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LATEX AND ACRYLIC BASED WASTE PAINT AS ADMIXTURE IN CONCRETE MASONRY BLOCKFILL

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Supervised by
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A thesis submitted in fulfilment of the requirements for the degree of Masters of Engineering in Civil Engineering

The University of Auckland, 2007
A significant volume of waste latex and acrylic paint exists in New Zealand, with the rate of supply growing at a substantial rate. This waste stream, once destined for landfills, has the potential to be a useful ingredient in cementitious applications. The study reported herein specifically investigated the use of waste paint as a polymer admixture in concrete masonry blockfill. Polymer concrete is not a new concept and has been used in practice for over 70 years. The success of polymeric admixtures is largely due to their ability to increase the workability of concrete and to reduce drying shrinkage. The objective of this study was to produce a blockfill mix capable of maintaining or improving the properties of the hardened material whilst increasing the efficiency of the construction process.

A blockfill mix design was created with the assistance of an industry partner and a number of tests were conducted to evaluate the various fresh and hardened concrete properties whilst investigating an optimum dosage of waste paint. Study into the fresh properties of blockfill focused upon workability, with specific attention given to investigating the change in rheological properties. Compressive strength, tensile strength, drying shrinkage and seismic performance were studied to assess the hardened properties of the blockfill. Industry trials were conducted to ensure that the material properties determined within the laboratory could be achieved at a larger scale.

It was established that waste latex and acrylic based paint was a suitable additive to concrete masonry blockfill, resulting in maintained strength and improved workability, providing a viable substitute to standard chemical admixtures currently used to achieve comparable results. Increased water content was required to ensure that the waste paint was distributed evenly within the mix, which led to maintained compressive strength without the addition of excessive air content. Pseudo-static testing of a reinforced concrete masonry wall confirmed that the seismic performance of the blockfill was comparable to that measured when using a standard blockfill.
Non-Technical Abstract

A large amount of left-over water based paint currently sits in homes and garages throughout New Zealand, awaiting disposal and eventually ending up in a landfill. An innovative solution is required to ensure that this does not happen, and that waste paint instead becomes a valuable resource. This study investigates the feasibility of utilising waste paint as an additive to blockfill, which is the concrete that is pumped into the hollow core of concrete masonry walls. The basic chemical ingredients of paint are similar to polymeric admixtures, which are chemicals that are presently used in advanced concrete applications to achieve superior material properties. Therefore there is an opportunity to use waste paint in a similar way.

A set of tests were conducted to evaluate the effect that the addition of waste paint had on blockfill properties, both at the time of mixing whilst the blockfill was in a fluid state, and also in its hardened form after it had gained suitable strength. The tests evaluated changes in the basic material properties such as workability, which describes the ability of the blockfill to flow easily through a concrete pump and into a wall, and also investigated the strength of the hardened blockfill in compression and tension.

It was determined that the blockfill exhibited superior workability, and needed less vibration to allow full compaction of the material within a concrete masonry wall. The addition of waste paint was also found to maintain strength, whilst not appearing to improve it. The success of the blockfill in an industry application was found to be dependent upon the accuracy demonstrated by the workers controlling the amount of each constituent that was administered to the blockfill. When waste paint is added to a blockfill a slightly ‘wetter’ mix is required, and thus the result of an accidentally ‘dry’ mix would prevent the paint from dispersing properly throughout the mix, leading to a low quality product.

The addition of waste paint to blockfill has the ability to be successful at an industry level, offering an environmental solution to a major waste stream, whilst providing a superior product capable of becoming commonplace within the New Zealand concrete market.
Dedicated to my parents John and Penny Haigh.

All of my success is testament to their love and support.
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List of Symbols

\( d_u \) = ultimate displacement
\( E \) = elastic Modulus
\( f'g \) = grout/blockfill compressive strength
\( f'm \) = masonry compressive strength
\( F_n \) = nominal flexural strength
\( H \) = wall height
\( H_e \) = effective wall height
\( L_w \) = length of masonry wall
\( V_{max} \) = maximum lateral strength recorded during testing
\( V_n \) = nominal shear strength
\( \Delta y \) = nominal yield displacement
\( \rho_h \) = horizontal reinforcement ratio
\( \tau_o \) = yield shear stress
\( \mu \) = plastic viscosity
CHAPTER 1

Introduction

For centuries, structures have been built using masonry construction, forming some of the world’s most significant architectural achievements. In the past 100 years developments in masonry technology have increased steadily, with one of the most significant being the development of concrete masonry. Other important developments were the use of masonry reinforcement and of new materials for use in grouts, mortars, and concrete masonry blocks themselves.

Currently there is much interest in the science and development of advanced forms of concrete, and the growing potential for its use. In addition to this there is also increasing pressure for the concrete industry to become more receptive to aspects of sustainability and the associated effects of concrete production on the natural environment. An opportunity to explore both of these issues has emerged in the development of a flowable blockfill grout for concrete masonry, to be known as Paintcrete. A consortium between a paint manufacturer (Resene, www.resene.co.nz), a specialist in product stewardship (3R Group, www.3r.co.nz), and a concrete and masonry manufacturer (Firth Industries Ltd, www.firth.co.nz), has been established to develop applications that utilize waste paint to enhance the properties of cementitious materials.

1.1 Motivation for this Investigation

A valuable resource exists in the waste stream of water-based acrylic and latex paints, which are currently being disposed of in landfills at a large economic and environmental cost. This paint exhibits many properties that are similar to polymer admixtures, which are commonly used in the manufacture of concrete. Polymer admixtures are used to increase the matrix bond between cement and aggregate and to increase the workability and flow of
cementitious materials, but they are often too expensive for many applications. The paint collection process is already active in New Zealand (see Figure 1.1) with over 150,000 litres of waste paint in supply and a fast growing balance that is projected to reach 600,000 litres over the next two years. Consequently, the need for a successful application is growing proportionally. The current New Zealand concrete market provides approximately 150,000 m$^3$ of ready-mixed blockfill annually. Assuming that paint was added to blockfill at 10% replacement for water by mass, this blockfill production could utilise up to 3.6 million litres of waste paint per year. This opportunity ensures that the successful development of Paintcrete would rectify the currently unused waste stream of water based paint in New Zealand.

![Figure 1.1. Resene Paintwise paint collection advertising.](image)

A ‘polymer’ is a substance composed of molecules consisting of repeating structural units, with the individual units of the polymer being referred to as monomers. A polymer-based (or polymeric) admixture is defined as an admixture which consists of a polymeric compound as a main ingredient that is effective at modifying or improving properties such as strength, deformability, adhesion, waterproofness and durability of cement, mortar and concrete.
Blockfill grout is a mixture of Portland cement, sand, gravel and water mixed to a fluid consistency, that can flow within the cores of hollow masonry units. Grout binds the reinforcement and the masonry into a structural system as well as providing fire resistance, sound transmission resistance and greater weight, thus improving overturning resistance. The addition of the polymer, which makes up a substantial proportion of the paint, assists the grout’s ability to flow, without negatively influencing strength, as would be the case if water were added for the same purpose. This increase in workability, attributable to the waste paint additive, should result in a less labour intensive construction process. The improved workability properties of the grout enable it to settle around congested reinforcement and small void areas and reduce the need for compaction and vibration, resulting in a faster, cheaper and safer construction task.

Masonry blockfill was chosen as the initial trial application of Paintcrete for several reasons, such as:

- Masonry walls have low risk implications and were accessible for early trials at an industry level;
- One of the primary advantages of the material, which is increased workability, had the potential to improve the filling capability of masonry units;
- Blockfill is hidden within a masonry unit and thus the slightly tinted appearance of Paintcrete would be hidden;
- Adding polymers to cementitious materials lowers the E value of the blockfill closer to the E value of the masonry unit, which conceptually enables the two materials to act more effectively in composite action during seismic loading, with reduced damage;
- The size of the New Zealand blockfill market was ideal in its potential to utilise the amount of projected available waste paint.

1.2 Environmental Concerns

With the rate at which population and urbanization are growing worldwide it is clear that there will be a corresponding growth in demand for the earth’s natural resources (Glass et
During the last century, Portland cement concrete emerged as the material of choice for many modern infrastructure needs and it follows that the concrete industry has become the largest consumer of natural resources such as sand, gravel, water, and crushed rock. It is also one of the most energy intensive and polluting industries worldwide and has come under increased scrutiny from regulatory agencies and the public to be more focused on sustainable development (Bjork, 1999). The initial motivation for the development of Paintcrete was to create a solution to the environmental problem of a growing waste stream of latex and acrylic paint. The delivery of further solutions will come from an increased awareness within the concrete and construction industry regarding sustainability and environmental protection.

As the importance of sustainability has been introduced to the concrete industry more focus has been placed on the topic, with conferences and papers having a sustainable theme appearing more commonly. At the 1999 Symposium on Concrete Technology for Sustainable Development, Bjork presented a technical report around the concept and recommended pathway to achieve sustainable development (Bjork, 1999).

At the 2000 CANMET/ACI International Symposium on Concrete Technology for Sustainable development, Swamy presented a paper similar to that by Bjork on designing concrete and concrete structures for sustainable development. The paper outlined the importance of the industry’s awareness of its effects upon on the environment and the need to adhere with changing concepts. This would demand a fundamental change in design approach, which should be holistic in integrating material characteristics and structural performance (Swamy, 2000).

1.2.1 The Environmental Effects of the Construction Industry

According to Swamy (2000), engineers cannot afford to ignore the impact of construction technology on their surroundings. The industry as a whole needs to accept that Portland cement is both a valuable resource and an energy intensive material. Every tonne of Portland cement that is produced requires about 1.5 tonnes of raw material, and approximately 4000 to 7500 MJ of energy. The energy cost to produce a tonne of cement is estimated to account for 40-45% of the total construction cost. The most important issue,
from an environmental perspective, is that every tonne of cement releases at least another tonne of carbon dioxide into the atmosphere, and further contributes to atmospheric pollution and the greenhouse effect. It is this by-product that has the most severe consequences on the environment, and which needs to be controlled (Pulselli et al., 2007).

Swamy suggests that addressing the durability of concrete is the first step to the sustainable development of concrete. To increase the durability of concrete, rather than to purely focus on strength, and thereby create a longer design life will result in more efficient use of concrete. The most successful way to increase the durability of concrete is to ensure that the hardened concrete is free of void space, thus removing the pathway for water to access corrosive material and subsequently cause cracking and spalling (Peris Mora, 2007). The recommended way to achieve this is with modified binders in the form of fly ash, slag, silica fume, natural pozzolans and volcanic ash. These materials are all excellent companions to PC and can form a long-life partnership of homogeneous interaction. The fundamental reason why this Portland cement-siliceous material partnership is essential for sustainable development in the cement and concrete industry is that every tonne of clinker that is replaced with one or many of the modified binders above, results in a directly proportional saving in carbon dioxide emissions. Thus using this method, the carbon dioxide emissions are reduced not only by the reduction in clinker, but also by the delayed replacement of the structure (Swamy, 2000).

1.2.2 Environmental Initiatives Worldwide

In 2004 the business leaders of ten global cement companies, who were also members of the World Business Council for Sustainable Development (WBCSD), created the Cement Sustainability Initiative (CSI) as a measure intended to promote the sustainable development of their industry. A document was created titled *The Cement Sustainability Initiative, Our Agenda for Action* that outlined a plan to guide the industry to a sustainable success (WBCSD, 2005). This was a significant event for the concrete industry as it was the first major collaboration of the cement industry’s major companies, with a theme of sustainability. The participating companies encompassed one third of the global concrete produced and operated in two thirds of the world’s construction markets (Mahasenan et al., 2003). The purpose of the initiative was to:
• Explore what sustainable development means for the cement industry;
• Identify and facilitate actions that can be taken as a group and individually to accelerate the movement toward sustainable development;
• Provide a framework through which other cement companies can become involved;
• Provide a framework for engaging external stakeholders.

A further interim report was produced in 2005 as was committed in the 2002 Agenda for Action. By this stage the contributors to the CSI represented over one half of the global concrete product. The document reported progress in all sectors with respect to what had been planned and carried a successful theme. A full progress report is due in 2007.

It is global initiatives such as this that create awareness of the need for sustainable development, and encourage industry to provide funding and support to projects and investigations with a sustainable theme.

1.2.3 Environmental Initiatives within New Zealand

The success of the worldwide environmental initiatives, as outlined in the previous section, is represented by the support generated at a nationwide or local level. It is likely to be the smaller scale initiatives which result in studies and investigations which can later be filtered back to the global community.

Concrete³ is an industry wide initiative released in 2007 by the Cement and Concrete Association of New Zealand (CCANZ), which is designed to raise awareness of concrete’s contribution to New Zealand’s sustainable development across all areas of economic, social and environmental development. CCANZ released a document with the aim of the demonstrating how concrete contributes to both this and future generations’ sustainable development. The initiative is based on the idea of the sustainable development – “the triple bottom line”, and is represented graphically is Figure 1:2 (CCANZ, 2007b).
A Sustainable Life Cycle
The purpose of Concrete³ is to promote the sustainable life cycle of construction materials and recognise that this cycle begins with creation. Construction can be designed with durability given high importance, resulting in a prolonged service life, and once the structure is no longer needed, its components can be recycled as aggregate or its structural elements reused. There are many ways to enhance the life cycle of construction materials, such as reuse and deconstruction, cement stabilisation, conversion of scrap metal into reinforcing steel and the reuse of water within a construction site (CCANZ, 2007b).

Concrete and the NZ economy
The New Zealand economy is developing well at present, and experiencing GDP growth of 2-3% per year. As the economy grows, so too does the size of the construction industry, and in turn the demand for concrete. The total sum of New Zealand building consents issued in 2006 was $11.18 billion, which was an increase of 2.2% over the previous year. New Zealand is virtually self-sufficient in concrete, locally obtaining almost all of the materials and labour required for production. Ready mixed concrete is generally produced within close proximity to where it is cast, thereby creating jobs throughout the country and reducing environmental impacts and cost resulting from transportation (CCANZ, 2007b).

1.2.4 The effective use of waste products
As the industry and academic communities become further aware of the importance of sustainability and the effects that the construction industry has upon its surroundings,
research into the field of waste product reuse and the creation of innovative solutions are becoming more common.

The use of recycled cement extracted from waste concrete was investigated by Katsutama et al. (2005) as a measure to reduce the carbon dioxide emissions of the cement industry. The process involved the extraction of calcium carbonate from waste concrete, which could then be used as a raw material in cement production. The net reduction of carbon dioxide could be realised as the amount of carbon dioxide from the recycled calcium carbonate in the calcination process, minus the carbon dioxide emission resulting from the power consumption of the recycling process. The process was successful in reducing carbon dioxide, whilst carrying a cost of USD 80 per tonne of carbon dioxide (Katsuyama et al., 2005).

Another measure to reduce the carbon dioxide emissions associated with cement production was investigated by Shi and Zheng (2007) in the use of recycled glass in Portland cement and concrete. Being amorphous and containing large quantities of silicon and calcium, glass has the potential to be pozzolanic or cementitious in nature when it is finely ground. Thus, it can be used as partial cement replacement in Portland cement concrete. The use of waste glass as concrete aggregate is also a feasible application, although the glass appears to have a negative effect on the workability, strength and freezing-thawing resistance of cement concrete. The main concern is expansion and cracking of the concrete containing glass aggregates. Further work is prompted to resolve these issues and further develop feasible applications (Shi et al., 2007).

The influence of siliceous waste on the properties of fly ash and blast furnace slag cement were studied by Fu et al. (2003). The strength, setting time, resistance to chemical attack, dry shrinkage, and impermeability of blended cement mixed with siliceous waste were investigated by different experiments. It was determined that siliceous waste could improve the strength and the ability of resistance to chemical attack of the cement, whilst reducing the dry shrinkage rate of mortar, but increase the water requirement to obtain a normal consistency. The optimum mixing amount in blended cement was determined as 8-15% (Fu et al., 2003).
The use of waste paint as an additive in cementitious applications has been investigated previously, and a literature review is presented in Section 2.2.7.

1.3 Summary

The objective of this study was to investigate the feasibility of using Paintcrete as a successful, efficient, safe, marketable product whilst also promoting the effective use of waste products. The cement, concrete and construction industries as a whole are beginning to adhere to the concept of not only considering the implications of their processes, but also committing to improving their practices with the reduction and also effective use of waste products.

Paintcrete is an innovation that effectively utilises and applies value to a waste stream that would otherwise be destined for landfill at great environmental and financial expense. Paintcrete has the potential to be developed into many applications beyond that of concrete masonry blockfill, and is limited only by the supply of available waste paint.
CHAPTER 2
Chemistry of Paint and Cement

2.1 Introduction

This chapter provides background information on the chemistry of paint and cement, which together form the basis of this investigation. Section 2.2 and 2.3 outline the current knowledge of polymer concrete and the use of fine particle packing, and this knowledge can be used to explain the change in material properties brought about through the addition of waste paint to concrete masonry blockfill. Section 2.4 establishes the primary ingredients of paint and discusses the possible influence that they will have on the properties of cementitious materials. Section 2.5 provides information on the science of rheology, which is used later in this investigation to assess the modification of workability with the addition of waste paint. Section 2.6 looks at the chemicals currently used as additives to concrete masonry blockfill and 2.7 looks at the viability of their replacement with waste paint.

