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Waste paint as an admixture in concrete

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A B S T R A C T

A significant volume of waste latex paint exists in New Zealand, with the rate of supply rapidly growing, prompting an investigation into the use of waste paint as a polymeric admixture in concrete due to similarities in chemical compositions of waste paint and polymeric admixtures. 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. The optimum dosage to achieve the required strength and workability was found to be approximately 12% replacement of mix water with waste paint, while the Modulus of Elasticity was found to be a function of compressive strength. Rheological testing indicated that regardless of paint concentration, the yield stress of the blockfill increased whilst the viscosity and separation rate decreased. It was established that waste latex paint was a suitable replacement for conventional admixtures in concrete masonry blockfill, resulting in maintained strength and improved workability.

1. Introduction

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 [1]. Although polymer-based/polymeric admixtures in many forms are used in cementitious composites such as 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 [2]. It is the formation of such a co-matrix phase that results in superior properties when compared with conventional cementitious materials. The fresh and hardened properties of polymer-modified concrete are markedly improved over those found in conventional mix designs and are affected by a range of factors such as polymer type, polymer–cement ratio, water–cement-ratio, air content and curing conditions. All of these factors can be controlled to manufacture the targeted properties.

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 latex varieties available in New Zealand, exhibits many properties that are similar to polymeric admixtures used in concrete production. Polymers make up the majority of the solid mass in paint, while polymeric admixtures have been an active ingredient in the modification of cementitious applications for well over 70 years. Polymeric 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.

The objective of this study was to investigate the use of waste paint as an admixture in masonry blockfill, recognising that one of the primary advantages of polymer-modified concrete is increased workability and improved filling of masonry units [1]. The improvement in workability enables settlement of the blockfill around congested reinforcement and small void areas, and reduces the need for compaction and vibration, resulting in faster, cheaper, and safer construction.

Paint is made up of numerous fine and ultra fine particles, in the range of 0.1–10 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. Because high strength concrete can be produced by incorporating large amounts of ultrafine fillers with reduced cement content, it was identified that a potential opportunity existed for saving cement by using waste paint as a polymeric admixture, with a resultant decrease in the production of carbon dioxide [3].

Recycled waste latex paint was used in urban concrete sidewalks in Ontario, Canada [4], where it was determined that the waste paint 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 that was modified with

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waste latex paint exhibited enhanced workability and finishing, and better durability to surface scaling and aggregate pop out.

A large number of constituents are included across the paint varieties available from New Zealand paint producers. The primary constituents expected to occur in high volume were:

Polymers – The continuous phase of latex 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. Emulsion polymers are common in paint and are usually made up of water, monomers and surfactants [5].

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 [6]. The nature and proportions of the two parts of the molecule will vary between applications [7].

Foam Controllers – Antifoams or defoamers are active in paint to control foaming, which is an unwanted product of surfactants. 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 constituents 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. It is a transparent particle, yet appears white because of the small particle size which causes light to be scattered back, and thus the eye receives the whole spectrum of light [8]. Titanium dioxide was expected to not 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.

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, being calcium lignosulfonate and triethanolamine [9]. Calcium lignosulfonate is an anionic polymeric surfactant which primarily acts as a water reducer or wetting agent, and is active at the interfaces of the water/air and water/particle surface, causing a decrease in the surface tension within the system, which results in an increased flow and spread of water across all surfaces, thus reducing the demand for water. Calcium lignosulfonate also works as a retarder which prolongs the cement hydration process, ultimately increasing the compressive strength [10]. Triethanolamine is an organic chemical compound which serves two purposes within the admixture. Its primary purpose is as a pH balancer to increase the pH of a mixture, 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 alkyl benzene sulfonic acid surfactant in order to stabilize the entrained air [11].

From an assessment of the active chemicals in paint, and the standard chemicals presently used within blockfill, conclusions can be developed regarding the conceptual success of chemical replacement using waste paint. A primary ingredient in both conventional admixtures is surfactant, which covers a wide range of chemicals. Latex 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 stabilizing particles. Many of the chemicals present in the paint will be inactive as a concrete admixture as they are present in minor concentrations that are only sufficient to serve their purpose when added to paint, whilst other chemicals are free to interact with cement. The polymers and surfactants found within waste paint have the potential to simulate the action of the calcium lignosulfonate as a hydration retarder [12].

