WASTE PAINT AS A POLYMERIC ADMIXTURE SUBSTITUTE IN CONCRETE

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SUMMARY

PaintWise is a nationwide paint recovery program which is based upon the recognition that waste paint is a valuable resource that is currently being disposed of in landfills at a significant economic and environmental cost. In order to utilize the beneficial properties of this waste paint as an active ingredient to produce concrete, a PaintCrete Partnership involving 3R Group Ltd, Fletcher Concrete and Infrastructure Ltd, and Resene Paints was formed. 3R Group is responsible for managing and implementing the PaintWise program, and in 2009 the 3R Group diverted away from landfill and processed over 160,000 litres of waste paint.

Waste paint exhibits many desirable properties that are similar to particularly expensive polymeric admixtures, which have been commonly used in the modification of cementitious applications for well over 70 years. These properties include improved rheology, strength, toughness and durability. These improvements are due to the polymer resins found in paint exhibiting similar advantages to polymers found in conventional polymeric admixtures.

An investigation was performed to identify the suitability of waste paint as a polymeric admixture substitute to improve the fresh and hardened properties of concrete mixes. A considerable amount of commercial emphasis is placed on the research methodology, with a range of different ongoing commercial applications monitored via testing of both fresh and hardened concrete, while analyzing and modifying the concrete mix designs and production procedure as required, achieving desired performance characteristics. Lab-based trials were also undertaken in order to identify mixes with the potential to be trialed at commercial levels.

Previous PaintCrete Partnership research into block-fill grout was not commercialized as insufficient full-scale trials were conducted, whereas the commercial emphasis of this investigation will be of assistance in producing the end result which is fully commercialized PaintCrete; a superior concrete solution which provides enhanced job-site productivity, improved strength and durability, and which is also good for our environment.

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INTRODUCTION

Currently in New Zealand an estimated 21 million litres of decorative coatings paint is sold per annum [1]. Paint is considered a hazardous product and leftover paint is a hazardous waste which must be managed appropriately. Paint can be highly toxic to the environment, and if poured down the drain it is harmful to wildlife and fish, and can also pollute groundwater if dumped on the ground [2]. The collection of paint as a hazardous waste has been conducted in New Zealand for several years, generally through household hazardous waste collections by Local and Regional Councils through publicized collection days.

Resene Paints and 3R Group Ltd together launched PaintWise in 2004 to develop a product stewardship program in order to minimize the impact of waste paint on the environment. A mobile PaintWise truck visits participating paint stores to collect any waste paint returned by paint users, and the processed waterborne paint is provided free to community groups and also used for graffiti abatement, while the processed solvent-borne paint is sent to solvent recovery where the solvents can be reused [3]. In 2009, over 160,000 litres of waste paint was diverted away from landfill and processed via the PaintWise program.

Polymer-modified concrete (PMC) has been researched extensively and has been shown to have improved fresh and hardened properties [4, 5, 6]. Paint exhibits many similar properties to those found in high-priced polymeric admixtures used in specialized concretes, which improve the workability and strength of the cement paste matrix. Recognising that there is a valuable resource existing in the waste stream of paint, a partnership between 3R Group Ltd, Fletcher Concrete and Infrastructure Ltd (involving Golden Bay Cement and Firth Industries), and Resene Paints was formed in 2006 to utilize waste paint in cementitious applications.

The study reported here focused on producing a viable PaintCrete mix to be used in low strength (~20 MPa) non-structural applications such as footpaths and driveways. This low strength concrete was achieved by conducting lab-trials to establish potentially successful mixes, while also conducting commercial trials to replicate the lab-based results and obtain additional input from contractors.

CONCRETE-POLYMER COMPOSITE

Polymer-based admixtures are used in many forms such as liquid polymers, polymer latex (paint), and re-dispersible polymer powders. In all polymer states, it is important that both the cement hydration process and the polymer film formation process interact to form a superior monolithic cement matrix [4]. While water is removed due to cement hydration and water evaporation, the polymer particles eventually coalesce together into a continuous polymer film that is interwoven throughout the hydrated cement particles, coating the particles and aggregates. The properties of the fresh and hardened PMC depend on the polymer type, polymer-cement ratio, water-cement ratio, air content, and curing conditions [4]. A simplified model is shown in Figure 1.

