were left in the moisture and left in moisture room; and the remaining specimens were placed in sodium hydroxide (NaOH) mixture and after curing, specimens were left in the oven at high temperature (80^{o}C); as previous researches and testings have shown moisture is an important factor to activate the alkali-silica gel, which will then expand and consequently will cause cracks on concrete structure, these cracks were measured, and then compression and indirect tensile tests were conducted.

Compression strength was reduced by 2.54% at from 28 days to 80 days after casting for cylinder standard size and smaller cylinders had presented reduction 47.3% at 114 days. Indirect tensile strengths percentage reductions were measured at 28, 49 and 77 days: 2.28%, 7.79% and 12.09% respectively. Bending test had percentage reduction of 41.45% at 132 days.

The crack will be analysed according to width and related to the stiffness of the structure and from tensile strength results the percentage of tensile lost will be recorded and associated to moisture and crack width.

Overall results will be related to field structure. Those results will give a guide about the tensile capacity of their structures.

Suggestions of methodology to prevent and/or mitigate ASR reaction on existing and new structures, focusing on existing structures mitigation and diagnosis.

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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.

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Acknowledgements

I would like to express my gratitude to my supervisors: Associate Professor Yan Zhuge for all her support and patience with me through this year and Dr. Wayne Roberts (Department of Transport and Main Roads) for his assistance during my research.

Furthermore, I would like acknowledge Tony Thomas (Boral Concrete – Chief Engineer) and Boris Humpola (Wagners – MEI Aust CPEng) for suppling material and technical guidance.

I also would like to acknowledge Tracey Knight, my partner for this project. She had helped me to search for materials and cast concrete, as well as giving me technical and personal advices.

Daniel Eising and Piumika Ariyadasa (University of Southern Queensland – Engineering Laboratory) for permitting us to use the required equipment, Brian Aston (University of Southern Queensland – Senior Technical Officer) for providing the moulds.

Last but not least, I would like to say thanks to my family and friends, who encouraged and motivated me through the entire degree.

This dissertation is dedicated to my parents who have always been supportive.

1. Introduction

The aim of the project is to conduct a concrete testing in order to assist Queensland's Department of Transport and Main Roads (TMR) gaining a better understanding of the effect of Alkali-Silica Reaction (ASR) on concrete structures.

Researches about ASR had been conducted over the past 80 years. The studies have indicated that ASR is mainly found in most cements and silicious components of the aggregates, a chemical reaction occurring over time among alkali, cement and water (moisture). This reaction produces an alkali-silica gel and increases in volume as it absorbs moisture, it consequently generating pressure that disrupts the material of the concrete. This swelling pressure causes expansion and deterioration in concrete structures.

While these publications provide very effective diagnosing on the presence of ASR, significant concern still exists regarding the evaluation of structural serviceability and safety after ASR occurs. Also some ASR mitigation and prevention methods; were reported, no further investigation or testing on efficiency and costs are being conducted.

There are some accelerating methods for ASR, which have similar procedures, involves heat, and includes chemical solution. However, they have different duration to produce results. Because of the duration of this project, the American Society for Testing and Materials (ASTM) C1260 (Test method for Potential Alkali Reactivity of Aggregate- Mortar bar method) was followed. The casting procedure was according to ASTM C1260.

Further casting was based on the British method (the usual method to cast concrete) and more tests were conducted on specimens to analyse the compressive, tensile and flexural strengths of the samples. Compressive testing machine was used to measure the compression and tension of specimens affected and non-affected by ASR. Comparison of the specimens in different stages of deterioration focused on tensile strength related to cracking dimensions.

2. Literature Review

2.1 Background

Aggregates containing certain components can react with alkali hydroxides in concrete. The reactivity is potentially harmful only when it produces significant expansions (Fainy, 2007). This alkali aggregate reaction is known as AAR.

AAR has two forms: Alkali- Silica Reaction (ASR) and alkali – carbonate reaction (ACR). ASR is more concern than ACR due to the fact that existence of reactive silica mineral is more common in aggregates. ACR aggregates have a specific composition that does not occur commonly (large amount of crystal of calcium –magnesium carbonate). ACR is relatively rare because aggregates susceptible to this reaction are usually unsuitable for use in concrete.

ASR involves the reaction of certain silica minerals such as opal, cristobalite, chert, microcrystalline quartz, and acidic volcanic glass, present in some aggregates (coarse or fine).

Alkali-Silica Reaction has been known worldwide as a cause of deterioration on concrete structures since the 1940s. Nevertheless, concrete structures have not been diagnosed with ASR until 1975 (The Institution of Structural Engineering, 1992). ASR is a chemical process that develops by the use of certain aggregates in concrete mixing that may result in a chemical process in which particular elements of the aggregates, for example silica, which can react with alkalis – sodium oxide (Na_2O) and potassium oxides (K_2O)- dissolved in the concrete pore solution. This reaction usually occurs with moisture as the final reactive of the composition. These three components damage the concrete by causing internal cracks. The external cracks occur mainly because the tensile stress created by the expansion of ASR gel that exceeds the tensile strength of the concrete.

The water absorbed by the gel can be: water not used in the hydration reaction in the cement process, water from rainfall, tides, rives, or water condensed from air moisture (Touma, 2000). As well as this, the moisture content in massive structures is rarely uniform.

$$\text{Alkali + silica} \rightarrow \text{gel reaction (sodium silicate)}$$

$$\text{Gel reaction product + moisture} \rightarrow \text{expansion}$$

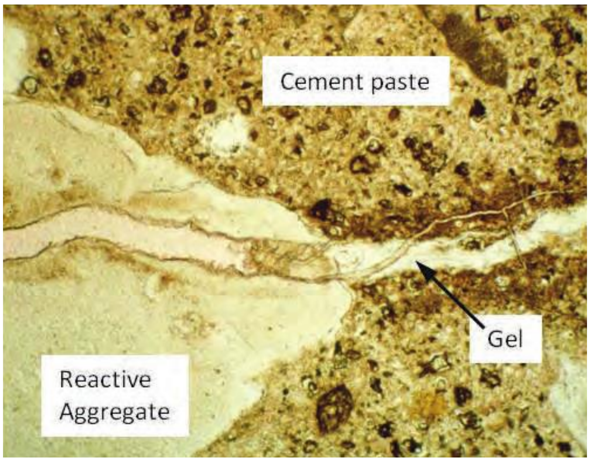

Figure 2.1 - Gel Formation (Thomas et all, 2011)

Figure 2.1 illustrates the alkali-silica gel in petrographic thin section of concrete from an affected structure.

Alkali, silica and moisture cause an internal deterioration on concrete structures. It forms an alkali-silica gel, which in contact with moisture will expand and consequently will cause cracks in the concrete. (Martin et al, 2013). Gel is found filling voids and fractures of the concrete, but large amounts of gel in concrete specimens do not indicate, on their own, that large expansion or extensive cracking has occurred.

The expansion forces caused by the gel depend on the gel composition as well as of the amount of the gel present in the concrete (Lindgard et al, 2011). The compositions of gel progresses with time; initially the gel absorbs water without taking in Na and K ions. In later phases, due to development of the reaction the gel becomes more viscous and expansive.

Research has shown that the degree of structural degradation also depends on the environment (Lea,1970):

- Where the structure was constructed;
- The structural design that retains moisture in the structure;
- External elements of the structure;

Also humidity and temperature are factors to be considered when analysing ASR. Environment related to humidity and temperature at a high rate causes an increase in the appearance of ASR cracks in the structure. ASR typical crack patterns are usually oriented in a parallel direction with major reinforcement or stress.

According to Whittle (2013), ASR can be manifested through some features, such as: presence of alkali-silica reaction on aggregate; crack pattern; exhibit of alkali-silica gel in cracks and voids; and reduction of Calcium Hydroxide ($Ca(OH)_2$) in the mix. ASR reaction is a long-term process because of the time taken for reactive minerals to spread, therefore it takes time before diagnosis can be done.

Visual symptoms on concrete structures affected by alkali-silica reaction are: indications of expansion, relative movement between structural members showing different expansion rates, cracking.

ASR compromises the mechanical properties of concrete, such as strength and elasticity. In additional, there are changes in the dimension (expansion, creep and shrinkage). Those are highly dependent on internal humidity and the temperature of the material (Saouma et all, 2014).

Main deleterious consequences of ASR are essentially related to potentially significant reductions in strengths and bond strength of the steel reinforcement. According to VicRoads (2008), there is not considerable evidence of significant reduction in structural capacity of the roads affected by ASR. However, the greatest concern is the long-term durability of the concrete structures because the network cracks (mapping cracks) with considerably increases the permeability to destructive agents.

Visual symptoms of ASR, however not exclusive relative to ASR (Fournier et all, 2010):

- Expansion causing deformation
- Relative movement and displacement
- Cracking
- Surface discoloration
- Gel release
- Pop-outs

Figure 2.2 - ASR damaged structures (Fournier et all, 2010)

Figure above shows damaged structures. On the left hand side, it shows expansion of bridge girder leading to loss of clearance between the girder and embankment. On the right hand side, it illustrate expansion causing spalling at joints in the concrete pavement, also longitudinal cracking in the middle part of the pavement section.

2.2 Testing Methods

2.2.1 ASTM C1260

Because of the long process that ASR reaction takes to occur, there are some methods to accelerate the reaction. One of those is by following an international standard American Society for Testing and Materials (ASTM) C1260 (Test method for Potential Alkali Reactivity of Aggregate- Mortar bar method). Another method is ASTM C1293 (Standard Test Method for Determine of Length Change of the Concrete to Alkali-Silica Reaction); still there are others that modify one or more of the above tests. ASTM C1293 gives a more realistic representation of field conditions and can obtain expansion results in a year. The most aggressive test is ASTM C1260, which can expand in 14 days. However, these accelerated tests may cause reactions that do not actually happen in the field.

ASTM C1260 consists of measuring the change in length of the mortar bars. The test cast has at least three specimen mortar bars of 285mm x 25 mm x 25 mm. They are cast with reactive aggregate and cement. The aggregate should be crushed to a particular grade, shown in the table below.

Table 2-1 - Grading Requirement - Source ASTM C1260

Sieve Size		Mass (%)
Passing	Retained on	
4.75 mm	2.36 mm	10
2.36 mm	1.18 mm	25
1.18 mm	600 µm	25
600 µm	300 µm	25
300 µm	150 µm	15

Figure 2.3 – Aggregate size

Figure 2.3 above shows the aggregate size after they had been sieved.

According to ASTM C1260 the bars are moist cured for 24 hours at room temperature. For another 24 hours, the samples are then submerged in 80^{o}C water or placed in an oven at the same temperature after recording the initial lengths. Consequently, the bars are then placed in a sealed plastic container of High Density Polyethylene (HDPE), which is resistant to Sodium Hidroxide (NaOH) and heat, then submerged in a NaOH alkali solution and placed at 80^{o}C water bath or oven for a period of 14 days, during this period regular length measurements should be taken. According to ASTM C1260, an expansion of less than 0.10% after 14 days expansion indicates an innocuous aggregate; while expansion greater than 0.20% indicates potentially reactive aggregate. Expansion between 0.10% and 0.20% “includes both aggregates that are known to be innocuous and deleterious in field performance” (ASTM C1260, 1994). If the test is in this range, it is suggested that further investigation and must be conducted.

2.2.2 ASTM C1293

Similarly, ASTM C1293 evaluates the potential of an aggregate to react and expand with pozzolan cement or slag. However, this test involves lower concentration of sodium hydroxide and lower temperature, which makes it less aggressive than the previously described ASTM C1260. Such test is more representative since is performed on a concrete specimen, unlike ASTM C1260, which is performed on mortar bar specimens. Nevertheless, the major disadvantage for ASTM C1293 is that it requires a year to complete the tests.

The methodology for this test requires high alkali content of 1.25% by mass of cement, and cement content of 420 kg/m^3. The water/ cement ratio is within the range of 0.42 to 0.45 by mass. The mix will contain coarse and fine aggregates. Those ratios and measures enable sufficient workability, and satisfactory compaction of the concrete in the moulds. The specimen size for ASTM C1293 is 285mm x 75mm x 75mm.

The concrete mix based on standards requires measurement of the slump immediately after mixing. The slump should be between 50 mm to 200 mm, according to ASTM C143 (2010).

The initial length reading is taken after 24 hours, when the mould is removed, before being placed in a storage room for 23.5 (+or – 5 hours) with relative humidity greater than 95%. Subsequently, specimens are placed in sealed plastic storage containers at 38^{o}C. The storage containers have to be within the standard requirements, as follows:

- 250 to 270mm at bottom
- 290 to 310mm at top
- 355 to 480mm high
- 19 to 22 L polyethylene buckets
- Make a rack at the bottom at approximately 30 to 40mm
- Add water to a depth of 15 to 25mm

Specimens are placed on a rack at the bottom of the containers not touching the water. Storage containers should not touch the walls or floor of the storage room; there should be satisfactory airflow around the containers. Figure below shows the specimens placed on the rack – rack was made with PVC pipe.

Figure 2.4 - Specimens into the container

Subsequent readings should be taken 7 days after the casting and then at intervals of 28 and 56 days; 3, 6, 9 and 12 months. However, before taking the readings, the specimen should be removed from the storage room and placed in a moist room for a period of 16 (+or- 4 hours) before reading. Moreover, the specimen should be inverted when placed back in the container. This will prevent the specimen being stored with the same faces up for two or more consecutive reading periods.

Table 2-2 shows the aggregate grading for the concrete mix and its proportions.

Table 2-2 - Grading Requirement – Source ASTM C1293

Sieve Size		Mass Fraction	
Passing	Retained	Coarse	Intermediate
19.0 mm	12.5 mm	1/3	- - -
12.5 mm	9.5 mm	1/3	1/2
9.5 mm	4.75 mm	1/3	1/2

After one year, an expansion of less than 0.04% is considered to be non-reactive, while an expansion of greater than 0.12% is considered highly reactive, though an expansion of 0.04% to 0.12% is seen as potentially reactive.

2.2.3 Compressive Test

All the mechanical properties of concrete are negatively affected by alkali silica, however not at the same expansion levels or same degree.

Concrete compressive strength is the most common and precise test conducted for acceptance of concrete.

The compressive test is the most widely used method to measure compressive strength of the concrete. The compressive strength is measured by breaking the specimen by compressor machine. According to Standards Australia and Concrete Association of Australia (2002) compressive test is a measure of specimen or structures capacity to resist loads when submitted crush action.

Compressive strength is determined by failure load (P_c in N) divided by cross-sectional area (A in m^2) of the specimen.

$$Compressive\ strength\ (\sigma) = \frac{P_c}{A}\ (MPa) \qquad \text{Equation 2-1}$$

The geometric shape of the specimen for compressive test is generally cylindrical, although some tests have been conducted with cubic samples. The practice of the test varies from country to country. In Australia the standard size of a specimen for the compressive test is 150mm (100mm) diameter x 300mm (200mm) cylinders. While cube 150mm samples are more often used in the United Kingdom.

However, An (2010) had found a relationship existing between the results for both cylinders and cubes. A higher specimen has a lower compressive strength than a shorter sample.

It is important to maintain the ratio of height (h) to thickness (t) when conducting a test, in accord with national standard specifications.

The compression test was analysed by Tracey Knight as part of her thesis (Alkali-Silica Reaction in Concrete Bridge Piles: Treatment and Strengthening with Fibre-Reinforced Polymers) and relevant results may also come from this study.

2.2.4 Tensile Test

Tensile strength of concrete is the capacity to resist loads when the sample or structures are subjected to stretch or bend actions. Cracks are a form of tension failure, hence determining tensile strength is important so that the load capacity of the structure can be controlled. The testing of pure tension is very difficult to reproduce in the laboratory. The most common test used is the splitting test (Brazilian test). It can be used for cylinders and cubes. Cubes are tested diagonally, according to Chen (1969).

Specimen size for this test is usually a cylinder 100mm in diameter and 200mm high. The same compressive machine is used for both the tensile and compressive test. However, for tensile test the sample is placed between the platens in a horizontal direction. The load is applied until the specimen splits. The indirect tensile strength is calculated by:

$$Indirect\ tensile\ strength = \frac{2P}{1000\pi DL}\ (MPa) \qquad \text{Equation 2-2}$$

Where:

P (kN) = maximum load at failure

D (m) = cylinder diameter

L (m) = cylinder length

According to Okine and Atique (2006), the ASR effect on tensile strength is more significant when applying the direct tensile strength test than the indirect tensile strength because its failure is along a predetermined line.

2.2.5 Flexural Strength Test

The flexural strength test is usually known as modulus of rupture, which significantly decreases with increasing the size of the beam. The concept of modulus of rupture is based on the elastic beam theory. The modulus of rupture is defined as the maximum normal stress in the beam.

The University of Southern Queensland (USQ) laboratory has the three point loading machine used for destructive test. The standard sizes of the specimens are 100 mm x 100 mm x 350 mm. However, the samples that was used are from the first and second batches (200 mm x 50 mm x 50 mm).

Equation 2-3 below, was used to calculate the modulus of rupture of the specimens.

$$Modulus\ of\ rupture\ (inside) = \frac{3PL}{2bd^2} \qquad \text{Equation 2-3}$$

Measuring strength it does not qualify the durability of the structure. Durability can be quantified by managing the permeability and shrinkage. They can extend the service life of the structure. And according to Obla (2005) concrete intend to have a low permeability when exposure to water.

2.2.6 Petrographic Analysis

The ASTM C295 - Standard Guide for Petrographic Examination of Aggregates for Concrete - summarises the procedures for petrographic examination of representative samples of the material. A petrographer of at least 5 years experience should perform all petrographic examinations of aggregates, for concrete use. It is usually the first procedure in the assessment of potential alkali-silica reaction in the aggregate.

This examination is suitable for investigating particular problems that require aggregate examination of selected components by additional procedures, such as X-ray diffraction (XRD) analysis, differential thermal analysis (DTA); and some other petrographic analyses.

Petrographic examination of the aggregate studied for use in hydraulic-cement also provides identification of types and varieties of rocks present in potential aggregates; in addition, it classifies aggregates' chemical components, and it also identifies the potentially alkali-silica reaction and alkali-carbonate reaction elements.

Moreover, ASTM C295 states the alkali-silica reaction elements found in aggregate include:

- Chalcedony
- Opal
- Cristobalite
- Volcanic glass
- Highly strained quartz
- Tridymite
- Microcrystalline quartz
- Strained siliceous glass

Because of different geological histories a rock type might be innocuous in one country or region and reactive in another. This examination is important to determine the potential ASR of aggregate used in the concrete mix.

The symptoms on concrete affected by ASR and ACR are usually similar. Petrographic examination generally allows differentiating both reactions; the deleterious expansion and cracking due to ASR relies on the formation of secondary reaction (alkali-silica gel).

2.2.7 Pessimum Effect

Different types of aggregates exhibit a linear relationship between potential reactive components and the measured expansions. The maximum level of expansion may occur at a particular content of the reactive components known as the pessimum. Decreasing the levels of expansion will develop for proportions of the reactive constituents below or above the pessimum. Furthermore, variations above or below the pessimum values expand or reduce the expansion.

Lindgard et al (2011) reported that the expansion increases until a certain level of alkali ir reached and then decreases for higher alkali contents.

The aggregates that contain rapidly reactive siliceous minerals show an unexpected behaviour with respect to the relation between the amount of reactive aggregate and expansion.

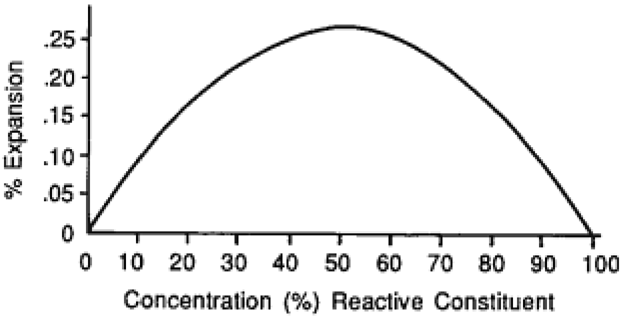

Figure 2.5- Pessimum Effect (Swamy, 1992)

The pessimum proportion relationship is illustrated in Figure 2.5, demonstrates the relationship between the concentration of alkali and the percentage of expansion. It does not always occur at the 50% level of concentration; A reactive aggregate having a higher rate of removal for alkali due to an increase in reactive elements, which removes a large proportion of the initial concentration of alkali, moving the graph to the left. Likewise, if the amount of aggregate present in concrete is either low or high, it will cause small or no expansion.

Measurements confirmed that the expansion rate was slower in the largest aggregate particles whatever the size of the specimen (Gao et al, 2012)

There are debates about the alkali amount in cement over the years. Based on Okine and Atique (2006) in the early 1940s the Na_2O equivalent of Portland cement is 0.60% maximum, and it was also noted that there was concrete distress caused by the alkali-silica reaction. The Na_2O equivalent is calculates as the sum of:

% Na_2O equivalent (%Na_2O_{eq}) = weight %Na_2O+0.658 x weight %K_2O

Where:

Na_2O – Sodium Oxide of cement content

K_2O – Potassium Oxide of cement content

Cement usually has a limit %Na_2O_{eq} of at 0.4 to 0.8. However, values lower than 0.60% was considered low alkali content.

The alkali content of the cement is represented by the K_2O/ Na_2O ratio, which generally ranges from 1 (unusually low) to 3 this ratio reflects in the gel composition (Lindgard et al, 2011). Adding extra Na_2O and K_2O into the concrete mixing for accelerating the reaction may affect the potassium hydroxide and sodium hydroxide ratio; which could affect the concentration of the chemicals in the mixture and consequently the expansion inside the concrete, which will reflect the pessimum curve.

ASR occurs only at high concentration of Hydroxide Ion (OH^-) at a pH of 13.5 and above. The pH of the water and Sodium Hydroxide solution are the measures for disposal purpose.

2.2.8 Cracking Index (CI)

The internal expansion due to ASR and structures subjected to drying and wetting cycles (climate and environment exposures). Structures usually show surface cracking because of induced tension. The cracks are most severe in areas that has constant source of moisture.

Cracking Index (CI) is a cracking mapping process that consists in the summation and measurement of crack widths along a set of lines drawn on the surface of the concrete (creating a grid on the face of the concrete). It is on site measurement procedure however, some concepts related to cracks such as width measurements and magnitude of cracks expansion was considered in this project.

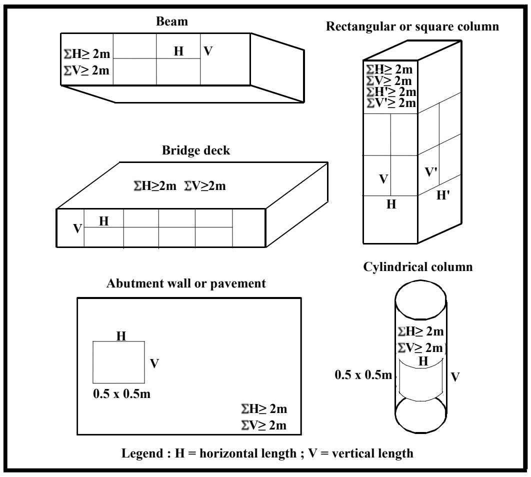

Figure 2.6 - Cracking Index grid

The number of the horizontal and vertical lines should be that a total 2 meters of line-measurements should be done in each direction.

Furthermore, a Cracking Index is calculated, and an average crack opening per unit length of the structure; it was adapted according to specimens' sizes.

The CI analysis is usually is combined with petrographic examination of structure cores (Fournier et al, 2010). CI will establish a reference of the extent of cracking in a concrete member. Fournier et al (2010) also recommend periodic measurement of the CI, which will generate data on the evolution of structure deterioration. Therefore, cracking index should be done on the members showing the most severe degree of deterioration (most critical structure members). In additional, CI should be conducted on the portions of the members exposed to moisture, as cracking will extensively develop (waterline in pier, behind retaining wall, underneath pavement slab, columns).

CI is also defined by the product of the extent area (sample area of the structure), intensity (total cracks length) and crack width (Paterson,1994).

2.2.9 Controlling ASR

It is recommended to have a site inspection when the concrete is slightly wet, such as, after a rainfall. The reasons for this particular recommendation according to Farny and Kerkhoff (2007) is because the fine cracks occurs irregularly on the surface and provides a contrast that makes them more noticeable.