2.2 Polymer Concrete

2.2.1 Introduction

In 1998, Ohama summarized the present knowledge of polymer-based or polymeric admixtures, describing a polymeric admixture as:

“an admixture which consists of a polymeric compound as a main ingredient effective at modifying or improving the properties such as strength, deformability, adhesion, waterproofness and durability of cement, grout and concrete. Such a polymeric compound is a polymer latex, redispersible powder, water-soluble polymer or liquid polymer”.

Polymers make up the majority of the solid mass in paint, which for this investigation is convenient as polymer based admixtures have been an active ingredient in the modification of cementations applications for well over 70 years. The first patent to adhere with the present concept of polymer modification was published in 1924 and referred to paving materials that incorporated natural rubber latexes.

The properties of polymer-modified concrete depend specifically on the polymer content or mass based polymer-cement (p/c) ratio, rather than the water-cement (w/c) ratio used when assessing ordinary cement concrete (Ohama, 1998).

### 2.2.2 Principle of Polymer Modification

Although polymer-based admixtures in many forms are used in cementitious composites such as grout and concrete, it is important to ensure that both cement hydration and polymer film formation proceeds well in order to yield a monolithic matrix phase with a network structure in which the cement hydrate phase and polymer phase interpenetrate (Van Gemert et al., 2005). It is the formation of such a co-matrix phase that results in superior properties compared with conventional cementitious materials. The co-matrix phase is generally formed according to the simplified model shown in Figure 2:1, where the inclusion of the aggregates within the matrix is shown (Ohama, 1998).

![Figure 2:1. Simplified model of polymer-cement co-matrix formation (Ohama, 1998).](image)
2.2.3 Properties of Polymer Modified Cementitious Material

Ohama describes the properties of polymer modified grout and concrete as being markedly improved over those found in conventional mix designs. The properties of fresh and hardened concrete are affected by a range of factors such as polymer type, polymer-cement ratio, water-cement-ratio, air content and curing conditions. However these can all be controlled to create the desired properties, which are outlined below.

Workability

The improved workability of polymer-modified grout and concrete is one of the primary advantages achieved when compared to unmodified cementitious materials. The addition of waste paint to blockfill to generate improved workability was one of the key motivations of this investigation. Workability is mainly interpreted in terms of improved consistency due to the ‘ball bearing’ action of the polymer particles, the quantity of entrained air and the dispersing effect of surfactants (see Section 2.4.2) in the polymer latexes (Wang et al., 2005). For any given workability, the water-cement ratio is markedly reduced with increase in polymer-cement ratio. This water reduction results in enhanced strength development and drying shrinkage reduction (Ohama, 1998).

Air entrainment

In most latex-modified mortars and concretes, the volume of entrained air is slightly more than that entrained in an ordinary cement mix. This is because of the effect of the surfactants contained in the polymer latex as emulsifiers and stabilizers. These ingredients are in the polymer to keep it correctly stabilized (avoiding flocculation and the settling of solid particles) and liquid at the correct viscosity. Some air entrainment is useful to obtain improved workability. Too much air entrainment causes a reduction in strength and increased susceptibility to freezing and thawing, which reduces durability. Advanced polymer admixtures contain an antifoaming agent, which considerably decrease air entrainment (Ohama, 1998).

Water retention

Polymer modified cement has markedly improved water retention over ordinary cement. The hydrophilic colloidal properties of the polymer latexes, and the filling and sealing effects of the polymer films formed, give the cement excellent water retention qualities.
which ensure that an amount of water sufficient for cement hydration is held within the matrix. The excellent water retention of latex modified concrete contributes to an increase in the long-term strength (Ohama, 1998).

Bleeding and Segregation
Concretes and cements with excellent workability usually carry a risk of bleeding and segregation. However due to the air-entraining and water-reducing effects of the surfactants contained within the polymer latexes, this is not the case for polymer cement. Accordingly, disadvantages such as reductions in strength and waterproofness caused by bleeding and segregation do not exist (Ohama, 1998).

Strength
In general, latex modified cement and concrete show a noticeable increase in tensile and flexural strength but no improvement in compressive strength when compared with ordinary cement mortar and concrete (Ohama, 1998). This can be explained by the high tensile strength of polymers and an overall improvement in cement hydrate-aggregate bond. Strength properties of latex-modified concrete are influenced by various factors that tend to interact with each other, such as the nature of materials, mix proportions, curing methods and testing methods (Bentur, 1982). Acrylic polymers are known to retard the hydration process and thus the strength of Portland cement, potentially due to the overlay of a polymer skin which prevents water reaching the particles (Su et al., 1991).

Elastic Modulus
Latex-modified cementitious materials contain polymers with significantly lower elastic modulus compared to cement hydrates. Consequently, their deformation behaviour can differ from those of ordinary cement mortar and concrete. In general the elastic modulus of the latex-modified mortars and concrete tends to decrease with increase in polymer-cement ratio (Ohama, 1998). An investigation by Cook and Crookham in 1978 reported that the load-deformation behaviour of polymer modified concrete indicated that the stiffness of the varying mixes relative to the control mixes closely followed trends indicated by strength behaviour. It was also reported that polymeric admixtures reduce the stiffness of the cement paste phase and hence increase the relative stiffness between the aggregate and paste phase. It was concluded that the greater the difference in the relative stiffness
between the aggregate and paste phases, the more ductile the failure of the concrete (Cook et al., 1978).

### 2.2.4 The Influence of Polymer Latex Modifiers

Lewis and Lewis detailed the influence of polymer latex modifiers on the properties of cementitious materials. They compared the properties of modified concretes with unmodified samples, on the basis of constant water/cement ratio, and of constant workability. A reduction in compressive strength amongst the polymer modified concretes was found to be significant, while improvements in flexural and tensile strength were observed. Testing was undertaken by varying the concentrations of polymer solids to cement (by weight), whilst assuming the percentage solids of the polymer to be 47-48% (Lewis et al., 1991).

Samples were taken after testing and the fractured surfaces were examined with a scanning electron microscope (SEM) in order to confirm how the polymer modifier was interacting with the cement matrix. There is considerable speculation as to what happens to the cement gel formation and the effects of the resultant structure on the mechanical and other properties of polymer modified concrete. Lewis and Lewis concluded that eventual polymer distribution could be considered as being somewhere between the extremes of:

- A completely homogeneous co-matrix, in which both polymer and cement gel are continuous; and
- A matrix consisting of only cement gel, with agglomerates of polymer as a dispersed phase within the matrix.

The morphology of latex-modified concrete was examined to establish the location of polymer in the cured concrete, using more established methods than had been used prior.

Examination of the fracture surfaces indicated that the preferred fracture path was through the cement matrix, rather than at the cement/aggregate interface, suggesting that the polymer modifier had increased the cement/aggregate bond. The SEM images showed that a non-uniform distribution of the polymer was found for polymer contents of 0.15 and
above. For these specimens, the polymer concentration was high at the cement/aggregate interface, and low within the rest of the cement matrix phase (Lewis et al., 1991).

2.2.5 Optimum Curing Conditions for Latex Modified Concretes

Lewis and Lewis used the findings reported by Ohama on the optimum curing conditions for latex modified concretes and cements. Ohama stated that in order to achieve optimum compressive strength a reasonable degree of cement hydration under wet conditions at early stages must be allowed, followed by dry conditions to promote a polymer film formation due to coalescence of the polymer particles. Tests suggested that the time for each of these periods is two days of saturation, whilst the cement is undergoing the greatest strength development, followed by 26 days in which to complete the industry recognised 28 day period of dry curing. Development of compressive strength in latex modified concretes was observed to be high, despite the considerable length of the dry curing period. The fundamental reasoning is that the polymer film formation, developed by the latex modifiers, exhibits excellent water retention and allows cement hydration to continue (Wang et al., 2005). Improved strength development was found to be one of the major advantages of latex modified concretes (Ohama, 1998).

2.2.6 Future Development of Polymer Concrete

Fowler (1999) reviewed the past and current use of polymer concrete and the realistic use of polymer modified materials in the future.

Fowler looked at polymer-impregnated concrete, polymer concrete and polymer-modified concrete as the key polymeric concretes of the previous 25 years and discussed their advantages and disadvantages. Attention was focused on the current use of these materials and the potential usage that polymeric admixtures could have in applications that would effectively utilise their unique properties. Improved repair technique, improvements in materials, structural applications, and architectural components were projected to be popular uses of concrete polymer materials (Fowler, 1999).
2.2.7 Prior Applications of Waste Paint in Concrete

Nehdi and Sumner (2003) reported on the application of recycling waste latex paint (WLP) in concrete, with a focus on use for urban concrete sidewalks in Ontario, Canada. WLP was used in concrete mixes as a partial replacement for virgin latex and mixing water. Nehdi and Sumner noted that previous attempts to recycle WLP in asphalt concrete had failed, despite positive test lab results, due to unpleasant odours being emitted from the mixture. Air quality analysis showed that hot-mix asphalt mixtures could release vapours of ethylene glycol in concentrations beyond the recommended levels for occupational health and safety. The motivation for the study conducted by Nehdi and Sumner was that 12% of all hazardous waste collected in Ontario was WLP, with its proportions on the rise and having an escalating cost of disposal. It was noted that based on the demand for new sidewalks and the current supply and growth of the WLP stream, almost all of the paint could be utilised, thus avoiding the negative environmental effects of land filling.

Nehdi and Sumner found that a significant part of the advantages imparted by virgin latex in concrete are also identifiable when using WLP, such as increasing flexural strength and decreasing chloride ion penetrability. A field demonstration sidewalk modified with WLP exhibited enhanced workability and finishing, more appealing colour, and better durability to surface scaling and aggregate pop outs. They concluded that more research was needed to investigate the effect of WLP on the stability and spacing factor of air bubbles in air-entrained concrete, the effect of WLP on expansion due to alkali-silica reaction, the variability of WLP in time, its effect on industrial concreting equipment, and the stability of contaminants that may be present in recycled paint (Nehdi et al., 2003).

2.3 The Effect of Fine Fillers

2.3.1 Introduction

Paint is made up of numerous types of small particles, with many in the range of 0.1 µm to 10 µm which are classed as fine and ultra fine materials. The addition of fine particles and the application of particle packing theory allows a concrete producer to use poorly shaped or poorly graded sand and aggregates while still producing user friendly, workable concrete. The addition of fine particles can also contribute to increased workability.
2.3.2 Application of fillers for advanced cement based materials

In 2003, an investigation was conducted by Lagerblad and Vogt with the intent of increasing the current knowledge of how ultrafine fillers (<10 µm in size) act in concrete, based on earlier studies that had indicated that ultrafine material has a more profound effect on concrete properties than normal fillers. It had been determined that by incorporating large amounts of ultrafine fillers with reduced cement content, it was possible to produce a high strength concrete which implied a great potential for saving cement.

The types of fillers normally used in self compacting concrete (SCC) are less than 150 µm in size. However due to the recent development of very effective superplasticizers, it is now possible to include large amounts of particles smaller than 10 µm. These particles are referred to as ultrafillers, which increase the strength of concrete and act as a cement replacement. Lagerblad and Vogt found that it is possible to replace up to 40% of the cement and still obtain similar strength. The optimum effect was achieved when the cement is replaced but the water/cement ratio was kept constant. As a result the fillers increased the workability of the mix. The incorporation of fine fillers also accelerated the cement hydration, with the rate increasing with the fineness.

The total energy consumption of the mix containing ultrafine fine fillers is reduced but the use of such material is probably not economical for the bulk production of concrete. This is due to the cost of grinding and handling the fine material for concrete production. By using wet ground material as slurry it is possible to avoid silicosis and other dust problems and the result could become commercially viable. Meanwhile, ultrafine fillers remain ideally suited to special environments such as where there is interest in low energy release, dense concretes, special high performance concretes or other cementitious products where it is ideal to keep the amount of cement to a minimum (Lagerblad et al., 2003).

Bache (1981) described the strength and durability improvements available through the use of fine particle packing. Fine particle packing describes the geometric and kinematic principles for arranging larger bodies in a desired configuration which results in a highly dense structure. This formation results in significant increases in strength and durability obtained from the mechanical “locking” of larger aggregates together. The application of
fine particle packing allows the use of a cheaper, rougher group of aggregates to produce a higher quality cementitious material at a lower cost (Bache, 1981).

2.3.3 Role of fine powder additions on workability

Ferraris and Karthik (2001) reported on the role of fine powder additions and their effect upon the workability of cementitious materials. Previously accepted theory stated that the addition of mineral admixtures results in workability reduction, thought to occur due to the increased surface area of the fine particles exerting a greater water demand. Ferraris and Karthik provided support to an alternate theory that in specific cases the spherical particles easily roll over each other, in between the much larger aggregates, reducing interpartical friction. In addition to this, they stated that the spherical shape also minimises the surface to volume ratio, resulting in a low fluid demand. Rheological tests were undertaken to confirm this hypothesis, using ultra fine fly ash (UFFA) as the fine mineral admixture (~3 µm). They determined that the mix containing UFFA required on average 16% less water, and 78% of the usual dosage of high-range water reducer to achieve similar workability to the control mix. In comparison to other mineral admixtures, it was concluded that if a reduced slump was desired, the most effective way of achieving this would be to use ultra fine particles (Ferraris et al., 2001).

2.4 Assessment of the Active Constituents of Waste Paint

The waste paint that is collected via the Paintwise program for use in this investigation represents a cross section of the waste latex and acrylic water-based paint available in New Zealand. Across the several paint producers and their paint varieties a large number of unique constituents are included. The primary constituents that are expected to occur in high volume are discussed below. Due to the commercially sensitive nature of these ingredients, the specific chemicals cannot be identified. Instead they are categorised based upon their function. A generic description of a basic paint follows in Figure 2:2.
2.4.1 Polymers

The continuous phase of latex and acrylic water based paint, also known as the “vehicle” is made primarily of polymer. This phase carries and then binds the other components of the paint such as the pigments and extenders, and then provides the continuous film forming component of the coating.

‘Poly-mer’ means “many parts” as a polymer molecule is composed of many smaller parts, contributed by similar or dissimilar simple molecules, which are joined together in a chain until there are hundreds of thousands of atoms in the polymer molecule. Emulsion polymers are common in paint and are usually made up of water, monomer and surfactant (Steward et al., 2000). Polymerisation takes place in the latex particles that form spontaneously in the first few moments of the process. Paint will “dry” or “cure” by one of two mechanisms involving atmospheric oxidation or the evaporation of water. During this phase polymerisation will occur, in which liquid polymers are converted into highly cross linked solids (Turner, 1988). The specifics of the polymer chemistry are beyond the scope of this project, other than to assume that the development of the polymer chains may assist in the development of the cement matrix within the blockfill, enhancing the tensile strength, but not necessarily the compressive strength. This is outlined above in Section 2.2.2.
2.4.2 Surfactants

A surfactant or surface active agent is a substance that reduces the surface tension of a liquid. Surfactants are chemicals whose molecules have two parts of widely differing polarity and solubility (Porterm, 1994). If there is a problem in which two materials will not wet or make chemical contact with one another, surfactants can bridge the gap. An example of a commonly used surfactant is one with a hydrophilic (attracted to water) head and a hydrophobic (repelled by water) tail often depicted in cartoon form as a tadpole (see Figure 2:3).

![Surfactant Diagram]

Figure 2:3. Representation of active surfactant.

The opposing forces of the surfactant molecule ensure that the hydrophobic tail avoids a water medium by burying itself into whatever solid/polymer particle it can find, thus leaving the hydrophilic head hanging out suspending the particle in the water and repelling any further solid particles (see Figure 2:3). Thus if enough surfactant is available, particles are encouraged to slide past and repel each other, rather than sticking together and reducing the dynamic of the system. The nature and proportions of the two parts of the molecule will vary between applications (Turner, 1988).

Many surfactants are active in producing foam, which can be desirable or undesirable depending on the application. For example household detergents contain surfactant, in which foam is desirable, whereas in the case of a cementitious material, the air entrained from foaming may be undesirable. Methods for the control of the foam are outlined in Section 2.4.3.
2.4.3 Foam controllers

The easiest way to control foam is by choosing a suitable surfactant, although for many practical applications there will be limitations on the choice of surfactant, especially in the case of waste paint in which a broad range of surfactants are involved. In these cases there is a requirement for agents to control the foam. These are available and known as antifoams or defoamers. The terms are not synonymous, as antifoam prevents the build up of foam, whereas defoamers cause the collapse of foam which has already formed. These are present in waste paint, as foaming of the paint is not desirable for its application.