![Figure 1: Simplified model of polymer-cement co-matrix [4]](image-url)
As most paint is based on polymer latex, the improved properties of PMC summarized below are attributable to the inclusion of polymer latex.

**Workability**

Surfactants are negatively charged molecules similar to those found in soap and detergents, and are used to help stabilize an interface by repulsive forces. In polymer latex, surfactants are adsorbed onto the polymer particles to ensure that they are evenly dispersed and that they do not flocculate within their liquid carrier (which is generally water). Ohama [4] reported that PMC has improved workability due to the surfactants being adsorbed onto the polymer and cement particles, generating a dispersing effect and an increase in entrained air, and also due to the ‘ball bearing’ action of the polymer particles. Lewis and Lewis [5] reported that surfactants have a lubricating effect on the wet concrete mix, reducing the viscosity, and hence high workability of the cement paste is achieved at a much lower water to cement ratio. These surfactants and polymers work in the same manner as do conventional water-reducers (super-plasticizers) added to concrete, helping to disperse the cement particles by reducing the inter-particle attraction, thereby reducing their tendency to clump together and requiring less water for the same workability [7].

**Strength**

Overall, the strength of PMC is increased due to a number of mechanisms. Optimal curing conditions require a wet curing period for cement hydration, followed by a dry curing period to promote the polymer film formation process. Once a dry curing period is introduced, and due to the interaction between the cement hydrates and polymer particles, the tensile strength of the binder matrix as well as the adhesion strength between the aggregate and the cement paste is increased [8]. The reduction in required mix-water allows a decrease in the water/cement ratio and an increase in compressive strength. The filling and sealing effects of the impermeable polymer films that are formed allow improved water retention, inhibiting the ‘dry-out’ phenomena and contributing to an increase in the long-term strength even while being dry cured [4]. Fine fillers and inert pigments that are an essential part of water-based paints also contribute to the reduced water demand and to placer-friendly rheology, ultimately increasing the final strength.

**Durability**

The sealing effect due to polymer films, or internal membranes, and the micro-fine fillers decreases permeability, helping to increase resistance to carbonation, chloride ingress, and chemical attack. Micro-cracks in PMC under stress are bridged by the polymer films, preventing crack propagation [4].

**PREVIOUS RESEARCH CONSIDERING USE OF PAINT IN CONCRETE**

Few commercial scale examples exist around the world of the use of paint in concrete, but existing lab-scale research was sufficient for understanding the advantages of adding paint into concrete, and to establish aspects that needed to be considered when conducting full-scale trials. In 2007, Chris Haigh [9, 10] investigated the use of waste paint as an admixture to enhance the properties of blockfill grout. From the compressive strength tests, spread tests, and flexural tensile strength tests, an amount of 12-16% replacement of water by paint was found to give optimum results. The seismic response of PaintCrete block-fill also behaved similar to that of a conventional block-fill grout, and indicated that PaintCrete had the potential to be successful on a larger scale.

A recent study was conducted at the University of Bath in 2008 [11], where the rheological and hardened properties of PMC mixes using recycled paint as the enhancing admixture were investigated. The addition of paint was found to either enhance or deteriorate the compressive and tensile strength depending on the water content, with air entrainment believed to be the main cause of deterioration (which
was thought to increase as the water content increased). The study demonstrated that polymers contribute to the enhanced strength, and that the effects of polymers on the workability of the mix are dependant on the polymer type. It was recommended that further study be conducted into the effects of different paint dosages, air entrainment, and mixing procedures.

**LAB-BASED TRIALS**

Lab scale trials were conducted in order to find an optimum paint dosage and paint mixture (to make use of the water and solvent borne paint produced) by testing air content and compressive strength of PaintCrete with different paint dosages. Once an optimum paint dosage and paint mixture was established, the PaintCrete was evaluated by further compressive strength testing (this time controlling the entrained air), trialing different curing conditions, and testing the flexural strength and sorptivity (water absorption).

Ingredients for the concrete mix were sourced from a local concrete plant and aggregate supplier, while the paint used was the processed paint collected by the Resene PaintWise program. Properties of this paint are given in Table 1. It is the polymers and pigments (and many other additives), which form the basis of PaintCrete.