Petrographic analysis which was described previously, is suggested by Standards Australia (1996) to be a suitable quality control to evaluate concrete structure damaged by ASR. This quality control method provides the quickest and least expensive.

There is a chart that that list the steps to be followed to control ASR reaction. (Farny and Kerkhoff, 2007). Figures bellows illustrate these charts.

The chart below assists ASR diagnosis and identification on concrete structure, as well provides guidance for further action.

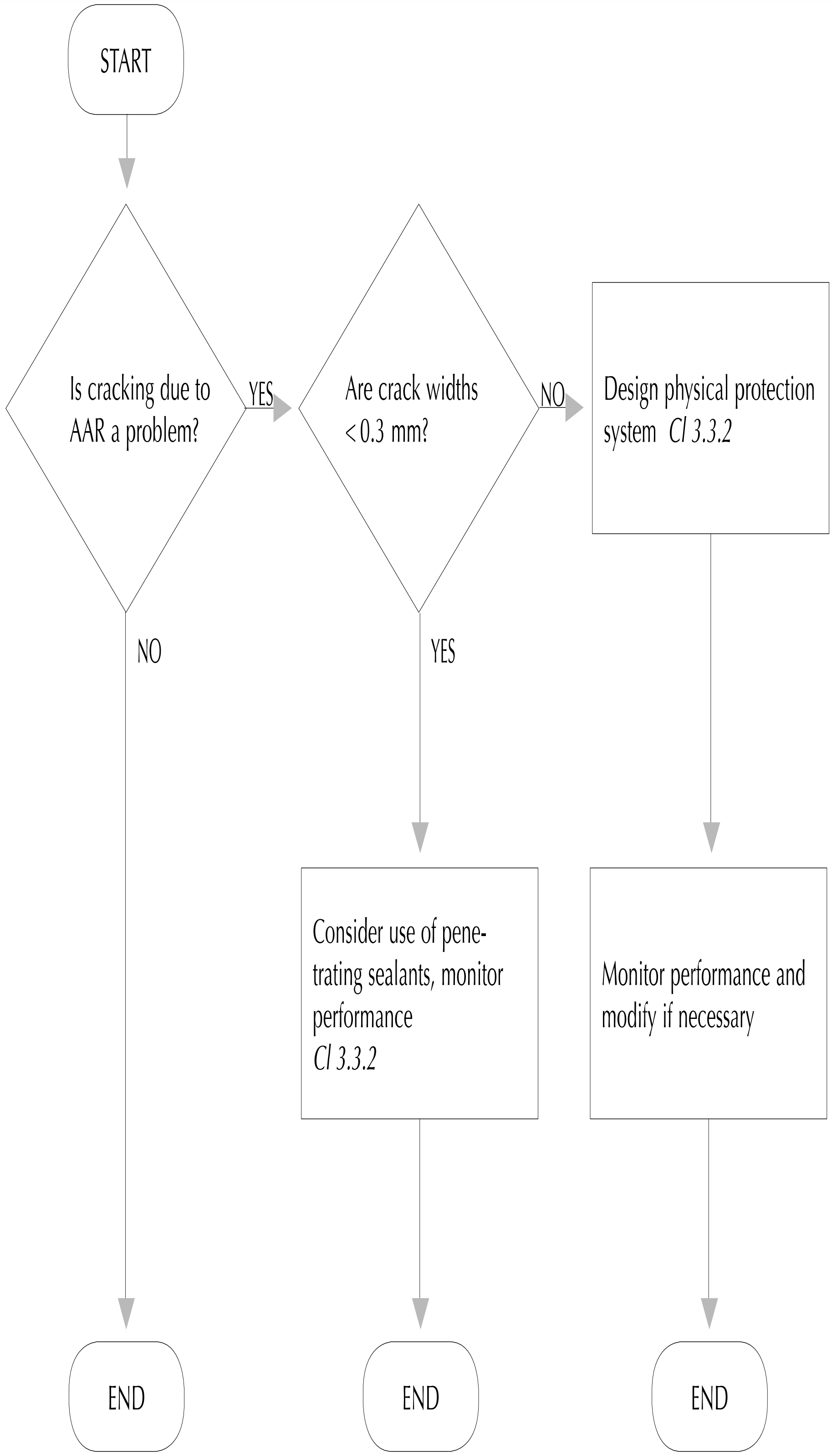

Figure 2.7 - ASR control chart (SAA HB79, 1996)

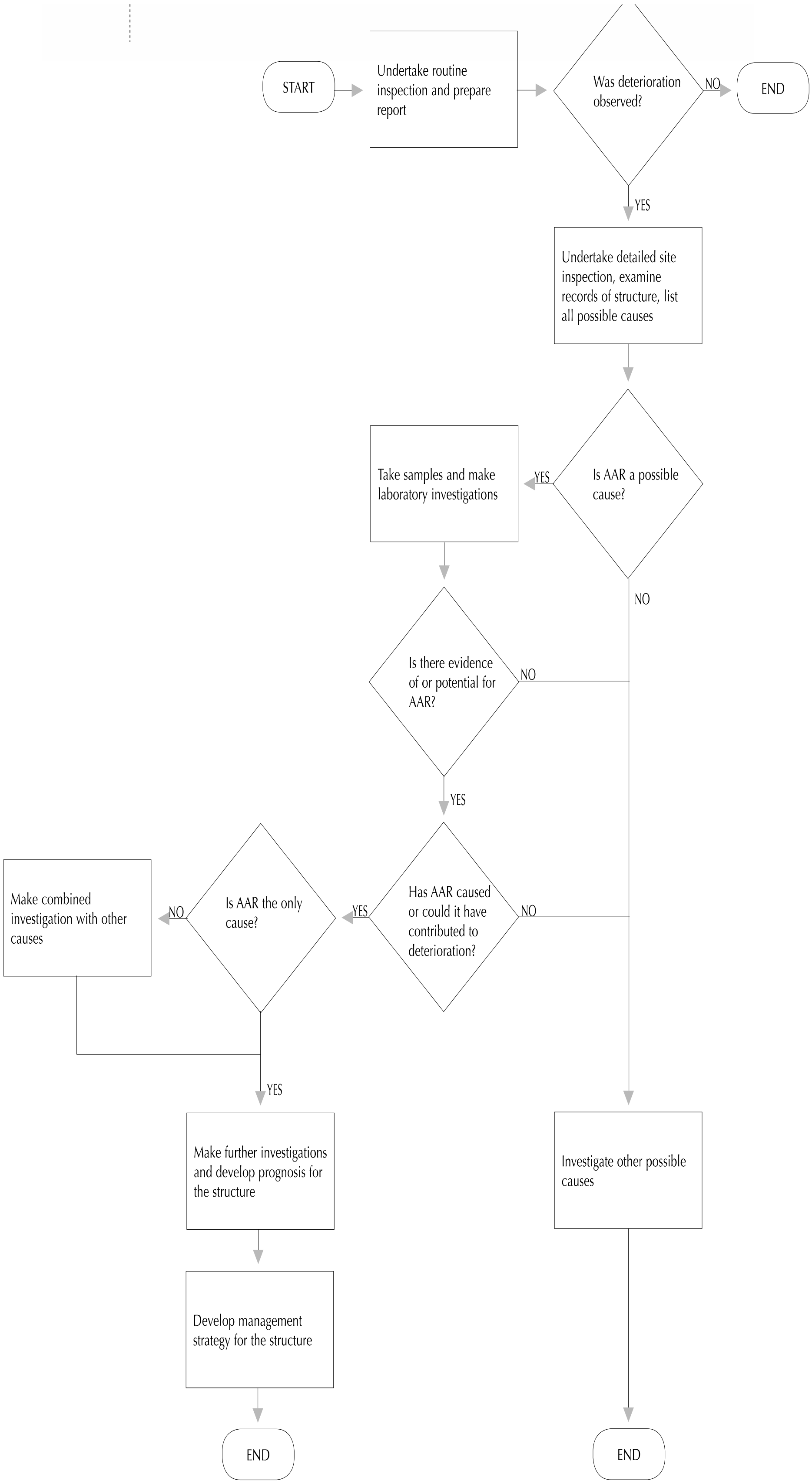

Figure 2.8 - Diagnosis flow chart (SAA HB79, 1996)

Cores are collected in concrete structures showing visual signs of deterioration subjective of ASR. The cores are subjected to petrographic analyse in the laboratory. When petrographic indicate alkali silica reaction deterioration, further steps needs to be followed: observe the severity of cracks.

These figures are strategies to determine the potential reactivity in a potentially affected area of the structure.

In-situ investigation program, which includes monitoring of expansion and deformation generally, provides the most reliable prognostic for ASR (Fournier et all, 2010). Due to the fact variations in weather a condition (which affects the progress of ASR) and the differences in the reactivity levels of aggregates and mix designs considerations; it is generally considered that minimum of 2 or 3 years are required for reliable decisions on the implementation of remedial actions. Site inspection should start after 3 year of structure uses, which is the initial time when ASR starts to react and increase the site inspection frequency according to areas and gravity of the damages.

3. Research Objectives and Methodology

The objective of the project is to investigate the Alkali Silica Reaction on concrete through casting concrete specimens and analysing the development of cracks caused by Alkali Silica Reaction. Crack width was measured and the compared with the associated tensile and compressive testing. It is expected that the relationship between the crack width and the structural strength is related to the structural degradation of the field structures.

The cylinder mould dimensions are 200mm x100mm. It was conducted in compliance with the relevant Australian Standards AS1012.9 (method for determining the compressive strength of concrete specimens), AS1012.10 (method for determining the tensile strength of concrete specimens), AS3600 (the Australian concrete structure code), AS1379 (Specification and supply of concrete), as well as an international standard, the American Society for Testing and Materials (ASTM) C 1260 (Test method for Potential Alkali Reactivity of Aggregate- Mortar bar method). Other applicable standard required along the testing and research where also implemented:

- Standard test method for determination of length change of concrete due to Alkali-Silica Reaction;
- Standard test method for strength tests on concrete;
- Standard test method for slump of hydraulic- cement concrete;

ASTM C1260 is an accelerated laboratory test for ASR. The test measures the expansion of a mortar bar. This technique uses a chemical reaction as the process to detect and activate the reaction on aggregates independent of alkali content of the cement. This method puts the material in conditions that increase the rate of reactions compared to reactions in the field. The aggregate was tested according to this standard. This method is the most suitable for the timeframe of this project.

Figure 3.1 – Bridge deck and Pier cap affected by ASR (Roberts, W 2014 – January meeting)

3.1 Methodology

The aggregate supplied was glassy basalt with dimensions of 20mm and 10mm. Basalt is considered highly reactive. The 10mm aggregates were crushed to achieve ASTM C1260 required sizes (

Table 2-1), using a compressor machine at 2000 kN. Subsequently, the aggregate was sieved and the mass of different sizes was recorded. This procedure was repeated until there was sufficient quantity to cast 3 mortar bars for the aggregate reactivity test.

The cement supplied has a low alkali content. Consequently, the ASTM C1260 states that the alkali content in the cement has a minor or negligible effect on expansion. The supplier also provided batch physical and chemical characteristics and raw data tests in appendix C and appendix D.

The first 3 mortar bars (200mm x 50 mm x 50mm) were cast and 3 cylinders (200 mm x 50mm) were made from glassy basalt and low-alkali cement (as specified on ASTM C1260); and water. The amount of each component is calculated in Appendix A for mortar bars and Appendix B for cylinders. The mould was greased to facilitate unmould; it was used USQ laboratory grease.

Figure 3.2 - Mould preparation

The original size of the mould was 300 mm x 100 mm x 50 mm; it was modify to comply the ASTM C1260 specifications. Figure 3.2 above, on the left hand side, shows the mould before placing the concrete paste and on the right hand side, the paste already placed in the wood mould.

Casting and length measurement procedures:

Cast the concrete with stainless steel screw in side. Stainless steel is not reactive with NaOH and does not rust with water. To measure expansion, a screw was inserted in each end of the specimens and as the concrete expands, the screws are expected to expel. Figure 3.4 below illustrates the bars with the screw attached.

- A mixing bowl was used along with a piece of timber as tamper.
- Specimens were removed from the moulds after 24 hours of being cast and initial measurements were taken.
- A water and hydroxide mix was prepared with 4 litres of water and 178g of NaOH.
- Some PVC pipes were placed at the bottom of the container. These formed a rack where the specimens could lie.
- 24 hours later a second measurement was taken, and the specimens were placed in plastic containers, with water, and then were placed in an oven at 80^{o}C.
- A further 24 hours later a third series of measurements were taken and the specimens were inserted into the chemical mix.

- After this process further measurements were taken at intervals of 48 hours, 48 hours and 72 hours, per week.

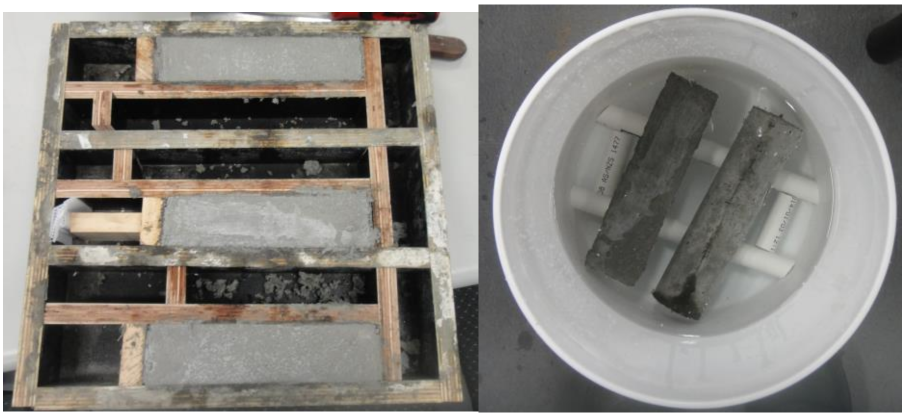

Figure 3.3 - Samples in the mould and later placed in NaOH solution

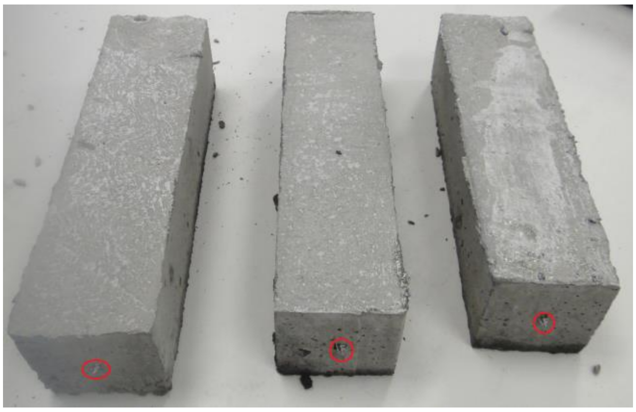

Figure 3.4 – Mortar bars with stainless steel screw as studs

Figure 3.3 shows the specimens in the mould after 24 hour in the moisture room and placed in NaOH and water mixture.

Figure 3.4 shows the specimens after had been taken from the mould. The stainless steel screws are indicated in the red circles.

3.2 Expansion Results

According to the standard ASTM C1260, expansions of less than 0.10% at 16 days after casting are innocuous; while, expansions of greater than 0.20% are potentially deleterious. To calculate the expansions were used the Equation 3-1 below:

$$\% \, expansion = \frac{L_n - L_o}{L_o} \qquad \text{Equation 3-1}$$

Where:

L_n = the measured length of the specimens at n days.

L_o = the initial length before being placed in the sodium hydroxide and water solution.

The detailed expansion results on reactive aggregate tests are showed on Appendix G. Cylinder samples had showed better results than the mortar bar. However, cylinder and mortar bar results are less than the expected result at 16 days. The results have approximately 0.02% expansion screw to screw. It was started measurements from face to face of the concrete since at 16 days previous measurement was not satisfactory.

Possible reason for the failure results: this is due to faulty measurement device (digital vernier caliper), which also may explain the negative results and higher peaks of positive results. The results are shown on Appendix G.

Using same sizes of nominal aggregates and same design mix, for different volumes of the specimens were different from ASTM C1260; with cylinders at 0.000393-m3 and mortar bar at 0.0005 m^3. Larger aggregate nominal size and specimens' size can delay the ASR reaction at early ages.

The second batch was casted according to ASTM C1260 and measurements from stud to studs and face-to-face measurement were taken. The result were compared and analysed.

The average measurement from stud to stud during 16 days for the second batch was 0.00276% (mortar bars). The cylinders average results were 0.03813%. The average results for both batches were significant lower than the expected; which was approximately 0.01724% lower for the first batch, and 0.01026% lower for the second batch. Those measurements were from screws or studs. However, face-to-face measurements had similar results to previous described.

Appendix G shows that the graphic expansion on cylinders and mortar bars for the first batch of samples were expanding very similarly. The peaks on the graph are due to error on measurement device and unmarked samples.

Further investigation is necessary to prove the actual causes of the peaks. In addition, Appendix G shows the graphic expansion on mortar bars, the negative number were from the inaccuracy of the vernie caliper device. Sample 4, as expected, does not show great discrepancy expansions.

The result did not agree to the ASTM C1260 standard results. This may be because the standard was adapted to suits the laboratory facility and available materials.

- Mould size and shape were different than described in the standard.
- It was used laboratory mixer. The lower end of the paddle was touching the bottom of the bowl.
- The support inside the containers were used PVC pipes, the material had slightly melted. It may have affected the results.
- The use of stainless steel screws instead of studs.

Those items may have influence expansion results on the samples; further investigation is necessary to certify actual reasons for poor results.

However, the first batch did not follow the expected changes on the release agent and screws type as desired, also second batch did not correspond to the expected results. Despite the expansion results, the mapping crack had appeared on all specimens' left in sodium hydroxide then, testing must be conducted.

The expansions graphic are illustrated on Appendix G. It shows that there were slight increases on expansion at early periods. The expansions had increased considerably after 40 days.

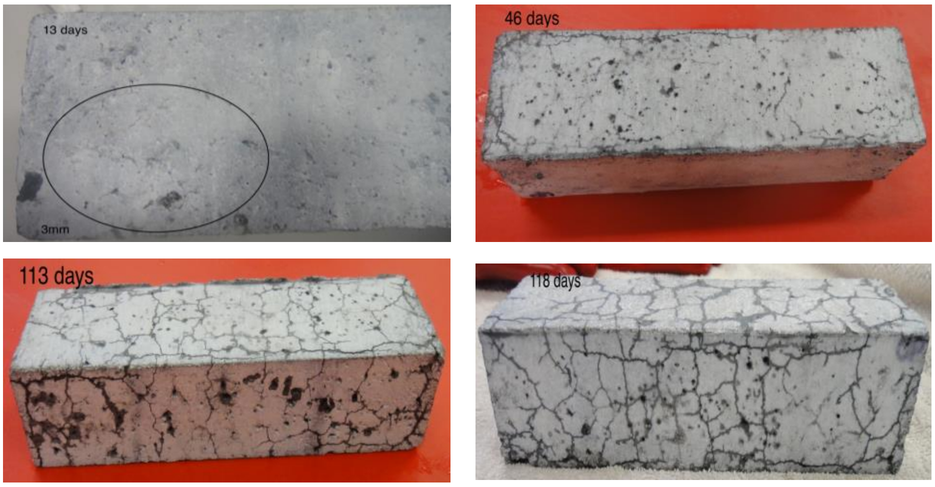

Figure 3.5 – Cracks development

Figure 3.5 above shows the development of the cracks during the project. The top left shows samples at 13 day, where the sample had 3mm cracks. On the right, it shows the specimen at 45 days starting a mapping look. On bottom left, specimens at 113 days and 118 days respectively were showing mapping crack; characteristic crack of ASR reaction.

The expansion did not occur rapidly as expected, however it had occurred. The desired look of mapping crack had showed on 113 days (week 16). Mapping crack usually starts to show at week 13 when exposured to accelerated ASR testing.

3.3 Preliminary Results

Preliminary results were analysed to identify wether there are ASR expansion reaction happening to specimens. There were some cracks showing on the face of the samples at roughly 16 day, the average length of the cracks differs, however they were approximately 3 mm as shown on Figure 3.5 above. The results found and respective actions are listed below:

According to ASTM C1260 mould preparation:

- A release agent that may in time affect or leave residue can obstruct water penetration on the specimen and should not be used. It is recommended to use TFE-fluorocarbon tape.
- Using incorrect release agent may have affected the screws. They were not expelled as was expected. The screws were replaced with engineering studs, which are different from the original type of screws. Different types of screws and studs were used for the purpose of checking the screw behaviour in relation to concrete expansion. Also, the screws were not straight. That could have compromised the measurements.
- The oven temperature drops severely when the oven door is opened for long periods of time could have affected the heating process of the specimen.
- As stated by ASTM C1260, after sieving, the aggregates need to be washed separately according to size to remove adhering dust and fine particles.
- Specimens were not marked. Consequently, measurements may have been taken from different faces of the concrete, which could have compromised the results. The new batch specimens have been marked.

Figure 3.6 below shows the screw, which is not following the concrete expansion. The stud had not been ejected by the sample as was expected. Future measurement must be done from one face to the opposite face of the concrete. Figure 3.6 also illustrates the first cracks between 9mm and 12mm.

Observation of mortar size was larger area than ASTM C1260 suggested. However according to Golmakani (2013) mortar bars with a smaller cross-section area expands sooner. NaOH also can spread rapidly and reacts faster.

A second batch was made from the same type of cement and aggregate. This overcomes the possible failures described previously, except that the same oven was used and the aggregate has not been washed as recommended by ASTM C1260.

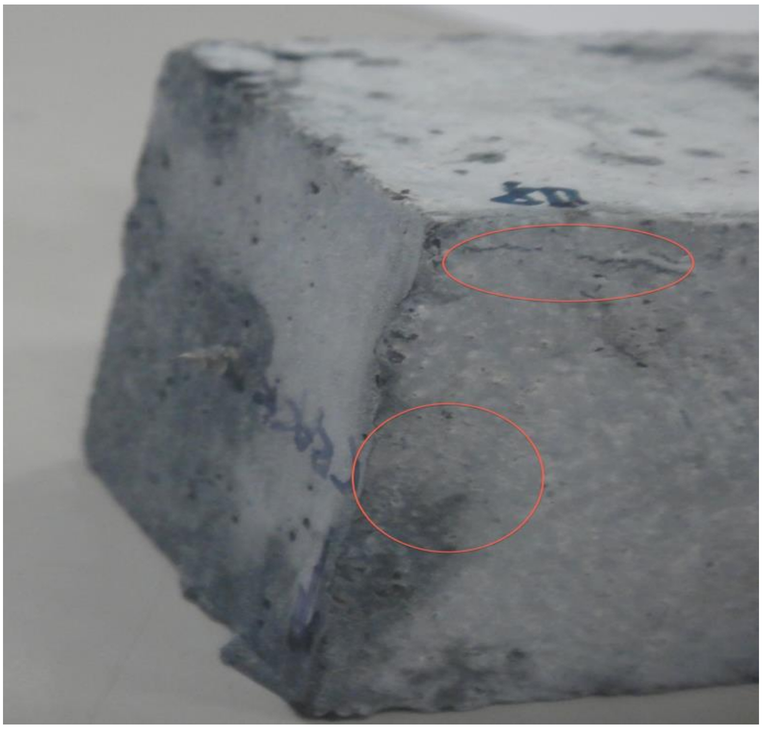

Figure 3.6 – Screw and Cracks

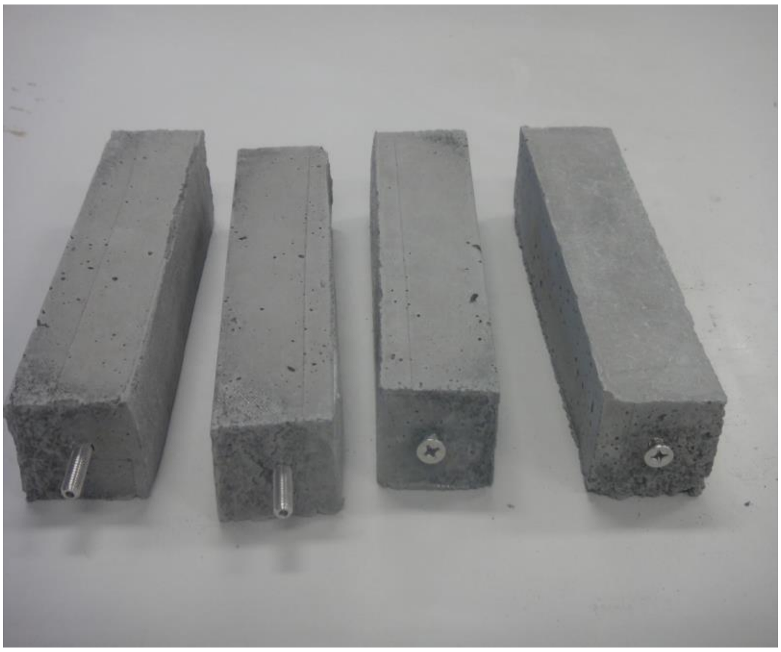

Figure 3.7 – Second batch ASTM C1260 testing

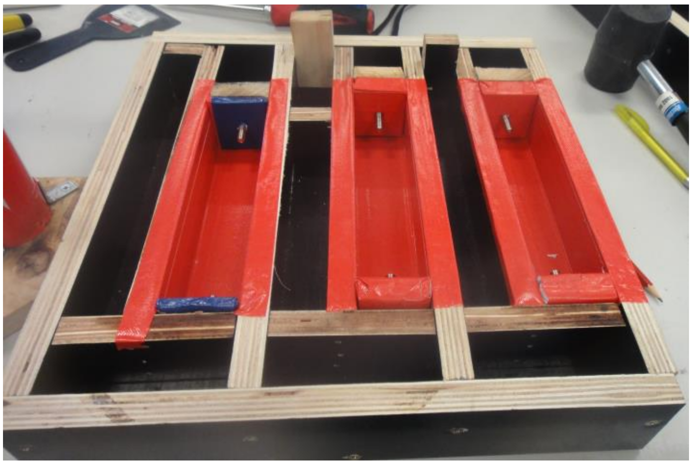

Figure 3.8 - Mouuld with TFE-fluorocarbon tape

Figure 3.7 above shows the modification on studs. On the left hand side, engineering studs were used, while on the right hand side, another type of stainless steel screws were used. Figure 3.8 is demonstrating the TFE-fluorocarbon tape had been placed on the mould.