2.4.4 Titanium Dioxide

Titanium dioxide is the primary white pigment used by the paint industry as it is the only pigment (other than zinc oxide) that is non toxic and easily obtainable. It is a transparent particle, yet appears white because of the small particle size which causes the light to be scattered back, and thus the eye receives the whole spectrum of light (Marrion, 2004).

The paint waste stream collected for use in this investigation is grey in colour, which is most likely due to the large percentage of white paint manufactured and sold. This ensures that there will be a substantial amount of titanium dioxide present in the waste paint. Titanium dioxide is not expected to have any substantial chemical effect on a cementitious material other than as fine material, the principles of which are outlined in Section 2.3. Titanium dioxide is an ultrafine material with particle sizes from 0.1 µm up to 0.8 µm although this is a finely graded material with most particles having a diameter around 0.3 µm.

Titanium dioxide particles are a primary catalytic ingredient, which prompts its use in de-polluting and self cleaning applications. Photo catalysts accelerate the chemical reaction whereby strong sunlight or ultraviolet light decomposes organic materials, in a slow natural process. This mechanism is unlikely to occur in concrete as the titanium dioxide used in coatings has been surface treated, which deactivates the ability of the particles to produce the free radicals required (Zhang et al., 2005).
2.4.5 Thickeners

Thickening agents are active in paint to control the consistency and ensure that workability is maintained during storage and application. Thickening agents work through several methods, the most simple and common being thickeners which develop long chains which interact with particles rather than water, creating a loose network. Resinous thickeners and associative thickeners fall into this category. They bond to a wide variety of particles, including the latex particles, pigments, extenders, and in this case, cement particles. The bond they create is reasonably weak and can be broken as shear is applied, which explains the result of a higher initial yield shear stress. Another type of thickener, which contain a lot of charged groups when neutralised with a base (e.g. fresh concrete) involve electrostatic interactions. These act in a similar way to the non-charged thickeners described previously. Other thickeners which are less common, although still very likely to be effective in the waste paint, are known as hydro-dynamic volume exclusion thickeners and act in a very simple manner. They function purely to occupy volume and create obstacles, thus reducing the mobility of the surrounding particles.

2.5 Rheology Modification

2.5.1 Rheology Overview

Tattersall and Banfill (1983) defined Rheology as “the science of deformation and flow of matter” which means that rheology is concerned with relationships between stress, strain, rate of strain, and time. The purpose of performing rheological measurements is to;

- Understand the interactions between ingredients in a product and get an insight into the structure of the sample. There is a relation between the size and shape of particles dissolved or suspended in a solvent and the viscosity of the same solution.
- Ensure the quality control of raw materials, processing conditions and final products. Rheological results can be used by a customer to confirm the properties of a product prior to acceptance (Tattersall et al., 1983).
Tests described by NZS 3112:1986 – “Methods of Test for Concrete”, such as spread and slump tests, have long been regarded as an inadequate measure of the workability of fresh concrete, particularly with the increasing use of chemical and mineral admixtures. Rheology provides a means of assessing the workability of cementitious materials from a scientific point of view.

The production of concrete, and the task of producing a “good concrete” requires that the material satisfies certain requirements with regard to strength, durability, and volume stability, along with appearance, at the lowest possible cost. Prior to that stage it must be transported and placed, in which the placing and consolidation process are extremely important to the final result.

2.5.2 Rheology and self-compacting concrete

Wallevik is a pioneer of both rheology and self compacting concrete. Wallevik (2006) described self-compacting concrete (SCC) as an innovative concrete that does not require vibration for placing and compaction. Its primary advantage is its ability to flow under its own weight, achieving full compaction whilst completely filling formwork and flowing between congested reinforcement. SCC offers a rapid rate of concrete placement, with faster construction. Rheology is an important tool to assess and optimise the use of self compacting and self levelling concretes (Wallevik, 2006).

Fresh concrete may be considered as a fluid, providing that a certain degree of flow can be achieved and that the concrete maintains its homogeneity. Most concretes with a slump of at least 90 mm or that exhibit ‘spread’ would fall into this category. Flow of a fluid can be described by the “shear stress – shear rate” concept. Concrete as a fluid is most likely to behave like a Bingham fluid and its flow is defined by two parameters; yield stress ($\tau_0$) and plastic viscosity ($\mu$). This is shown graphically in Figure 2:4.
For normal concrete a minimum force is required to break the initial yield shear stress and bring concrete to flow, which in most cases occurs through vibration. In the case of SCC, the yield shear stress of the material approaches zero, thus tending towards a Newtonian fluid. This means that SCC does not require any external forces to bring it to flow. It is thus apparent that normal concrete exhibits a high yield stress and moderate plastic viscosity whilst self-compacting concrete exhibits a low yield stress, and an increased plastic viscosity. The accurate rheological description of SCC can vary widely between concrete specialists and regions based upon the materials available. It is generally accepted that if a plastic viscosity is low, <40 Pa.s, then the SCC should have a significant yield value, >60 Pa, whilst a high plastic viscosity SCC would require the yield value to be close to zero (Wallevik, 2006).

If the yield shear stress and viscosities are known from a rheological study, they can be analysed to give an indication of the best suited applications. If plotted in relation to a reference point or control sample, as shown in Figure 2:5, comparisons can be made and the changes in properties can be converted to a basic description and applications discussed.
Wallevik states that a rheological device is essential in order to obtain a good SCC in respect of flowability and stability, and to find robust as well as economical solutions. Rheology gives a scientific viewpoint of the properties of fresh concrete and an indication of how to obtain an optimal solution.

2.5.3 Rheology Modification from Paint Addition

The rheology of paint is an important property for paint manufacturers, primarily for reasons involving storage and application. The Rheology of paint is a unique situation as paint is expected to ‘hold up’ on a surface, whilst ‘flow’ out of a can. The rheological behaviour of paint is described as thixotropic, which is defined as a material which shows a time dependant change in viscosity. Thixotropic fluids take a finite amount of time to attain an equilibrium viscosity when introduced to a step change in shear rate.

An ideal particle distribution consists of a completely uniform distribution of isolated particles throughout the liquid. These particles will begin to move as they are affected by gravity and by collisions with other moving liquid and polymer particles. When suitable parts of these particles come in to contact, inter-attractions may be strong enough to prevent the particles from separating by their own motion. If this pairing up process continues, quite large groups or clusters may form. A cage like structure may even form through the liquid. Such an arrangement would give the appearance in the pale of being a very thick viscous material. Once the pale is stirred, the structure breaks up and the
particles begin to separate under the applied shear. This is the cause of the time dependant rheological properties.

Some of these mechanisms will be transferred into concrete with the addition of waste paint. The primary rheological modifications to blockfill due to the addition of waste paint are most likely to be due to the actions caused by emulsion polymers, surfactants and thickeners. These rheological effects of adding waste paint to concrete masonry blockfill are investigated in Chapter 5.

2.6 Chemicals Currently Used in Concrete Masonry Blockfill

The following are the standard chemicals used by a local ready mix concrete supplier in the production of standard 17.5 MPa blockfill.

2.6.1 Pozzolith 370C

Pozzolith 370C is non-retarding, non-chloride, water reducing, strength enhancing admixture. It is made up of two key ingredients; calcium lignosulfonate and triethanolamine (BASF, 2006b).

*Calcium lignosulfonate* is an anionic polymeric surfactant which primarily acts as a water reducer, or wetting agent. It is found active at the interfaces of the water/air and water/particle surface and decreases the surface tension within the system. The result is an increased ability of the flow and spread of water across all surfaces, thus reducing the need for water. Calcium lignosulfonate also works as a retarder which prolongs the hydration process of cement, ultimately increasing the compressive strength (Griersona et al., 2005).

*Triethanolamine* is an organic chemical compound which serves two purposes within the admixture. Its primary purpose is as a pH balancer and aims to increase the pH of a mixture (although the pH of concrete water will already be high) but it also helps to keep the lignosulfonate in its charged (active) form.
2.6.2 Micro Air

Micro Air is primarily an alkylbenzene sulfonic acid surfactant and is active in stabilising foam. It works by keeping air stabilised in small bubbles and is used in high volumes within many industries due to its relatively high performance with respect to its cost (BASF, 2006a).

There is a significant chemical difference between this surfactant and the calcium lignosulfonate found in the Pozzolith 370C, but the practical difference is in the amount of foam stabilisation, the degree of substrate wetting (surface tension) and the strength of interaction between the surfactant and particles in the mixture. These factors have the net effect of influencing the fluidity/viscosity of the mixture, hydration rate, and final properties to some extent if the degree of interaction affects crystal growth during hydration.

2.7 Discussion: The Viability of Standard Chemical Replacement with Paint

From an assessment of the active chemicals in paint, and the standard chemicals presently used within blockfill, conclusions can be drawn on the theoretical success of the chemical replacement.

A primary ingredient in both Micro Air and Pozzolith 370C is surfactant, which covers a large range of chemicals (see Section 2.4.2). Water based paint is almost always alkaline and contains amines similar to triethanolamine, as well as various other types of surfactant of various nature suitable for dispersing and stabilising particles. Many of these will be inactive as they are present in concentrations that ensure that they are only effective in serving the purpose for which they were added to paint, whilst others are free to interact with other ‘species’ such as cement. The surfactant availability of paint varies by formulation and is difficult to determine given the range of formulations present in a waste stream. The total surfactant content in paint can vary up to several mass percent, including the surfactant within the polymer itself, through to the surfactant used during paint manufacture to aid in the dispersion of each ingredient. Pozzolith 370C contains a water reducer, which again based on the amount of chemical that is actually available, can be
found in waste paint in the form of a surfactant. The action of the calcium lignosulfonate found in Pozzolith 370C as a hydration retarder could possibly be simulated by the acrylic polymers found within waste paint which are known to retard the hydration of Portland cement (Wang et al., 2005).

In summary, the chemicals found within waste paint are similar to the chemicals currently used as admixtures in blockfill and possess the ability to act as air entrainers and water reducers. The concentrations and availability of these chemicals is not known and thus investigation is required to confirm their effectiveness.
CHAPTER 3

Phase One: Basic Material Properties

3.1 Introduction

Laboratory testing was completed to determine an initial approximation of the optimal paint dosage to achieve the desired properties of workability and strength. The results reported below on the various fresh and hardened properties of Paintcrete verify the potential of waste paint as a successful cementitious admixture. This ensured that the later experimental phases involving tests on a larger scale were undertaken with an enhanced knowledge of the optimal paint dosage, giving results comparable to that expected to occur when the material is applied at industry level.

It was decided that information would be collected on blockfill compressive strength, tensile flexural strength and spread (workability). The spread information was recorded as the blockfill was batched, while the flexural strength data was recorded after 28 days. Data were required on the compressive strength, and the strength gain with time, and hence cylinders were tested after 7 days, 28 days and 56 days.

Testing consisted of nine concrete cylinder samples, three flexural beams and three spread tests completed at 0%, 4%, 8%, 12%, 16% and 20% paint replacement of water by mass. Phase one retained the proportion of chemical admixtures used by the blockfill producer for a conventional mix, although the possibility of removing the admixtures was investigated later in the study.
3.2 Materials Used in Testing

3.2.1 Cementitious Materials

All materials used in phase one testing were identical to those found in the 17.5 MPa blockfill produced by a local ready-mix concrete plant. The mix design contained a water/cement ratio of 0.7 and a maximum aggregate size of 7 mm, as is standard for blockfill mixes in New Zealand. Sand and aggregate were collected directly from loading bins at the ready mix plant whilst the general purpose Portland cement was sourced directly from the cement manufacturer in Portland, Whangarei. These materials were assumed to have constant properties throughout phase one testing. The sand and aggregate contained a small amount of moisture, 4.2% and 3.4% respectively, which was not adjusted for in the mix design, which led to a slightly wetter mix with a corrected w/c ratio of 0.8. This was done to ensure that the blockfill was sufficiently ‘wet’ to enable the paint to uniformly disperse throughout the mix.

The mix contained aggregate, sand, ordinary Portland cement and water although the specific mix proportions and constituents have been intentionally omitted here due to the commercially sensitive nature of this information.

3.2.2 Chemical Admixtures

The following are standard chemical admixtures commonly used in a New Zealand blockfill mix. Refer to Section 2.6 for a chemical breakdown of these admixtures.

*Micro Air 940*

Micro Air 940 is an ultra stable air-entraining admixture used in all types of concrete. Micro-Air is particularly recommended when the desired air content has previously been difficult to maintain. Micro-Air is supplied as a ready-to-use aqueous solution, free of added chloride. It improves durability and workability, resistance to freeze/thaw cycles and it reduces permeability (BASF, 2006a).
Pozzolith 370C

Pozzolith 370C is a ready-to-use liquid admixture formulated to improve the performance of concrete in both the plastic and hardened states. Pozzolith 370C is a non-retarding, water reducing, strength enhancing admixture which does not contain added chloride (BASF, 2006b).

3.2.3 Waste Paint

The waste paint used in testing was sourced directly from the Resene Paintwise program, which recovers paint and packaging back from the community for useful application, rather than being consigned to bulk disposal. The paint is collected in large storage tanks, which results in a consistent end product, with little variation in properties. This ensures a stable national average in material quality, given the variety of paints collected.

The paint was sampled and tested at the paint collection factory to determine the variability of water content, pigment content and polymer content. Twenty samples were taken across four drums of paint, with the drum average results presented in Table 3-1.

The data shown in Table 3-1 indicates that paint is made up of approximately 50% water, ensuring that as water is removed prior to waste paint replacement, 50% of that water remains present in the mix. The remaining solid content of the paint, made up of polymers and pigments, is the source of possible variability, as paint manufacturers use many different pigments and polymers. As discussed in Section 2.4, paint contains many additives, in addition to the pigments and polymers, that are present in order to keep the paint stable. It is the summation of these constituents which generate changes in the way concrete behaves, with possible changes to air content, workability, setting times, and concrete density.

The paint was supplied for this testing program in 10 litre pales, and was subjected to approximately one minute of agitation by hand mixing prior to phase one testing. Based on visual inspection the paint was returned to a uniform state, ready for use within the blockfill mix. The colour of the paint was an “off grey”, slightly lighter, but not unlike the colour of typical concrete (see Figure 3:1).
Figure 3:1. Waste paint used in testing.

Table 3-1. Variability of paint samples obtained from the Resene Paintwise program.

<table>
<thead>
<tr>
<th>Drum</th>
<th>% Water</th>
<th>% Pigment</th>
<th>% Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46.6</td>
<td>28.9</td>
<td>24.5</td>
</tr>
<tr>
<td>2</td>
<td>47.9</td>
<td>22.5</td>
<td>29.6</td>
</tr>
<tr>
<td>3</td>
<td>48.7</td>
<td>26.9</td>
<td>24.4</td>
</tr>
<tr>
<td>4</td>
<td>47.1</td>
<td>28.8</td>
<td>24.1</td>
</tr>
<tr>
<td>Average</td>
<td>47.6 %</td>
<td>26.8 %</td>
<td>25.6 %</td>
</tr>
</tbody>
</table>

3.3 Test Procedure

All Phase One testing was completed in the Materials Laboratory within the Department of Civil and Environmental Engineering at the University of Auckland (see Figure 3:2). Blockfill was batched using two concrete mixers with 0.1 m³ and 0.01 m³ capacities, depending on the required output. The dry ingredients were added to the bowl and mixed for 2 minutes with 80% of the mix water. The waste paint was then added with the remaining mix water and mixed for 15 minutes.
Testing was undertaken in accordance with the relevant standard NZS 3112:1986 (SNZ, 1986).
3.4 Results

3.4.1 Cylinder Test Results

Three cylinders were tested for each paint dosage and time period. Results from crushing of the three cylinders (see Figure 3:4) were averaged and the data in Figure 3:5 shows this average value.

![Cylinder undergoing compression testing.](image)

Figure 3:4. Cylinder undergoing compression testing.

The 7 day results indicated peak strength at 12% water replacement for paint (see Figure 3:5). Data accuracy was ±0.5 MPa and with the spread of data points being approximately 2 MPa, the trend did not hold sufficient evidence to be considered valid (Refer to Appendix A.1). Also, the control test had a stronger compressive strength than the samples containing waste paint, suggesting that the paint had either reduced the cement matrix strength or simply retarded the mix, slowing down the speed at which strength was developed. Refer to Appendix A.1 for the full data set.

The trend witnessed after 28 days (see Figure 3:5) became further apparent, as expected. However the trend was slightly left-skewed, with the optimum value shifting towards 16%.
There existed a decline either side of this point, which suggested that the addition of too little waste paint was as detrimental as too much waste paint. It is also noted that the 16% data point exceeded the 17.5 MPa target, which is the standard required 28 day strength specified in NZS 4210, although the samples containing paint continued to lag behind the control test to a lesser degree than after 7 days.

