INFLUENCE OF WASTE LATEX AND ACRYLIC PAINT ON CONCRETE MASONRY BLOCKFILL

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ABSTRACT
A significant volume of waste latex and acrylic paint exists in New Zealand, with the rate of supply growing at a substantial rate. The paper specifically investigated the use of waste paint as a polymer admixture in concrete masonry blockfill. 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. 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, and seismic performance were studied to assess the hardened properties of the blockfill. 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.

INTRODUCTION
An advanced cementitious material that is environmentally sustainable has been developed as a flowable blockfill for concrete masonry. Waste paint is a valuable resource, which is currently being disposed of in landfills at a substantial economic and environmental cost. This waste paint, which includes all water based acrylic and latex varieties available in New Zealand, exhibits many properties that are similar to polymer admixtures used in concrete production. Polymers make up the majority of the solid mass in paint, which for this investigation was convenient as polymer admixtures are used in concrete production 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. Consequently, by adding waste paint to blockfill the addition of polymer assists the blockfill’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, which is attributable to the waste paint additive, results in a less labour intensive construction process. The improved workability properties of the blockfill enable it to settle around congested reinforcement and small void areas and reduce the need for compaction and vibration, resulting in faster, cheaper and safer construction.

PAINT AND POLYMER CONCRETE
A polymeric admixture is described as an admixture which consists of a polymeric compound as a main ingredient effective at modifying or improving properties such as strength, deformability, adhesion, waterproofness and durability of cement, blockfill and concrete. 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). Although polymer-based admixtures in many forms are used in cementitious composites such as blockfill and concrete, it is important to ensure that both cement hydration and polymer film formation proceeds 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.

Recycling waste latex paint (WLP) was used in urban concrete sidewalks in Ontario, Canada. It was determined that WLP contributed in a similar form to virgin latex by exhibiting the same advantages in cementitious materials, such as increasing flexural strength and decreasing chloride ion penetrability. A field demonstration sidewalk modified with WLP exhibited enhanced workability and finishing, and better durability to surface scaling and aggregate pop out (Nehdi and Sumner 2003).

Paint is made up of numerous fine and ultra fine particles, in the range of 0.1 µm to 10 µm. The addition of fine particles and the application of particle packing theory allows concrete to be manufactured using poorly shaped or poorly graded sand and aggregates while still producing workable concrete. It had been determined that by incorporating large amounts of ultrafine fillers with reduced cement content, it is possible to produce

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a high strength concrete which implied a great potential for saving cement and resultant decrease in the production of carbon dioxide (Lagerblad and Vogt 2003).

The waste paint used in this study was sourced directly from a paint collection program and stored in large 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 facility to determine the variability of water content, pigment content and polymer content. The data indicated that paint is made up of approximately 50% water, indicating that when water is replaced by waste paint, 50% of that water content remains present in the mix. The remaining solid content of the paint, made up of polymers and pigments, is the source of possible variability in air content, workability, setting times, and concrete density. Across the several New Zealand paint producers and their paint varieties a large number of unique constituents are included. The primary constituents expected to occur in high volume were:

Polymers - The continuous phase of latex and acrylic water based paint is primarily made 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. (Steward et al. 2000).

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).

Foam Controllers - Antifoams or defoamers are active in paint to control foaming, which is an unwanted product of surfactants.. These are present in waste paint, as foaming of the paint is not desirable for its application.

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. (Marrion 2004). Titanium dioxide was not expected to have any substantial chemical effect on cement.

Thickeners - Thickening agents are active in paint to control consistency and ensure that workability is maintained during storage and application.

THE VIABILITY OF PAINT REPLACEMENT OF CONVENTIONAL CHEMICAL ADMIXTURES
A standard chemical admixture as used by a New Zealand ready mix concrete supplier for the production of standard 17.5 MPa blockfill is a non-retarding, non-chloride, water reducing, strength enhancing admixture 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. A second chemical admixture also used in the production of blockfill is an air entrainer, composed primarily of an alkylbenzene sulfonic acid surfactant in order to stabilise the entrained air. (BASF 2006a). There is a significant chemical difference between this surfactant and the calcium lignosulfonate found in the water reducer, 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 cement hydration.

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 chemical admixtures is surfactant, which covers a large range of chemicals. Water based paint is almost always alkaline and contains amines similar to triethanolamine, as well as various other types of surfactant that are suitable for dispersing and stabilising particles. Many of the paint chemicals discussed 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 chemicals active in the water reducer, which again are based on the amount of chemical that is actually available, can be found in waste paint in the form of a surfactant. The acrylic polymers found within waste paint have the potential to
simulate the action of the calcium lignosulfonate as a hydration retarder (Wang et al. 2005).

**TESTING OF BASIC MATERIAL PROPERTIES**
Laboratory testing was completed to determine the optimal paint dosage for the target blockfill workability and strength properties. Testing was completed in two stages, initially with the industry recommended chemical admixtures, and then in the absence of these chemical admixtures.