These detailed are significant input to further studies if analysing the possible reasons for unexpected results.

4. Resources

4.1 Coarse Aggregate

For this project highly reactive aggregate is essential in order to produce damaged concrete specimens. Research on the different quarries was conducted to find out the required aggregates that have been known to have the alkali silicate reaction. Tracey Knight had spoken to Tony Thomas from Boral Concrete and Tony Thomas suggested glassy basalt from the Boral Teven Quarry.

The Boral Teven Quarry is located on the slope of the Teven Valley alongside Maguires Creek in New South Wales. This quarry has two types of rock; metamorphic rocks (argillite) and volcanic (basalt).

Argillite is from carbonaceous, feldspathic, silty mudstone. It has the fine recrystallization and was hardened and strengthened attributed for over 425 million years.

The basalt belongs to the Lismore basalt of middle Tertiary Age (12 and 50 million years). Basalt flows have thin ash layers, which is covered by clay. Basalt is a dark black/grey and is considered strong, hard and durable with components that are relatively glassy. They are extracted from different parts of the quarry.

Silica is the most common oxide in the earth's solid crust. The more soluble the form of the silica, the faster and more intense is the reaction. Varieties of silica minerals are listed below in order of decreasing reactivity. The list is very general because the order is dependent on the degree of disorder to be found within the particular variety and mode of occurrence of the mineral.

- Amorphous silica: volcanic glass
- Opal
- Unstable crystalline silica: cristobalite and tridymite
- Chalcedony
- Cryptocrystalline forms of silica
- Metamorphically granulated
- Quartz

The list below shows the rocks that have been found to be deleteriously reactive and thus can be considered potentially reactive. The actual reactivity of rocks is dependent on the type and amount of reactive component present.

- Volcanic rocks including tuffs
- Sedimentary rocks
- Gneiss, schist, phylitte, argillite, slate
- Granite, granodiorite, chamockite
- Quartzite, sandstone, siltstone, shale, greywacke, siliceous limestone
- Chert

Boral had tested the basalt glassy aggregate following the ASTM C1260 principles and the results were reported as follows:

Table 4-1 - Result from ASTM C1260 Test

Time (days)	Expansion (%)
10	0.352
14	0.527
21	0.814

Roughly 400 kg of aggregates of 10mm - 20mm was collected from Boral Teven Quarry.

4.2 Fine aggregate

White sand from Ravensbourne Quarry was used. This quarry has been operating for more than 20 years. The main extractive resource is sand.

This quarry is part of the Toowoomba Regional Council region, located at northeast of the town of Ravensbourne off the Esk-Hampton Road, which is the main road to the quarry as shown in (Figure 4.1). The sand is transported to a short distance along Philip Road to the main road.

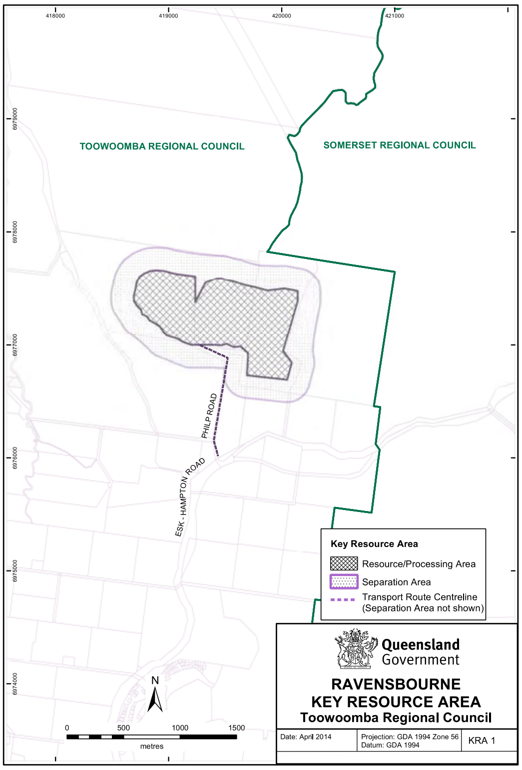

Figure 4.1 - Ravensbourne Quarry

The sand contains weathered soft, crushed sandstone that underlies basalt lavas to the northeast of Ravensbourne. The clay is washed from the sand to prepare a suitable grade for general purposes.

The resource supplies Toowoomba and the northeastern Darling Downs of construction sand. Because of the scarcity of natural sand for construction purposes in Toowoomba and Daring Downs, the Ravensbourne resource is conveniently situated to fill this demand.

White sand was used into the design mix for the standard samples.

4.3 Cement

Portland cement contains, in addition to the major element oxides of calcium, aluminium, and silicon, small quantities of other oxides that occur in the raw material. The alkalies Na_2O and K_2O have a particular interest because of their unfavourable reaction with certain types aggregates used in concrete, and during the burning process these minor oxides affect the temperature at which the first liquid forms and the nature and quantity of the phases that constitute the residue. The nature and quantity of the phases determine the physical and chemical properties of the cement. They are showed on Appendixes D and E.

Wagner Cement, Pinkenba, supplied the cement. The plant can produce up to 200 tonnes of bagged cement a day. The cement provided is General Purpose (GP) and has been considered as having low alkali content. According to ASTM C1260, the alkali content in cement has been found to have a minimum or negligible effect on expansion in this test. Four bags of 20kg each was supplied at this stage of the project.

The alkalis, sodium and potassium, in Portland cement are derived from clay components present in the raw mix and coal; their total amount is expressed as Na_2O equivalent.

The % Na_2O equivalent is less than 0.40%, which might cause deleterious expansion on the structures. To assess the total content of available alkalis present in cement, it has become standard practice to express the alkali content in terms of sodium oxide equivalent (Na_2O_{eq}).

Wagner had conducted tests with the cement and results are provided in Appendixes D and E.

From appendix D data table:

% Na_2O_{eq} = 0.06 + 0.658 x 0.57 = %0. 43506.

Cement has similar Na_2O_{eq} nevertheless different K/Na ratio can increase differently in accelerated laboratory tests. However, the sodium oxide equivalent for standard specimens will vary between the range values (0.4% to 0.8%).

5. Testing Methodology

The mortar bars test had shown the desired damaged expansion. Figure 5.1 below shows that an indirect tensile test can be conducted using the same principle for accelerating the specimens.

Figure 5.1 – Damaged cylinder week9 of age

5.1 Mixing design

The standard cylinders were cast according to the British method (the usual method to cast concrete). It was casted 18 cylinders (200mm x 100mm), the coarse aggregate for the concrete mixing was the glassy basalt aggregate (20mm and 10mm) from Boral Teven Quarry, cement from Wagner Cement, Pinkenba. The sand was from Ravensbourne. This white sand is expected to have a higher for potential reaction in the mix.

Figure 5.2 - Aggregates and moulds

Figure 5.2 shows the aggregates, cement and water ready to be mixed, On the right hand side, the moulds used for the cylinders test had areas of (0.00785 m2) and volume of (0.00157 m3) then design mix could be detemined.

The mixing design was based on the worst-case scenario. It was assumed that a characteristic strength (C) of 50 MPa would give the target strength shown below:

$$\text{Target Strength (T)} = C + 1.65\ S \qquad \text{Equation 5-1}$$

Where;

T= Target strength – mean compressive strength at 28 days (MPa)

C= Characteristic strength – compressive strength at 28 days (MPa)

Himsworth coefficient – 1.65 for 5% probability of failure

S = Standard deviation (MPa)

The exposure classification was B2, which consider surface of member in water: Permanently submerged (AS3600, 2009). Characteristic strength for B2 is 40 MPa.

Table 5-1- Assumed Standard Deviation (USQ, 2014)

Grade designation	**Characteristic strength (MPa)**	**Assumed standard deviation (MPa)**
Standard grades		
25	25	4.8
32	32	5.34
40	**40**	**5.9**
50	50	6.2
Flexural grades		
F2.5	2.5	0.5
F3.5	35	0.6 /0.5
Indirect tensile grades		
IT2.0	2.0	0.5
IT2.5	2.5	0.5

The result from Equation 5-1 is T= 40 +1.65 x 5.9 = 49.735 MPa rounding up 50 MPa.

Moreover, the water/cement ratio can be determined using the graphic below as 0.45. The lower is the water/cement ratio, the greater strength is achieved, however workability is reduced.

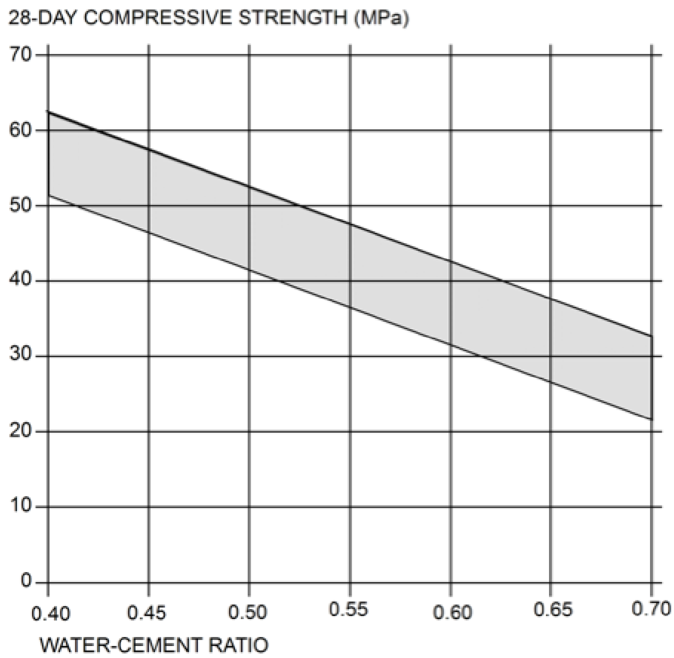

Figure 5.3 - Water/cement ration versus strength (USQ, 2014)

For practical purposes the effect of self- dehydration might become important for concrete with water/cement ratio ≤ 0.45. At lower water/cement ratio this effect is larger and may reduce the relative humidity (below 80%) over a period of time, as long as there is no water supply from structure surrounding. The minimum water/cement ratio for laboratory test is 0.4. Nevertheless, increasing water/cement ratio will result in a higher and more continuous porosity, and consequently internal reaction will be accelerated, the rate of alkali discharge will increase and water will penetrate more easily.

Irregular aggregate was used with a nominal size of 20mm. The aggregate/cement ratio was determined by using Figure 5.4 below. It was also assumed that the mix should have a high degree of workability and a grading curve of 3, which for irregular aggregate is the highest number for the aggregate/cement ratio 3.2.

20 mm aggregate

Aggregate/cement ratio by weight

Degree of workability slump (mm)	Rounded gravel 'Medium' 25–50				Rounded gravel 'High' 50–120			
Grading no. (Figure 3.3)	1	2	3	4	1	2	3	4
Total water/cement ratio by weight 0.40	4.2	4.2	3.9	3.6	3.7	3.8	3.6	3.3
0.45	5.3	5.3	5.0	4.6	4.6	4.8	4.5	4.1
0.50	6.3	6.3	6.0	5.5	5.5	5.7	5.4	4.8
0.55	7.3	7.3	7.0	6.3	6.3	6.5	6.1	5.5
0.60			8.0	7.1	S	7.2	6.8	6.1
0.65				7.8		7.7	7.4	6.6
0.70							7.9	7.1
0.75								7.6
0.80								

Degree of workability slump (mm)	Irregular gravel 'Medium' 25–50				Irregular gravel 'High' 50–120			
Grading no. (Figure 3.3)	1	2	3	4	1	2	3	4
Total water/cement ratio by weight 0.40	3.3	3.4	3.4	3.2	3.1	3.2	3.2	2.9
0.45	4.0	4.1	4.1	3.9	S	3.8	3.8	3.5
0.50	4.6	4.8	4.8	4.5		4.4	4.4	4.1
0.55	S	5.4	5.3	5.1		4.9	4.9	4.7
0.60		6.0	5.9	5.6		S	5.4	5.2
0.65		S	6.4	6.1			5.8	5.7
0.70			6.8	6.6			6.2	6.1
0.75			7.2	7.0			6.6	6.5
0.80			7.5	7.4			S	7.0

Degree of workability slump (mm)	Crushed rock 'Medium' 25–50				Crushed rock 'High' 50–120			
Grading no. (Figure 3.3)	1	2	3	4	1	2	3	4
Total water/cement ratio by weight 0.40								
0.45	3.7	3.7	3.4	3.3	3.5	3.5	3.2	3.1
0.50	4.2	4.2	3.9	3.8	S	3.9	3.8	3.5
0.55	4.7	4.7	4.5	4.3		S	4.3	4.0
0.60	S	5.2	4.9	4.8			4.7	4.5
0.65		5.7	5.4	5.2			5.2	4.9
0.70		6.2	5.8	5.7			5.5	5.3
0.75		S	6.2	6.1			5.8	5.7
0.80			6.6	6.5			6.1	6.0

Figure 5.4 - Aggregate/cement ratio required for 20mm aggregate (USQ 2014)

The aggregate/cement ratio is usually within the range encountered with typical concrete mixes, it is unlikely to have a significant impact on the outcome of the accelerate test unless an aggregate exhibit a noticeable pessimum behaviour.

A slump test is usually performed to measure the workability of the concrete. The slump test was conducted for concrete at measurement of between 50mm and 100mm as recommended for beams and columns according to the British method.

Figure 5.5 - Slump Test

The slump test for the samples that was used for a compressive test was 70 mm as showing Figure 5.5. The slump for the indirect tensile test was 80 mm. The reason for this variance was due to different casting day.

The design mix proportions were:

- Cement =1
- Water =0.4
- Aggregate = 3.2 (irregular and 20mm nominal size)

Grading curve 3 – 20mm =28%

– 10mm = 38%

– Sand = 34%

Consequently, the proportions by weight using 10kg bags of cement:

Cement =1 x 10 = 10 kg

Water =0.4 x10 = 4 kg

Aggregate – 20mm = 3.2 x 0.28 x10 = 8.96 kg

– 10mm = 3.2 x 0.38 x10 = 12.16 kg

– Sand = 3.2 x 0.34 x10 = 10.88 kg

This mixture gave a very dry paste, with a slump of 180mm. More water had to be added to the mixture components of the mix had to be increased.

Cement =1.75 kg

Water =0.70 kg

Aggregate – 20mm = 1.57 kg

– 10mm = 2.13 kg

– Sand = 1.90 kg

This mixture gave a slump of 80mm, acceptable for the testing purpose. Figure 5.6 below shows the specimens after were taken from the mould.

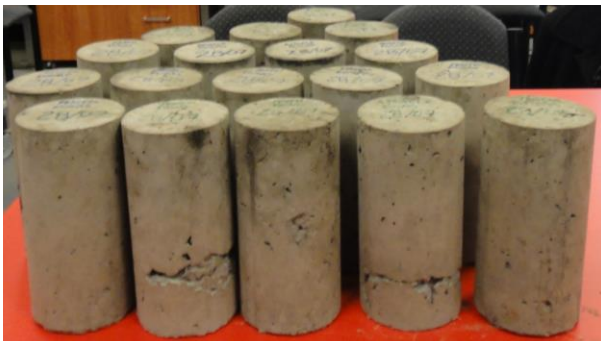

Figure 5.6 - Specimen after takign out of the mould

The figure illustrates defected samples. Some of the defects were left for normal curing and some were placed in a plastic container with NaOH and water mixture. The defected samples were tested, however if they had significant variance from standard samples, the results were not included.

There were a total of six plastic containers used; specifically, three 10L and three 20L containers. Into the small containers was placed one specimen and in the large container were placed two samples. In the small container, 7 L of water and 280 grams of NaOH were added, and in the large container, 14 L of water and 560 grams of NaOH were added.

The test procedure had taken the average indirect tensile strength of 3 samples to determine how to minimise the negative effect and poor results caused by the defected specimens.

The larger containers could not hold two specimens and 14 litres of water and NaOH mixture. The containers had cracked at the bottom in the centre; the specimens had to be re-located in 10 litres containers.

Leakage was cleaned as instructed at the Material Safety Data Sheet (MSDS).

5.2 Indirect Tensile Strength Test Procedures

The specimens were left for 24 hours in the moisture room to cure. Afterwards, the specimens were removed from the moulds. Nine samples were left in the moisture room for usual curing and nine were placed in plastic containers, submerged in water for 24 hours and another 24 hours submerged in a mix of water and NaOH, following the ASTM C1260 processes.

The amount of NaOH was proportional what is described in ASTM C1260, specifically: for a 1.57L per cylinder, has 40g NaOH for every 1000 ml of water.

Indirect tensile tests were conducted at 28 days, 7 weeks (49 days) and 12 weeks (77 days).

There were six samples tested. This included three damaged samples and three regular samples. The results were recorded and the average of 3 damaged samples and the average of 3 standard samples was calculated including visual analysis of the cracks and measurement of the crack length and width. The same release agent (USQ release oil) was the same used in the first batch when testing ASTM C1260. As stated by Lindgard et al. (2011) aggregate grading has influence on ASR reaction, they affirm that large aggregates tend to take long time to expand than fine aggregates in early ages. However it will increase continuously at later stages. Coarse aggregates need more prolonged exposure than finer aggregates, yet are more harmful to the structure than fine aggregates.

The lengthwise expansion of the cylinder was not monitored since the laboratory did not have the necessary equipment. Another modification from previous batches was that engineering studs or screws were not inserted in the concrete cylinders.

The indirect tensile test was conducted following the AS1012.10 Australian Standard using the 3 damaged and 3 normal curing specimens at 28 days after casting.

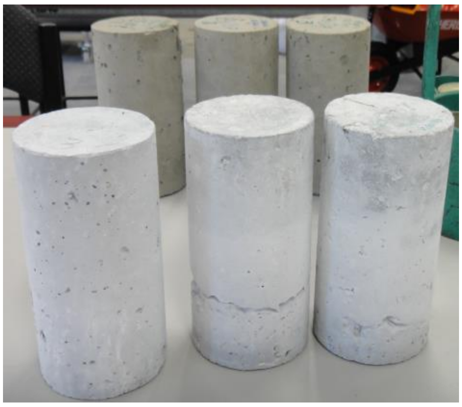

Figure 5.7 -Cylinders ready for tensile strength testing

First, the weight of the cylinder in grams (g) was measured, which later was converted to kilograms for calculating the density of the concrete cylinder. This was done using Equation 5-2 below. The results are shown on Appendix F – Indirect Tensile Test Results.

$$Density\ (kg/m^3) = \frac{\text{Weight (kg)}}{\pi R^2 L} \qquad \text{Equation 5-2}$$

There was no significant variance between the normal and damaged samples densities. However, the damaged samples resisted 5.4 kN less than the normal cured samples when the load was applied.

Second, the dimensions of the specimens were measured. They were slid into the extensometer machine to measure the diameter and the length of each specimen after 28 days of curing. Cylinders were slid against the fixed feeler and swung around until they pressed against the feeler attached to the measuring gauge. The diameter of the samples according to the Australian Standard was measured at least the nearest 0.2 mm at right angles to each other (nearest to the centre of the length of the specimen). Therefore, the averages of these two diameters were calculated and this was used in the indirect tensile strength equation.

The length measurement followed the same procedure. However, it did not have as much variance as compared to the diameter measurement.

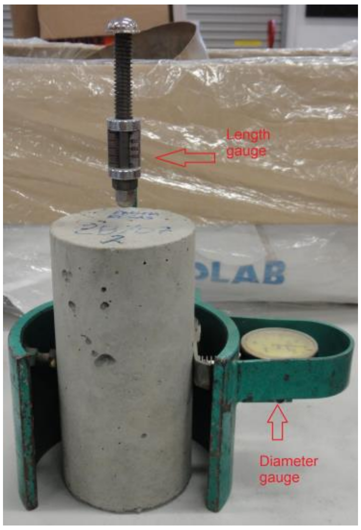

Figure 5.8-Cylinder diamensions measurement

Two bearing strips are needed according to As1012.10. In this case it was two strips of timber (295 mm x 85 mm x 10 mm). The force is applied without shock, with increased continuously at a constant rate of 1.5 ± 0.15 MPa/minute. Indirect tensile stresses were applied until no increase in force can be applied. The figure below shows the specimen after maximum load was applied. Figure 5.10 shows the specimen after taken from the machine. On the left hand side is the normal specimen and on the right is the NaOH damaged specimen. The porous nature of the sample affected by the chemical was noticeable.

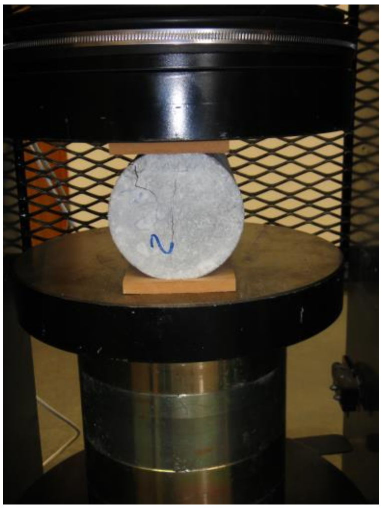

Figure 5.9 – Indirect Tensile Test

Figure 5.10 – Cracked sample after load was applied

The maximum load applied and calculated average of loads were showing on Appendix F – Indirect Tensile Test Results. The average loads of the normal and damaged specimens were 191.3 kN and 185.9 kN, respectively. The damaged samples showed a slight weaker result for maximum load than the normal.

The indirect tensile strength of the specimens was calculated according to Equation 2-2 and the results were:

- Normal cured specimen = 5.97 MPa
- NaOH specimen = 5.84 MPa

At 49 days, another indirect tensile test was conducted. It followed the same procedures as described previously.

The second test result detailed data is also on Appendix F, and on Table 5-2 below shows summary of the average strength results.

- Average failure load for standard samples were: 171.1 kN
- Indirect tensile strength is 5.32 MPa
- Average failure load for damaged samples were: 156.9 kN
- Indirect tensile strength is 4.90 MPa
- The average length of the cracks between all three damaged samples was 15.77 mm.

The first test showed a difference in tensile strength of 0.13MPa. At the second test the difference in tensile strength is slightly greater than the previous test with 0.42 MPa.

Figure 5.11- Beginning of mapping crack at 49 days

The result at 77 days is also on Table 5-2 below.