![Graph](image)

Figure 3.5. Phase one compressive strength results.

The 56 day results (see Figure 3.5) continued to follow the trend shown after 7 and 28 days, with a further increase in strength. The overall result was that at around 8%-12% an optimum strength occurred, with both points safely above the specified 17.5 MPa minimum compressive strength (SNZ, 2001).

### 3.4.2 Spread Test Results

Spread tests were undertaken on the fresh blockfill on each day, prior to casting cylinders and beams. The purpose of this test was to investigate the material workability, allowing it to flow under its own weight. As dictated by NZS 3112, the blockfill was allowed to flow through an inverted slump cone, onto a level low friction surface forming a circular mound as shown in Figure 3.6. Two dimensions were measured at right angles to each other and averaged to obtain the spread data. The spread test is used in place of the more conventional slump test, in which the slump cone is used to leave the material in a cone shape, exhibiting a slump as the cone is removed. Due to the inability of the material to
hold the cone shape, the blockfill is thus allowed to spread. Three tests were completed per batch and the variance observed between tests was found to be negligible.

![Figure 3:6. Phase one completed spread test.](image)

The trend observed within the compressive strength data was also apparent in the spread test results, with a peak occurring at 12% paint replacement for water (see Figure 3:7). This peak spread value was 580 mm, which was well above the specified minimum of 450 mm (SNZ, 2001). Refer to Appendix A.2 for the full data set.

![Figure 3:7. Phase one average spread value.](image)
This trend was a convenient result, as when a higher workability occurs at the same time as higher compressive strength, it suggests that water can be removed from the mix and an even stronger hardened material can be achieved. This served as potential to bring the compressive strength of the Paintcrete samples closer to, or greater than the control sample, while maintaining a superior workability.

The other notable point is that the addition of paint increased the workability from a low paint replacement percentage, rather than the decrease observed in the compressive strength data, followed by a gradual increase. The trend did suggest however that the inclusion of too much paint will cause the paste to seize up, and lose workability.

### 3.4.3 Flexural Beam Results

Flexural beams were tested after 28 days using the procedure specified by NZS 3112 Part 2. The beams were loaded with two point loads and zero torsional restraint (see Figure 3:8), and the tensile flexural strength was calculated from the result.

![Figure 3:8. Phase one flexural beam sample ready for point load testing.](image-url)
Tensile flexural strength tests can be heavily affected by imperfections in the samples, which can cause early failure. This was evident in two tests and thus the data points were removed from the results. Refer to Appendix A.3 for the full data set.

The tensile flexural strength results (see Figure 3:9) further confirmed the apparent trend with the optimum value, which was similar to the strength of the control test, occurring at 12% water replacement for paint. The result was similar in scale and trend to the compressive strength results when compared to the control tests, and confirmed that the addition of paint did not specifically negatively affect the flexural tensile strength.

![Figure 3:9. Average tensile flexural strength results.](image)

### 3.5 Conclusions

The preceding tests were completed with the inclusion of both the standard chemical admixtures and waste paint. An optimum result was found to occur identically at 12-16% in compressive strength, workability and tensile strength. This was a positive result and indicated that Paintcrete had the potential to be successful on a larger scale.

The result of the mix containing both standard chemical admixtures and waste paint has resulted in excess levels of polymers and air entrainers. It was concluded that it is feasible that waste paint has the ability to replace standard chemical admixtures. This indicated the need to continue laboratory level experimentation to investigate the removal of chemical admixtures, before larger scale investigation commenced.
CHAPTER 4

Phase Two: Removal of Standard Chemical Admixtures

4.1 Introduction

The aim of the phase two laboratory testing was to confirm the ability of waste latex and acrylic based paint to replace standard chemical admixtures presently used in concrete masonry blockfill.

Investigation was required to confirm that:

- Compressive strength and workability was maintained within the limits of NZS 4210:2001;
- Workability was maintained over time. This simulated the event of a ready mix truck encountering delays whilst in transit;
- Air content was not excessively high or low, affecting yield and density;
- Excessive shrinkage did not occur.

This was confirmed through the use of modified mix designs and:

- Compressive cylinders;
- Spread tests;
- Air content tests;
- Shrinkage tests.
4.2 Materials Used in Testing

The materials used for phase two laboratory testing were identical to those described in Section 3.2.

4.3 Phase Two Compressive Strength Results

Phase two compressive strength testing involved the removal of the standard chemical admixtures and variation of the water/cement ratio (w/c) and polymer/cement ratio (p/c).

The standard 17.5 MPa mix design as provided by a ready mix concrete manufacturer, with a specified 0.7 w/c ratio, was used. Two mix designs were trialled, one with a standard w/c ratio, referred to as Series A, and one with a higher w/c ratio, referred to as Series B. In each test a different percentage of paint by mass was added, with the identical mass of water removed. The net variation of w/c ratio within tests was due to the varying amount of water removed being based upon the percentage of paint added. The water content of the mix included the water content of the waste paint itself (~47.6%). The parameters for each trial are outlined in Table 4-1.

Six cylinders were tested for each paint percentage in Series A and B. The full data set is shown in Appendix A.4.

Table 4-1. Water/cement (w/c) and polymer/cement (p/c) ratios of phase two compressive testing.

<table>
<thead>
<tr>
<th>Paint %</th>
<th>Series A</th>
<th>Series B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/c</td>
<td>p/c</td>
</tr>
<tr>
<td>0%</td>
<td>0.700</td>
<td>0</td>
</tr>
<tr>
<td>4%</td>
<td>0.686</td>
<td>0.007</td>
</tr>
<tr>
<td>8%</td>
<td>0.672</td>
<td>0.014</td>
</tr>
<tr>
<td>12%</td>
<td>0.658</td>
<td>0.021</td>
</tr>
</tbody>
</table>
4.3.1 Test Procedure
Testing was completed in the Materials Laboratory within the Department of Civil and Environmental Engineering at the University of Auckland (see Figure 3:2). Blockfill was batched using a concrete mixer with 0.1 m³ output. The dry ingredients were added to the bowl and mixed for 2 minutes with 80% of the mix water. The waste paint was then added with the remaining mix water and mixed for 15 minutes.

Testing was undertaken in accordance with the relevant standard NZS 3112:1986 (SNZ, 1986).

4.3.2 Phase Two Compressive Strength – Test A

![Graph showing the relationship between water replacement by paint and compressive strength](image)

Figure 4:1. Phase Two 28 Day compressive strength – Test A.

The results of Test A after 28 days (see Figure 4:1) showed a distinct linear decrease in compressive strength as the waste paint content was increased. It can be seen from the density of the cylinders (see Table 4-2) that this was due to the increasing air content. The linear relationship between the increased paint content and decreased strength confirms that the increased paint proportion was having a negative effect on the strength of the blockfill. The finding was contrary to the result obtained from phase one testing. Chemical admixtures were present in phase one and the water content was higher, which led to an increase in compressive strength with the addition of waste paint.
### 4.3.3 Phase Two Compressive Strength – Test B

The trend shown in Figure 4:2 indicates that the required strength had been achieved similar to the trend observed in phase one. This result contradicts conventional concrete theory, which would suggest that the addition of water results in strength loss. Without the addition of waste paint, increased water content would have reduced the compressive strength of the blockfill. This indicates that the paint has made a contribution to compressive strength, with the Paintcrete mix reaching a similar strength to the control sample. It is apparent that the waste paint has not enabled a greater overall strength to be attained, but instead causes a decrease in compressive strength if not added in the correct conditions. It remains to be determined why the paint was not aiding in strength development at the lower w/c ratio.

### Table 4-3. Density of Phase Two cylinders – Test B.

<table>
<thead>
<tr>
<th>% Paint</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2138</td>
<td>2119</td>
<td>2238</td>
<td>2210</td>
</tr>
</tbody>
</table>
4.3.4 Discussion

The amount of water available within the blockfill to which waste paint was added offers several possible explanations for the strength variation. It is possible that any combination of the following explanations could be responsible for the observed results. More specific testing with a broad understanding of chemistry is required to confirm which theories are active. Refer to Chapter 2 for the relevant background theory to the following discussion.

Deactivation/activation of chemicals affecting foaming

An initial explanation prompts that the water is activating/deactivating the ingredients within paint that control foaming. Paints are stabilised with surfactants (see Section 2.4.2) which, unfortunately, also help to stabilise air introduced during manufacture and application. Paint also contains ingredients such as antifoams (see Section 2.4.3) which primarily work by lowering the surface tension in the neighbourhood of the foam, causing them to break and thus minimise foaming, which would be detrimental to the application of paint (Lambourne et al., 1987). Increased air content has the obvious implication of a decreased concrete density and resulting concrete strength lost.

Flocculation avoidance

A more likely explanation is that the higher water content allows the particles to avoid flocculation. Should the particles be given a larger medium, the particles would be spread out causing flocculation to become less likely. This would suggest that the method used to add the waste paint to concrete could be just as important as the presence of extra water in the first instance. Should particles be allowed to flocculate they would produce weak points within the hydrated cement. Should the particles avoid flocculation, the number and size of the weak points would be minimised, whilst the even distribution of the finer material would assist in increasing the density due to the application of fine particle packing (see Section 2.3). The avoidance of flocculation is also a function of how the paint is added to the cementitious material. Should paint be added to a drier material, flocculation would be encouraged, and the addition of water after the event may not necessarily break up the flocculated particles, or may require a large amount of shear.
Diluting of surfactants
A further plausible theory that could be working in parallel with the preceding theories is that the surfactant which stabilises the bubbles (which cause high air content) could be lowered in concentration with the extra water, resulting in a reduced amount of foam. The amount of free surfactant active in the paint is not known; although it is more likely to be a small amount, in which case the addition of 15-20% more water would effectively dilute the chemical to a large extent. This is shown from the densities in Table 4-3, which appear to have increased from those shown in Table 4-2.

4.4 Elastic Modulus

Elastic modulus data was collected during the compression testing of the phase two – test B cylinders. Two strain gauges were fitted to the cylinders, measuring displacement which was then converted to strain (see Figure 4:3).

![Figure 4:3. Compressive strength test collecting stress and strain data.](image)

4.4.1 Results
The two strain gauges measured vertical deflection data which was transmitted through a data logger, into a computer which plotted the stress data against the strain data, from
which the elastic modulus, $E$, was assessed. The elastic modulus was taken from an early section of the stress/strain profile which was deemed to be linear. The results of three tests at each percentage were collected for 4%, 8% and 12%, from which the average $E$ value was taken and plotted on the graph shown in Figure 4:4. Refer to Appendix A.4 for the full data set.

![Figure 4:4. Elastic modulus data.](image)

Comparison of the elastic modulus data to the compression strength data for the cylinder shown in Figure 4:2 shows that both data sets followed a similar profile. This indicates that the elastic modulus of concrete masonry blockfill with the addition of waste paint is a function of the compression strength, not the presence of polymers. The data point for the 12% paint replacement for water is the only outlier, with identical strength to the 8% specimens, but having a lower elastic modulus. This suggests that as the polymer content becomes high enough, it begins to have a greater effect on the elastic deformation of the material, whilst still maintaining strength.

### 4.4.2 Discussion

The trend shown in the results in which the compressive strength and elastic modulus are related, is concurrent with the investigation carried out by Cook and Crookham (1978) in which “the load-deformation behaviour for polymer modified concrete indicated that the stiffness of the varying mixes relative to the control mixes closely followed trends indicated by strength behaviour” (see Section 2.2.2). Cook and Crookham also noted that the failure mode exhibited more ductility, although that data was not collected in this study.
4.5 Drying Shrinkage

Drying shrinkage testing was completed to ensure that the extra water was not increasing the amount of shrinkage. Shrinkage occurs as the masonry units extract water from the blockfill during the curing process, and thus excess water can lead to greater shrinkage, introducing cracking in the porous matrix and reducing the bond between the blockfill and the masonry units themselves. Drying shrinkage is influenced by a variety of factors including; environmental conditions, area of material and volume of aggregate. However the main variable is water content (Wittmann, 1982).

4.5.1 Test Procedure

Four stacks of 20 series (190 mm) masonry blocks that were six units high were constructed with mortar and filled with the same blockfill as used in Phase Two Compression Testing – Test B (as outlined in Section 4.3.1) with two stacks for each 8% and 12% dosages. Twenty five cycles with a tamping rod were applied three times as the blocks were filled; at 1/3 grouted, 2/3 grouted and full. The 20 series masonry blocks were used because shrinkage occurs as a function of the area of a material, and thus the greater cross sectional blockfill area required with 20 series blocks, as opposed to 15 series, places a higher demand on the material to avoid shrinkage. The test setup was constructed against a wall for lateral support as shown in Figure 4:5.

![Figure 4:5. Shrinkage test setup.](image-url)
The water content of the mix design selected, being higher than the mix design used commonly within the concrete industry, simulated a worst case scenario, as the amount of drying shrinkage observed is closely related to the water content. Three days after the stacks were filled, before the blockfill had gained significant strength but after shrinkage had occurred, the test specimens were broken at several points over their height, and the internal shrinkage of the grouted cores was observed.

4.5.2 Results

The 8% block stack showed good interface between the blockfill and the concrete masonry units. The absence of cracks and uniform bond indicated that the blockfill did not exhibit excessive shrinkage during the drying process. A small amount of water appeared in several locations on the exterior of the blocks, mainly in the mortar region between the units. However this was minimal and not considered greater than usually expected during the blockfill curing period.

The off-grey section of the blockfill showed where the tapered section of the interior channel of the concrete masonry units had overlapped. This zone can indicate vertical shrinkage and if the blockfill had shrunk at any point, the bond between the two surfaces would have been lost. This grey fracture area represents where that bond was broken as the specimens were fractures for analysis and thus ensured that the bond had been maintained.

Figure 4:6. Full view (left) and zoomed view (right) showing a cross section of the 8% block stack.
The 12% block stack showed similar results to the 8% stack, with a uniform bond between the blockfill and the concrete masonry units. No cracking was evident and the off-grey region again confirmed that a bond was achieved at the underside of the overlapping region.

Figure 4:7. Full view (left) and zoomed view (right) showing a cross section of the 12% block stack.

4.6 Change in Workability over Time

Spread tests were carried out at a constant waste paint percentage of 12%, based on the optimum suggested by earlier testing. Variation was introduced by removing the admixtures and introducing waste paint, in an effort to indentify the best and worst case scenarios. The following mix design additives were tested (see Table 4-4), by being added to a standard 17.5 MPa blockfill mix that had quantities of cement, aggregate, sand and water as instructed by a local ready mix concrete provider.

Table 4-4. Slump vs. Time mix designs

<table>
<thead>
<tr>
<th>Material</th>
<th>Micro Air</th>
<th>Pozzolith</th>
<th>Paint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test One</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Test Two</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Three</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Test Four</td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>
4.6.1 Test Procedure

Testing was completed in the Civil Materials Laboratory within the Department of Civil and Environmental Engineering at the University of Auckland. Blockfill was batched using a concrete mixer with 0.1 m³ output. Testing was undertaken in accordance with the relevant standard NZS 3112:1986 (SNZ, 1986).

The materials used for phase two laboratory testing were identical to those as described in Section 3.2.

Slump tests were then carried out at 20 minute intervals over 80 minutes, with the blockfill mix being left static over the 20 minutes between tests. Immediately prior to each test the mix was given 20 seconds of mixing to ensure that any bleeding or segregation that may have occurred was not causing inconsistencies within the material. The slump cone and test surface were wet immediately prior to each test.

4.6.2 Results

![Figure 4:8. Slump vs. Time results](image)

The results of this test on the change in workability over time of Paintcrete were very positive (see Figure 4:8) as it is immediately noticeable that the only mix design that exhibited poor performance was the one that contained no admixtures or waste paint, test two. During testing it was observed that test two seized up completely at the conclusion of 80 minutes and was almost unable to pass through the inverted slump cone. The
performance of the other three tests was almost inseparable and the blockfill maintained a consistent slump for the duration of the test. Refer to Appendix A.6 for the full data set.

It was thus concluded that waste paint on its own is just as effective as conventional concrete admixtures (Micro Air and Pozzolith 370C) at maintaining workability.

### 4.7 Conclusion

The tests reported in this chapter indicated that when waste paint is added to concrete masonry blockfill in the right concentration, in conjunction with sufficient water content, it can perform successfully without the need for conventional chemical admixtures. Strength and workability are maintained and improved respectively, with no excessive shrinkage or changes in elastic modulus.

Increased water content was required to allow the waste paint to contribute positively to the material properties of the blockfill. This was due to the deactivation/activation of chemicals affecting the air content, as well as to create a medium which encouraged the even dispersion of particles within the mix.