All materials used in the study corresponded to those found in the 17.5 MPa blockfill produced by a New Zealand 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. Paint was sourced from the paint collection program discussed earlier. Dry ingredients were added and mixed for 2 minutes with 80% of the mix water. 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).

**STAGE ONE TESTING WITH THE INCLUSION OF CHEMICAL ADMIXTURES**
Stage one 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. This is a relatively small percentage addition of paint in respect to the size of the mix and represents approximately 0.5% - 2% of the entire mass of the blockfill. Stage one retained the proportion of chemical admixtures used by the blockfill producer for a conventional mix.

Three compressive cylinders were tested for each paint dosage at time periods of 7, 28 and 56 days. The 7 day results (see Figure 1a) indicated peak strength at 12% water replacement for paint. Data accuracy was ±0.5 MPa. The control test had a larger 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. This trend was also witnessed after 28 days, with the optimum value shifting towards 16%. These results suggested that the addition of too little waste paint was as detrimental as the addition of too much waste paint. The 16% data point exceeded the 17.5 MPa target, which was the standard required 28 day strength specified in NZS 4210. The 56 day results also followed the trend shown after 7 and 28 days, with a further increase in strength. The overall finding was that at around 12%-16% an optimum strength occurred, exceeding the specified 17.5 MPa minimum compressive strength (SNZ 2001).

![Figure 1](https://via.placeholder.com/150)

**Figure 1: Stage one test results.**

Spread tests were undertaken on the fresh blockfill 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 at which point two orthogonal dimensions were measured. Three tests were completed per batch and the variance observed between tests was found to be negligible. 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 1b). This peak spread value was 580 mm, which was well above the specified minimum of 450 mm (SNZ 2001). The trend suggested that
water could be removed from the mix, and that the inclusion of too much paint caused the paste to lose workability.

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, and the tensile flexural strength was calculated. The results (see Figure 1c) further demonstrated the apparent trend with the optimum value occurring at 12% water replacement for paint. This confirmed that the addition of paint did not specifically negatively affect the flexural tensile strength.

It was recognized that as the mixes contained both standard chemical admixtures and waste paint, they had resulted in excess levels of polymer and air entrainer. It was concluded that it was feasible to use waste paint as a replacement for standard chemical admixtures. This indicated the need to continue laboratory level experimentation to investigate the removal of conventional chemical admixtures, before larger scale investigation commenced.

**MATERIAL TESTING IN THE ABSENCE OF CONVENTIONAL CHEMICAL ADMIXTURES**

To assess compressive strength 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. The test was designed in this manner based on the assumption that the extra water would allow complete dispersion of the paint throughout the mix. 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. The parameters for each trial are outlined in Table 1.

The results of Series A after 28 days (see Figure 2a) 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 1) that this was due to the increasing air content. The linear relationship between the increased paint content and decreased strength in conjunction with a lower w/c ratio indicated that the increased paint proportion was having a negative effect on the strength of the blockfill. Series B strength results are shown in Figure 2b, with companion density results reported in Table 1. The trend was similar to that of Series A. This result contradicted conventional concrete theory, which would suggest that an increased w/c ratio would correspond to reduced compression strength and reduced density. By comparison with the control sample containing 0% paint, it is apparent that the waste paint did not enable a greater overall strength to be attained, but instead causes a decrease in compressive strength if not added in the correct conditions.

**Table 1**: Water/cement (w/c) and polymer/cement (p/c) ratios, compressive strength and density of phase two compressive testing.

<table>
<thead>
<tr>
<th>Paint %</th>
<th>Series A</th>
<th>Series B</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/c</td>
<td>p/c</td>
<td>f’c (MPa)</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>

**Figure 2**: Phase Two 28 Day compressive strength.

Spread tests were conducted 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 mix formulation case scenarios.
(see Table 2). Slump tests were 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.

Table 2: Slump vs. Time mix designs.

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

The results (see Figure 3) indicated that the mix design containing no admixtures or waste paint (Test Two) was the only scenario that performed unsatisfactorily. This mix scenario was effectively unable to pass through the inverted slump cone at the conclusion of 80 minutes. The performance of the other three tests was inseparable and the blockfill maintained a consistent slump for the duration of the test. From this data it was concluded that waste paint alone was as effective as conventional concrete admixtures at maintaining workability.

Elastic Modulus data was collected during series B compression testing of phase two cylinders. 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. The E data shown had a similar profile to the compression strength data in Figure 2b. This indicated that the elastic modulus of concrete masonry blockfill with the addition of waste paint was a function of compression strength, not the presence of polymers. This is consistent with existing code-defined equations for the calculation of E, in which the magnitude is a function of compression strength. The data point for the 12% paint replacement for water was the only outlier, with identical strength to the 8% specimens, but having a lower elastic modulus. This suggested 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.