- Average failure load for standard samples were: 162.8 kN
- Indirect tensile strength is 5.05 MPa
- Average failure load for damaged samples were: 144.0 kN
- Indirect tensile strength is 4.44 MPa
- The average length of the cracks between all three damaged samples was 20.2 mm.
- The samples start to show mapping cracks, which is illustrated on Figure 5.11

Table 5-2 - Indirect tensile strength results

Age	Samples	Strength (MPa)	Average strength (MPa)
28 days	Standard Samples		
	1	5.9960	5.9715
	2	5.9784	
	3	5.9402	
	Damaged Samples		
	1	5.8057	5.8355
	2	5.8402	
	3	5.8605	
49 days	Standard Samples		
	1	5.2593	5.3182
	2	5.3398	
	3	5.3554	
	Damaged Samples		
	1	4.8922	4.9039
	2	4.8466	
	3	4.9730	
77 days	Standard Samples		
	1	5.0610	5.0485
	2	5.0336	
	3	5.0510	
	Damaged Samples		
	1	4.4014	4.4379
	2	4.4958	
	3	4.4165	

The average reduction on tensile strength were:

- At 28 days – 2.2775%
- At 49 days - 7.7902%
- At 77 days – 12.0947%

The decrease of strengths was developing proportionally with the time in the sodium hydroxide. The time between tests was approximately 25 days, and the percentage reduction is approximately 5.0%.

It is observed that based on time exposure in the chemical solution the specimens were getting weaker in strength.

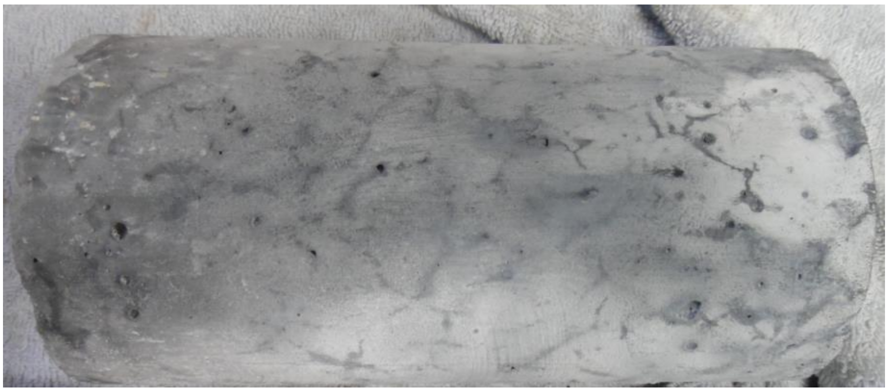

Figure 5.12- Mapping crack at 77 days

The cracks widths were measure at 77 days were 0.5 mmm or smaller (in standard size samples). The relationship between strength and crack width may be more suitable for specimens that were exposed to NaOH for a longer period of time or on damaged structures (field inspections).

The cracks width started thicker around the surface voids and got smaller along the length of the specimen. The widths of the cracks for the small specimens were approximately 1 mm.

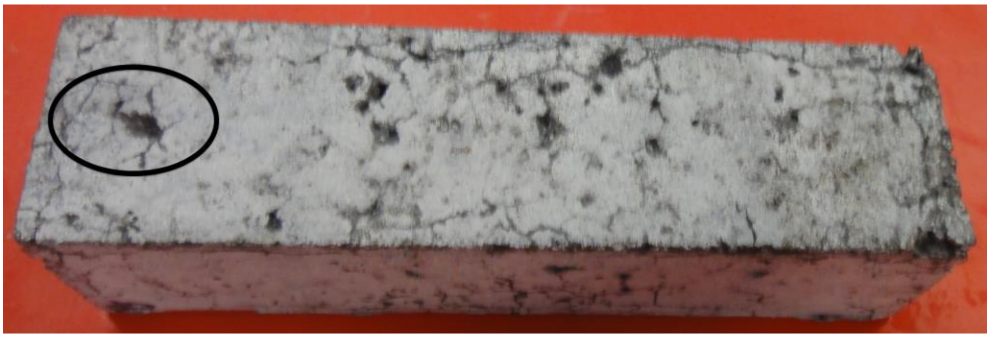

Figure 5.13 - Cracks forming from voids

5.3 Compressive Strength Test

The same measurement procedures were conducted for compressive test. Tracey had conducted the compression test using three specimens that were cured in the moisture room for 28 days. The force applied on the sample was calibrated differently than for indirect tensile test. The force is also applied without shock and increased continuously at a rate of 20 ± 2 MPa/minute until no increase can be sustained. The average result for the compression strength test was 43.159 MPa that is 6.841 MPa smaller than the designed (50 MPa) results are acceptable for further testing and comparison.

Tracey also weighted the cylinder, measure its height and diameter; visually analyse the default cylinde. Analysing the samples demonstrated some of the cylinder presented significant voids (poor compact). These poor data were not included to the average results.

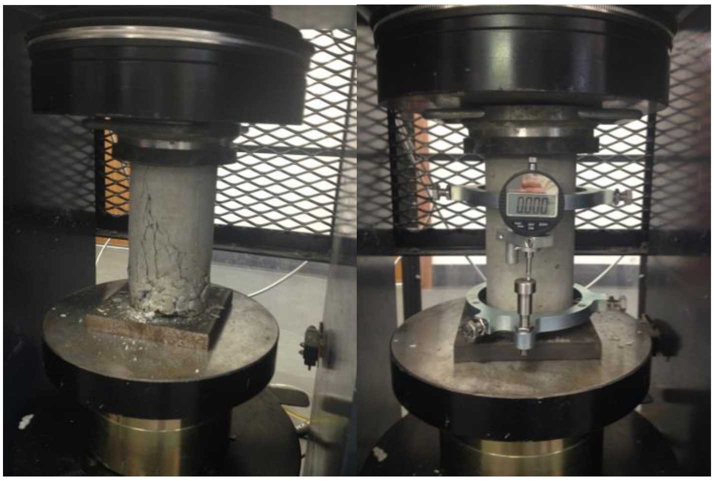

Figure 5.14 - Compressive Strength Test

Picture above shows samples in the compressor machine, The left hand side of the above figure was conducted standard compressive test with the specimens and on the right hand side has dial gauge to measure the change in length of the sample for strain calculation then also determined the cylinders stress and Young’s Modulus of Elasticity.

Table 5-3 Samples Specification

Age	**Sample**	**Dimension (mm)**					**Weight (g)**	**Density (kg/m^3)**	**Load (kN)**
		Diameter		**AVG**	**Radius (m)**	**Height (m)**			
28 days	1	100	100.3	100.15	0.0501	0.2	3.618	2296.36	131
	2	100.1	100.3	100.2	0.0501	0.1995	3.644	2316.17	334
	3	100.2	100.3	100.25	0.0501	0.199	3.674	2338.95	347

Table 5-4 – Compressive Strength Results (Standard Specimens)

Age	Samples	Strength (MPa)	Average strength (MPa)
28 days	**Standard Samples**		
	1- significant voids	16.63	**43.16**
	2	42.36	
	3	43.96	
80 days	**Standard Samples**		
	1 – significant void	13.86	**40.21**
	2	41.28	
	3	39.14	
	Damaged Samples		
	1	39.13	**39.19**
	2	39.25	

To conduct a compressive test on the small specimen, Tracey had cut down the size of the samples from 200 mm x 50 mm to 100 mm x 50 mm.

The sample age was 136 days for the first batch samples and 114 days for the second batch at the time the test was conducted. The load applied for the compressive test was 0.5 kN/s.

The percentage reduction on compressive strength at 80 days was 2.54%, testing standard size samples. Table 5-5 below shows the small samples average result of the compressive test.

Table 5-5 - Compressive Strength Results

Smaller Samples	Strength (MPa)
With ASR (136 days)	25.43
With ASR (114 days)	20.68
Standard (114 days)	39.27

The reduction compressive strength was:

- At 136 days – 35.24% (however standard sample is not from the same batch)
- At 114 days – 47.34%

It is noticeable the size of the samples does not prevent the reaction to happen inside the concrete samples. The results of either size samples show the affected specimens were weaker than standard specimens.

5.4 Flexural Test

Bending test (flexural strength test) is common in brittle materials such as concrete whose failure behaviours are liner. Within the elastic range, brittle materials show a linear relationship of load and deflection where yielding occurs on a thin layer of the specimen surface at the midspan. This leads to cracks initiation, which finally proceeds to sample failure. Ductile material however provides load-deflection curves which deviate from a linear relationship before failure takes place.

Flexural test is a mechanical consideration for a brittle material and is define as a material's ability to resist deformation under load. The flexural strength is also defined as the maximum normal stress in the beam calculated from the ultimate bending moment M_u under the assumption that the beam behaves elastically where beam depth (D) is equal to beam width (b).

The test was conduct in a three point loading machine, where the specimens were simply supported at each end and the load is applied at the mid-span. In the three-point loading the cross section at midspan is subjected to maximum moment.

The size of the specimen had effect on the performance of the test. The flexural strength of the concrete significantly decreased with increasing the size of the beam. The nominal size of the aggregate also influenced the flexural strength; flexural strength is higher for smaller coarse aggregate sizes.

Test procedures necessitates that the load was applied at the centre point of the span, normal to the load surface to the mortar bar. The forces applied to the samples will be vertical only and applied without eccentricity. The direction of the reactions had to be parallel to the direction of the applied load at all times during the test.

The load was applied without shocking and increased continuously at rate equivalent to 1 ± 0.1 MPa.

The laboratory equipment was connected to a computer, which had provided graphics. In Appendix H the graphics (bell curves) are illustrated for all the tested samples. The graph displayed load (kN) against displacement (mm). It showed the initial load through the maximum load (failure load).

To conduct this test, it was assumed that there were approximations when testing concrete beams to failure in which Equation 2-3 was based on statement that the concrete behaves as a liner elastic material throughout the test.

All the samples were approximately (200 x 50 x 50 mm). First batch samples were 155 day old and second batch samples were 132 days old at the time of the test. The span was 180 mm for all the specimens. Figure 5.15 below shows the specimens ready for test.

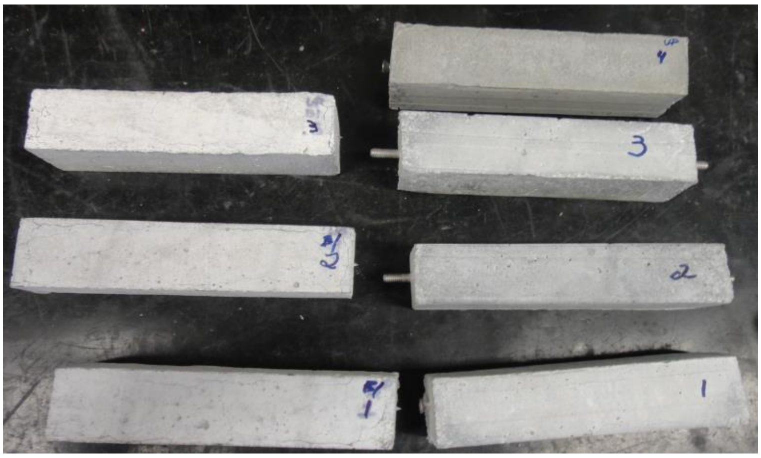

Figure 5.15- Specimens

Brittle material has higher strength in compression than in tension. The material failure under bending is therefore due to the tensile stresses along the surface opposite the load direction.

All the 7 samples tested showed failure as expected at the tensile face of the sample; Figure 5.15 depicts the sample after the failure.

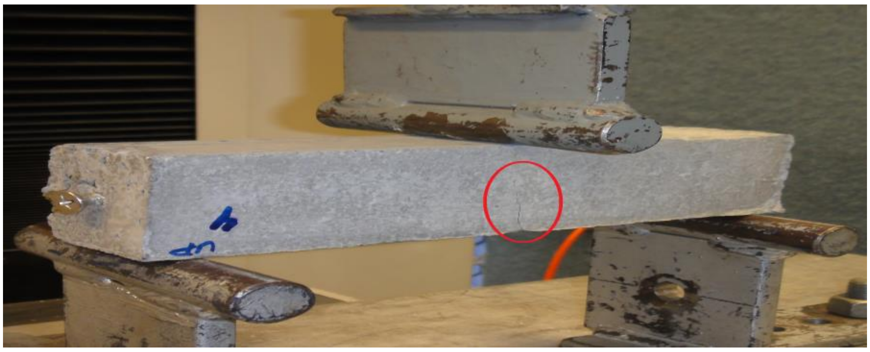

Figure 5.16- Flexural strength test on standard sample

Table below shows the failure loads and the module of rupture of all tested samples. The results showed that the older samples were 0.8251 MPa weaker than the younger samples; and the sample that was not affected by NaOH was stronger (sample 4 = 7.8278 MPa) than all the damaged samples.

As longer the specimens were exposed to ASR; the ability to deform under load decreases. Batch 1samples had an average of 3.76 MPa and Batch 2 samples had an average of 4.58 MPa.

The three-point loading machine was set up to demonstrate the displacement versus load for every specimen tested; the graphics are shown in Appendix H.

Table 5-6 - Flexural Stregngth Results

Batch 1	Failure Load (N)	Displacement (mm)	Modulus of rupture (MPa)	
sample 1	1592	0.337	3.43872	**3.7584**
sample 2	1723	2.084	3.72168	
sample 3	1905	1.68	4.1148	
Batch 2				
sample 1	2223	0.52	4.80168	**4.5835**
sample 2	2172	0.489	4.69152	
sample 3	1971	0.818	4.25736	
sample 4	*3624*	*0.973*	***7.82784***	*Standard*

The loads failures for the first set of specimen were similar with an average of:

- Batch 1 – 1740 N (damaged samples)
- Batch 2 – 2122 N (damaged samples)
  3624 N (standard sample)

The reduction bending was:

- Batch 1 – 52%
- Batch 2 – 41.45%

The crosshead displacement had varied differently; there are substantial changes in crosshead on samples 2 and 3 of the first batch and sample 3 of the second batch.

The cracks depths of all damaged samples were measured after the test. It was found that the average depth of the first batch was 4.4 mm and for the second was 2.9 mm. The crack depths were larger for specimens that were in the chemical solution for longer period of time. An internal deterioration was manifested on all samples. However the ASR reaction on second batch had showed quicker expansion and cracks than the first set of specimens.

Figure 5.17 shows the sample after being submitted to the bending test. The sample had split due to the load. Therefore, the crack depth could be measured and the average depth of each specimen was recorded.

Figure 5.17 - Samples after flexural test

The length of the cracks could not be measure because of the mapping crack appearance, the wide cracks were easy to see, however the fine cracks are not always visible. Fine cracks may be easier to see on a wet concrete surface that is beginning to dry.

Table 5-7 - Crack Depth

Batch 1	***depth***
sample 1	4.86
sample 2	3.84
sample 3	4.485
Batch 2	***depth***
sample 1	2.365
sample 2	3.972
sample 3	2.34

5.5 Chemical Disposal

According to Kohlman (2003), all processes, which include water, have need for pH (potential Hydrogen) measurement. The pH measurement of the hydrogen ion concentration [H+] can range from 0 to 14 pH, where values above 7 pH show basic (alkaline) properties and below 7 pH show acidic properties. The 7 pH is the centre of the measurement scale (either base or an acid) is known as neutral. Pure water has pH near 7.

The pH inside the experimental containers had to be adjusted to balance the chemical formula to neutral pH since it is important to have an accurate measurement for disposal of the chemical into the drainage system.

The solution inside the containers was highly concentrated and had a high temperature. Therefore, the containers were left labelled underneath the benches for 24 hours after the testing to cool down the liquid. Kohlman (2003) also states that temperature affects the pH measurement. Specifically, there is a change in separation constants of the ions in the solution as temperature varies. Consequently, the pH values changes.

The pH of the substance was checked subsequently using a colour indicator strips. They are designed to change colour when exposed to different pH values. The colour of wetted samples strip paper is matched to a colour on colour chat indicator. These strips can be purchased in any local pool shop. Hydrochloric acid (HCl) was the chemical used to balances (neutralise) the chemical formula, was used for safety disposal. Hydrochloric acid is also a highly corrosive as it is commonly used to reduce the pH and total alkalinity in spas and swimming pools.

The alkali content on the solution was found very high as shown in Figure 5.19 below. On the top on the left hand side was the first measurement without adding hydrochloric.

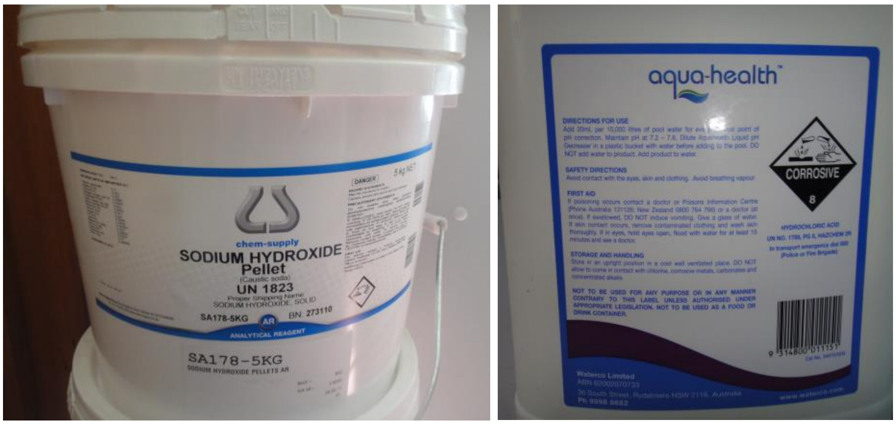

Figure 5.18 - Sodium Hydroxide and Hydrochloric Acid

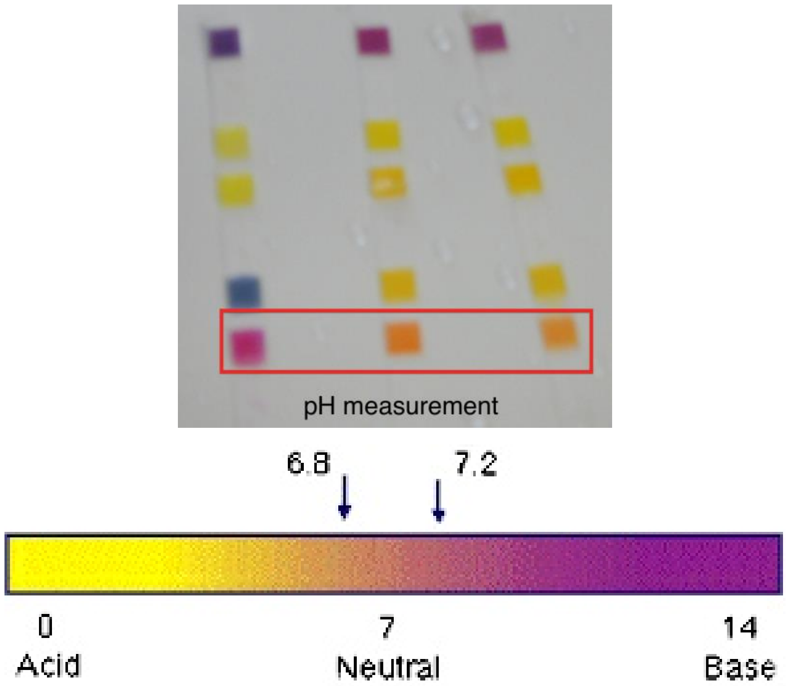

Figure 5.19- pH indicator strips and chart (Altered States -2012)

The pH test procedure:

- A 100 ml of the hydrochloric acid was added into the NaOH and water mixture.
- Measure the pH. There were no significant changes in it.
- Add more acid into the solution, a large amount than the previous.
- Keep monitoring the pH.

- The total amount for the 10L container was 1200 ml. Consequently, for a 20L the amount was doubled (2400 ml), the result is illustrated on Figure 5.19 above.
- The solution was disposed on the sink drain and buckets were rinsed.
- The ratio for the disposal is for 1 L of water and sodium hydroxide it is needed of 0.170 L of hydrochloric acid.

6. Risk Assessment

The main purpose of risk assessment is to eliminate if possible reduce, or control the risks. This project involved some risks during test preparation and execution, especially the people in the laboratory area. For USQ laboratories entry policy entails that enclosed shoes must be worn at all times. Appendix I tables listed down the responsibilities, risks, risk probability, and consequences. The project deals with sodium hydroxide (NaOH), which is considered a class 8 corrosive substance. Another important factor about NaOH powder is when mixed with water, it produces an exothermic reaction, which can be explosive. Exothermic refers to a reaction that releases energy (heat) to the surroundings, translating to an increase in temperature. Further, water and NaOH mix was mixed with room temperature water. A Material Safety Data Sheet (MSDS) was provided from supplier, specifying that NaOH is reactive to hot water. NaOH is also incompatible with ammonium salt, aluminium, tin, and zinc.

All plastic containers are labelled and contact numbers particularly, those that contain sodium hydroxide.

Because of the high risks involved in this project, it is essential to wear Personal Protective Equipment (PPE). Wearing PPE is necessary for measuring and testing specimens that were submerged in hot water and NaOH these equipments include glasses, mask, apron, and gloves. The gloves and apron are heat and NaOH resistant.

Basic personal hygiene is important in the laboratory and polite procedure should be maintained, which includes wash hand before leaving the premises. Food or drink consumption smoking, and no jewellery are not allowed when dealing with sodium hydroxide, work stations are kept clean and organised at all times. It is also essential to return any borrowed material to its place; clean and store used material; and turn off any equipment after use.

There are some procedures to be undertaken immediately after an incident occurs, which will avoid severe injury or minimise their consequences, such as:

Table 6-1- NaOH immediately injury procedures

Injury type	First aid measures
Ingestion	Rinse mouth carefully with potable water. Do not induce vomiting. If occurs, give the victim water. Seek immediate medical assistance.
Skin	Wash affected area with water in abundance. Remove contaminated clothing, and cover skin with an emollient. (According to MSDS of NaOH)
Eye	Immediately wash with plenty of water for at least 15 minutes (According to MSDS of NaOH). Eyelid need to be held open. Seek immediate medical assistance.
Inhalation	Bring victim to fresh air. Seek urgent medical assistance.

Fire measures for the NaOH:

- May liberate toxic fumes
- Extinguishing media
- For small fire, it is recommended to use dry chemical, Carbon Dioxide (CO2) or water spray
- For large fire, it is recommended to use water spray, fog or foam (do not use water jet)

Besides the Sodium Hydroxide, Hydrochloric acid (HCl) was used to balance the chemical reaction inside the plastic containers. HCl is a very hazardous, in case of skin and eye contact (corrosive and irritant), and slightly hazardous when inhaled (lung sensitizer). However, it is non-corrosive for lungs.

HCl in liquid or spray mist may damage tissues particularly of the mucous membrane of eye, mouth and respiratory tract. Material Safety Data Sheet for this chemical affirms that severe over exposure can result to death.

Hazard identification symptoms:

- Sink contact: skin burns.
- Eyes contact: redness, watering, and itching.
- Inhalation: coughing, chocking, shortness of breath.

First aid measures should be followed the procedure described on Table 6-1.

Fire measures for HCl:

- Extinguishing media
- Fine water spray.
- Normal foam.
- Dry agent (CO_2, dry chemical powder).

7. Managing Affected or New Structures

ASR deteriorates the mechanism of concrete. However, there are methods and repair techniques to minimize the reaction and/ or the internal deterioration. For existing ASR damaged on structures it is relatively difficult to repair. The mitigation procedures enable to minimize or even avoid moisture penetration into the concrete, this can be done by using sealants (spray lithium compound), waterproof membrane and electrochemical (detect reinforcement corrosion). The severity of the structure damaged will determine the adequate method.

There is no practical method of stopping alkali silicate reaction once it has commenced, the aim of most methods is to improve appearance and/or maintain serviceability of the structure.

The main prevention or mitigation for deterioration of new structures caused by ASR can be achieved by:

- Limiting the moisture by using mineral admixtures, in addition, it is another suitable solution applied as a protective coating to concrete.
- Selecting non-reactive aggregate.
- Minimizing alkalis: $Na_2O_{equivalent}$ of less than 0.60% and even less than 0.40%
- Mineral admixtures: fly ash, silica fume, ground-granulated slag and calcined clay.
- Chemical admixtures: lithium salts and lithium nitrate ($LiNO_3$).
- Regulare site inspection and maintenance of the structure. Site inspections should start after 3 years use.