The optimum paint dosage was found to be 8-12% for replacement of water on a basis of achieving the required 17.5 MPa compressive strength, whilst maintaining workability and drying shrinkage. The varying elastic modulus value was determined to be primarily a function of compressive strength. However at a higher paint dosage (12%) an elastic modulus decrease was recorded, suggesting that a higher volume of paint is required in order for it to affect stiffness properties.
CHAPTER 5

Paintcrete Rheology

5.1 Introduction

The accurate description of a cementitious material’s ability to flow is often difficult as the generally accepted methods of assessment are qualitative and results can vary widely based on testing conditions such as force application, friction and equipment condition. These qualitative tests include slump tests, spread tests and L-box tests, which all involve factors that are difficult to keep as a constant.

A desired property of Paintcrete is to reduce or remove the need for vibration after its placement in a concrete masonry wall. This requires the rheological properties of Paintcrete to be similar to that of self-compacting concrete (as outlined in Section 2.5.2).

Rheological information was gathered to apply a more scientific description to the effects that the addition of waste latex and acrylic based paint had on the concrete masonry blockfill. A series of tests were completed at the University of Canterbury, Civil Engineering testing facility, with varying dosages of waste paint for replacement of mix water. The basic quantity and quality of constituents in the mix were constant throughout testing, with waste paint being the only variable.

5.2 Testing Details

5.2.1 Testing Materials

The materials used for rheological testing were identical to those described in Section 3.2, sourced from the same locations and relocated to Christchurch for testing.
5.2.2 Viscometer

Testing was completed on the BML4 Viscometer, shown in Figure 5:1 and Figure 5:2, which is a coaxial cylinder viscometer suitable for measurement of cement paste, mortar and concrete with an 80 mm slump or higher. The rheological properties are described by the fundamental parameters of the Bingham model: yield value and the plastic viscosity.

Figure 5:1. The BML4 Viscometer used to obtain rheological data.

Figure 5:2. Paintcrete undergoing rheological testing in the BML4 Viscometer.
5.2.3 Testing Procedure

Blockfill was mixed in a small mixer capable of a 0.025 m³ batch volume. The dry ingredients were combined together and then subjected to shear whilst the mix water was added. Blockfill was transferred from the mixer into the viscometer, which was filled to the top surface to ensure that the rotating blades made maximum contact with the material.

The viscometer blades were lowered into the material by releasing the hydraulic jack. The test was then initiated, which consisted of varying rates of shear, applied to the material in steps over a time period. The elapsed time during each rate of shear was divided into two parts. For the first short period of time, no torque or shear stress was logged, to allow the major breakdown of agglomerates to occur, after which the data was recorded, which represented the equilibrium shear stress for the given rate of shear. At the conclusion of the test the shear was increased to the maximum, and then reduced to 2/3 of the maximum when an additional measurement was done, in order to evaluate any change in the results. This last measurement indicated the growth of segregation during testing. This is explained in the graph shown in Figure 5:3.

![Figure 5:3. Change in rate of shear over time whilst collecting rheological data.](image)

At the conclusion of each test the majority of the blockfill was put back into the mixer with the remaining mix and rotated to ensure the blockfill was consistent prior to the next test.
5.2.4 Mix Design
The mix design used for this testing was consistent with that used in the initial laboratory studies as discussed in Section 3. This consisted of the standard 17.5 MPa blockfill mix with 0%, 4%, 8%, 12% and 16% replacement of water with waste paint by mass.

5.3 Results

5.3.1 Yield Shear Stress
Fresh concrete requires a force to be applied in order for it to flow i.e. it has a certain resistance to flow. The force required to initiate the flow is called the yield shear stress, \( \tau_0 \). Refer to Section 2.5 for a more detailed description of the rheological properties described below.

The rheological data shows a simple result for the change in yield shear stress with the addition of waste paint (see Figure 5:4). The trend suggests that at 0 minutes with the addition of waste paint the yield shear stress of the material increases by 30%, to be an approximately constant amount regardless of the paint concentration of the paint.

![Figure 5:4. Yield shear stress at 0 minutes.](image-url)
5.3.2 Plastic Viscosity

The plastic viscosity, \( \mu \), is a measure of the resistance of the material to an increase in the rate of flow. This is the force that must be resisted once the initial yield shear stress has been overcome.

The viscosity of the mix experienced a large drop with the inclusion of waste paint (see Figure 5:5). It is notable that the viscosities observed from the mixes containing paint were lower than any others that the operator of the viscometer had seen throughout his use of the machine. The resistance that must be overcome to keep the material flowing once it has been initiated was thus very small.

![Figure 5:5. Viscosity at 0 minutes.](image)

5.3.3 Separation

The hazard associated with a mix containing a low viscosity is that segregation will occur due to the aggregates “falling” though the mix. This occurs because when shear is being applied, the mix behaves in a liquid manner, creating a scenario comparable to dropping a handful of pebbles into a glass of water and observing them settle at the base. The separation data from the tests shown in Figure 5:6 give very different results from this theory.
The trend shows that as the viscosity decreases with paint concentration increase, the separation is also observed to decrease. The separation data was collected by the viscometer by repeating a rate of shear at the conclusion of the cycle and comparing it to the result found initially. This gave an indication of how much separation had occurred during the test while the material had been subject to differing rates of shear.

5.3.4 Change in Rheological Properties over time

Data was collected at 15, 30, 45 and 60 minutes after the initial test at 0 minutes. This data indicated the change in rheological properties over time.

The change in yield shear stress, $\tau_o$, over time is shown in Figure 5:7. It can be observed that the greatest increase in $\tau_o$ occurred in the 0% paint control mix. The remaining mixes which include paint, showed a lesser increase of $\tau_o$ which suggested that whilst the addition of paint has increased the overall value of $\tau_o$, over time it aids in retaining $\tau_o$ and avoiding stiffening of the material.
The change in plastic viscosity, \( \mu \), over time is shown in Figure 5:7. There is a gradual increase in \( \mu \) across all mixes with no trend apparent based on the presence of waste paint. The gradual increase is explained by the concrete stiffening up as the cement hydration process commenced.

Figure 5:8. Change in plastic viscosity over time.
5.4 Discussion

The results obtained above for the rheological modification of concrete masonry blockfill with the addition of waste paint are discussed below. This is done with reference to the principles and theory discussed in Chapter 2.

5.4.1 Yield Shear Stress

The most common method used in instances where it is considered desirable to increase the yield shear stress of a mix is to reduce the mobility of the particles, which can be done simply through the addition of particles, creating an effect similar to trying to move quickly through a dense crowd of people. The close packing of particles makes some flocculation inevitable, causing particles to impede the movement of their surrounding particles (Turner, 1988). Another method involves introducing some force that holds the particles together, discouraging movement. The unique situation of adding paint to concrete means that the many ingredients that are in paint to make it suited to its application, are introduced to a new medium, and have the ability to alter its properties. The additives that are active in increasing the yield shear stress, which can be found as an ingredient in paint market-wide, are known as thickening agents. A description of the function of thickeners is detailed in Section 2.4.5.

5.4.2 Plastic Viscosity

As shown earlier in Figure 2:5, increased air content can lead to a viscosity reduction. The air contents of the mixes used in the above rheological testing are shown in Table 5-1. The increasing air content within the mix is likely to partly explain the plastic viscosity reduction. The air content increase is consistent with that observed in the compression testing of Section 4.3, but is likely not the only mechanism affecting viscosity given the number of other chemical interactions involved.

Table 5-1. Air content of mixes used in rheological testing.

<table>
<thead>
<tr>
<th>Paint Content</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
<th>16%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Content</td>
<td>6.3%</td>
<td>11.5%</td>
<td>11.5%</td>
<td>11.5%</td>
<td>11%</td>
</tr>
</tbody>
</table>
The drop in viscosity could also be explained by the large amounts of surfactant within paint. A description of the function of a surfactant is detailed in Section 2.4.2.

Whilst normal concrete chemical admixtures contain surfactants, the higher quality and quantity that might result from the concentrations of surfactant within paint indicate that they may have a greater effect. It is unavoidable if a surfactant is added to a medium that contains a lot of water that there will be an interruption of the surface interactions between the particles, resulting in a viscosity decrease. This action is not likely to be the only explanation for the dramatic viscosity decrease as the amount of the free surfactant available within the paint is likely to be minimal, as it will primarily be tied up with the latex and pigments.

An alternative and more likely reason for the viscosity reduction observed is related to the neutralising of relatively strong interactions within the concrete itself. There are several types of reactions active within concrete, although electrostatic interactions with assistance from hydrogen bonding are the most obvious (Taylor, 1997). Electrostatic interactions depend upon the angular orientation of the surfaces on which they act, and thus in the case of the angular particles within concrete, there will likely be sites with higher electric charge than other sites (Adamczyk, 2003). If these sites interact with each other, resulting in stronger bonds holding the mixture together, it is possible that surfactant could be effective in neutralising some of the charges and hence reduce the effectiveness of the bond. The result of weakening the electrostatic interactions would be observed primarily as a viscosity decrease. This result would not require a large amount of surfactant, as an equilibrium would be set up favouring surfactant-particle interaction at the highest charge location on the particle surface. Most of the surfactant within paint is non-ionic and is reported to not interact with cement (Merlin et al., 2005). Non-ionic surfactants do not have an electrical charge, which makes them more durable as they are immune from electrical deactivation due to positive charges that can be present in “hard water”. There is a small amount of anionic (negative charge carrying) surfactant active within paint, as well as a reasonable amount of polymeric anions. The charge provided by these anionic particles could provide sufficient force to upset the electrostatic interactions described above.
5.4.3 Separation

The improvement in segregation can be explained with a similar theory to that found in the yield shear stress data. The thickeners that are found active within paint, which grab hold of any particle available whilst avoiding water, are largely disabled with the application of shear. The bond between particles is broken, but the thickeners are left holding on at either end to some extent, and are able to still suspend the particles within the mix and prevent or slow down their ability to separate. The other likely phenomenon occurring is due to the polymers within the paint. The polymers create a ‘structure’ within the paint, similar to the concept of thixotropy discussed in Section 2.5.3.

5.5 Conclusions

The rheological information gathered in the preceding explanation allows the following conclusions to be drawn. It was a goal for Paintcrete to exhibit the rheological properties of self-compacting concrete (SCC). As discussed in Section 2.5.2, a rheological description of SCC can vary widely between concrete specialists, although it is generally accepted that if plastic viscosity is low, <40 Pa.s, then the SCC should have a significant yield value, >60 Pa. Opposed to this, if the SCC has a high plastic viscosity, the yield value must be close to zero (Wallevik, 2006). This theory cannot be applied directly to Paintcrete as it is based around the idea that there is a risk of the course aggregate separating through the mix if either value becomes too low. There is less risk of this happening in Paintcrete due to the mechanisms introduced from the paint working against this, as shown by the extremely low viscosity value with little to no separation.

The increase in yield shear stress has caused Paintcrete to fall outside the envelope of traditional SCC and suggests that whilst there should be improvements in the flow characteristics, a small amount of vibration should be required. Based on the rheological properties, once the yield shear stress has been overcome primarily using gravity and the force applied by the concrete pump as Paintcrete is pumped into a concrete masonry wall, the material should have almost no resistance to flow. It is not clear from this data what will happen at this point as to whether the blockfill will retain its liquid properties and commence flow, “splatter” and come to a rest, or be affected by the friction from the
interior of the masonry blocks and reinforcing steel. A fair approximation may be that Paintcrete is not likely to flow quite like SCC, although given the low plastic viscosity only a tiny amount of vibration will be required to overcome the yield shear stress and produce a uniform fill throughout the wall, and around congested reinforcement.

Full scale trials are required to confirm how the rheological properties are transferred into full scale application.
CHAPTER 6

Full Scale Industry Trials

6.1 Introduction

Based on the results from the rheological testing in Chapter 5, which gave a quantitative description of the workability of Paintcrete and its ability to function as a blockfill, large scale testing was required to assess if the properties identified were valid at industry level.

Qualitative testing on concrete masonry walls was conducted at two sites which had low risk applications, to assess the ability of Paintcrete to perform successfully at a larger scale and in an industry application. The aim of the tests was to observe the ability of Paintcrete to flow within the wall, and examine what properties it exhibited which were superior to conventional blockfill, such as:

- Faster rate of filling;
- Filling from fewer points;
- Eliminating the need for vibration;
- The ability to flow around corners and openings.

6.2 Current Methods of Grout Consolidation

The consolidation and reconsolidation process of masonry grout is imperative to ensure the overall success of a grouted concrete masonry structural element. It ensures a low void grout that provides a secure interface to the masonry units and any reinforcement present. This process can represent a significant portion of the time and cost of grouted masonry construction (NCMA, 1999). It is this economical importance which has led to research into optimising the consolidation process and the development of self-compacting grout technology.
NZS 4210:2001 sets out requirements for the materials and workmanship of clay, concrete and natural stone masonry to be used in conjunction with NZS 3604, NZS 4229 and NZS 4230 for the construction of masonry buildings and veneers in New Zealand (SNZ, 2001). The term ‘compaction’ is used, referring to grout consolidation which in the case of masonry walls is referring to an Immersion Vibrator. These are commonly referred to as ‘poker’ or ‘spud’ vibrators and consist of a tubular housing which contains a rotating eccentric weight which creates a ‘vibration’. When immersed in concrete the vibration is translated and causes the concrete to compact. The size and amount of vibration required is a function of the workability of the concrete or blockfill. Thus a more workable material requires less vibration and less labour (CCANZ, 2007a).

NCMA (1999) reported on the various grout consolidation techniques currently used within industry and if an opportunity existed to save material or time in reducing overall project cost. The goal was to determine if the method of consolidation, addition of grout admixture, or the time between consolidation and reconsolidation had a significant impact on the physical properties of the constructed masonry. The research consisted of the testing of 10 individual piers constructed from conventional masonry blocks, 1 unit in depth and 9 units in height. The method of consolidation, presence of grout admixture and time between consolidation and reconsolidation were varied amongst samples. After construction, core samples were taken from each pier and tested for compressive strength and bond strength between the grout and the face shell of the concrete masonry unit (NCMA, 1999).

The results of the study showed that while the various consolidation methods appeared to have only minor effects on the resulting compressive strength and measured shear strength, the addition of grout admixture to the grout significantly decreased the bond capacity between the unit and the grout while having no effect on compressive strength.
6.3 Trial Wall One

A wall with low risk implications was located at a processing factory and selected to be subject to the first full scale industry trial of blockfill grout containing latex and acrylic water based paint. The wall was designed as a wash bay, with very little structural demand, and a simple design containing a “U” configuration with no openings, and is shown in Figure 6:1 and Figure 6:2.

![Figure 6:1. Trial wall one detail.](image)

The test was planned to be purely qualitative in nature, with no physical data being collected. The undemanding properties of the wall made it an ideal project to highlight the positive and negative effects of the waste paint. This step was required to establish that the masons involved in the construction phase were satisfied with the material.
Figure 6:2. Trial wall one prior to filling.

Figure 6:3. Waste paint being added to the ready-mix blockfill.
The mix design consisted of the standard 17.5 MPa blockfill mix as provided from a local ready mix provider, with the chemical admixtures removed and 8% water replacement for waste paint on mass. The waste paint was not from the Paintwise paint recovery stream; rather it was recovered from the Resene Paints factory from a rejected batch of paint. The particular paint Lumbersider is Resene’s highest selling paint and it is a reasonable approximation that this paint would make up 20-40% of the waste paint stream collected by the Paintwise program. It was mixed and measured on site and added directly to the ready-mix truck on arrival as shown in Figure 6:3.

Paintcrete was pumped from the concrete truck by several men with the use of a concrete pump and crane arm through a hose into the wall as shown in Figure 6:4. The wall was initially filled from one end and the blockfill was observed to flow well around the first corner.
During filling of the wall the contractors operating the pump, who had extensive experience with the filling of concrete masonry walls, formed positive impressions about the qualities of the blockfill. They made comments on the strange texture that was “a bit smoother” than standard blockfill. While smoothing off the top surface of the wall, comment was made that the blockfill was easy to trowel and was similar in texture to “icing a cake”. Observed shrinkage was minimal as shown in Figure 6:5.

![Figure 6:5. The same section of wall before (left) and after (right) the blockfill had cured, showing minimal Paintcrete shrinkage.](image)

The only negative comment to come from the contractors was in reference to the slight odour that came from the blockfill as a result of the paint. The smell of paint was clearly present although not excessive and had dissipated within a short time of the wall being filled.

The end result was a successful trial and the masons on site were pleased with the end product and had several positive things to say. They felt that Paintcrete “flowed well, clearly with no need for re-vibration”.
6.4 Trial Wall Two

The second test wall was located at the ready-mix blockfill plant, and was contained internally within a portal frame building. The wall was to have low structural importance and was designed in accordance with NZS 4229:1999. 15 series masonry units were selected for the job as they were narrower than the 20 series masonry used most commonly within the industry. This was considered to be a worst case scenario, and highlighted the ability of PaintCrete to flow within confined spaces.