In this study waste paint was used as a partial replacement for mixing water, with testing completed in two stages: initially with the industry-recommended chemical admixtures to establish if waste paint is a suitable additive for a conventional blockfill mix; and then in the absence of these chemical admixtures, to understand the potential of waste paint as a replacement for conventional chemical admixtures. Fresh concrete properties including in-depth rheology analysis, compressive strength, and flexural strength were evaluated for various blockfill mixtures and results are reported.

2. Materials

All materials used in the study corresponded to those found in a standard 17.5 MPa blockfill mix produced by a New Zealand ready-mix concrete plant, with a maximum aggregate size of 7 mm. Sand and aggregate were collected directly from loading bins at the ready mix plant with moisture content noted and factored into the mix design, whilst the general purpose Portland cement was sourced directly from the cement manufacturer in Portland, Whangarei. The chemical composition and physical properties of the cement are presented in Tables 1 and 2 respectively. The waste paint used in this study was sourced from a paint collection program, with various samples of the waste paint obtained and analysed. The obtained properties of this waste paint are summarised in Table 3. The paint had a mean density of 1.3 g/cm^3 and was comprised of approximately 50% water, such that when water is replaced by waste paint the w/c ratio is proportionally reduced. The remaining solid content of the paint was comprised of polymers and pigments, whose proportions vary significantly over time, but recognising that this paint was a non-controlled waste product, the variation shown in Table 3 was considered acceptable. For the reference concrete, the admixtures used were Pozzolith 370C, which is a non-retarding, non-chloride, water reducing strength enhancer and Micro Air, which is an anionic polymeric surfactant water reducer.

3. Experimental methods

3.1. Optimal paint dosage

Laboratory testing was completed to determine the optimal paint dosage for the target blockfill workability and strength properties, with a w/c ratio of 0.70 for the reference blockfill mixture.

Table 1
Chemical composition of cement.

Compounds	% (By weight)
SiO_2	22.8
Al_2O_3	4.2
Fe_2O_3	2.3
CaO	64.8
MgO	1.0
Na_2O	0.2
K_2O	0.5
Free lime (CaO)	1.3
Hypothetical compounds	
Lime saturation factor	97.0
C_3S	68.0
C_2S	14.0
C_3A	7.0
C_4AF	7.0

Table 2
Physical properties of cement.

Properties	
Specific surface area (m^2/kg)	343
Initial setting time (min)	116
Final setting time (h:min)	3:18
Soundness (mm)	1
SO_3 (%)	2.0
Specific gravity (g/cm^3)	3.15

Table 3
Typical compositions of waste paint.

Sample	Water (%)	Polymers (%)	Pigments (%)
1	46.6	28.9	24.5
2	47.9	22.5	29.6
3	48.7	26.9	24.4
4	47.1	28.8	24.1
Average	47.6	26.8	25.6
S.D	0.922	2.995	2.639

Ingredients were added and mixed with 80% of the mix water for 2 min. Waste paint was then added with the remaining mix water, and mixed for 10 min. Testing was undertaken in accordance with the relevant standard NZS 3112:1986 [13].

3.1.1. Stage one testing with the inclusion of conventional chemical admixtures

Stage one testing consisted of nine 100 × 200 mm concrete cylinder samples, three 100 × 100 × 350 mm flexural beams and three spread tests completed at 0%, 4%, 8%, 12%, 16% and 20% Paint Replacement Of Water (PROW) by mass, whilst retaining the chemical admixtures (discussed earlier in Section 2) ordinarily used by the blockfill producer for a conventional mix. These PROW proportions resulted in a relatively small percentage addition of paint with respect to the size of the mix, and represented approximately 0.5–2% of the entire mass of the blockfill.

For each mixture, the compressive strength of three cylindrical specimens was measured at time periods of 7, 28 and 56 days. 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. 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.

3.1.2. Stage two testing with the exclusion of conventional chemical admixtures

Two blockfill mix designs, each with three cylinders tested at each paint concentration, were trialled to assess compressive strength, with one mix having a standard w/c ratio (referred to as Series A) and the other mix having a higher w/c ratio (referred to as Series B). This test design was adopted based on the assumption that the extra water added in Series B (disregarding the 0% paint mix) 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, resulting in the net w/c ratio within each test being due to a reduction in mix water but an addition of water contained within the paint. The parameters for each trial are outlined in Tables 4 and 5.