<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>
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<tr>
<td>3</td>
<td>48.7</td>
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<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>
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For all lab trials, a mixer with a vertical rotating action was used, resembling site-batched concrete (truck batched) more closely than typical lab-style mixers with a horizontal rotating action. All specimens were tested after a maximum of 28 days curing. All testing was conducted according to NZS 3112.2:1986 [12] and ASTM C 1585-04 [13]. A modification was made in terms of curing the PMC specimens in order to give the polymer film a chance to form.

**Optimum paint dosage and effects of solvent borne paint**

The optimum paint dosage and effects of solvent borne paint were investigated by testing the air content and compressive strength of different PaintCrete mixes which consisted of different paint dosages, and different proportions of solvent borne paint added. As air entrainment had previously been identified as an issue with PaintCrete [11], and because many de-foamers are oil-based, it was deemed necessary to trial solvent-borne paint. The different paint dosages trialed were 1 L/m³, 5 L/m³, and 12 L/m³. The different paint mixtures were 100% water borne paint (PWS 1000), 95% water borne and 5% solvent borne paint (PWS 9505), and lastly 90% waterborne and 10% solvent borne paint (PWS 9010). As solvent borne paint is volatile, higher percentages of solvent borne paint were not trialed as volatility of the potential PaintCrete mix can have a harmful effect on the contractors using the concrete, even though it would be no worse than when using solvent borne paint to coat a surface.

All the cylinders were wet cured at all times. It was found that the solvent borne paint did not have the desired effect on the air content and compressive strength, as the air content was still too high, being between 6-10% for the PaintCrete mixes. The addition of paint did have a negative effect on the air content, but as can be seen in Figure 2, the compressive strength was improved.
As the paint dosage increased, the mix became more workable, and hence the water content had to be decreased to achieve the same slump. Although the inclusion of paint did increase the quantity of entrained air, the decrease in water/cement ratio (including the water contained in paint) compensated for the increase in air, as reflected by the effect that paint had on compressive strength (especially the dosage of 12 L/m³).

From this testing it was concluded that PWS 9010 would be used at a dosage of 12 L/m³, and that a de-foamer would be required for optimum results.

**Wet and dry curing**

Literature suggested that the optimum curing condition for PMC is a period of wet curing to allow the cement to hydrate, followed by a period of dry curing (50-70% humidity) to allow the polymer film formation [5, 8]. The normal weather patterns in New Zealand can be relied upon to mimic this ideal curing regime and favour PaintCrete more than conventional concrete. A trial was conducted to determine whether this curing process would have any effect on the compressive strength of PaintCrete, using a curing process that included 16 days of wet curing and 12 days of dry curing, as the cement paste would have gained at least 80% of its strength within 16 days wet curing, and the polymer would have a chance to form with 12 days of dry curing. The paint used was PWS 9010 at a dosage of 12 L/m³ for the PaintCrete mix. Prior to this trial a suitable de-foamer was identified and hence a proprietary de-foamer was included in all trials from this point onwards. All cylinders were tested at 28 days. See Table 2 for a summary of the results.
The air content of both mixes was acceptable. The PaintCrete mix (12 L/m³) had a significantly greater ‘wet/dry strength’ than ‘wet/wet strength’, which was expected due to formation of the polymer film attaining full strength; compensating for the loss in strength due to the cement not hydrating completely. The PaintCrete mix had a higher compressive strength than the conventional concrete mix for both curing conditions, which was partly due to the decrease in water/cement ratio and air content. The conventional concrete mix had a greater ‘wet/wet strength’ than ‘wet/dry strength’, as expected.

The dry curing process of polymer concrete will not reduce the cement hydration greatly compared to conventional concrete, due to improved water retention of polymer concrete and the polymer encapsulation of cement grains trapping water in close proximity and ensuring better hydration, which was why the partly dry cured PaintCrete had a greater compressive strength.

**Flexural strength**

Generally the standard method of specifying concrete for most structural applications is by compressive strength, which is not always the most appropriate strength parameter. For example, an important parameter for a ground-supported slab is flexural tensile strength.

Different curing conditions were used to investigate what effect wet and dry curing had on the flexural strength of PaintCrete in comparison to conventional concrete. Usually, as the compressive strength of concrete increases, so does the flexural tensile strength. Therefore, it was expected that the curing condition that would yield the greatest tensile strength is one with a period of wet curing (allowing the cement to hydrate) followed by a period of dry curing (promoting the polymer film to form and increase the interface bond between the aggregate, and the cement paste matrix [8]). As shown in Figure 3, the strength of conventional concrete did increase as the period of moist curing increased, which was expected (as the cement is allowed to hydrate for a longer period).