The wall was far more complicated than the previous example, and was to contain openings, a corner and a tighter channel width due to the reduced block size of 140 mm. The wall is detailed in Figure 6:6, with two blocks removed on the long side, and replaced with Perspex windows to allow observation of how well the blockfill flowed.

![Figure 6:6. Trial wall two layout details.](image-url)
The mix design employed in this trial was identical to the mix design used in section 4.3.3. This was the standard 17.5 MPa blockfill mix with the higher water content, which achieved a higher compressive strength. Again the dosage of waste paint was 8% water replacement for paint based on mass.

6.4.1 Results

The concrete masonry wall was filled with Paintcrete on Friday 5\textsuperscript{th}, October 2007. The ready mix truck was filled with aggregate, sand, cement and water, at which point spread tests were taken before waste paint was added to the truck by hand. The blockfill was then rotated at high speed in the ready mix truck for 15 minutes. The ratio of actual/calculated constituents used in mix by mass is shown in Table 6-1 and indicates the accuracy to which the material was added to the ready mix truck. An excess of the dry ingredients, sand and water (~20%) were added to the truck, which coupled with a deficiency of water (~5%) led to a dry mix. This was human error by the blockfill plant operator, and is understood to happen regularly. Therefore this situation represented a typical scenario.

Table 6-1. Summary of trial wall 2 showing percentage error whilst batching the mix.

<table>
<thead>
<tr>
<th>Material</th>
<th>Actual/Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>106%</td>
</tr>
<tr>
<td>Sand</td>
<td>114%</td>
</tr>
<tr>
<td>Cement</td>
<td>95%</td>
</tr>
<tr>
<td>Water</td>
<td>96%</td>
</tr>
</tbody>
</table>

The lack of water from the mix can be seen from the spread data (see Table 6-2), taken 15 minutes after the truck had left the batching plant but before the addition of paint. The blockfill that was in the truck prior to the addition of paint had a higher water content than the mix design prescribed by the local ready mix supplier due to the alterations made to the design based on the results of laboratory testing. This should have ensured that the workability of the mix should have been at least as workable as the standard blockfill currently used within the Auckland industry. The spread result of 315 mm is far below the expected 500 mm spread.
Table 6-2. Spread test results from blockfill prior to the addition of paint.

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spread (mm)</td>
<td>315</td>
<td>320</td>
</tr>
</tbody>
</table>

After the addition of paint to the ‘dry’ blockfill mix, the workability was restored as can be seen from the spread results in Table 6-3. The average spread value of 510 mm was an acceptable value for which a wall can be filled with blockfill. However in this application a higher spread should have been recorded had the materials been added with more precision.

Table 6-3. Spread test results from blockfill after the addition of paint.

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spread (mm)</td>
<td>480</td>
<td>520</td>
</tr>
</tbody>
</table>

The compressive strengths were lower than the standard required 17.5 MPa and are shown in Table 6-4. The average compressive strength result of 16 MPa was 8% lower than was expected. Air content data was not collected on the day of testing due to failure of equipment. However from the average density of the compressive strength test cylinders conclusions can be drawn on the air content of the mix. The density of the mix was 1924 kg/m³, which was 10% lower than the desired 2128 kg/m³.

Table 6-4. 28 day compressive strength of trial wall 2.

<table>
<thead>
<tr>
<th>Cylinder 1</th>
<th>Cylinder 2</th>
<th>Cylinder 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f' c$ (MPa)</td>
<td>16.55</td>
<td>16.04</td>
</tr>
</tbody>
</table>

6.4.2 Qualitative Results

The addition of waste paint markedly improved the properties of the fresh concrete, from a dry mix unsuitable for use in a concrete pump, to a workable usable product. The block masons expressed no negative opinions towards the blockfill and were satisfied with the end result. The blockfill did not flow as was hoped around the corner and past the Perspex windows. The blockfill performed in a similar fashion to standard blockfill and required filling from several points.
It can be observed in Figure 6:7 that the Paintcrete was not self levelling or flowing, and acted in a similar way to standard blockfill coming to rest on reinforcement and against the inside of the masonry blocks. The contractors decided that the wall did not require
vibration and were happy that Paintcrete had settled in suitably amongst the reinforcing and into tight corners. The result as seen from above the wall is shown in Figure 6:8.

6.4.3 Discussion

It is an immediate observation that the low compression strength was consistent with the results recorded in Chapter 4 in which the compressive strength is reduced as a result of high air content brought about due to the lack of mix water. This creates concern that Paintcrete is less resilient to errors at the blockfill plant than standard blockfill and carries a greater risk, or at least requires more care during preparation. Despite this, it is a clear observation that the addition of waste paint was able to save a blockfill mix that would have otherwise been useless. Given the way in which the ready mix industry operates in NZ, should a mix arrive at site in a similar condition to the 315 mm mix observed before the addition of paint, water would have been added by the truck driver, until the blockfill reached the required spread. This would have had an even greater effect in lowering the compression strength than the addition of paint, as the water/cement ratio would increase rapidly.

The results of this test suggest that it may be necessary to measure the spread of the blockfill before the addition of waste paint, to ensure that the paint is being added to a medium in which it is able to properly disperse. Having a suitable amount of free mix water appears to be primary in ensuring the waste paint contributes positively to the compressive strength of the material.

6.5 Conclusion

Both Paintcrete trial walls, ignoring experimental and human error, were successful. If more time was available, it would have been useful to carry out one more full scale trial with the correct dosage of materials to see how Paintcrete flowed and to confirm the compressive strength theories expressed in Chapter 4 on a larger scale.

Paintcrete was received positively by the experienced block layers and contractors who worked with it. It is important that the people within the industry are happy with the
product and are willing to use it. They deal with blockfill on a daily basis and outside of the direct science that can be applied, are the most qualified to decide if Paintcrete suits its application.

The blockfill supplied for both walls lacked the intended water content and thus direct conclusions cannot be drawn on the workability advantages of Paintcrete. It can be concluded that the addition of waste paint saved the workability of an otherwise dry unusable mix.

Paintcrete does appear to carry more risk than standard blockfill and the success of the product is dependent on the accurate measurement of the ingredients that make up blockfill. This accurate measurement will ensure that the waste paint is added to a medium in which it can contribute positively to the fresh and hardened properties of blockfill.
CHAPTER 7

Full Scale Seismic Testing

7.1 Introduction

A concrete masonry cantilever wall was constructed in the Civil Engineering Test Hall at the University of Auckland. The primary objective of this experiment was to investigate the simulated seismic performance of Paintcrete blockfill by comparison to a nominally identical test wall with a standard 17.5 MPa blockfill that was constructed and testing during an earlier study. The purpose of the test was to examine if the pseudo-static performance of Paintcrete blockfill held any advantages over the standard blockfill, or exhibited any major flaws. Unless otherwise noted, both walls were constructed and tested under nominally identical conditions.

7.2 Construction Details

7.2.1 Wall Specification

The masonry wall selected for testing (wall A) was chosen from a series of walls completed by Voon (2007) during a doctoral investigation of the in-plane seismic response of concrete masonry structures at the University of Auckland. The walls were designed to fail in shear and thus exhibited excessive vertical reinforcement with minimal horizontal reinforcement. The details of this wall are shown graphically in Figure 7:1, with the dimensions and reinforcement details presented in Table 7-1. The wall constructed for comparison, fully grouted with Paintcrete blockfill, is referred to as wall B.

Both walls were fully grouted with vertical reinforcement distributed evenly at 400 mm centres. The horizontal shear reinforcement was distributed evenly over the height of the wall at 400 mm centres and hooked (180° bend) onto the outermost vertical reinforcement.
Vertical reinforcement was lapped to the starter bars, which protruded from the base 800 mm, to achieve full development length as specified in NZS 4230:2004, hooked (90° bend) and tied to the top horizontal reinforcement bar. This method of mounting the vertical reinforcement used in wall B differed slightly to that used in wall A. Wall A used threaded bar which screwed into the base, as the foundation was to be reused several times. The vertical reinforcement in both walls was considered to be capable of achieving full plastic strength.

Table 7-1. Masonry wall dimension and reinforcement details.

<table>
<thead>
<tr>
<th>H</th>
<th>L_w</th>
<th>Effective width</th>
<th>H_e</th>
<th>H_e/L_w</th>
<th>Reinforcement</th>
<th>ρ_h</th>
<th>Grouting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>1800</td>
<td>140</td>
<td>1800</td>
<td>1.0</td>
<td>5-D20</td>
<td>0.05</td>
<td>Full</td>
</tr>
</tbody>
</table>

Figure 7:1. Masonry wall reinforcing detail.

Wall B was constructed on a reinforced concrete foundation beam with D20 starter bars at 400 mm centres protruding 800 mm from the foundation beam, which can be seen in Figure 7:2. The starter bars were grouted with a high strength grout SIKADUR 42 into the base after it had been poured, and had 20 mm steel plates welded to the bottom to ensure that pull-out of the bars during testing was not possible. Wall A utilised a re-usable foundation beam which consisted of DH32 starter bars spaced at 400 mm centres, that were drilled and tapped to accommodate the D20 vertical reinforcement. The foundation beam was then stressed down to the laboratory floor with high strength rods to eliminate
slip between the footing and the floor. A layer of mortar was also present between the foundation beam and the floor. Due to a complication with the bond between the loading beam and the surface of the masonry wall, the loading beam was held in place with a layer of trade mortar and end plates which distributed the load uniformly over the first two courses of masonry blocks.

![Diagram of concrete footing](image)

Figure 7:2. Details of concrete footing.

### 7.2.2 Construction Materials

Walls were constructed by experienced masons under supervision, using 15 series (140 mm wide) precast concrete masonry units (CMU) in a running bond configuration. Open-end bond beam CMU’s having a depressed web were used throughout the wall height to allow the horizontal shear reinforcement to be positioned at all levels and to enhance continuity of grout.

Dricon™ trade mortar, being bagged 1:4 portions of Portland cement and sand by volume was used throughout. The grout used in wall A was a standard 17.5 MPa ready-mix blockfill, with standard chemical admixtures. The grout used in wall B contained waste paint at 8% replacement for water on mass, with no further chemical admixtures.
7.2.3 Material Properties

Masonry prisms and blockfill compression cylinders were constructed at the completion of each wall (refer to Appendix 0 for results). Masonry prisms were constructed from 3 CMU’s stacked on top of each other and were filled with blockfill using identical materials and construction methods to those employed for the concrete masonry walls. On the day of testing the masonry prisms were tested using an Avery Testing Machine as shown in Figure 7:3. This type of test was the most accurate method of acquiring an estimate of the masonry compressive strength. Cylinders were also tested on the day of testing to ensure that the blockfill had reached the standard specified 17.5 MPa compression strength.

![Figure 7:3. Masonry prisms subject to compressive testing.](image)

Samples were taken from reinforcing bars used as flexural and shear reinforcement in the masonry walls. The samples were subjected to tensile testing (see Figure 7:5) and the average yield strengths for the R6 and D20 reinforcing steel were found to be 411 MPa and 312 MPa respectively. An illustration of the tensile results for the D20 reinforcing steel is shown in Figure 7:4.
Figure 7:4. Stress-strain curve for D20 vertical reinforcing bars.

Figure 7:5. D20 steel during tensile testing.

7.3 Testing Details

The test setup consisted of a reinforced concrete footing and a horizontally mounted hydraulic actuator providing a horizontal shear force to the top of the wall through a 150 x 75 steel channel (herein referred to as the loading beam) as shown in Figure 7:6. The wall was stabilised in the out-of-plane direction by two parallel horizontal struts hinged to the loading beam and a rigid reaction frame.
The hydraulic actuator was capable of push and pull forces of 370 kN and 275 kN respectively. It is recognised that this type of horizontal force transfer is of a cantilevered wall type and therefore may not be representative of all structures.

### 7.3.1 Instrumentation

The instrumentation used to measure loads and displacements on the wall included two types of instruments: load cells and portal displacement transducers. Both types of devices were calibrated on a regular basis and were considered to be accurate during testing. Throughout testing, every 0.5 mm or 2 kN, all displacements from the transducers and loads from the load cell were scanned and recorded by a computer.

The setup and detail of the transducers and load cell are shown in Figure 7:7. A load cell to measure the magnitude of lateral force was setup between the actuator and the loading beam, denoted by a [1] in the figure. Portal displacement transducers, denoted by [2] and [3], measured lateral displacements at the top of the wall. Uplift between the wall and the foundation beam were monitored by displacement transducers [4] and [42], while relative slip was monitored by displacement transducers [5] and [42]. Any slip between the wall and the loading beam was monitored by displacement transducer [6], while slip between the foundation beam and floor was monitored by displacement transducer [7]. The displacement transducers on the face of the wall measured flexural and shear deformations.
7.3.2 Wall Strength Prediction

The nominal flexural and shear strength of the walls were predicted before experimental testing was conducted. The result of the doctoral study by Voon, from which the wall chosen for comparison in this study was found, was the development of an expression capable of calculating the shear strength of concrete masonry walls. This expression is now found in NZS 4230:2004. Consequently, it was decided to use this method in the calculation of the design strength of the walls. This data is presented in Table 7-2.

7.3.3 Testing Procedure

Masonry prism testing was completed on the same day as wall testing to obtain the masonry strength $f'_m$. Wall testing was completed on the 28th day after grouting with a cyclic loading sequence as shown graphically in Figure 7:8 and consisted of a series of displacement controlled components. The original wall (Wall A) was tested to a maximum displacement of 14 mm, while the wall tested for this investigation was only able to achieve 10 mm due to an experimental error with the loading beam. The aim in both tests was to achieve failure, which was deemed to be the point on the loading curve at which the wall strength had reduced to 80% of the maximum strength recorded, in whichever direction occurred first. This displacement capacity, $d_{in}$, was the point at which failure occurred (see Figure 7:9).
The procedure for calculating the nominal yield displacement, $\Delta_y$, is shown in Figure 7:9. The procedure for obtaining nominal yield displacement involved measurement of the lateral forces when the wall loaded in its first cycle of 1 mm displacement.
7.4 Test Results

7.4.1 Force-Displacement Response

Experimental complications during testing of wall B due to spalling in the region where portal displacement transducers (see Figure 7.7 items [2] and [3]) were fixed limited the range over which the force-displacement results shown in Figure 7.10 could be considered accurate. This occurred during the second 10 mm cycle in the push direction, and thus brought the test to a conclusion prior to the 14 mm lateral displacement achieved by wall A. This spalling effect was considered to be due to experimental error and not a function of the material properties. The resulting number and displacement size of loading cycles that were able to be achieved by wall B were less than wall A and as a consequence physical damage of the wall was reduced also.

The yield strength of the vertical reinforcement in wall A and B were 318 kN and 311 kN respectively and thus for the purpose of this experiment the material properties were suitably similar to avoid normalisation of the force-displacement response. General wall behaviour is summarized in Table 7-2, in which $V_{\text{max}}$ is the maximum lateral force, and $d_{\text{vmax}}$ is the corresponding displacement. This shows a simple comparison between the walls and demonstrates that they exhibited similar displacement ductility capacity.

Table 7-2. Summary of test results.

<table>
<thead>
<tr>
<th>Wall</th>
<th>Prediction</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F_n$ (kN)</td>
<td>$V_n$ (kN)</td>
</tr>
<tr>
<td>A</td>
<td>229</td>
<td>219</td>
</tr>
<tr>
<td>B</td>
<td>221</td>
<td>214</td>
</tr>
</tbody>
</table>

* $\mu_{\text{vmax}} = \frac{V_{\text{max}}}{d_{\text{vmax}}}$
Examination of the force-displacement data shows the quantitative results of the test and allows comparisons to be drawn on the expected response of the walls. The experimentally obtained force-displacement curves for the two walls are shown in Figure 7:10. Due to wall B being unable to achieve the displacement achieved by wall A, the best comparison of results is given by the force-displacement envelope shown in Figure 7:11.

7.4.2 Discussion

It can be seen that the two walls exhibit a similar profile, achieving similar displacements at similar loading values. The initial elastic region of each wall is similar, with the two walls following approximately identical force displacement profiles to a displacement of \( \sim 2 \) mm. After this cycle, as the lateral displacement reached 4 mm at the end of the elastic range, wall B appeared to sustain larger forces within the elastic displacement range, which resulted in the impression that it was stiffer. As can be seen in Table 7-3, this was achieved with slightly less physical damage, suggesting a superior result within the elastic range.

After the elastic range, during which the wall was subjected to displacements of 4-10 mm, the profiles of the force-displacement envelopes were slightly different. Wall A appeared to maintain higher forces as the lateral displacement increased, whilst wall B began to exhibit failure slightly earlier, requiring less force to reach similar displacements. This suggests that wall B was less ductile (also noted in Table 7-2). It is concluded that wall A exhibited superior performance in the plastic range. The range of 10-14 mm cannot be examined as the data from wall B was not considered to be reliable.