There are three factors to be met to initiate and sustain alkali silica reaction in concrete:

- Sufficient concentration of alkali (sodium and potassium) hydroxides in the concrete. (Predominant in Portland cement).
- Sufficient amount of reactive silica aggregate.
- Supply of water (external moisture).

For existing ASR affected structures, the first two requirements are already present, and it is only feasible to attempt to control the water supply. In certain circumstances, it may be possible to introduce lithium into concrete and change the nature of the reaction. Those two methods are solutions that are able to stop or retard the ASR reaction.

Controlling the water penetration on the structure it is necessary a critical assessment of the drainage system. Modifications could be implemented to allow water to drain away from the structure instead of through parts of the structure. Waterproofing membranes or epoxy resin are techniques used to limit water infiltration into the structure.

For existing structures the actions to control ASR is consist:

- Detail assessment of the present condition of the structure
- Determine if ASR is the primary contributor of the deterioration
- Observe visual distress
- Detect moisture penetration
- When is possible, remove the affected concrete and replaced with new concrete that is not susceptible to ASR.

8. Conclusion

Alkali Silica Reaction (ASR) was defined as the cause of concrete internal deterioration for more than 70 years. It is a chemical composition in between the main components of concrete (water, cement and aggregate). The deterioration compromises the mechanical properties of the concrete: compressive, tensile and flexural strengths. It is a reaction between cement and aggregate it is not related to the steel, the reaction would happen whether or not steel was present in the structure.

There are three requirements to be met to initiate and sustain alkali silica reaction in concrete:

- A sufficient concentration of alkali (sodium and potassium) hydroxides in the concrete. (Predominant in Portland cement).
- A sufficient amount of reactive silica aggregate.
- A supply of water (external moisture).

It is important to realise that the concrete structures behave differently from laboratory studies. However, the laboratory studies are not irrelevant. It is needed both types of investigation. It is necessary to have an understanding of material properties and performance; also combine the laboratory and field results to determine the causes of structure damages.

The methodology used for this project was from the American Society for Testing and Materials (ASTM), which certifies that the aggregate from Boral Teven Quarry was reactive. The ASTM C1260 was followed in operating laboratory facilities, as well as provding location accessibility of the equipment, material and resources.

However, the desired percentage expansion of the first concrete batch (200 mm x 50 mm x 50 mm) did not achieve the required result at the expected time. At approximately 60 days the expansion had reached 0.2%.

Reason for the poor results of the first batch could be attributed to the release agent. Also it can be die to the use of stainless steel screws (instead of engineering studs) and the vernier caliper was working properly.

A contingent action was taken to overcome the unexpected expansion failure by having a new batch casted. However, the specimens did not achieve the expected results, having compromised expansions and cracks. As for the second batch, 0.2% expansion was achieved after 70 days.

It was noticed that the longer the time that the specimens were exposed to ASR reaction, the greater was the strength deterioration. The depths of the cracks were also greater than in older samples.

It also was noticed that the expansion was increasing. Consequently, the reaction was present inside concrete samples. And planning tests could be conducted.

Compressive and indirect tensile strengths were conducted on standard specimens (200 mm x 100 mm) at 28 days. The compressive strength was 43.159 MPa, which was slightly lower than the design strength (50 MPa). The average result for tensile strength was a comparison between standard samples (5.97 MPa) and samples submerged in Sodium Hydroxide (5.84 MPa). Both strength tests did not present significant change in strength and did not visual damage cylinders.

The flexural strength was conducted using the small specimens (200 mm x 50 mm x 50 mm). The first batch average was 3.76 MPa and the second batch was 4.58 MPa against standard mortar bar (7.83 MPa).

The crack width and length were monitored during regular measurements. The length was approximately 14mm before the mapping cracks appearance took place. The cracks widths were equal or less than 1mm. Consequently, the desired relationship between crack widths and strength (compressive, tensile and flexural) could not be accomplished.

This project dealt with two different and corrosive chemicals: sodium hydroxide ($NaOH$) and hydrochloric acid (HCl). Personal Protective Equipment (PPE) was essential in the laboratory. Furthermore, the plastic containers with $NaOH$ mixture were labelled to avoid hazard inside the laboratory.

Research about safety handling and hazard was made to ensure the health and safety of people involved in the project, as well as the laboratory facility.

9. Recommendation

The following recommendations are offered for related research project associate to Alkali Silica Reaction.

1. Use the same material used for previous year research project (cement, aggregate and sand).
2. In case using different aggregate; if possible use a qualify laboratory to test ASTM C1260.
3. If possible, measure standard cylinder for change in length regularly.
4. Certify the material is adequate for the experiment.
5. Try to get a relationship between crack and percentage of expansion, if possible.
6. Analyse of efficiency, costs and benefits of mitigation methods.
7. Keep record of the mix design and cement and aggregates properties.
8. Coarse aggregates need more prolonged exposure than finer aggregates, therefore cast standard cylinder as earlier as possible.
9. If possible, conduct cracking index analyse on damaged structures.

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Appendices

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/ENG4112- Research Project

PROJECT SPECIFICATION

FOR: Angela Beatriz Rodrigues ROSAS

TOPIC: Experimental investigation on the Alkali Silica Reaction effect on concrete strength degradation.

SUPERVISORS: Dr Yan Zhuge

Dr Wayne Roberts, Department of Transport and Main Roads

ENROLMENT: ENG4111 –S1, March, 2014

ENG4112 –S2, July, 2014

PROJECT AIM: This project aim to investigate the Alkali Silica Reaction on concrete through casting mortar bars specimens and analyse the development of cracks caused by Alkali Silica Reaction. Crack width will be measured and the results will be compared with the associated with tensile and compressive testing.it is expected that the relationship between the crack width and the structural strength could be related to structural degradation of the field structures.

SPONSORSHIP: Department of Transport and Main Roads

PROGRAMME: Issue A, 07th March 2014

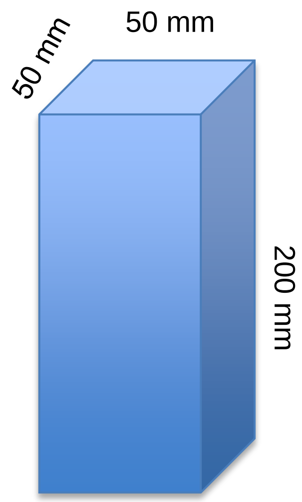
1. Research the background information relating to Alkali Silica Reaction (ASR) on concrete structure.
2. Research on Accelerated Laboratory Testing for ASR using American Society for Testing and Material (ASTM1260).
3. Sample mixing and curing. It will cast 3 batches with 10 samples in each.
4. Analyse and measure, of samples after curing, cracks width followed by specimen dimension measurement.
5. Evaluate compression strength and tensile strength tests with respect of crack width.

As time permits:

5. Analyse structures damaged by ASR and recommend solutions to minimise the damages.

AGREED: Angela Rosas and Yan Zhuge on 28th of March of 2014

Appendix B – Concrete mixing calculation - bars



Volume of mortar bar

Bar size 200 x 50 x 50 mm each

Converting to meters (0.2 x 0.05 x 0.05 = 0.0005 m^3)

Volume of each is 0.0005 m^3

Volume of 3 bars (3 x 0.0005 = 0.0015 m^3)

Converting to litres – 1 litre is 10^3 m^3 so 1.5 L

Using British method (USQ 2014, p. 213) 40 kg cement bag

If 40 kg cement bag makes 63.6 L of cement, so for 1.5 L is necessary 0.943 kg of cement.

Mix proportions:

Cement 1

Water - 0.47 (by ASTM C1260 water cement ratio)

Aggregate – 2.25 (assumed aggregate with relative density equal or greater than 2.45)

Mix quantities

Cement – 1 x 1.5 = 1.5 kg

Water – 0.47 x 1.5 = 0.705 kg

Aggregate – 2.25 x 1.5 = 3.375 kg

Dividing mass for specific gravity (SG)

Cement – 1.5 / 3.15 = 0.476 L

Water – 0.705 / 1 = 0.705 L

Aggregate – 3.375 / 2.8 = 1.205 L

Adding mass – 0.476 + 0.705 + 1.205 = 2.386 L

Aggregate proportion according to ASTM C1260

Sieve grading retaining

#8 (10%) – 0.338 kg

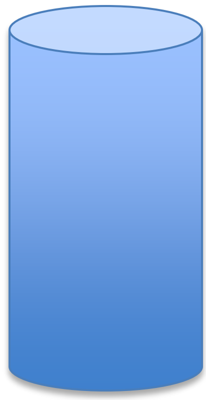
#16 (25%) – 0.844 kg

#30 (25%) – 0. 844 kg

#50 (25%) – 0. 844 kg

#100 (15%) – 0.506 kg

Appendix C – Concrete mixing calculation - cylinder



Volume of cylinder

Bar size 200 x 50 mm each

Converting to meters ($0.2 \times (0.05^2 \times \pi)/4) = 0.000393\ m^3$)

Volume of each is $0.000393\ m^3$

Volume of 3 cylinders ($3 \times 0.000393\ m^3 = 0.00118\ m^3$)

Converting to litres – 1 litre is $10^3\ m^3$ so 1.18 L ≈ 1.2L

Using British method (USQ 2014, p. 213) 40 kg cement bag

If 40 kg cement bag makes 63.6 L of cement, so for 1.2L is necessary 0.755 kg of cement.

Mix proportions:

Cement 1

Water - 0.47 (by ASTM C1260 water cement ratio)

Aggregate – 2.25 (assumed aggregate with relative density equal or greater than 2.45)

Mix quantities

Cement – 1 x 1.2 = 1.2 kg

Water – 0.47 x 1.2 = 0.564 kg

Aggregate – 2.25 x 1.2 = 2.7 kg

Dividing mass for specific gravity (SG)

Cement – 1.2 / 3.15 = 0.381 L

Water – 0.564 / 1 = 0.564 L

Aggregate – 2.7 / 2.8 = 0.964 L

Adding mass – 0.381+ 0.564 + 0.964 = 1.909 L

Aggregate proportion according to ASTM C1260

Sieve grading retaining

#8 (10%) – 0.270 kg

#16 (25%) – 0.675 kg

#30 (25%) – 0. 675 kg

#50 (25%) – 0. 675kg

#100(15%) 0.405kg

Appendix D – Properties and Composition of Cement Portland

Physical test results

Units			%	%	%	%	%
Sample Time	PlantName	SampleCode	LOI	xrfSO3	NaEqTotal	Chloride	NormalConsistency
11/03/14 12:14	Pinkenba	WQP140311-0089	1.2	2.6	0.44		29.2

min	min	mm	m²/kg	% ret	MPa	MPa	MPa
VicatInit	VicatFinal	Expansion	Blaine	Mic45FinenessResidue	MortarStrn3Average	MortarStrn7Average	MortarStrn28Average
105	180		418	4	34.3	46.8	63.5

Chemical tests results

Units			%	%	%	%	%	%	%
Sample Time	ProductType	SampleCode	xrfSiO2	xrfFe2O3	xrfCaO	xrfAl2O3	xrfK2O	xrfNa2O	NaEqTotal
11/03/14 12:14	P30	WQP140311-0089	21.4	3.2	63.7	5.3	**0.57**	**0.06**	0.44

%	%	%	%	%	%	%	%
xrfMgO	xrfSO3	xrfTiO2	xrfP2O5	xrfCr2O3	xrfZnO	xrfMnO	xrfSrO
2.6	2.6	0.25	0.08	0.006	0.012		0.04

Source from Wagners

Appendix E – Cement Sample Characterisation –Raw Data

Sample Time	PlantName	SampleCode	LOI	xrfSO3	NaEqTotal	Chloride	NormalConsistency	VicatInit	VicatFinal	Expansion
11/03/14 12:14	Pinkenba	WQP140311-0089	1.18	2.64	**0.43506**		29.16666667	105	180	

Blaine	Mic45FinenessResidue	MortarStrn3Average	MortarStrn7Average	MortarStrn28Average
418	3.96	34.3	46.8	63.5

Sample Time	PlantName	SampleCode	LOI	xrfSO3	NaEqTotal	Chloride	NormalConsistency	VicatInit	VicatFinal	Expansion
22/03/14 6:13	Pinkenba	WQP140322-0188	1.64	2.53	0.40558					

Blaine	Mic45FinenessResidue	MortarStrn3Average	MortarStrn7Average	MortarStrn28 Average
402	3.06			

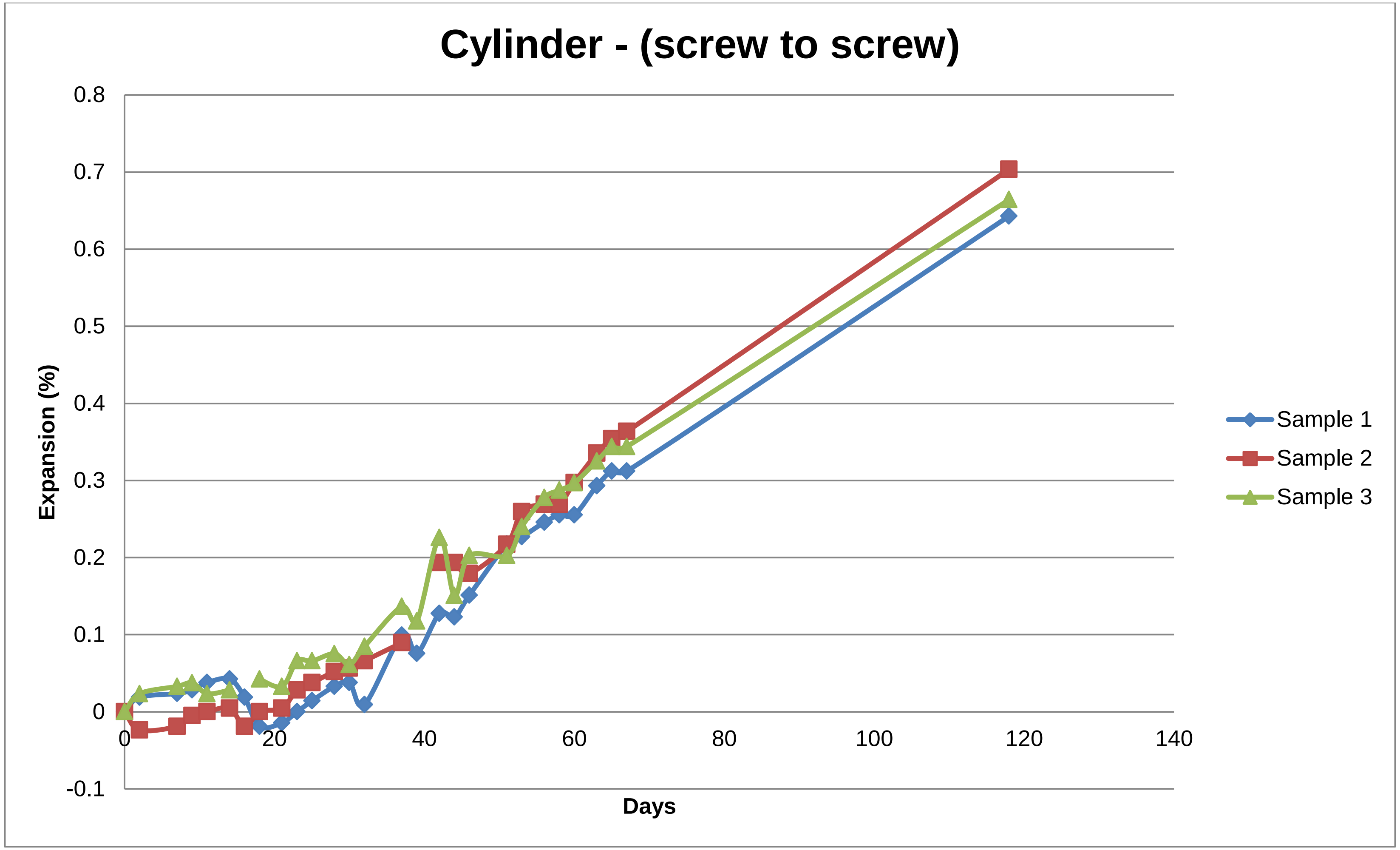
Source from Wagners

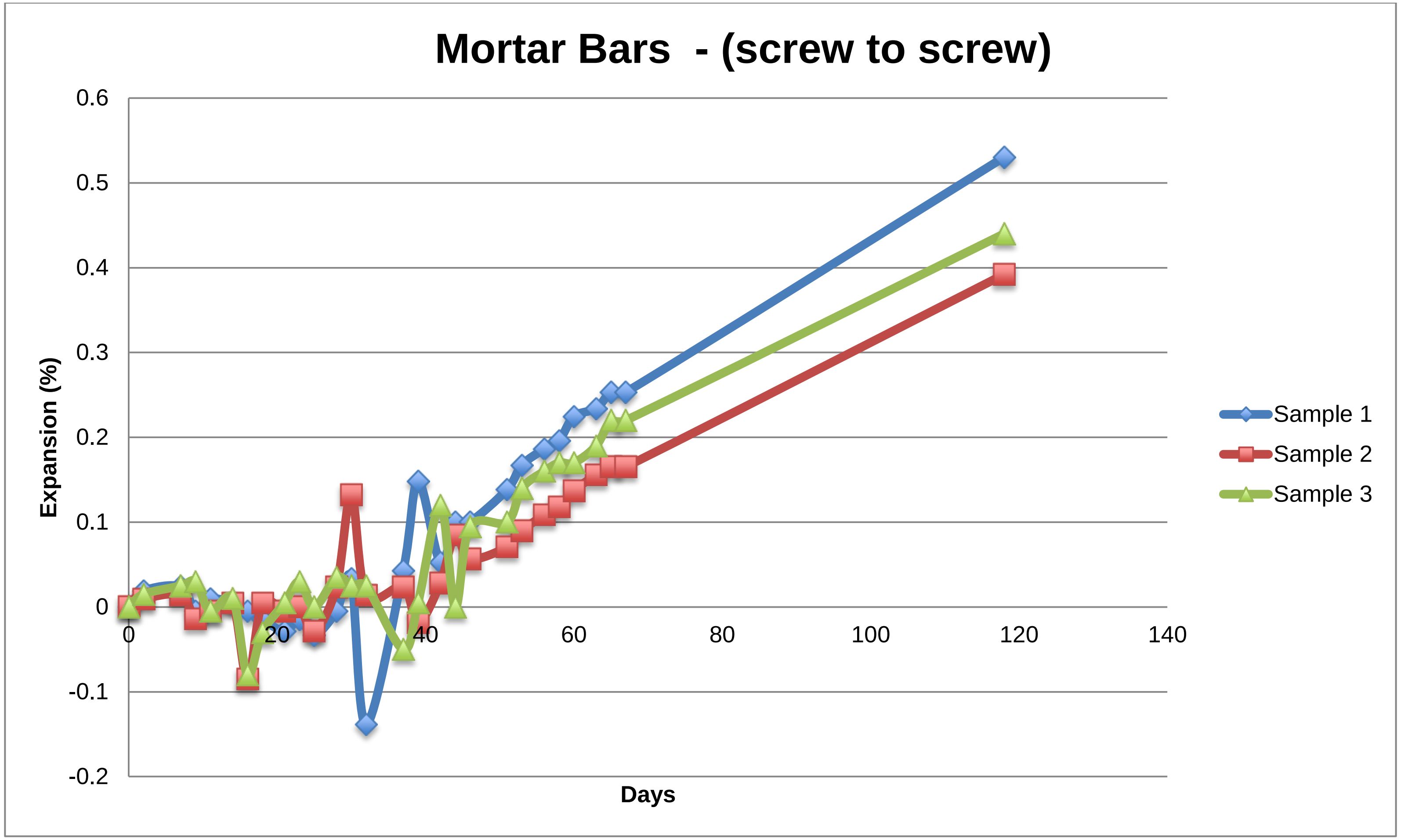
Appendix F – Indirect Tensile Test Results

Age	Standard Samples									
	Samples	Weight (kg)	Dimension (mm)				Density (kg/m^3)	Force (kN)		Force (Mpa)
			Diameter		Average	Height		Failure Load	Average	
28 days	1	3.674	100.3	100.8	100.55	202	2290.518	217.3	**191.3**	**0.1913**
	2	3.677	100.2	100.5	100.35	203	2290.198	193.2		
	3	3.708	100.1	100.9	100.5	204	2291.330	163.4		
49 days	1	3.759	100.8	100.2	100.5	206	2300.293	175	**171.0**	**0.1710**
	2	3.698	100.4	100	100.2	203.5	2304.502	161		
	3	3.718	100.4	100.9	100.65	202	2313.346	177.1		
77 days	1	3.589	101.3	101.5	101.4	202	2200.170	136	**162.8**	**0.1628**
	2	3.689	101.4	101.5	101.45	203	2248.116	181.5		
	3	3.412	101.3	101.9	101.6	202	2083.437	171		

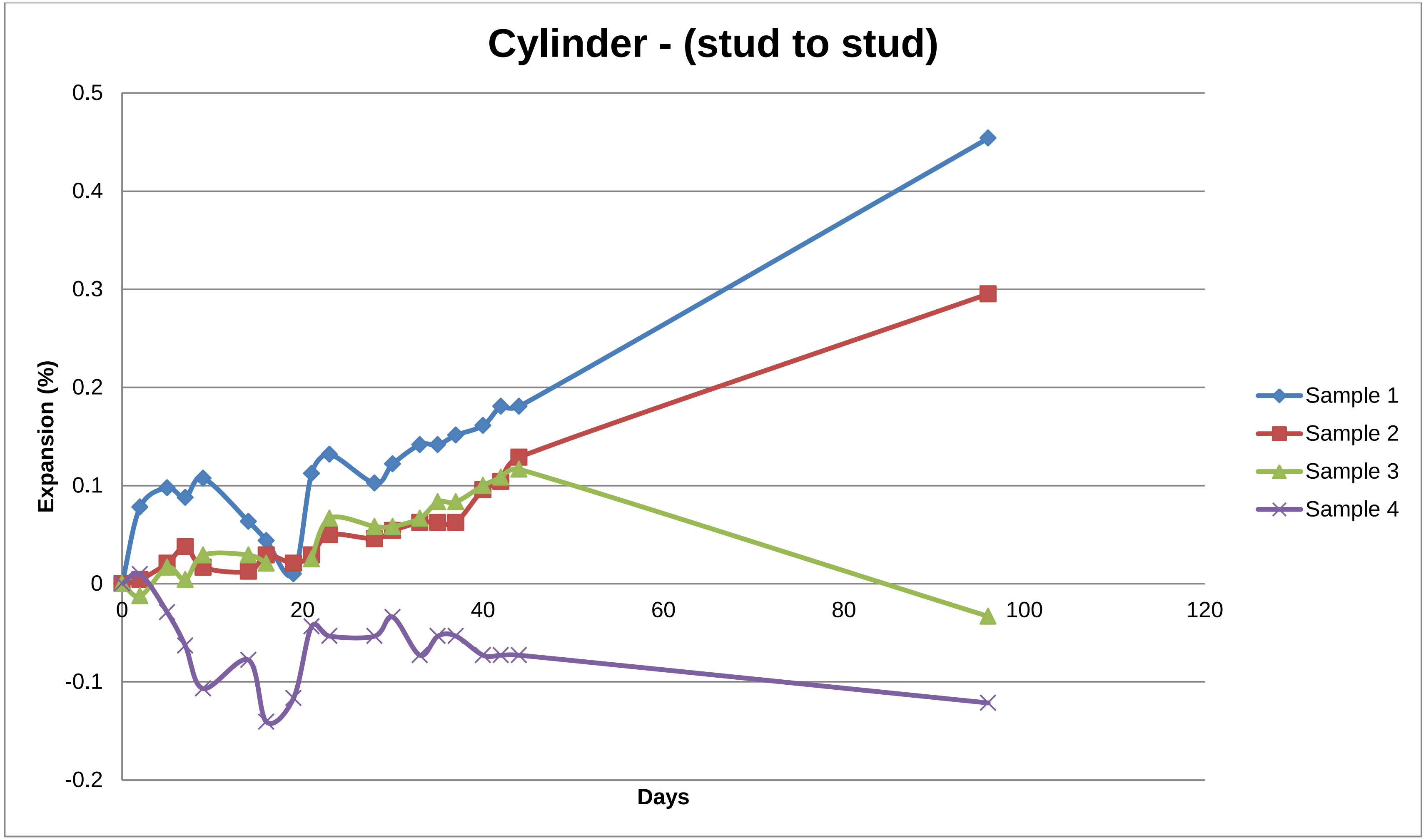
Age	Damaged Samples									
	samples	Weight (kg)	Dimension (mm)				Density (kg/m^3)	Force (kN)		Force (Mpa)
			Diameter		Average	Height		Failure Load	Average	
28 days	1	3.678	100.2	100.6	100.4	203	2288.539	198.3	185.9	0.1859
	2	3.663	100.1	100.5	100.3	202	2295.059	166.1		
	3	3.8	100.2	100.7	100.45	201	2385.601	193.2		
49 days	1	3.694	100.7	100.5	100.6	203	2289.365	142.3	156.9	0.1569
	2	3.776	100.6	101	100.8	204.5	2313.810	164.9		
	3	3.691	100.6	100.3	100.45	200	2328.758	163.6		
77 days	1	3.76	102	101.7	101.85	204.5	2256.745	112.4	144.0	0.1440
	2	3.721	101.5	101.9	101.7	200.5	2284.618	169.9		
	3	3.791	102.2	101.8	102	203.5	2279.813	149.7		