Spread tests were conducted at a constant waste paint percentage of 12%, based on the optimum proportion suggested by earlier testing. Variation was introduced by removing the admixtures and introducing waste paint, in an effort to identify the best and worst mix formulation case scenarios (see Table 6). Spread tests were carried out at 20 min intervals over 80 min, with the blockfill mix being left static over the 20 min between tests. Immediately prior to each test the mix was given 20 s of mixing to ensure that any bleeding or segregation that may have occurred was not causing inconsistencies within the material.

The elastic modulus was also evaluated during Series B compression testing, using data 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% PROW, from which the average *E* value was measured.

3.2. 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. 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 based paint had on the concrete masonry blockfill.

Testing was completed using a BML4 Viscometer, which is a coaxial cylinder viscometer suitable for the 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. Ingredients were combined together and then subjected to shear whilst the mix water was added. Tests were performed with an identical mix design to that reported in the previous section in the absence of conventional admixtures, at dosages of 0%, 4%, 8%, 12%, 16% and 20% PROW by mass, at time intervals of 0, 15, 30, 45 and 60 min. Further details of the testing methods were reported by Haigh [14].

4. Results and discussion

4.1. Stage one

The 7 day results (Fig. 1a) indicated peak strength at 12% PROW, with a data accuracy of ±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 strength of the cement matrix 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% PROW. These results suggested that the addition of too little waste paint was as detrimental as the addition of too much waste paint. The 16% PROW data point exceeded the standard 17.5 MPa target, which was the required 28 day strength specified in NZS 4210

Table 4
Series A water/cement (w/c) and polymer/cement (p/c) ratios, compressive strength and density at the time of stage two compressive testing.

Paint (%)	w/c	p/c	f'_c (MPa)	Density (kg/m^3)
0	0.7	0	21	2138
4	0.686	0.007	14.6	1953
8	0.672	0.014	12.6	1920
12	0.658	0.021	11.4	1879

Table 5
Series B water/cement (w/c) and polymer/cement (p/c) ratios, compressive strength and density at the time of stage two compressive testing.

Paint (%)	w/c	p/c	f'_c (MPa)	Density (kg/m^3)
0	0.7	0	21	2138
4	0.891	0.007	15.9	2119
8	0.877	0.014	21.6	2238
12	0.863	0.021	21.3	2210

Table 6
Mixture designs for spread vs. time tests.

Mix	Micro air	Pozzolith	Paint
1	*	*	
2			
3	*	*	*
4			*

[15]. 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 12–16% PROW an optimum strength occurred, exceeding the specified 17.5 MPa minimum compressive strength.

The trend observed within the compressive strength data was also apparent in the spread test results, with a peak occurring at 12% PROW (Fig. 1b). Note that the data point at 8% PROW was omitted due to an error in testing methodology. This peak spread value was 580 mm, which was well above the specified minimum of 450 mm [15], suggesting that water could be removed from the mix and that the inclusion of excess paint caused the paste to lose workability. The results for the flexural beams (Fig. 1c) further demonstrated the apparent trend, with the optimum value occurring at 12% PROW. This observation confirmed that the addition of paint did not specifically negatively affect the flexural tensile strength.

Recognising that the Stage one mixes had contained both standard chemical admixtures and waste paint, resulting in excess levels of polymer and air entrainer, the results emphasised the need to continue laboratory experimentation in order to investigate the viability of removing the conventional chemical admixtures and relying exclusively on the waste paint for added workability, prior to the commencement of a larger scale investigation.

4.2. Stage two

The results from Series A testing after 28 days (Fig. 2a) showed a distinct linear decrease in compressive strength as the waste paint content was increased, which was attributed to an increasing air content and an associated decrease in concrete density (see Table 4). 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 had a negative effect on the strength of the blockfill. Series B strength results are shown in Fig. 2b, with companion density results reported in Table 5. These results 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 addition of waste paint did not result in a greater overall strength, but instead caused a decrease in compressive strength if not added in the correct quantities. The data point for the 12% PROW was the only outlier, with identical strength to the 8% PROW specimens, but having a lower elastic modulus (Fig. 4). These observations suggested that as the polymer content approaches a threshold value, the waste paint begins to have a greater effect on the elastic deformation of the material, whilst maintaining strength.