The elastic modulus results showed a similar trend to that of the compressive strength. This is concordant 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”. Cook and Crookham also noted that the failure mode exhibited more ductility, although that data was not collected in this study.

The reasons for the results observed in materials testing in the absence of conventional chemical admixtures involved industrial chemistry and was outside the scope of the study, however the following explanations are suggested;

- Higher water content allows the particles to avoid flocculation. Should the particles be given a larger medium they would be spread out, causing flocculation to become less likely.
- Increased water content is activating/deactivating the ingredients within paint that control foaming. Paints are stabilised with surfactants which, unfortunately, also help to stabilise air introduced during manufacture and application (Lambourne and Strivens 1987).
- 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.
RHEOLOGY

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. 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.

Testing was completed using a BML4 Viscometer, 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 plastic viscosity. Dry ingredients were combined together and then subjected to shear whilst the mix water was added. Testing methods can be found in the relevant thesis (Haigh 2007).

The rheological data showed a distinct change in yield shear stress with the addition of waste paint (see Figure 5a). Immediately following (0 minutes) the addition of waste paint the yield shear stress of the material increased by 30%, to be an approximately constant amount regardless of the paint concentration of the paint. Viscosity dropped with the inclusion of waste paint (see Figure 5b). The separation data in Figure 5c shows that as the viscosity decreased with paint concentration increase, the separation was also observed to decrease.

As with the explanation for the compressive strength results, the specific reasoning for the rheological changes observed is outside the scope of the study, however the following explanations are offered.

- The additives that are active in paint to increase yield shear stress, are known as thickening agents. Increased air content can lead to a viscosity reduction. The air content of the mixes in the rheological testing are shown in Table 3. The increasing air content within the mix explained the plastic viscosity reduction. The air content increase is consistent with that observed in the compression testing, but is likely not the only mechanism affecting viscosity given the number of other chemical interactions involved.
- The drop in viscosity is attributable to large amounts of surfactant within paint. When surfactant is added to a medium that contains that there will be an interruption of the surface interactions between the particles, resulting is a viscosity decrease.

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

<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>

Table 3: Air content of mixes used in rheological testing.
Viscosity reduction could be 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, the surfactant will 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).

The improvement in segregation is a result of the thickeners which are present within paint. The thickeners, 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 phenomenon occurring is due to the polymers within the paint. The polymers create a 'structure' within the paint, similar to the concept of thixotropy.

**SEISMIC RESPONSE**

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 a concrete masonry wall containing blockfill with the addition of waste paint. Results were compared against those reported by Voon (Voon and Ingham 2007).

**CONSTRUCTION DETAILS**

The test wall was designed to fail in shear and thus had a large quantity of vertical reinforcement with minimal horizontal reinforcement. The wall was 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) around the outermost vertical reinforcement bars. Vertical reinforcement was lapped to the starter bars, which protruded 800 mm above the base, to achieve full development length as specified in NZS 4230:2004.

The wall was 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 blockfill. Dricon™ trade mortar, being bagged 1:4 portions of Portland cement and sand by volume was used throughout. The blockfill contained waste paint at 8% replacement for water on mass, with no other chemical admixtures.

Wall testing was completed on the 28th day after grouting with a cyclic loading sequence and consisted of a series of displacement controlled components. Wall failure was deemed to occur when the wall strength had reduced to 80% of the maximum strength recorded, in whichever direction occurred first. The displacement associated with failure was defined as $d_u$. The procedure for obtaining nominal yield displacement involved measurement of the lateral forces when the wall was loaded in its first cycle to ±1 mm displacement.

**TEST RESULTS**

Measured material properties were sufficiently similar to those reported by (Voon and Ingham 2007) to facilitate direct comparison of recorded data from the two studies. It was determined that the two walls exhibited similar displacement ductility capacity. The force-displacement envelopes are compared in Figure 6, further experimental data is reported in Haigh (2007). The initial elastic region of each wall was similar to a displacement of ~2 mm. 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. It is concluded that wall A exhibited superior performance in the plastic range.
Following the laboratory materials testing, industry level trials were pursued. A blockfill producer in East Tamaki was chosen as the trial plant for this work as it serviced a sufficient demand for blockfill, had and automated batching system, and was of close proximity to the paint source. The paint was initially stored in 1000L plastic bins at the plant, however this was quickly revaluated as the paint needs to be agitated all the time and the average impeller is too large to fit in the mouth of the bins.

A flow meter allows accurate measurement of paint and is linked into the automated batching system so that the pump can be controlled and the paint dispensed and monitored in the same manner as the other admixtures. This system has been proven to work with the water system, but flakes in the paint have caused issues thus far.

Trials were attempted at the plant but the test results were not successful as air contents were too high with resultant drop in strengths. These problems are currently being addressed.

**ACKNOWLEDGEMENTS**

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**INDUSTRY TRIALS**

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