Appendix G – Mortar Bars Expansion Graphics

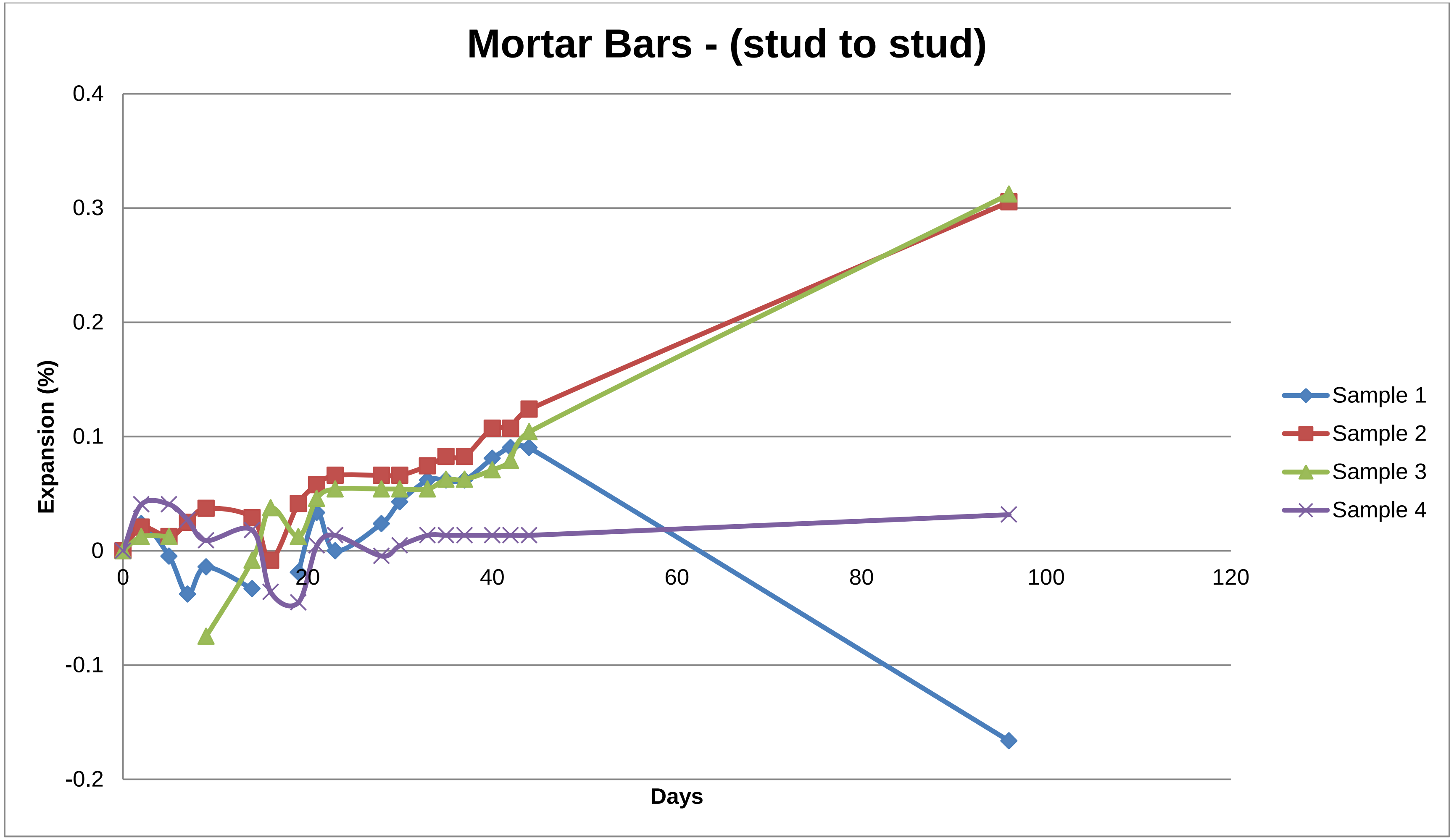


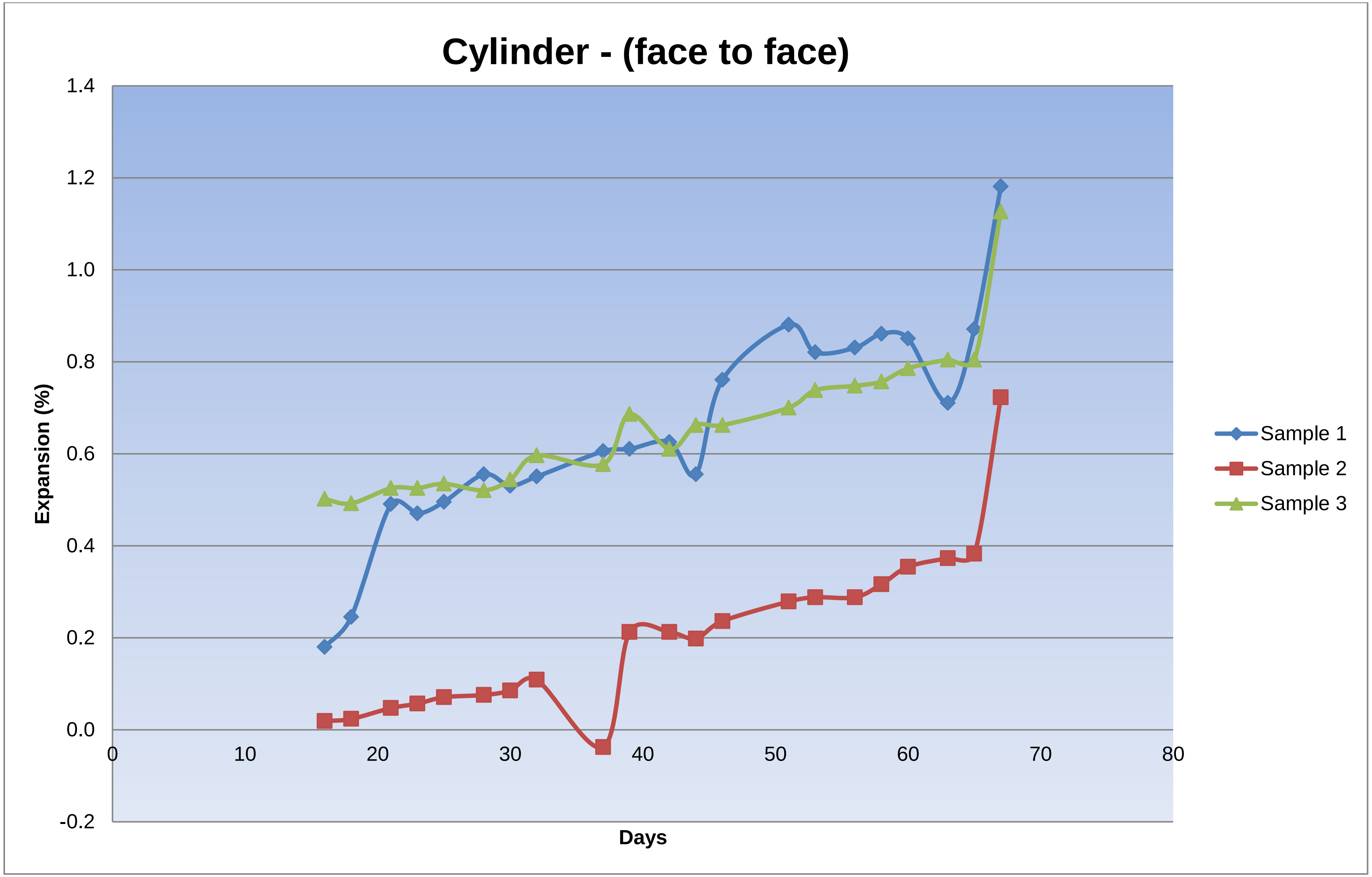


Mortar Bars - (screw to screw)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Expansion (%)
0
20
40
60
80
100
120
140
Days
Sample 1
Sample 2
Sample 3

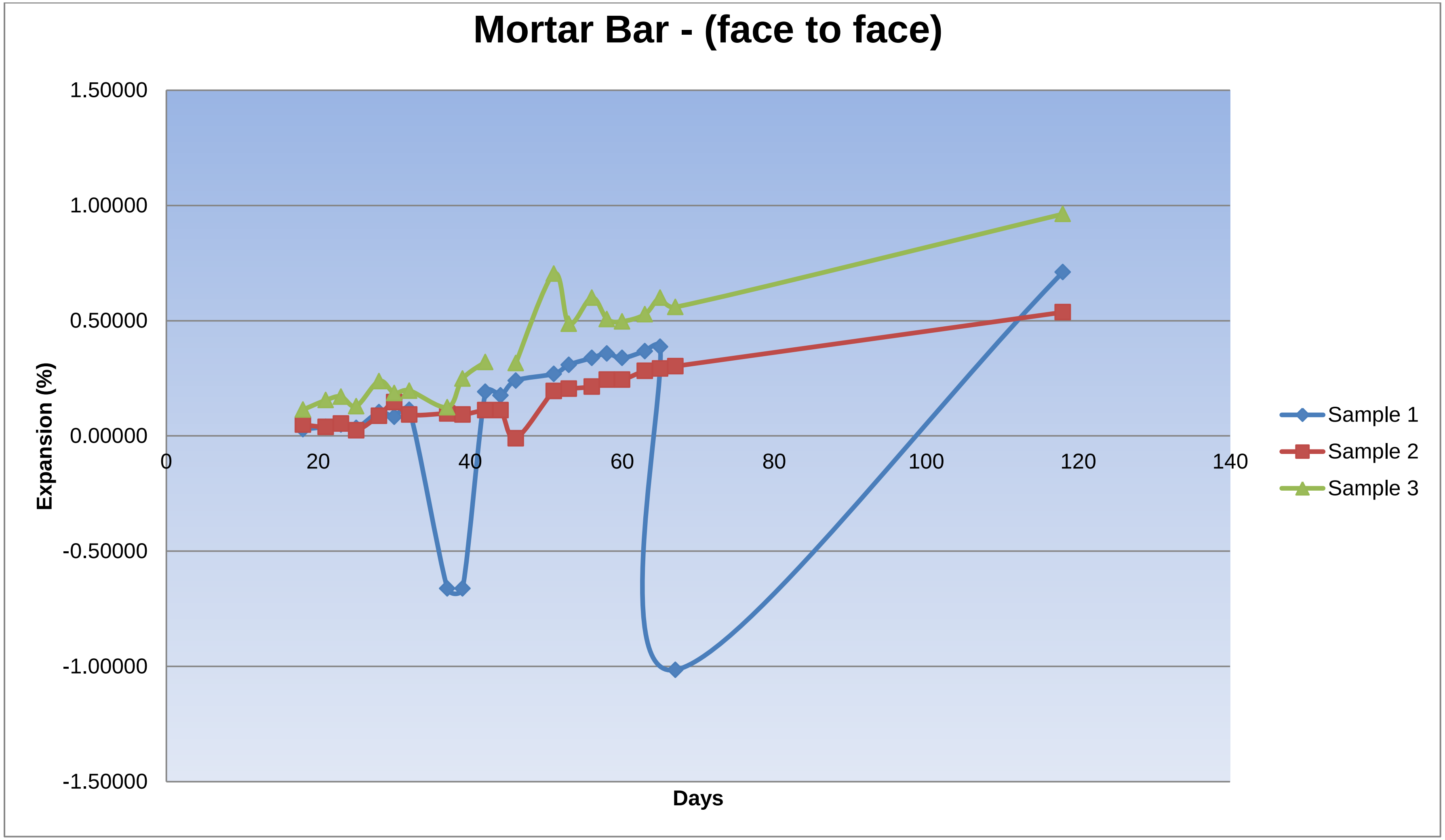


Cylinder - (stud to stud)
Expansion (%)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
20
40
60
80
100
120
Days
Sample 1
Sample 2
Sample 3
Sample 4

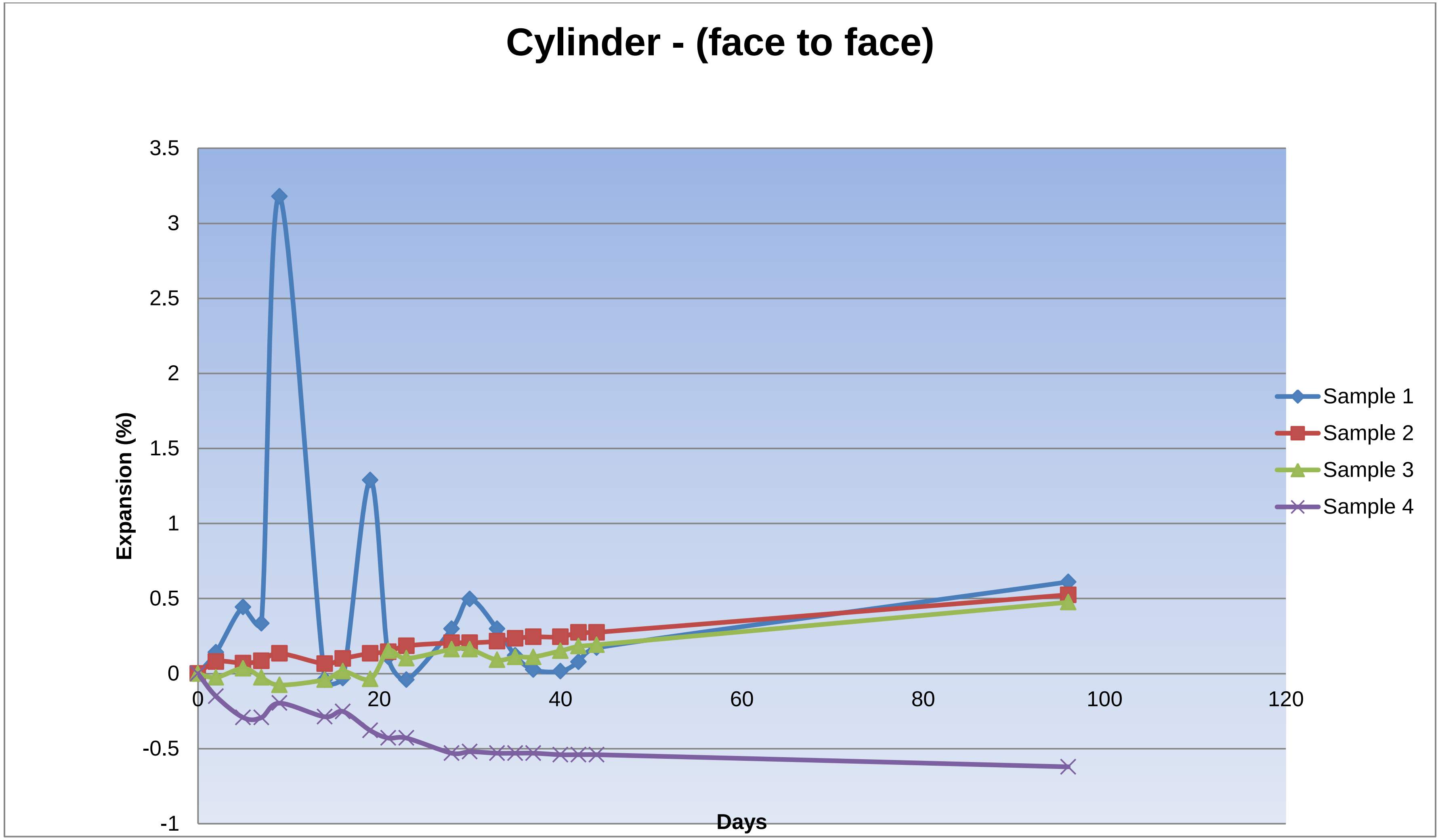

Mortar Bars - (stud to stud)
Expansion (%)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
20
40
60
80
100
120
Days
Sample 1
Sample 2
Sample 3
Sample 4



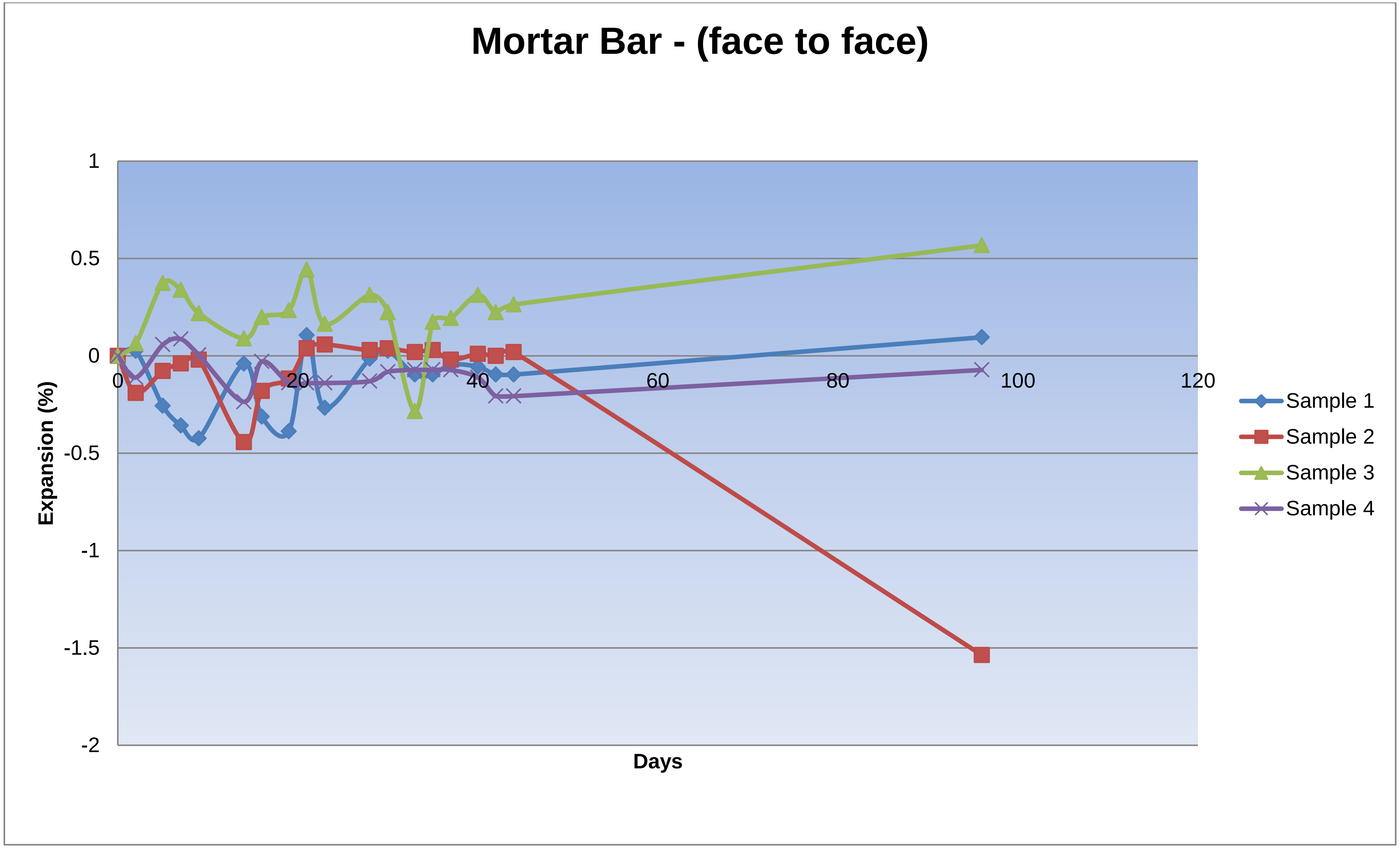
Cylinder - (face to face)
Expansion (%)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
10
20
30
40
50
60
70
80
Days
Sample 1
Sample 2
Sample 3



Mortar Bar - (face to face)
1.50000
1.00000
0.50000
0.00000
-0.50000
-1.00000
-1.50000
Expansion (%)
0
20
40
60
80
100
120
140
Days
Sample 1
Sample 2
Sample 3



Cylinder - (face to face)
Expansion (%)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
20
40
60
80
100
120
Days
Sample 1
Sample 2
Sample 3
Sample 4



Mortar Bar - (face to face)
Expansion (%)
1
0.5
0
-0.5
-1
-1.5
-2
0
20
40
60
80
100
120
Days
Sample 1
Sample 2
Sample 3
Sample 4

Expansion Results for Batch 1 – Screw to screw measurement

Batch 1	**Cylinders (mm)**			**Expansion (%)**			**Average exp (%)**	**Mortar bars (mm)**			**Expansion (%)**			**Average exp (%)**
	1	**2**	**3**	**1**	**2**	**3**		**1**	**2**	**3**	**1**	**2**	**3**	
Days	Screw to screw							Screw to screw			Measured screw to screw			
	211.46	211.94	212.2					209.27	211.52	199.87				
0	211.54	211.79	212.27	0	0	0	0	209.29	211.65	199.96	0	0	0	0
2	211.58	211.74	212.32	0.0189	-0.0236	0.02355	0.00629	209.33	211.67	199.99	0.01911	0.00945	0.01500	0.01452
7	211.59	211.75	212.34	0.0236	-0.0190	0.03298	0.01258	209.34	211.68	200.01	0.02389	0.01417	0.02501	0.02102
9	211.60	211.78	212.35	0.0284	-0.0047	0.03769	0.02044	209.28	211.62	200.02	-0.0048	-0.0142	0.03001	0.00368
11	211.62	211.79	212.32	0.0378	0.00000	0.02355	0.02046	209.31	211.64	199.95	0.00956	-0.0047	-0.0050	-0.00006
14	211.63	211.80	212.33	0.0426	0.00472	0.02827	0.02518	209.30	211.66	199.98	0.00478	0.00472	0.01000	0.00650
16	211.58	211.75	211.30	0.0189	-0.0188	-0.457	-0.15231	209.28	211.47	199.80	-0.0048	-0.0851	-0.0800	-0.05661
18	211.50	211.79	212.36	-0.0189	0.00000	0.04240	0.00783	209.26	211.66	199.90	-0.0143	0.00472	-0.0300	-0.01321
21	211.51	211.80	212.34	-0.0142	0.00472	0.03298	0.00784	209.23	211.64	199.97	-0.0287	-0.0047	0.00500	-0.00946
23	211.54	211.85	212.41	0.00000	0.02833	0.06595	0.03143	209.26	211.65	200.02	-0.0143	0.00000	0.03001	0.00522
25	211.57	211.87	212.41	0.01418	0.03777	0.06595	0.03930	209.22	211.59	198.87	-0.0335	-0.0284	ERROR	-0.02060
28	211.61	211.90	212.43	0.03309	0.05194	0.07538	0.05347	209.28	211.70	200.03	-0.0048	0.02362	0.03501	0.01795
30	211.62	211.91	212.40	0.03782	0.05666	0.06124	0.05191	209.36	211.93	200.01	0.03345	0.13229	0.02501	0.06358
32	211.56	211.93	212.45	0.00945	0.06610	0.08480	0.05345	209.00	211.68	200.01	-0.1386	0.01417	0.02501	-0.03313
37	211.75	211.98	212.56	0.09927	0.08971	0.13662	0.10853	209.38	211.70	199.86	0.04300	0.02362	-0.0500	0.00554
39	211.70	211.67	212.52	0.07564	-0.0567	0.1178	0.04558	209.60	211.61	199.97	0.14812	-0.0189	0.00500	0.04474
42	211.81	212.20	212.75	0.12764	0.19359	0.22613	0.18245	209.40	211.71	200.20	0.05256	0.02835	0.12002	0.06698
44	211.80	212.20	212.59	0.12291	0.19359	0.15075	0.15575	209.50	211.83	195.03	0.10034	0.08505	ERROR	0.06180
46	211.86	212.17	212.70	0.15127	0.17942	0.20257	0.17776	209.50	211.77	200.15	0.10034	0.05670	0.09502	0.08402
51	212.00	212.25	212.70	0.21745	0.21720	0.20257	0.21241	209.58	211.80	200.16	0.13856	0.07087	0.10002	0.10315
53	212.02	212.34	212.78	0.22691	0.25969	0.24026	0.24229	209.64	211.84	200.24	0.16723	0.08977	0.14003	0.13234
56	212.06	212.36	212.86	0.24582	0.26913	0.27795	0.26430	209.68	211.88	200.28	0.18634	0.10867	0.16003	0.15168
58	212.08	212.36	212.88	0.25527	0.26913	0.28737	0.27059	209.70	211.90	200.30	0.19590	0.11812	0.17003	0.16135
60	212.08	212.42	212.90	0.25527	0.29746	0.29679	0.28318	209.76	211.94	200.30	0.22457	0.13702	0.17003	0.17721
63	212.16	212.50	212.96	0.29309	0.33524	0.32506	0.31779	209.78	211.98	200.34	0.23412	0.15592	0.19004	0.19336
65	212.20	212.54	213.00	0.31200	0.35412	0.34390	0.33667	209.82	212.00	200.40	0.25324	0.16537	0.22004	0.21288
67	212.20	212.56	213.00	0.31200	0.36357	0.34390	0.33982	209.82	212.00	200.40	0.25324	0.16537	0.22004	0.21288