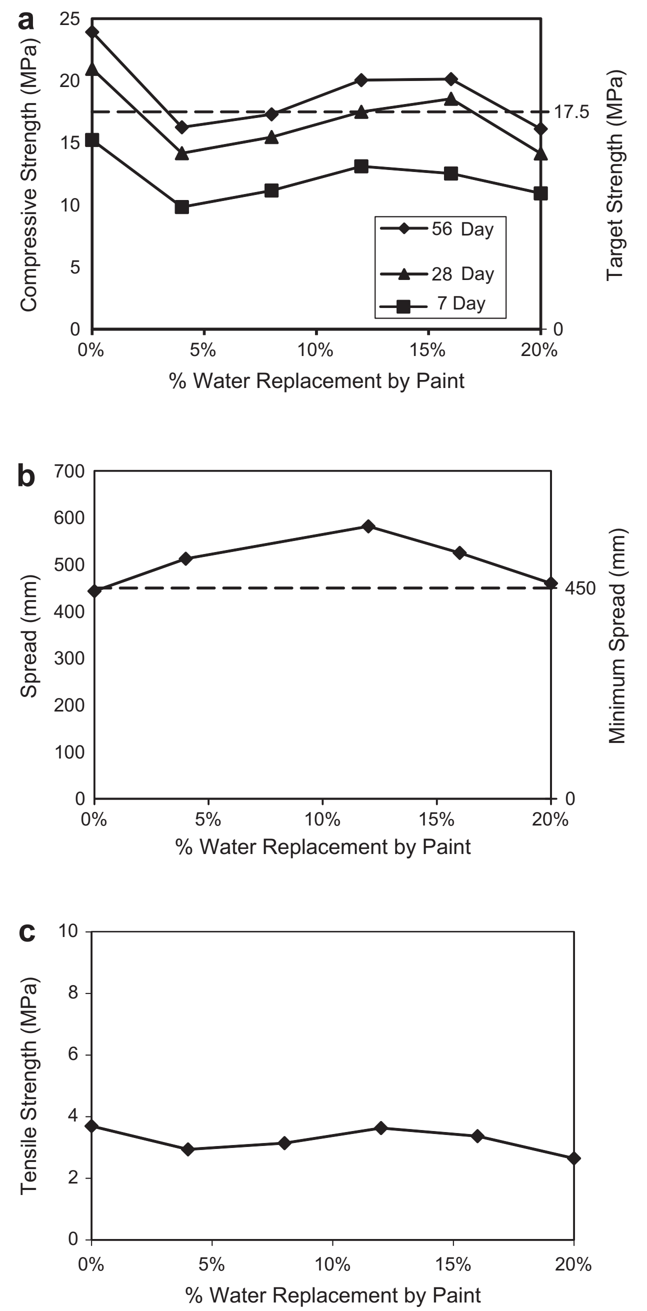

Fig. 1. Stage one test results: (a) Stage one compressive strength results. (b) Stage one average spread value. (c) Average tensile flexural strength results.

Spread test results (Fig. 3) indicated that the mix design containing no admixtures or waste paint (Mix 2) was the only scenario that performed unsatisfactorily, effectively being unable to pass through the inverted slump cone at the conclusion of 80 min. The performance of the other three mixes was inseparable and the blockfill maintained a consistent spread 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 (Fig. 4) had a similar profile to the compression strength data in Fig. 2b, indicating that the elastic modulus of concrete masonry blockfill with the addition of waste paint was a function of compression strength, rather than being influenced by the presence of polymers. This observation is consistent