When considering the stiffness of Paintcrete versus a standard blockfill, it is useful to consider the data shown in Section 4.4, which evaluated the elastic modulus of Paintcrete. It was determined that at lower percentages of paint (up to and including 8%) the stiffness of the blockfill was a function of compressive strength. With this conclusion it was reasonable to expect that if a Paintcrete blockfill is of similar strength to a standard blockfill, its performance in pseudo-static testing should be similar. However this does not take into account factors such as bond strength and adhesion to the concrete masonry units and the reinforcement.
Figure 7:10. Force-displacement response of test walls.

Figure 7:11. Force-displacement envelope of walls A and B for comparison.
7.4.3 Qualitative Results

The condition of the wall was examined during the testing of both walls and is reported below in Table 7-3 for comparison. Investigation of wall damage and crack development was carried out at the end of each displacement cycle as shown in the left hand column of Table 7-3.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Wall A</th>
<th>Wall B</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5 mm</td>
<td>No clear evidence of cracking. Maximum lateral forces of 49 kN and -60 kN were achieved at the target displacement.</td>
<td>No clear evidence of cracking. Maximum lateral forces of 26 kN and -55 kN were achieved at the target displacement.</td>
</tr>
<tr>
<td>1 mm</td>
<td>An uplift of 0.28 mm was measured in the push direction at the tension toe, creating a base crack approximately 0.5 m long. A single hairline horizontal crack was identified on the tension side in the pull direction. Maximum lateral forces of 72 kN and -85 kN were achieved at the target displacement.</td>
<td>An uplift of 0.58 mm was measured in the push direction at the tension toe, creating a base crack approximately 0.4 m long. No other clear evidence of cracking was observed. Maximum lateral forces of 48 kN and -69 kN were achieved at the target displacement.</td>
</tr>
<tr>
<td>2 mm</td>
<td>An uplift of 0.5 mm was measured at the tension toe, extending the crack to approximately 0.8 m along the base. Four flexure cracks were identified on mortar joints at the wall edge on the tension side in the pull direction. Maximum lateral forces of 117 kN and -121 kN were achieved at the target displacement.</td>
<td>Uplift of 0.6 mm and 0.2 mm were measured in the push and pull directions respectively at the tension toe. A crack was visible along the base of the wall. No other clear evidence of cracking was observed. Maximum lateral forces of 88 kN and -117 kN were achieved at the target displacement.</td>
</tr>
<tr>
<td>4 mm</td>
<td>Diagonal shear cracking was initiated, inclined at an angle of approximately 45° to the horizontal. This resulted in a loss of strength between 3-4 mm. Maximum lateral forces of 150 kN and -176 kN were achieved at the target displacement.</td>
<td>Hairline diagonal cracks initiated in both directions inclined at approximately 45° to the horizontal. Minor flexural cracking was observed in the push direction. Maximum lateral forces of 187 kN and -196 kN were achieved at the target displacement.</td>
</tr>
<tr>
<td>6 mm</td>
<td>A significant amount of new diagonal cracks were identified at the conclusion of Small extensions and widening development of the previously formed...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>This load step. Small extensions to cracks that formed in the previous pull cycle were also observed. Maximum lateral forces of 198 kN and -205 kN were achieved at the target displacement.</td>
<td>Diagonal cracks. Hairline cracks formed at the compression toe in the push and pull directions. Maximum lateral forces of 210 kN and -217 kN were achieved at the target displacement.</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>8 mm</strong></td>
<td>Further development of new diagonal cracks was observed, accompanied by significant uplift of about 2 mm at the tension toe. There was no sign to indicate crushing or spalling of masonry at this stage. Maximum lateral forces of 205 kN and -193 kN were achieved at the target displacement.</td>
<td>Further development of diagonal cracks and widening of the compression toe crack was observed. Uplift of about 1 mm was observed in both the push and pull direction. Spalling was beginning to occur around the loading beam. Maximum lateral forces of -219 kN and -217 kN were achieved at the target displacement.</td>
</tr>
<tr>
<td><strong>10 mm</strong></td>
<td>First sign of compression toe distress due to masonry crushing was observed at the compression toe. Maximum lateral forces of 217 kN and -194 kN were achieved at the target displacement.</td>
<td>Further development of diagonal shear cracking, with no evidence of flexural cracking. Further cracking at both compression toes, but no spalling was observed. Excessive spalling due to the loading configuration around the instrumentation caused the displacement results to become unreliable past this point. Maximum lateral forces of 186 kN and -188 kN were achieved at the target displacement.</td>
</tr>
</tbody>
</table>

The two walls showed a similar development of shear cracking and compression toe damage at the end of the 10 mm displacement cycle. The notable difference between the walls was the absence of significant flexural cracking within wall B. Minor flexural cracks were apparent after 4 mm in the push direction. After 10 mm there was no damage in that region in the pull direction. The presence of a base crack in wall B suggested that uplift had occurred, which would have led to yielding of the vertical reinforcement. Wall B can thus be said to have failed in a combination of flexure and shear, similar to wall A which also exhibited a combination of flexure and shear failure. The testing of wall B did not continue to the point which was defined as failure by this investigation (the point at when
the wall strength had reduced to 80% of the maximum strength recorded) and thus the failure mode can only be approximated. The final cycle of wall B, at 10 mm, appeared to show a drop off in force-displacement response that was not consistent with wall A.

### 7.4.4 Photos

The physical damage of both walls is examined in the following photos. Figure 7:12 shows the walls during construction by experience masons and Figure 7:13 shows the instrumentation prior to testing. Figure 7:14 and Figure 7:15 show the damage of wall A and wall B respectively after the 6 mm displacement cycle. Slightly less damage and the lack of flexural cracking on wall B can be observed. Figure 7:16 shows the compression toe damage after the 10 mm cycle with slightly less damage evident on wall B.

The complete set of photos from the doctoral investigation by Voon (2007) were not available and thus visual comparison is drawn from limited photos. The summary of wall damage in Table 7-3 draws a greater comparison.

![Figure 7:12. Concrete masonry wall construction.](image-url)

(a) Wall A  
(b) Wall B
(a) Wall A
(b) Wall B

Figure 7:13. Test wall instrumentation prior to testing.

Figure 7:14. Wall A condition after 6mm displacement cycle.
Figure 7:15. Wall B condition after 6 mm displacement cycle.

(a) Wall A
(b) Wall B

Figure 7:16. Compression toe degradation after 10 mm displacement cycle.
7.5 Conclusion

The two walls exhibited a similar pseudo-static response as can be observed in the force-displacement envelope shown in Figure 7:11. The only discrepancies observed between wall A and B were slightly different responses within the elastic and plastic ranges, with wall B exhibiting superior performance in the elastic range but exhibiting the early onset of failure in the plastic range.

The slightly lower calculated ductility capacity of wall B (see Table 7-2) was evident in the results. Wall B appeared to sustain less physical damage, specifically in the form of flexural cracks and compression toe degradation. However it is difficult to conclude that the overall damage to wall B was less than occurred to wall A as experimental error ended the test prematurely. The only reliable conclusion that can be made is that both walls demonstrated similar non-linear force-displacement response.
CHAPTER 8

Scanning Electron Microscope Analysis

8.1 Introduction

Analysis using the Scanning Electron Microscope (SEM) was completed in the Chemical and Materials Department within the School of Engineering at The University of Auckland. This phase of testing was carried out to investigate how the paint constituents, primarily the polymers, were located within the cement/aggregate matrix and what effect they were having on the cement hydration.

8.2 Testing Details

8.2.1 Test Materials

All samples used were approximately 10 mm x 10 mm x 5 mm in dimension. The samples were all taken from clean surfaces and kept isolated from dust or human contact prior to testing. The samples were mounted on small seats with an adhesive, then coated in platinum and mounted within the SEM. The samples can be seen in Figure 8:1. Two variations of test sample material were used: a blockfill and a cement paste.

The *blockfill samples* were taken from the failure surface of the compressive cylinders used in phase two, series B testing, as detailed in Section 4.3.
The cement paste samples were cast in small cubes in the laboratory using a w/c ratio of 0.3, with half of the samples having 8% replacement of water with paint by mass. The samples were then chipped with a hammer and chisel to obtain a failure surface.

Figure 8:1. Blockfill samples ready for analysis in the SEM.

**8.2.2 Test Equipment**

The SEM used in this investigation was a Philips XL30S Field Emission Gun with Lithium drifted Energy Dispersive Spectrometer (EDS) as shown in Figure 8:2.

Figure 8:2. The Philips SEM used in microscopic analysis.
8.2.3 Paintcrete Vs. Standard Blockfill at 260x Magnification

Figure 8:3 and Figure 8:4 show a section of material approximately 1000 µm (or 1 mm) across. When addressing the chemical structure of a cement matrix, this is a large area. A change in the ratio between the Calcium, Silicon and Oxygen with the addition of paint is apparent in the elemental analysis. As was expected there was also an increase in carbon (contained in the polymer of paint) and the introduction of titanium (titanium dioxide is the pigment used in white paints). The results of the elemental analysis of Figure 8:3 and Figure 8:4 are shown in Table 8-1.

Table 8-1. Elemental analysis of Figure 8:3 and Figure 8:4 respectively by percentage mass and atomic makeup.

<table>
<thead>
<tr>
<th>Element</th>
<th>0% Paint Wt%</th>
<th>0% Paint At%</th>
<th>8% Paint Wt%</th>
<th>8% Paint At%</th>
<th>Notable Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>9.11</td>
<td>16.03</td>
<td>13.63</td>
<td>22.71</td>
<td>*</td>
</tr>
<tr>
<td>O</td>
<td>40.39</td>
<td>53.37</td>
<td>41.65</td>
<td>52.1</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>1.09</td>
<td>1.00</td>
<td>0.66</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>0.57</td>
<td>0.49</td>
<td>0.49</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>2.4</td>
<td>1.88</td>
<td>2.76</td>
<td>2.05</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>13.23</td>
<td>9.96</td>
<td>9.16</td>
<td>6.53</td>
<td>*</td>
</tr>
<tr>
<td>S</td>
<td>0.59</td>
<td>0.39</td>
<td>0.53</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>0.94</td>
<td>0.51</td>
<td>0.42</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>29.38</td>
<td>15.49</td>
<td>28.3</td>
<td>14.13</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>0</td>
<td>0</td>
<td>0.46</td>
<td>0.19</td>
<td>*</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td></td>
</tr>
</tbody>
</table>

In Figure 8:3 a smooth surface in the top left corner of the image is what appears to potentially be a section of aggregate (indicated by an arrow) showing through the cement matrix. This could be an explanation for the strong silica peak in the elemental analysis. Apart from this feature there does not appear to be any large difference in the major elemental peaks, suggesting that the cement matrix has formed in a similar way in both the regular blockfill, and the blockfill with waste paint addition.
Figure 8:3. Standard blockfill at 260x magnification.

Figure 8:4. Paintcrete blockfill at 260x magnification.
8.2.4 Paintcrete Vs. Standard Blockfill at 5000x Magnification

The images shown in Figure 8:5 and Figure 8:6 appear to have significantly different structure and elemental make up. This section of material is approximately 60 microns across, and thus it is entirely possible that the observed effects are local to this portion of material and not representative of the complete material. Figure 8:5 appears to be a good representation of a section of cement matrix, with strong calcium and oxygen peaks in the elemental analysis. Figure 8:5 exhibits good examples of calcium silicate hydrate (C-S-H), which are evident as the fibrous particles, which appear fluffy. As this section is a failure surface it is possible that the smooth section in Figure 8:5 is a piece of calcium hydroxide cement hydrate, from which a piece of aggregate has torn away. As exhibited by the strong Si peak in Figure 8:3, the same situation appears to be happening in Figure 8:6, in which a piece of aggregate is exposed, generating the increase in Si. The increase in Si and Al suggest that the aggregate could be a piece of feldspar, which is contained within the 7 mm aggregate used as a constituent within the blockfill. The percentage elemental analysis is shown in Table 8-2.

Table 8-2. Elemental analysis of Figure 8:5 and Figure 8:6 respectively by percentage mass and atomic makeup.

<table>
<thead>
<tr>
<th>Element</th>
<th>0 % Paint Wt%</th>
<th>At%</th>
<th>8 % Paint Wt%</th>
<th>At%</th>
<th>Notable Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>10.8</td>
<td>18.51</td>
<td>15.74</td>
<td>24.53</td>
<td>*</td>
</tr>
<tr>
<td>O</td>
<td>41.98</td>
<td>54</td>
<td>42.06</td>
<td>49.24</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>0.62</td>
<td>0.55</td>
<td>2.98</td>
<td>2.43</td>
<td>*</td>
</tr>
<tr>
<td>Al</td>
<td>1.87</td>
<td>1.43</td>
<td>7.61</td>
<td>5.28</td>
<td>*</td>
</tr>
<tr>
<td>Si</td>
<td>11.19</td>
<td>8.2</td>
<td>19.25</td>
<td>12.83</td>
<td>*</td>
</tr>
<tr>
<td>K</td>
<td>0.79</td>
<td>0.41</td>
<td>1.62</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>29.05</td>
<td>14.92</td>
<td>9.77</td>
<td>4.56</td>
<td>*</td>
</tr>
<tr>
<td>Fe</td>
<td>2.08</td>
<td>0.77</td>
<td>0.73</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>0</td>
<td>0</td>
<td>0.24</td>
<td>0.09</td>
<td>*</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
Figure 8:5. Standard blockfill at 5000x magnification.

Figure 8:6. Paintcrete blockfill at 5000x magnification.
8.2.5 Paintcrete Vs. Standard Blockfill at 10000x Magnification

The images shown in Figure 8:7 and Figure 8:8 are the same portion of material as shown in Figure 8:5 and Figure 8:6 respectively, but at a higher magnification of 10,000x. The same peaks as shown in 8.2.4 are evident, although a closer inspection of the microstructure is available. Despite the possibility of local effects, as this is a very small section of material, the cement matrix shown in Figure 8:7 appears to have quite a porous structure, in which the acicular nature of the cement hydrate products is clear. By comparison, Figure 8:8, appears to have more density with the appearance of the acicular cement hydration products reduced. A possible explanation for this is that the waste paint is dispersed amongst the cement matrix, giving the appearance of an increased density.

Figure 8:7. Standard blockfill at 10000x magnification.
8.2.6 Comparison of Air Bubble in Cement Paste with the addition of Paint

The images shown in Figure 8:9 and Figure 8:10 are air bubbles found within the cement paste, with 0% and 8% waste paint respectively. There is a clear difference between the surfaces of the bubbles, in which the sample containing 0% paint is smooth, and the sample containing 8% paint is rough. This was not a local effect and could be observed consistently within all of the bubbles present on both samples.

An initial theory is that the sample containing 8% paint may have had a higher water content, which caused the growth of calcium hydroxide through precipitation. This prompts that the air bubble contained excess water, causing cement hydration. The water content of the paste used in both the 0% sample and 8% sample was identical, and thus ignoring experimental error, another phenomenon is likely to be active. The surrounding cement matrix observed outside the bubble is of similar structure, suggesting that the effect is specific to the air voids. This is a possible result of the surfactant found within paint, which acts as a foam stabiliser/wetting agent and will be active in these regions.
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Figure 8:9. Cement paste air bubble at 2500x magnification.

Figure 8:10. Cement and paint paste air bubble at 2500x magnification.
8.2.7 Cement Paste Vs. Cement and Paint Paste at 10000x Magnification

The images shown in Figure 8:11 and Figure 8:12 are possibly the best images from which to draw conclusions on the effect of waste paint on the cement matrix. An initial observation is that in the elemental analysis, the cement hydration products are still predominant in the sample containing paint, and thus it must have little affect on the structural integrity of the matrix. The sample containing paint appears to have a slightly higher density of calcium silicate hydrate, with less evidence of the acicular cement hydration products. The cement paste sample containing 0% paint appears to have more void space, with the ‘needles’ of the acicular calcium silicate hydrates evident. This is consistent with behaviour discussed in 8.2.5, where the same density comparison was drawn.

The presence of the titanium in the elemental analysis in Figure 8:12 is consistent with the addition of paint, and suggests the fine material (< 2 µm) may be having a filling effect, as discussed in Section 2.3.

![SEM image](image1)

![EDS data](image2)

Figure 8:11. Cement paste at 10000x magnification.
Waste paint appears to have had an affect on the microstructure of the cement matrix. The constituents of paint are present in the elemental analysis, such as the titanium dioxide and carbon (polymer). The acicular nature of the cement hydration products is evident in the blockfill and cement paste mixes not containing paint. However in the samples containing paint this is not the case, and the structure appears denser. This could be a result of the paint occupying the void space.

In all cases the elemental analysis shows that the cement hydration products were predominant so it appears that the paint had little effect on the structural integrity of the cement matrix.
CHAPTER 9

Conclusions

Following a theoretical investigation of the constituents found in waste paint and the constituents found in conventionally used chemical admixtures utilised in standard blockfill, it was determined that the waste paint constituents were capable of replacing conventional chemical admixtures. The concentrations and availability of these chemicals in the waste paint was unknown and thus investigation was required to confirm their effectiveness.