Expansion Results for Batch 1 – Face to face measurement

Batch 1	**Cylinders (mm)**			**Expansion (%)**			**Avg exp (%)**	**Mortar bars (mm)**			**Expansion (%)**			**Avg expa (%)**
	1	**2**	**3**	**1**	**2**	**3**		**1**	**2**	**3**	**1**	**2**	**3**	
days	Face to Face			Measured face to face				Screw	Screw	Screw	Measured face to face			
16	199.84	211.75	211.30					203.95	204.9	193.16				
18	200.20	211.79	212.36	0.18014	0.01889	0.50166	0.23356	204.01	205	193.38	0.02942	0.04880	0.11390	0.06404
21	200.33	211.80	212.34	0.24520	0.02361	0.49219	0.25367	204.03	204.98	193.46	0.03923	0.03904	0.15531	0.07786
23	200.82	211.85	212.41	0.49039	0.04723	0.52532	0.35431	204.05	205.01	193.49	0.04903	0.05368	0.17084	0.09119
25	200.78	211.87	212.41	0.47038	0.05667	0.52532	0.35079	204.02	204.95	193.41	0.03432	0.02440	0.12943	0.06272
28	200.83	211.90	212.43	0.49540	0.07084	0.53478	0.36701	204.16	205.08	193.62	0.10297	0.08785	0.23814	0.14299
30	200.95	211.91	212.40	0.55544	0.07556	0.52059	0.38386	204.12	205.2	193.52	0.08335	0.14641	0.18637	0.13871
32	200.9	211.93	212.45	0.53042	0.08501	0.54425	0.38656	204.18	205.09	193.54	0.11277	0.09273	0.19673	0.13408
37	200.94	211.98	212.56	0.55044	0.10862	0.59631	0.41846	202.6	205.10	193.4	-0.6619	0.09761	0.12425	-0.1467
39	201.05	211.67	212.52	0.60548	-0.0378	0.57738	0.38169	202.60	205.09	193.64	-0.6619	0.09273	0.24850	-0.1069
42	201.06	212.20	212.75	0.61049	0.21251	0.68623	0.50308	204.34	205.13	193.78	0.19122	0.11225	0.32098	0.20815
44	201.09	212.20	212.59	0.62550	0.21251	0.61051	0.48284	204.31	205.13	188.63	0.17651	0.11225	-2.3452	-0.6855
46	200.95	212.17	212.70	0.55544	0.19835	0.66257	0.47212	204.44	204.88	193.77	0.24025	-0.0098	0.31580	0.18210
51	201.36	212.25	212.70	0.76061	0.23613	0.66257	0.55310	204.5	205.30	194.52	0.26967	0.19522	0.70408	0.38966
53	201.6	212.34	212.78	0.88070	0.27863	0.70043	0.61992	204.58	205.32	194.1	0.30890	0.20498	0.48664	0.33351
56	201.48	212.36	212.86	0.82066	0.28808	0.73829	0.61567	204.64	205.34	194.32	0.33832	0.21474	0.60054	0.38453
58	201.5	212.36	212.88	0.83066	0.28808	0.74775	0.62216	204.68	205.40	194.14	0.35793	0.24402	0.50735	0.36977
60	201.56	212.42	212.90	0.86069	0.31641	0.75722	0.64477	204.64	205.4	194.12	0.33832	0.24402	0.49700	0.35978
63	201.54	212.50	212.96	0.85068	0.35419	0.78561	0.66349	204.7	205.48	194.18	0.36774	0.28306	0.52806	0.39295
65	201.26	212.54	213.00	0.71057	0.37308	0.80454	0.62940	204.74	205.50	194.32	0.38735	0.29283	0.60054	0.42690
67	201.58	212.56	213.00	0.87070	0.38253	0.80454	0.68592	201.88	205.52	194.24	-1.015	0.30259	0.55912	-0.0511
118	202.20	213.28	213.68	1.18094	0.72255	1.12636	1.00995	205.40	206	195.02	0.71096	0.53685	0.96293	0.73691

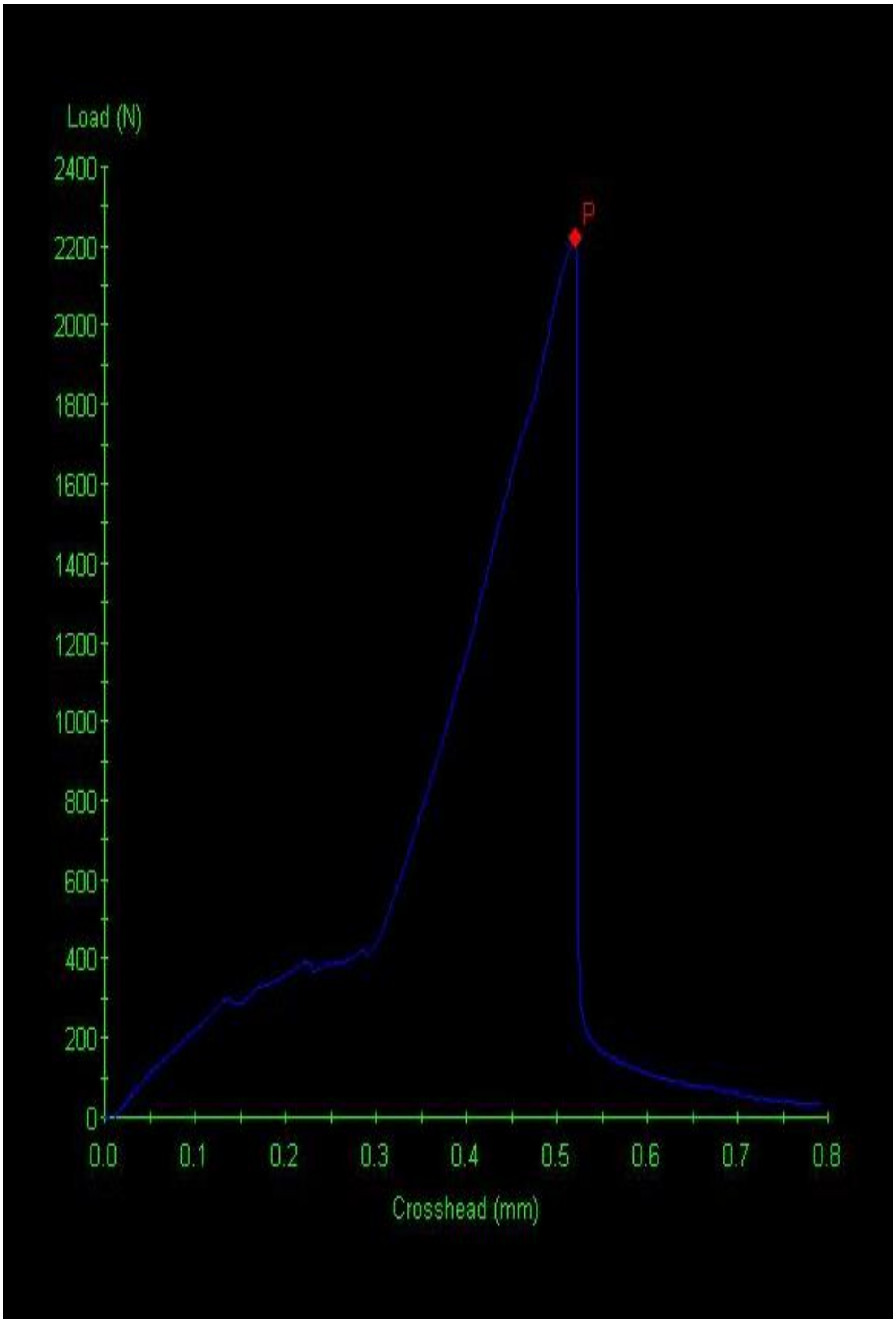
Expansion Results for Batch 2 –Studs to studs measurement

	Cylinders (mm)				Expansion (%)				Avg exp (%)	Mortar bars (mm)				Expansion (%)				Avg exp (%)
	1	2	3	4	1	2	3	4		1	2	3	4	1	2	3	4	
days	Screw	Stud	Stud	screw	Screws to screws					Screw	Stud	Stud	Normal	Screws to screws				
	204.87	240.32	239.89	205.7						210.3	242.2	240.07	221.3	0	0	0		0
0	204.89	240.47	240.08	205.75	0	0	0	0		210.33	242.3	240.23	221.2	0	0	0	0	0
2	205.05	240.48	240.05	205.77	0.07809	0.00416	-0.01250	0.0097	0.02325	210.38	242.4	240.26	221.3	0.02377	0.02064	0.01249	0.04069	0.01897
5	205.09	240.52	240.12	205.69	0.09761	0.02079	0.01666	-0.029	0.04502	210.32	242.3	240.26	221.3	-0.00475	0.01238	0.01249	0.04069	0.00670
7	205.07	240.56	240.09	205.62	0.08785	0.03743	0.00417	-0.063	0.04315	210.25	242.4	293.18	221.2	-0.03804	0.02476		0.02713	
9	205.11	240.51	240.15	205.53	0.10737	0.01663	0.02916	-0.107	0.05106	210.3	242.4	240.05	221.2	-0.01426	0.03714	-0.0749	0.00904	-0.0174
14	205.02	240.50	240.15	205.59	0.06345	0.01248	0.02916	-0.078	0.03503	210.26	242.4	240.21	221.2	-0.03328	0.02889	-0.0083	0.01809	-0.0042
16	204.98	240.54	240.13	205.46	0.04393	0.02911	0.02083	-0.14	0.03129	205.23	242.3	240.32	221.10		-0.00825	0.03746	-0.03	0.00974
19	204.91	240.52	242.5	205.51	0.00976	0.02079		-0.1166	0.01018	210.29	242.4	240.26	221.1	-0.01902	0.04127	0.01249	-0.0452	0.01158
21	205.12	240.54	240.14	205.66	0.11226	0.02911	0.02499	-0.04	0.05545	210.4	242.4	240.34	221.2	0.03328	0.05778	0.04579	0.00452	0.04562
23	205.16	240.59	240.24	205.64	0.13178	0.04990	0.06664	-40.05	0.08277	210.33	242.5	240.36	221.2	0.00000	0.06603	0.05411	0.01356	0.04005
28	205.1	240.58	240.22	205.64	0.10249	0.04574	0.05831	-0.054	0.06885	210.38	242.5	240.36	221.2	0.02377	0.06603	0.05411	-0.0045	0.04797
30	205.14	240.60	240.22	205.68	0.12202	0.05406	0.05831	-0.034	0.07813	210.42	242.46	240.36	221.2	0.04279	0.06603	0.05411	0.00452	0.05431
33	205.18	240.62	240.24	205.60	0.14154	0.06238	0.06664	-0.07	0.09019	210.46	242.5	240.36	221.20	0.06181	0.07429	0.05411	0.01	0.06340
35	205.18	240.62	240.28	205.64	0.14154	0.06238	0.08331	-0.054	0.09574	210.46	242.5	240.38	221.2	0.06181	0.08254	0.06244	0.01356	0.06893
37	205.2	240.62	240.28	205.64	0.15130	0.06238	0.08331	-0.054	0.09899	210.46	242.50	240.38	221.2	0.06181	0.08254	0.06244	0.01356	0.06893
40	205.22	240.7	240.32	205.6	0.16106	0.09565	0.09997	-0.073	0.11889	210.50	242.6	240.4	221.2	0.08083	0.10730	0.07077	0.01356	0.08630
42	205.26	240.72	240.34	205.6	0.18058	0.10396	0.10830	-0.073	0.13095	210.52	242.6	240.42	221.2	0.09033	0.10730	0.07909	0.01356	0.09224
44	205.26	240.78	240.36	205.6	0.18058	0.12891	0.11663	-0.073	0.14204	210.52	242.6	240.48	221.2	0.09033	0.12381	0.10407	0.01356	0.10607
96	205.82	241.18	240.00	205.50	0.45390	0.29526	-0.03332	-0.12	0.23861	209.98	243	240.98	221.24	-0.16641	0.30541	0.31220	0.03	0.15040

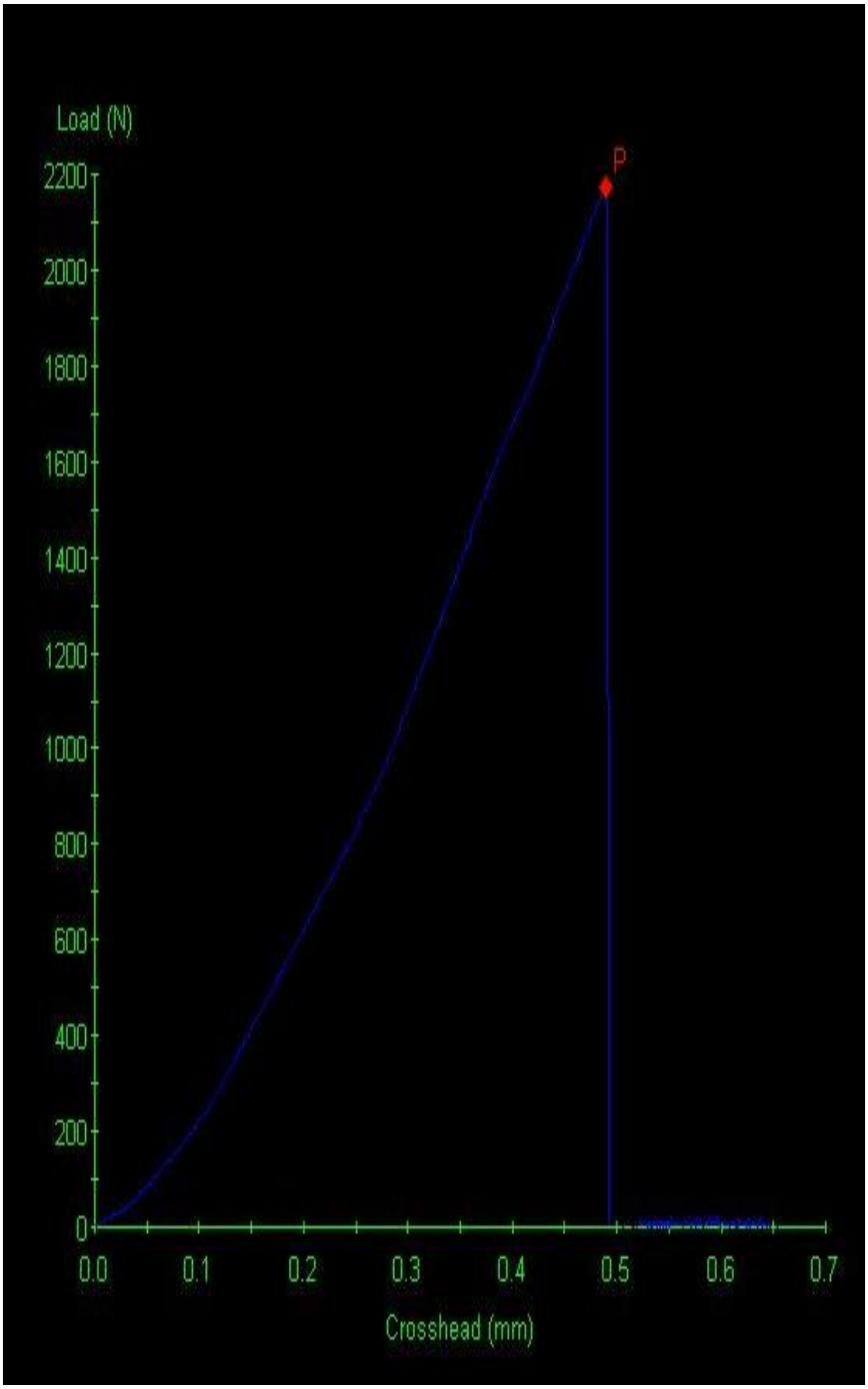
Expansion Results for Batch 2 –Face to face measurement

	Cylinders (mm)				Expansion (%)				Avg exp (%)	Mortar bars (mm)				Expansion (%)				Avg exp (%)
	1	2	3	4	1	2	3	4		1	2	3	4	1	2	3	4	
days	Screw	Stud	Stud	screw	Face to face					Screw	Stud	Stud	Normal	Face to face				
	191.56	199.95	198.04	197.1						197.76	204.87	200.57	208.19	0	0	0		0
0	191.53	200.07	197.72	198.05	0	0	0	0		198.41	205.04	200.75	208.03	0	0	0	0	0
2	191.8	200.23	197.67	197.75	0.14097	0.07997	-0.0253	-0.15	0.06522	198.46	204.65	200.88	207.8	0.02520	-0.19021	0.06476	-0.11056	-0.0334
5	192.38	200.21	197.79	197.47	0.44379	0.06998	0.03540	-0.29	0.18306	197.9	204.88	201.5	208.15	-0.2570	-0.07803	0.37360	0.057684	0.01284
7	192.17	200.24	197.67	197.47	0.33415	0.08497	-0.0253	-0.29	0.13128	197.7	204.96	201.43	208.21	-0.3578	-0.03902	0.33873	0.086526	-0.0194
9	197.62	200.34	197.57	197.66	3.17966	0.13495	-0.0759	-0.2	1.07958	197.57	205	201.19	208.04	-0.4233	-0.01951	0.21918	0.004807	-0.0746
14	191.45	200.20	197.64	197.48	-0.0418	0.06498	-0.0405	-0.28	-0.00575	198.33	204.13	200.93	207.54	-0.0403	-0.44382	0.08966	-0.23554	-0.1315
16	191.47	200.27	197.75	197.55	-0.0313	0.09997	0.01517	-0.25	0.02794	197.79	204.67	201.15	207.97	-0.3124	-0.18045	0.19925	-0.02884	-0.0979
19	194.00	200.34	197.7	197.3	1.28962	0.13495	-0.0354	-0.37	0.46305	197.64	204.8	201.22	207.74	-0.3880	-0.11705	0.23412	-0.1394	-0.0903
21	191.74	200.36	198.02	197.2	0.10964	0.14495	0.15173	-0.42	0.13544	198.62	205.12	201.64	207.74	0.1058	0.03902	0.44334	-0.1394	0.19607
23	191.45	200.44	197.92	197.2	-0.0418	0.18494	0.10115	-0.42	0.08144	197.88	205.16	201.08	207.74	-0.2671	0.05853	0.16438	-0.1394	-0.0147
28	192.1	200.48	198.04	197	0.29760	0.20493	0.16185	-0.53	0.22146	198.38	205.1	201.38	207.76	-0.0151	0.02926	0.31382	-0.12979	0.10932
30	192.48	200.48	198.04	197.02	0.49601	0.20493	0.16185	-0.52	0.28759	198.46	205.12	201.2	207.86	0.02520	0.03902	0.22416	-0.08172	0.09613
33	192.1	200.5	197.90	197	0.29760	0.21492	0.09104	-0.53	0.20119	198.22	205.08	200.18	207.88	-0.0957	0.01951	-0.28394	-0.0721	-0.1201
35	191.76	200.54	197.94	197	0.12009	0.23492	0.11127	-0.53	0.15542	198.22	205.1	201.1	207.88	-0.0957	0.02926	0.17435	-0.0721	0.03595
37	191.58	200.56	197.94	197	0.02611	0.24491	0.11127	-0.53	0.12743	198.32	205	201.14	207.88	-0.0453	-0.01951	0.19427	-0.0721	0.04313
40	191.56	200.56	198.02	196.98	0.01566	0.24491	0.15173	-0.54	0.13744	198.30	205.06	201.38	207.8	-0.0554	0.00975	0.31382	-0.11056	0.08938
42	191.68	200.62	198.08	196.98	0.07832	0.27490	0.18208	-0.54	0.17843	198.22	205.04	201.20	207.6	-0.0957	0.00000	0.22416	-0.2067	0.04280
44	191.86	200.62	198.1	196.98	0.17230	0.27490	0.19219	-0.54	0.21313	198.22	205.08	201.28	207.6	-0.0957	0.01951	0.26401	-0.2067	0.06259
96	192.7	201.12	198.66	196.82	0.61087	0.52482	0.47542	-0.62	0.53704	198.60	201.89	201.89	207.88	0.09576	-1.53629	0.56787	-0.0721	-0.2909

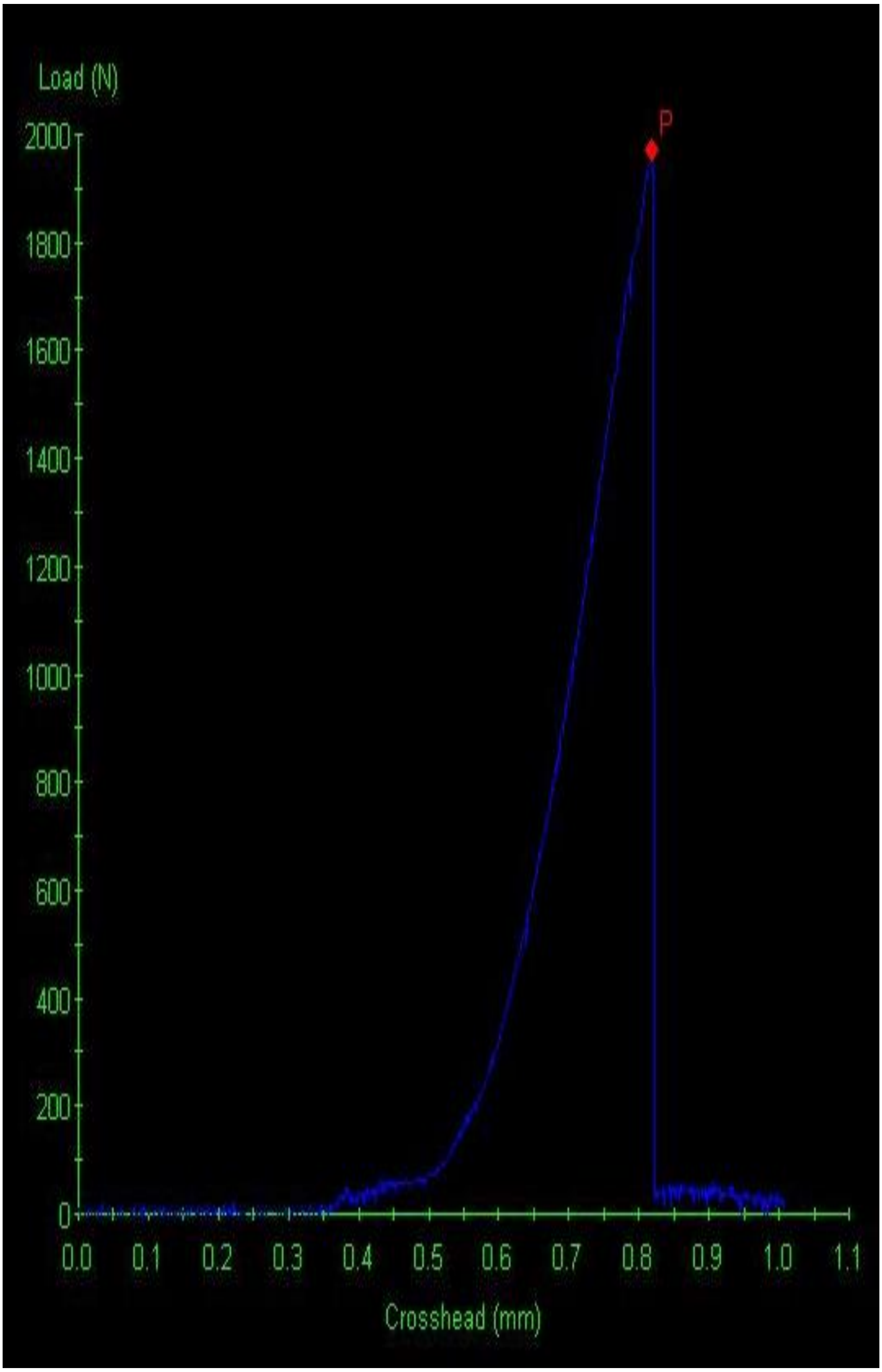
Appendix H – Flexural Strength Test Results