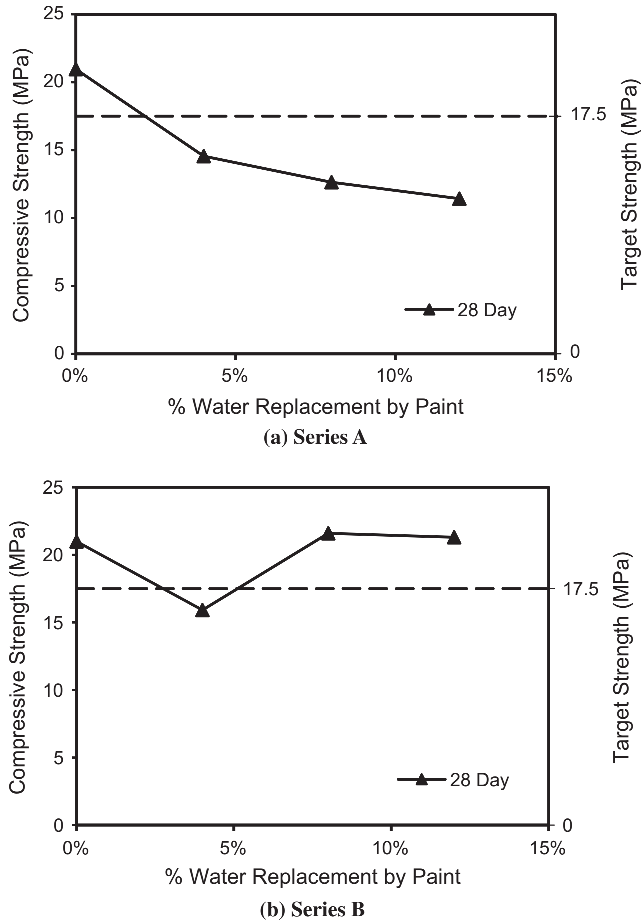

Fig. 2. Stage two 28 day compressive strength.

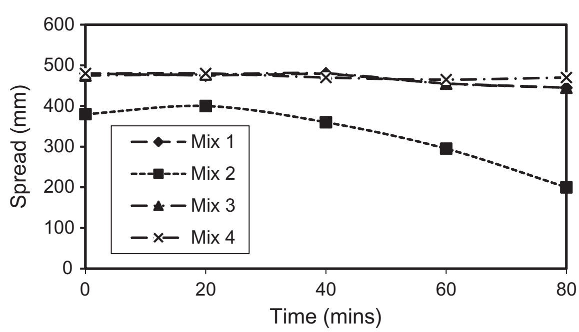

Fig. 3. Spread vs. time results.

with existing code-defined equations for the calculation of E, in which the magnitude is a function of compression strength.

An intimate understanding of the chemical processes responsible for the results observed in materials testing in the absence of conventional chemical admixtures involved knowledge of industrial chemistry that was outside the scope of the study. However the following explanations for the observed results are suggested:

- Higher water content allows the paint particles to avoid flocculation. Should the particles be given a larger medium they would be more spread out, causing flocculation to become less likely.
- Paints are stabilized with surfactants which, unfortunately, also help to stabilize air introduced during manufacture and application. Increased water content activates/deactivates the ingredients within paint that control foaming [16].
- A further plausible mechanism is that the surfactants which stabilize the bubbles (which cause high air content) have a reduced concentration due to the addition of extra water, resulting in a reduced amount of foam.

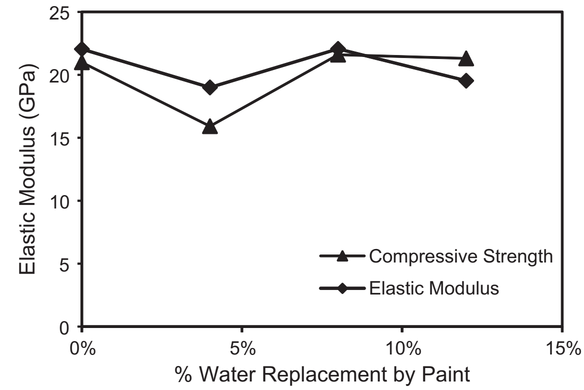

Fig. 4. Elastic modulus data.

The observation that elastic modulus results exhibited a similar trend to that of the compressive strength is concordant with the findings of Cook and Crookham [17] 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 [17] also noted that the failure mode exhibited more ductility, although that data was not collected in this study.