Phase one laboratory testing was conducted to establish the basic changes in the material properties of blockfill compressive strength, tensile strength and workability due to with the addition of waste paint. Conventional concrete admixtures were present at the industry suggested dosages in this phase of testing. The investigation was completed with a standard blockfill and with 0%, 4%, 8%, 12%, 16% and 20% waste paint replacement of water by mass. An optimum result was found to occur at 12-16% waste paint replacement of water by mass. Improved properties were identically encountered in compressive strength, workability and tensile strength.

Phase two laboratory testing was conducted to establish the viability of using Paintcrete without the presence of conventional chemical admixtures. Increased water content was required to allow the waste paint to contribute positively to the material properties of the blockfill. This was due to the deactivation/activation of chemicals affecting the air content, and to create a medium which encouraged the even dispersion of particles within the mix. The optimum paint dosage was found to be 8-12% paint replacement of water by mass on a basis of achieving the required 17.5 MPa compressive strength, whilst maintaining workability and drying shrinkage. The varying elastic modulus value was determined to primarily be a function of compressive strength. However at a higher paint dosage (12%) an elastic modulus decrease was recorded, suggesting that a higher volume of waste paint is required in order to affect stiffness properties.
Rheological information was gathered to apply a more scientific description to the affect on workability associated with the addition of waste latex and acrylic based paint to concrete masonry blockfill. It was a goal for Paintcrete to exhibit the rheological properties of self-compacting concrete (SCC). An increase in yield shear stress and decrease in plastic viscosity caused Paintcrete to fall outside the envelope of a traditional SCC mix and suggests that whilst there will be improvements in the flow characteristics, a small amount of vibration should be required to produce a uniform fill throughout the wall, and around congested reinforcement. The change in rheological properties with the addition of waste paint was primarily due to the actions of the emulsion polymers, thickeners, surfactants and increased air content.

Qualitative testing on two concrete masonry walls was conducted at two sites which had low risk applications, to assess the ability of Paintcrete to perform successfully at a larger scale and in an industry application. The aim of the tests was to observe the ability of Paintcrete to flow within the wall, and to determine if any properties it exhibited were superior to those of conventional blockfill. Both walls were of only limited success as human error was encountered as a result of the industry suppliers that were involved. Paintcrete was received positively by the experienced block layers and contractors who worked with it. Paintcrete does appear to carry more risk associated with incorrect mix properties than standard blockfill, and the success of the final product is dependent on the accurate measurement of the constituents that make up the blockfill. This accurate measurement will ensure that the waste paint is added to a medium in which it can contribute positively to the fresh and hardened properties of blockfill.

Pseudo-static testing was completed to investigate the seismic performance of Paintcrete when compared to the comparable response from standard blockfill. Both walls exhibited reasonably similar performance, with slightly different properties in both the elastic and the plastic ranges. Wall B exhibited superior performance in the elastic range, but the early onset of failure in the plastic range was measured. Wall B appeared to sustain less physical damage, although it is difficult to make definitive conclusions as experimental error ended the test prematurely.
The microscopic analysis of Paintercrete led to the conclusion that waste paint had an affect on the microstructure of the cement matrix. It was observed that the paint appeared to be filling the void space around the acicular cement hydrate products, but was not likely to be affecting the overall cement matrix structural integrity.

The final recommendation derived from the results of this project is that Paintercrete exhibits material properties capable of producing a blockfill that can be successful at an industry level, providing a product capable of becoming commonplace within the New Zealand concrete market. This will ensure that Paintercrete effectively utilises and applies value to the waste stream of water-based acrylic and latex paints in its entirety.
CHAPTER 10

References


SNZ. (1986). NZS 3112 - Methods of Test for Concrete Standards Association of New Zealand.


APPENDIX A.

Experimental Data

A.1 Phase One Compressive Cylinder Test Data

Appendix A.1 contains the individual cylinder compressive test results for the testing conducted in phase one. The results in Section 3.4.1 report the average of the data shown below.

Table A-1. 7 day compressive strength data (MPa).

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
<th>16%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15.2</td>
<td>7.59</td>
<td>11.34</td>
<td>12.7</td>
<td>12.41</td>
<td>10.7</td>
</tr>
<tr>
<td>B</td>
<td>15.4</td>
<td>10.63</td>
<td>11.3</td>
<td>12.95</td>
<td>12.91</td>
<td>11.19</td>
</tr>
<tr>
<td>C</td>
<td>15.1</td>
<td>11.28</td>
<td>10.85</td>
<td>13.69</td>
<td>12.28</td>
<td>10.92</td>
</tr>
<tr>
<td>Average</td>
<td>15.23</td>
<td>10.96</td>
<td>11.16</td>
<td>13.11</td>
<td>12.53</td>
<td>10.94</td>
</tr>
</tbody>
</table>

Table A-2. 28 Day compressive strength data (MPa).

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
<th>16%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>20.4</td>
<td>14.23</td>
<td>15.5</td>
<td>17.1</td>
<td>17.81</td>
<td>13.75</td>
</tr>
<tr>
<td>C</td>
<td>22.7</td>
<td>14.1</td>
<td>16.1</td>
<td>17.2</td>
<td>18.7</td>
<td>14.8</td>
</tr>
<tr>
<td>Average</td>
<td>20.96</td>
<td>14.165</td>
<td>15.47</td>
<td>17.5</td>
<td>18.55</td>
<td>14.14</td>
</tr>
</tbody>
</table>

Table A-3. 56 day compressive strength data (MPa).

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
<th>16%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>23.82</td>
<td>16.35</td>
<td>17.91</td>
<td>20.05</td>
<td>19.97</td>
<td>16.06</td>
</tr>
<tr>
<td>C</td>
<td>22.99</td>
<td>16.16</td>
<td>17.02</td>
<td>20.65</td>
<td>20.13</td>
<td>16.2</td>
</tr>
<tr>
<td>Average</td>
<td>23.92</td>
<td>16.26</td>
<td>17.30</td>
<td>20.05</td>
<td>20.13</td>
<td>16.13</td>
</tr>
</tbody>
</table>
Figure A-1. Phase one 7 day compressive strength.

Figure A-2. Phase one 28 day compressive strength.

Figure A-3. Phase one 56 day compressive strength.
A.2 Phase One Spread Test Data

Appendix A.2 contains the individual spread test results for the testing conducted in phase one. The results in Section 3.4.2 report the average of the data shown below.

Table A-4. Phase one spread test data (mm).

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
<th>16%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>460</td>
<td>507.5</td>
<td>482.5</td>
<td>582.5</td>
<td>535</td>
<td>450</td>
</tr>
<tr>
<td>B</td>
<td>437.5</td>
<td>517.5</td>
<td>480</td>
<td>582.5</td>
<td>520</td>
<td>470</td>
</tr>
<tr>
<td>C</td>
<td>432.5</td>
<td>512.5</td>
<td>485</td>
<td>580</td>
<td>520</td>
<td>460</td>
</tr>
</tbody>
</table>

Figure A-4. Phase one spread test data.

A.3 Phase One Flexural Strength Data

Appendix A.3 contains the individual tensile flexural strength test results for the testing conducted in phase one. The results in Section 3.4.3 report the average of the data shown below.

Table A-5. 28 day tensile flexural strength (MPa)

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
<th>16%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.49</td>
<td>3.02</td>
<td>3.12</td>
<td>3.63</td>
<td>2.66</td>
<td>2.64</td>
</tr>
<tr>
<td>B</td>
<td>3.90</td>
<td>2.84</td>
<td>3.29</td>
<td>3.62</td>
<td>3.42</td>
<td>2.75</td>
</tr>
<tr>
<td>C</td>
<td>1.27</td>
<td>2.96</td>
<td>3.02</td>
<td>3.65</td>
<td>3.32</td>
<td>2.55</td>
</tr>
<tr>
<td>Average</td>
<td>3.70</td>
<td>2.94</td>
<td>3.14</td>
<td>3.63</td>
<td>3.37</td>
<td>2.65</td>
</tr>
</tbody>
</table>
Figure A-5. Phase one 28 day flexural tensile strength.

A.4 Phase Two Compressive Strength Data

Appendix A.4 contains the individual cylinder compressive test results for the testing conducted in phase two. The results in Section 3.4.1 report the average of the data shown below.

Table A-6. Test A - compressive strength data (MPa).

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.78</td>
<td>14.5</td>
<td>12.81</td>
<td>11.46</td>
</tr>
<tr>
<td></td>
<td>20.4</td>
<td>14.77</td>
<td>12.49</td>
<td>11.71</td>
</tr>
<tr>
<td></td>
<td>22.7</td>
<td>14.39</td>
<td>12.73</td>
<td>11.33</td>
</tr>
<tr>
<td></td>
<td>21.11</td>
<td>14.49</td>
<td>12.66</td>
<td>11.21</td>
</tr>
<tr>
<td></td>
<td>20.91</td>
<td>14.5</td>
<td>12.79</td>
<td>11.69</td>
</tr>
<tr>
<td></td>
<td>21.06</td>
<td>14.33</td>
<td>12.33</td>
<td>11.14</td>
</tr>
<tr>
<td>Average</td>
<td>21.0</td>
<td>14.6</td>
<td>12.6</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Table A-7. Test B - compressive strength data (MPa).

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0%</th>
<th>4%</th>
<th>8%</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.78</td>
<td>14.64</td>
<td>21.65</td>
<td>20.88</td>
</tr>
<tr>
<td></td>
<td>20.4</td>
<td>17.83</td>
<td>21.65</td>
<td>20.37</td>
</tr>
<tr>
<td></td>
<td>22.7</td>
<td>15.92</td>
<td>20.63</td>
<td>22.15</td>
</tr>
<tr>
<td></td>
<td>21.11</td>
<td>15.02</td>
<td>21.39</td>
<td>21.39</td>
</tr>
<tr>
<td></td>
<td>20.91</td>
<td>15.53</td>
<td>22.92</td>
<td>21.39</td>
</tr>
<tr>
<td></td>
<td>21.06</td>
<td>16.55</td>
<td>21.34</td>
<td>21.65</td>
</tr>
<tr>
<td>Average</td>
<td>21.0</td>
<td>15.9</td>
<td>21.6</td>
<td>21.3</td>
</tr>
</tbody>
</table>
A.5 Phase Two Elastic Modulus Data

Appendix A.5 contains the individual elastic modulus results for the testing conducted in phase two. The slope of the linear portion of the line (taken for consistency as the first 4-5 MPa) is taken as the elastic modulus. The results reported in Section 4.4 report an average of the elastic modulus at each paint dosage.

![Graph A-6](image)

Figure A-6. 0% compressive cylinder 1 elastic modulus.

![Graph A-7](image)

Figure A-7. 0% compressive cylinder 2 elastic modulus.
Figure A-8. 4% compressive cylinder 1 elastic modulus.

Figure A-9. 4% compressive cylinder 2 elastic modulus.

Figure A-10. 4% compressive cylinder 3 elastic modulus.
Figure A-11. 8% compressive cylinder 1 elastic modulus.

Figure A-12. 8% compressive cylinder 2 elastic modulus.

Figure A-13. 8% compressive cylinder 3 elastic modulus.
**Figure A-14.** 12% compressive cylinder 1 elastic modulus.

**Figure A-15.** 12% compressive cylinder 2 elastic modulus.

**Figure A-16.** 12% compressive cylinder 3 elastic modulus.
Table A-8. Phase 2 elastic modulus data.

<table>
<thead>
<tr>
<th>Paint %</th>
<th>0</th>
<th>0</th>
<th>4</th>
<th>4</th>
<th>4</th>
<th>8</th>
<th>8</th>
<th>8</th>
<th>12</th>
<th>12</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (MPa)</td>
<td>26.1</td>
<td>18.0</td>
<td>20.8</td>
<td>19.2</td>
<td>17.0</td>
<td>23.7</td>
<td>19.3</td>
<td>23.2</td>
<td>22.1</td>
<td>14.8</td>
<td>21.7</td>
</tr>
</tbody>
</table>

Figure A-17. Phase 2 elastic modulus data.

A.6 Phase Two Change in Workability over Time Data

Appendix A.6 contains the individual spread test results for the testing conducted in phase two. The results in Section 4.6 report the average of the data shown below.

Table A-9. Change in workability over time data (mm).

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Test One</td>
<td>480</td>
<td>480</td>
<td>470</td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td>Test Two</td>
<td>380</td>
<td>380</td>
<td>410</td>
<td>390</td>
<td>360</td>
</tr>
<tr>
<td>Test Three</td>
<td>470</td>
<td>480</td>
<td>480</td>
<td>475</td>
<td>480</td>
</tr>
<tr>
<td>Test Four</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>470</td>
<td>470</td>
</tr>
</tbody>
</table>

Table A-10. Change in workability over time average data (mm).

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spread Test One</td>
<td>480</td>
<td>475</td>
<td>480</td>
<td>455</td>
<td>445</td>
</tr>
<tr>
<td>Spread Test Two</td>
<td>380</td>
<td>400</td>
<td>360</td>
<td>295</td>
<td>200</td>
</tr>
<tr>
<td>Spread Test Three</td>
<td>475</td>
<td>477.5</td>
<td>480</td>
<td>455</td>
<td>445</td>
</tr>
<tr>
<td>Spread Test Four</td>
<td>480</td>
<td>480</td>
<td>470</td>
<td>465</td>
<td>470</td>
</tr>
</tbody>
</table>
### A.7 Rheological Data

Appendix A.7 contains the rheological test results for the investigation conducted in Chapter 5.

**Table A-11. Rheological data for 0% paint.**

<table>
<thead>
<tr>
<th>time (mins)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress (Pa)</td>
<td>179</td>
<td>189</td>
<td>195</td>
<td>239</td>
<td>241</td>
</tr>
<tr>
<td>Viscosity (Pa.s)</td>
<td>10.1</td>
<td>10.5</td>
<td>10.6</td>
<td>12.3</td>
<td>11.3</td>
</tr>
<tr>
<td>Separation (%)</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Spread (mm)</td>
<td>525</td>
<td>515</td>
<td>475</td>
<td>460</td>
<td>445</td>
</tr>
</tbody>
</table>

**Table A-12. Rheological data for 4% paint.**

<table>
<thead>
<tr>
<th>time (mins)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress (Pa)</td>
<td>241</td>
<td>261</td>
<td>280</td>
<td>309</td>
<td>299</td>
</tr>
<tr>
<td>Viscosity (Pa.s)</td>
<td>1.3</td>
<td>1.6</td>
<td>0.3</td>
<td>1.2</td>
<td>2</td>
</tr>
<tr>
<td>Separation (%)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Spread (mm)</td>
<td>490</td>
<td>490</td>
<td>470</td>
<td>470</td>
<td>460</td>
</tr>
</tbody>
</table>

**Table A-13. Rheological data for 8% paint.**

<table>
<thead>
<tr>
<th>time (mins)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress (Pa)</td>
<td>238</td>
<td>271</td>
<td>262</td>
<td>280</td>
<td>277</td>
</tr>
<tr>
<td>Viscosity (Pa.s)</td>
<td>1</td>
<td>2.1</td>
<td>2.3</td>
<td>2.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Separation (%)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Spread (mm)</td>
<td>520</td>
<td>490</td>
<td>470</td>
<td>470</td>
<td>460</td>
</tr>
</tbody>
</table>

**Table A-14. Rheological data for 12% paint.**

<table>
<thead>
<tr>
<th>time (mins)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress (Pa)</td>
<td>221</td>
<td>235</td>
<td>249</td>
<td>271</td>
<td>262</td>
</tr>
<tr>
<td>Viscosity (Pa.s)</td>
<td>0.8</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>Separation (%)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Spread (mm)</td>
<td>510</td>
<td>500</td>
<td>490</td>
<td>490</td>
<td>500</td>
</tr>
</tbody>
</table>
Table A-15. Rheological data for 16% paint.

<table>
<thead>
<tr>
<th>time (mins)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress (Pa)</td>
<td>239</td>
<td>244</td>
<td>255</td>
<td>253</td>
<td>255</td>
</tr>
<tr>
<td>Viscosity (Pa.s)</td>
<td>0.9</td>
<td>1.6</td>
<td>2.2</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Separation (%)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Spread (mm)</td>
<td>480</td>
<td>470</td>
<td>450</td>
<td>450</td>
<td>450</td>
</tr>
</tbody>
</table>

A.8 Full Scale Seismic Test Data

Table A-16. Material properties of walls used in seismic testing.

<table>
<thead>
<tr>
<th>Wall</th>
<th>$f'_g$ (MPa)</th>
<th>$f'_m$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.4</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>9.3</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td>9.3</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>19.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.88</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>19.48</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>20.12</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>20.16</td>
<td></td>
</tr>
</tbody>
</table>