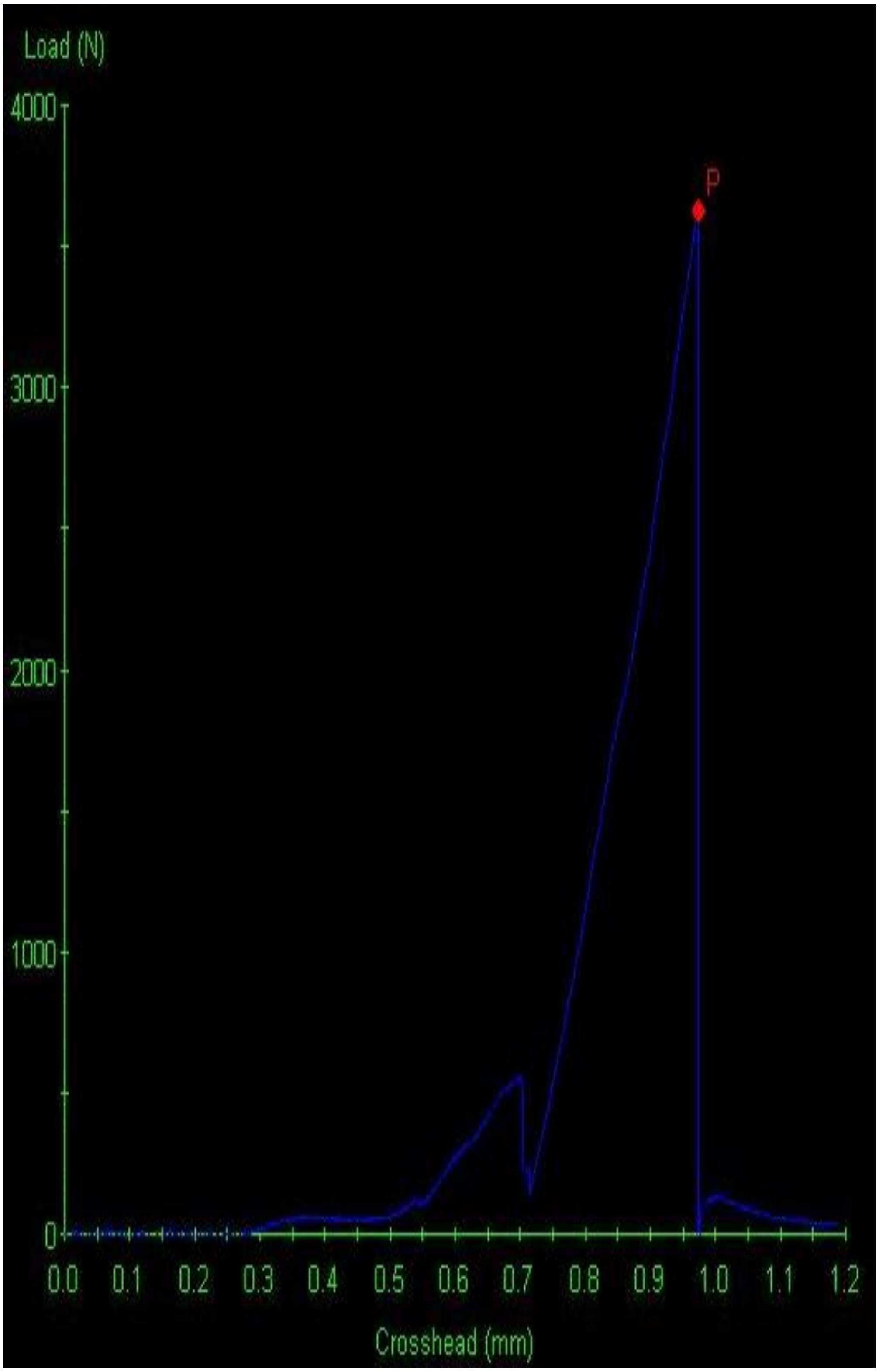
Sample 1 from batch 2 (2223 N, 052 mm)



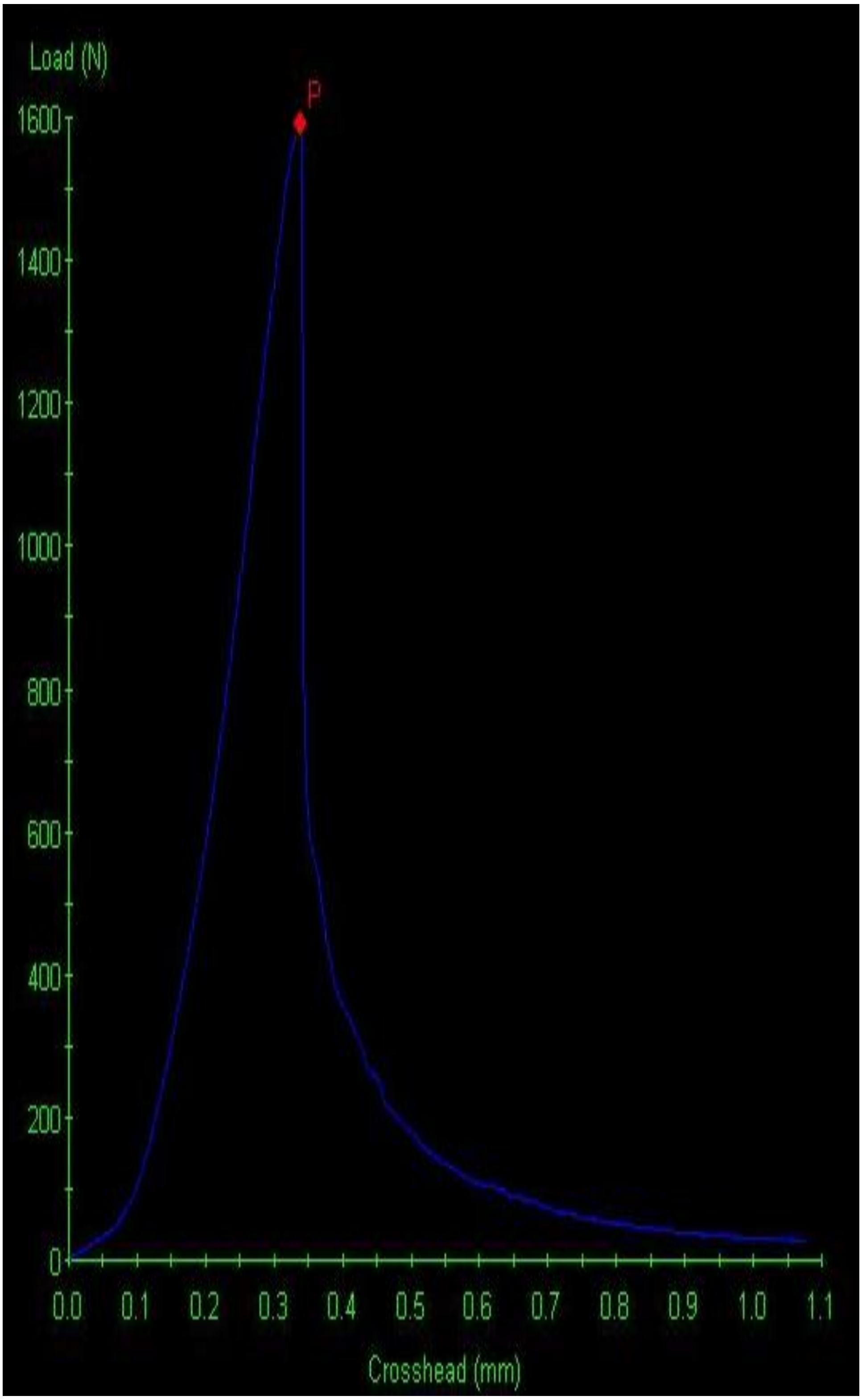
Sample 2 from batch 2 (2172 N, 049 mm)



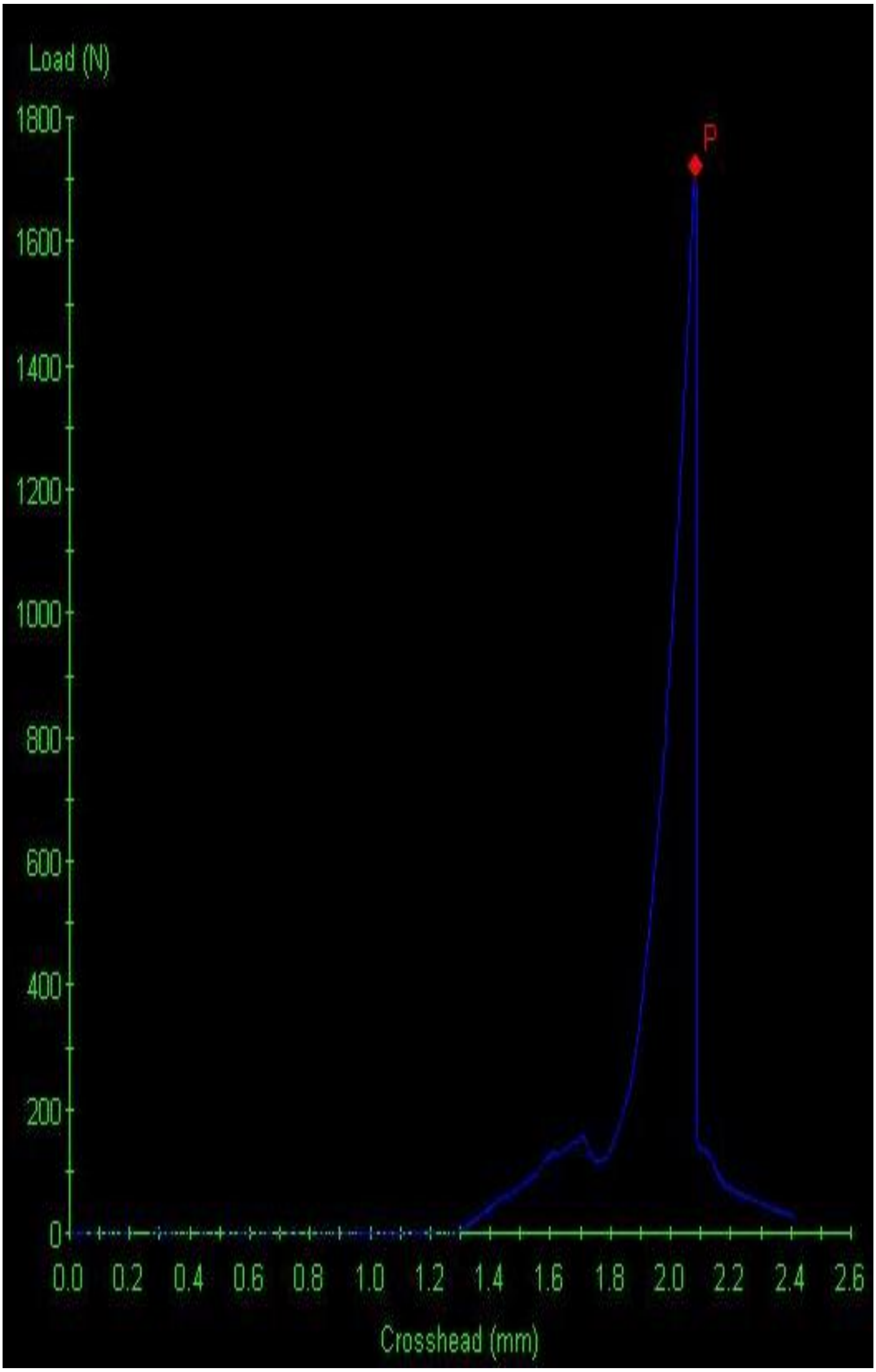
Sample 3 from batch 2 (1971 N, 082 mm)



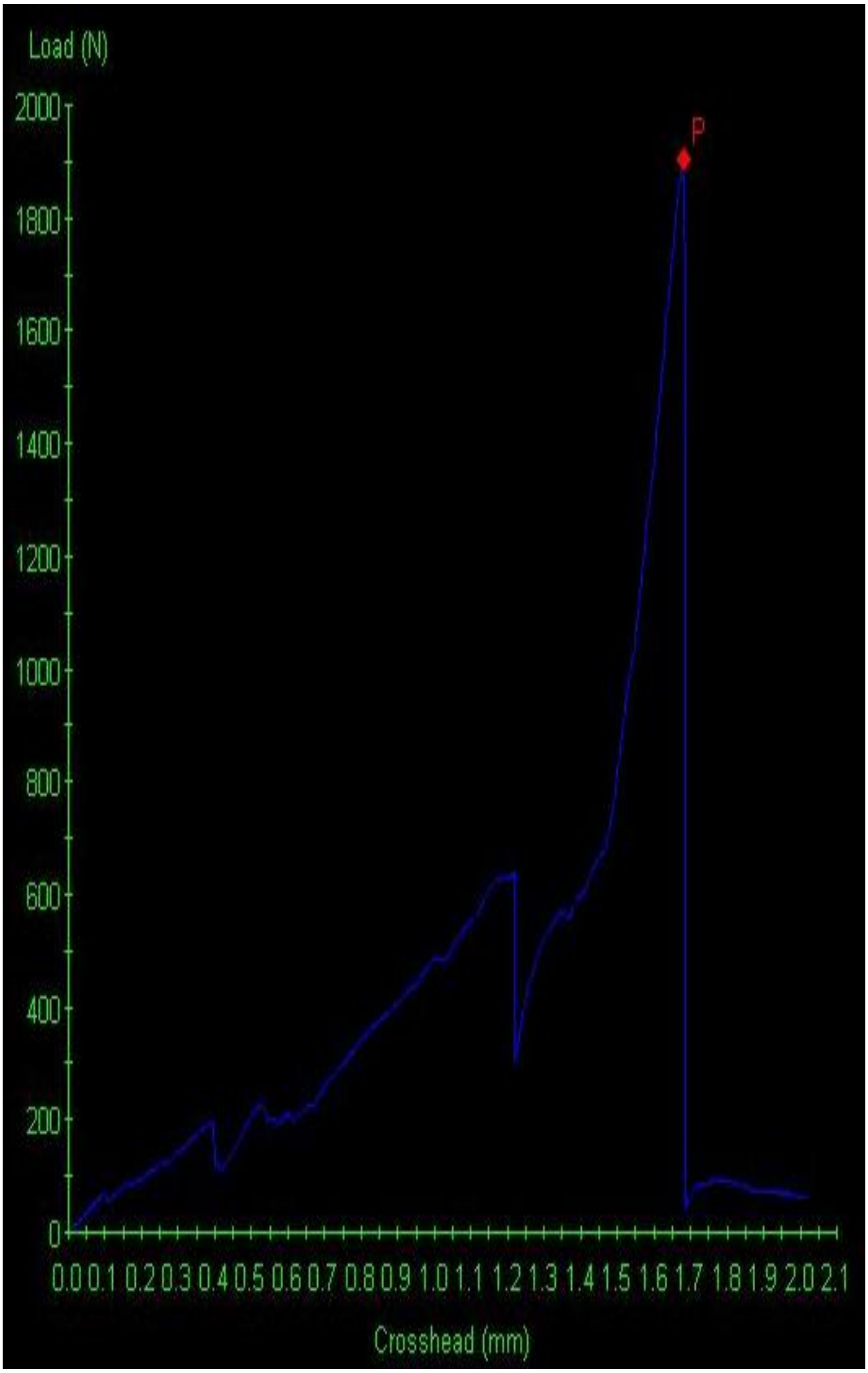
Sample 4 from batch 2 (3624 N, 0.97 mm)



Sample 1 from batch 1 (1592 N, 0.34 mm)



Sample 2 from batch 1 (1723 N, 2.084 mm)



Sample 3 from batch 1 (1905 N, 1.68 mm)

Appendix I – Risk Assessment

University of Southern Queensland

Faculty of Engineering and Surveying

Risk Assessment Plan

Activity Description: To investigate the Alkali Silica Reaction (ASR) on concrete through casting mortar bars, according to mainly American Society for Testing Materials - ASTM1260 that is an accelerate reaction testing, which introduce sodium hydroxide to the experiment. ASTM1260 test potential ASR on aggregates, and after 14 to 16 days expansion it shows visual cracks. They will be related to beams and compare the compressive and tensile strengths.			Date: 01/05/2014
Supervised by: Associate Professor Yan Zhuge	**Sponsored by:** Department of Transport and Main Road - Queensland	**Conducted by:** Angela Rosas Tracey Knight	

Risk Analysis

Activity description	**Hazard/ Risk description**	**Control Measures**
1–Crushing aggregate	Physical injure from aggregate fragments. Dust inhalation and eyes exposure	Ensure that cage is secure. Wear safety glasses, safety boots, safety mask
2-Mixing Concrete	Physical injury from cement mixer.	Wear safety Gloves
3-Mixing Concrete	Skin and eye exposure Cement and fine aggregate powder inhalation.	Wear safety gloves, safety glasses, safety mask, safety boots. Ensure environment ventilation is adequate.
4- Hot water for ASR test	Skin burn, eye burn from the steam	Wear safety gloves resistant to heat, safety glasses
5-Measure specimen	Skin burn	Wear gloves resistant to heat, safety glasses (steam)
6-Preparing sodium hydroxide (NaOH)	Splash/ spill Class 8- Corrosive chemical inhalation.	Wear safety gloves resistant to NaOH, safety glasses, safety mask and safety boots. Be aware of reaction adding water on sodium hydroxide it can explosive. NaOH powder is mixed with water. Ensure the containers are labelled
7-Heat chemical solution with concrete samples	Inhalation and burns	Wear safety gloves resistant to heat and NaOH, safety mask, safety glasses, and safety boot. Be careful with spills.
8- Tests: Compression and Tension	Physical injure from concrete fragments.	Ensure that cage is secure. Wear safety glasses, safety boots.
9- Weight from the buckets	Knees or back injure from lifting 4 litres of water and NaOH. Burn	Bend knees, when picking up from the floor to place in the oven. Ensure stability to avoid burn or lean on oven shelf.

Risk Measures

Activity description	Hazard/ Risk description	Level of Risk		
		Likelihoold	Rating	Consequences
1–Crushing aggregate	Physical injure from aggregate fragments. Dust inhalation and eyes exposure	2	D	L
2 - Mixing Concrete	Physical injury from cement mixer.	2	D	L
3- Mixing Concrete	Skin and eye exposure Cement and fine aggregate powder inhalation.	2	D	L
4- Hot water – for ASR test	Skin burn, eye burn from the steam	2	D	L
5- Measure specimen	Skin burn	2	D	L
6- Preparing sodium hydroxide (NaOH)	Splash/ spill Class 8- Corrosive chemical inhalation.	2	D	L
7- Heat chemical solution with concrete samples	Inhalation and burns	2	D	L
8- Tests: Compression and Tension	Physical injure from concrete fragments.	2	D	L
9- Weight from the buckets	Physical injure	3	C	M

Consequence Scale

Level	Description	Example of description
1	Insignificant	No injuries. Minor delays.
2	Minor	First aid required, Small/spills treated on local area
3	Moderate	Medical treatment required. Large spills treated with USQ emergency services
4	Major	Multiple injuries or very affected. Hospitalisation requirement.
5	Catastrophic	Death. Toxic substance.

Probability Range

Level	Description	Example of description
A	Certain	Very high probability for damage
B	LIkely	High probability of damage
C	Possible	Moderate probability of damage
D	Unlikely	Low probability of damage
E	Rare	Very low (rare) probability of damage

Risk Rating

Frequency/ Probability	**Consequence**				
	Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
A	Medium	High	High	Very High	Very High
B	Medium	Medium	High	High	Very High
C	Low	Medium	High	High	High
D	Low	Low	Medium	Medium	High
E	Low	Low	Medium	Medium	High

Legend with procedure and interference:

- Low – means low risk manage by routine procedures, unlikely to need specific application of resources
- Medium – means moderate risk manages by specific monitoring or response procedure, with supervisor or laboratory technician approval.
- High (urgent procedures) and very high (immediately procedures)– means supervisor attention needed, action plans implemented.

Safety Report Sheet

Date/ Time	Name person and /or material involved	Injury and/or damage Yes/ No	Incident description	Procedure action
13/05/14	NaOH (Angela)	Yes	It had spilled some water with Naoh on the floor, beside the table.	-Wiped out the floor -Got towel to protect the floor
18/08/14	Oven (Daniel, Tracey and Angela)	Yes	Chemical spilled on the oven. One of the containers was found empty. The bottom shelf of the oven was cover by a sort of foam. (NaOH mixture) Left some stain in the oven. The oven is still working.	- Oven was wiped out with damped cloth
01/09/14	Oven (Daniel, Tracey and Angela)	Yes	Another cracked container consequently, more leakage. 20L containers were replaced for 10L because most of them are faulty (3 out of 4 had cracked). Oven's fan stopped working.	-Sweep the floor - Wipe the oven.
02/09/14	Floor	Yes	The chemical spill on the floor had left white stains.	-scrubbed the floor with white vinegar
Signature:				

Appendix J – Project Gant Chart

Final Year Gant Chart - University of Southern Queensland

"Experimental investigation on the Alkali Silica Reaction effect on concrete strength degradation"

		2013			2014									
Activities	Status	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Assessment														
Project Topic	Complete	■	■											
Proposal	Complete		■	■	■	■	■							
Project Specification	Complete					■	■							
Preliminar Report	Complete						■	■	■					
Project Progress	Complete						■	■	■	■				
Partial Draft	Complete									■	■	■	■	
Presentation	Complete												■	
Final Dissertation	Complete													■
Proposal														
Meeting with Yan Zhuge	Complete	■												
Contact TMR showing interest on ASR	Complete	■												
Meeting with Yan Zhuge and Dr Wayne Roberts	Complete		■											
Meeting with Yan Zhuge and Dr Wayne Roberts	Complete				■									
Meeting with Yan Zhuge	Complete				■		■							
Meeting with Yan Zhuge	Complete										■			
Literature Review														
Alakali Silica Reaction (ASR) on concrete structures	Complete	■	■	■	■	■	■	■	■	■	■	■	■	■
Accelerated Laboratory ASR reaction	Complete				■	■	■	■	■	■	■	■	■	■
Concrete Mix	Complete				■	■	■							
Aggregate research	Complete								■	■	■	■		

Cement research	Complete													
Control ASR	Complete													
Project Specification														
Design Mix	Complete													
Curing Method - ASTM 1260	Complete													
Cracking Measurement	Complete													
Testing Procedure - Strength tests	Complete													
Testing Procedure														
Cracking Measurement	Complete													
Specimen Dimension	Complete													
Compression	Complete													
Tension	Complete													
Dissertation Progess														
First Draft	Complete													
Final Dissertation	Complete													