4.3. Rheology

The rheological data showed a distinct change in yield shear stress with the addition of waste paint (see Fig. 5a). Immediately following (0 min) the addition of waste paint, the yield shear stress of the material increased by 30%, to be an approximately constant amount regardless of the concentration of the paint. Viscosity dropped with the inclusion of waste paint (Fig. 5b). The separation data in Fig. 5c shows that as the viscosity decreased with paint concentration increase, the separation was also observed to decrease. Identifying the specific reasoning for the rheological changes observed was 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 is shown in Table 7. The increasing air content within the mix explained the plastic viscosity reduction. The air content increase was 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.
- 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 [18]. 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 [19]. If these sites interact with each other, resulting in stronger bonds holding the mixture together, the surfactant will

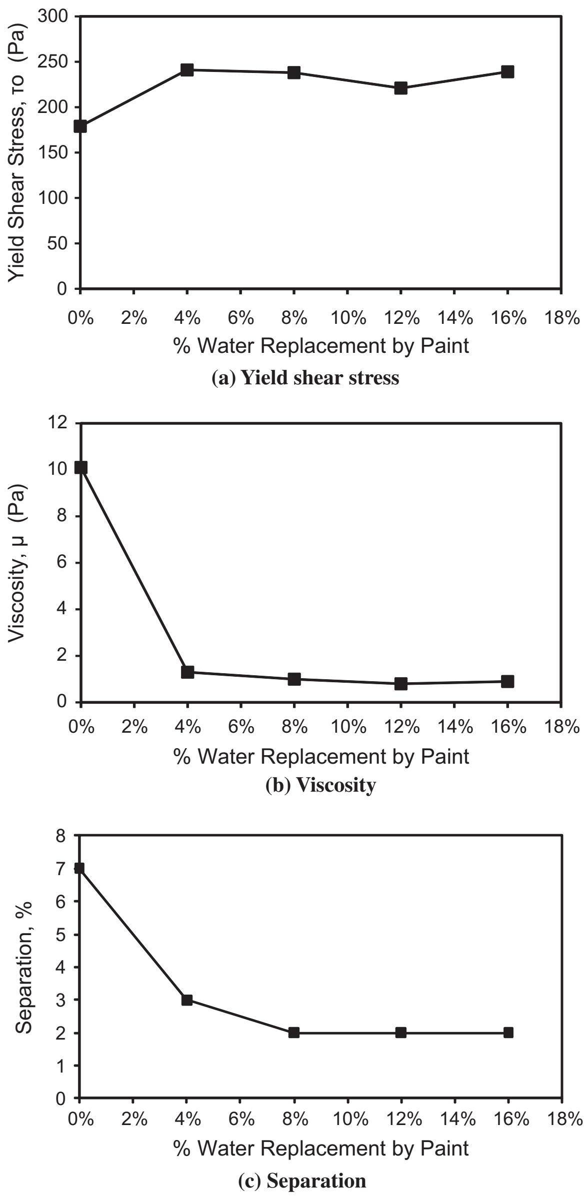

Fig. 5. Rheological data at 0 min.

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 developed that favoured 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 [20].

- The improvement in segregation is a result of the thickeners which are present within paint. The thickeners, which become attached to any particle available whilst being repelled by water, are largely disabled with the application of shear. The bond between particles is broken, but the thickeners continue to remain attached, suspending the particles within the mix and preventing or slowing down their ability to separate. The other phenomenon occurring is due to the polymers within the paint, which create a 'structure' within the paint, similar to the concept of thixotropy.

Table 7
Air content of mixes used in rheological testing.

Paint content (%)	0	4	8	12	16
Air content (%)	6.30	11.50	11.50	11.50	11

5. Conclusion

This study investigated the use of waste paint as a partial replacement for mixing water and polymeric admixtures in masonry blockfill. The motivations for this investigation were to effectively utilise the available resource of waste paint, and to exploit similarities in the chemical compositions of waste paint and the polymeric admixtures used in conventional concrete to increase workability.

It was established that waste paint was a suitable additive to blockfill mixes that also contained conventional chemical admixtures (Stage one testing), with dosages of 12–16% PROW resulting in maintained strength and improved workability. In the absence of conventional admixtures (Stage two testing) it was determined that dosages of 8–12% PROW led to optimal material properties of blockfill compressive strength, tensile strength and workability, while an increase in water content (Series B) ensured a more uniform distribution of waste paint within the mix, leading to maintained compressive strength without excessive air entrainment.

Waste paint was found to improve the workability and rheology of masonry blockfill, resulting in an increase in spread and a significant decrease in viscosity and separation, and hence waste paint was found to be viable as a replacement for conventional chemical admixtures. Additional testing and analysis should be undertaken to confirm these results and also understand the effects of waste paint on other performance requirements such as long-term durability.

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