![Figure 3: 28-day flexural strength of PaintCrete and conventional concrete](image-url)
There were also some unexpected results; the first was the flexural strength for the PaintCrete specimen moist cured for 20 days being not greater than the flexural strength for the PaintCrete specimen moist cured for 28 days. A moist curing period followed by a dry curing period for PaintCrete resulted in stronger concrete in all previous lab-scale and full-scale trials, but it has been documented that when flexural strength specimens are left to dry prior to testing, a tensile stress is induced within the outer skin, weakening the specimen [6]. The second unexpected result was the flexural strength for the PaintCrete specimen moist cured for zero days (2.3 MPa) being slightly lower than the flexural strength for the conventional concrete specimen moist cured for zero days (2.4 MPa), although the cement would have more time to hydrate in the PaintCrete specimen due to potentially improved water retention. Overall, the flexural strength of concrete was improved with the addition of paint.

**Sorptivity**

The performance of concrete when subjected to aggressive environments depends on the permeation properties (absorption, permeability, diffusivity) of the concrete. The main mechanisms involved in the movement of chloride ions and liquids into concrete (especially when concrete is in a marine environment) are sorption and diffusion, and the ingress of chloride ions can deteriorate concrete by corroding the reinforcement. For concretes exposed to air and subject to wetting and drying, the capillary system of the cement paste is usually only partially saturated, and absorption (rather than diffusion) plays an important role in the penetration of fluid into concrete.

A further trial was performed to measure the sorptivity (rate of water absorption) of PaintCrete and compare the data to the sorptivity of conventional concrete. The exposed surface of a number of unsaturated concrete specimens was immersed in water and the rate of absorption (dominated by the capillary suction mechanism) was determined by measuring the increase in mass of a specimen (resulting from the absorption of water) as a function of time. The PaintCrete specimens were wet cured for 16 days and dry cured for 12 days, while the conventional concrete specimens were fully wet cured. This curing regime allowed optimum strength development for each type of concrete and provided an opportunity to determine the potential performance of the concrete once nearly fully matured. The testing procedure was based on the method proposed by “Hall, C” [14], and ASTM 1585-04 [13].

![Figure 4: Sorptivity results of specimens cured for 28 days](image)

The rate of water absorption (sorptivity coefficient) is the gradient of the trend line shown in Figure 4, and was found to be $175 \times 10^{-4} \text{ mm}^3/\text{mm}^2/\text{min}$ for PaintCrete, and $196 \times 10^{-4} \text{ mm}^3/\text{mm}^2/\text{min}$ for conventional concrete. The lower sorptivity coefficient for PaintCrete suggested that a polymer membrane had formed and that the fillers and pigments in the paint had partially filled voids, reducing porosity and water absorption, and
that PaintCrete was potentially more durable than conventional concrete, especially in a marine environment. Further lab-trials are being conducted, including chloride diffusion, drying shrinkage, and thermal property testing, to compare PaintCrete with conventional concrete.

FULL-SCALE TRIALS

Throughout the research project, full-scale trials were regularly conducted, depending on the availability of suitable applications and progress in lab-scale trials. One of the main objectives of this research was to carry out full-scale trials using commercial production facilities and achieve acceptable results.

Paint was trialed in over 70 m³ of concrete during the first half of 2010, involving applications such as footpaths, driveways, and a cattle yard. All full-scale trials were conducted in Hastings, as this is where the research was based. Throughout the year, as more trials were conducted, the trial process and paint mixture were refined and improved, while communication between 3R Group and Firth Industries has increased considerably as more trials were conducted. These initial steps were important in improving relationships within the PaintCrete Partnership. The paint mixture used in all trials was PWS 9010, though a de-foamer was not used at the start, but once a suitable dosage was found, the de-foamer was trialed and the dosage was increased if required. A summary of some trials is outlined below.

**Apley road – Cattle Yard**

Angus McMillan (Angus McMillan Concrete) heard a presentation from a Director at 3R Group on the potential benefits of PaintCrete, and after a short meeting, decided to be the first contractor to use PaintCrete. It was also the first opportunity to work with a Firth concrete plant to batch PaintCrete.

A 9 m³ cattle yard pour was proposed, but because the air entrainment issue had not been solved at this point and a de-foamer had not been trialed in the lab, the dosage of paint was decreased from the optimum 12 L/m³ down to 5 L/m³ (for the first truck load) and to 1 L/m³ (for the second truck load). As expected, air entrainment was an issue and the first truck load (6 m³) had an air content of 14.5%, with the second truck load (3 m³) having an air content of 9%. Once the first truck arrived at the site, the contractors were in a positive frame of mind immediately, with the flow and ease of finishing the concrete, and its ability to hold its shape when workers put ‘grip lines’ through the concrete with the screed, making life easier for the workers.

Cylinders were also cast and tested at 28 days after being fully wet cured (due to optimum curing conditions not being trialed prior to this). The 28 day compressive strength was 22 MPa, despite the high air content. The concrete was assessed on a monthly basis to determine durability characteristics in terms of abrasion resistance and chemical attack, from the cattle hooves and excrement. Overall, the contractor was happy with the performance and ease of using the PaintCrete, and a few months after pouring the concrete, no damage could be seen on the hardened concrete. Much was learnt from the experience which was incorporated into the next trial.

**Nottingley Road – Footpath**

Paint was used in approximately 45 m³ of concrete footpath on Nottingley Road, poured in four phases. The dosage for all concrete was 12 L/m³ and a de-foamer was used to control the air. Fulton Hogan was the contractor for the pours and mentioned that the mix did improve as the trials progressed, with air content being controlled at an acceptable level once a final de-foamer dosage was found. In general, as mentioned by all contractors who have worked with PaintCrete, Fulton Hogan also liked the creaminess and ease of working with PaintCrete (see Figure 5).

The average air content of Nottingley Road footpaths was 5.4%. The average 28-day compressive strength of the cylinders fully wet cured for 28 days was 22.5 MPa, while the average 28-day compressive strength of the cylinders wet cured for 16 days and dry cured for 12 days was 26.5 MPa, representing an 18% increase in strength. This result is very positive as this full-scale trial replicated the lab-scale wet and
dry curing trial mentioned earlier. More footpaths on Nottingley Road will possibly be poured over the second half of 2010, making use of more waste paint in the region.

Nelson Street – Driveway

Due to the addition of paint allowing a decrease in water/cement ratio and enhanced strength when partly dry cured, a trial involving reduced cement and the addition of lime was conducted on a 2.4 m² driveway.

Although the 28-day fully wet cured compressive strength was 17.5 MPa, the cylinder wet cured for 16 days and dry cured 12 days had a compressive strength of 21.5 MPa, which was a 23% increase in compressive strength, again confirming the optimum curing process for PMC. The contractor was pleased with the concrete mix in nearly every aspect (see Figure 5). Finishing the concrete was very easy, and the concrete was very glossy, creamy, and shiny; which are all proven aspects of PaintCrete. However, the mix did take longer than usual to set, due to the lower cement content, but overall the project was considered a success.

![Figure 5: Nottingley Road footpath (left); Nelson Street driveway (right)](image)

Full-scale trials are currently being conducted at Firth Mt Maunganui and Firth Albany to see what effects the different concrete mixtures and aggregates have on the properties of PaintCrete and especially entrained air. For each different concrete plant used for a full-scale trial, lab-scale trials were initially conducted using the same mix and specifically aggregates as the concrete plant does. This assists in terms of finding a suitable de-foamer dosage, and also further becoming familiar with the process of batching PaintCrete at different concrete plants with different setups.

In the future it is likely that PaintCrete will be batched with various more environmentally friendly cementitious materials and recycled aggregates; and a suitable custom cement blend is currently being trialed.

CONCLUSIONS

Through careful mix design and suitable defoamer use, the high air content issue with PaintCrete was controlled and the use of paint in concrete has been proven to improve the fresh and hardened concrete properties through lab-scale and full-scale trials.
At the end of this study it is anticipated that waste paint will be a commercial reality, allowing paint to be a suitable replacement for polymeric admixtures used in concrete production, be an accepted product at an industry level, and add value to the waste stream of paint.

REFERENCES