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Recycling waste latex paint in concrete

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Abstract

Currently, in Ontario, Canada, around 21.7% of the total hazardous waste (HZW) collected by municipalities is waste paint. Waste latex paint (WLP) alone constitutes 12% of the total HZW. It is estimated that only 10–30% of this waste is presently being collected but this proportion is growing with public education efforts. In addition, due to increasingly more stringent environmental regulations on volatile organic compounds (VOCs), more latex-based paints will be produced compared to solvent- and oil-based alkyds. This will result in more WLP being generated annually in Ontario and across North America. The disposal cost of such waste currently varies between Can$0.90 and Can$1.40 per litre. This study was conducted in collaboration with the City of London, Ontario and the Ontario Paints and Coatings Association and aims at investigating the benefits of recycling WLP in concrete with a special focus on concrete sidewalks. WLP was used in concrete mixtures both as a partial replacement for virgin latex and for mixing water. This paper demonstrates that concrete mixtures incorporating WLP can have improved workability, higher flexural strength, lower chloride ion penetrability, better resistance to deicing salt surface scaling and can be more economic because they require less water-reducing and air-entraining admixtures. The results also indicate that the annual urban concrete sidewalk construction could use the yearly production of WLP while producing sidewalks with enhanced properties and durability.

Keywords: Recycling; Waste; Latex paint; Concrete; Sidewalks; Chloride ions; Surface scaling

1. Introduction

In the wake of an escalating waste disposal crisis, the Ministry of Environment in Ontario implemented the 3R's management strategy (reduction, reuse, and recycling). As part of this program, the collection of hazardous waste (HZW), including waste paint, has been conducted for several years. In 1999, 6364 tons of HZW was collected in the province, among which 21.7% is waste paint. Waste latex paint (WLP) alone constitutes 12% (around 500,000 l) of the total HZW and has been accumulating since the inception of its collection policy. It is projected that the collected WLP will grow substantially for two reasons: (a) current collection programs result in the capture of only 10% to 30% of the total HZW; public education programs can raise this level significantly, and (b) increasingly more stringent environmental regulations on volatile organic compounds (VOCs) will increase the production and use of latex paints relative to other solvent-based paints, consequently increasing the generated WLP.

Attempts to recycle WLP in asphalt concrete have failed. Although laboratory tests provided positive results, field pavement trials indicated that unpleasant odours were emitted from the mixture. Air quality analyses showed that hot-mix-asphalt mixtures incorporating recycled latex paint could release vapours of ethylene glycol in concentrations beyond the recommended levels for occupational health and safety. Experiments were conducted to examine the possibility of removal of ethylene glycol. It was concluded that there was no practical and economical way of stripping the harmful vapours out of asphalt concrete. This option was therefore terminated [1].

The objective of this study is to investigate using WLP as an admixture in portland cement concrete. The idea of using polymers in cement-based materials dates back to the early 1920s when the first patents on using natural rubber polymer-modified cementitious systems were issued [2]. The first patent on the use of synthetic rubber latexes in such application was issued in 1932 [2]. Since then many products, patents, and applications have been developed. In North

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America, latex-modified concrete (LMC) was used as a bridge overlay in Michigan as early as 1958. In Ontario, the first major application of LMC was a 1980 overlay on collector lanes of Highway 401 in North York. However, information on the use of WLP in concrete was not accessible in open literature, and it is not understood whether WLP could contribute improvements to the behaviour of concrete similar to those imparted by virgin latexes.

Two distinct approaches for using WLP in concrete could be adopted. First, to use it as a value-added product for partial replacement of virgin latex in LMC. This method requires that the beneficial effects of using this by-product must be equivalent to those imparted by virgin latexes. Often, LMC is used in demanding applications such as bridge deck overlays to mitigate corrosion problems. The latter approach of using WLP implies that stringent quality control procedures must be implemented to assure that the performance of such a variable and noncontrolled by-product can match that of a factory-controlled product, which is difficult to achieve. The second approach is to use the WLP in concrete that is normally not intended to be polymer modified. The use of the recycled latex paint must either improve or maintain equal rheological, mechanical, and durability performance of the host concrete. Concrete sidewalks seem to be a good application for the latter case since the reduction of permeability and porosity due to the latex polymer may enhance the resistance of concrete to surface scaling and other physical and chemical attack. The yearly WLP collected in Ontario can be recycled in about 9000 m^3 of concrete, which can roughly make 48 km of sidewalk (assuming 50 l of WLP per cubic metre of concrete, each cubic metre of concrete can make 5.3 m of sidewalk 1.5 m wide and 0.125 m deep). Therefore, the concrete sidewalk industry can potentially recycle most WLP each year.

In this study, WLP was used both as partial replacement for virgin latex and as partial replacement for mixing water. Fresh concrete properties, compressive strength, flexural strength, rapid chloride penetrability, and resistance to deicing salt surface scaling were evaluated for various concrete mixtures and results are discussed in this paper.

2. Materials

CSA Type 10 (ASTM Type 1) cement, slag, coarse and fine aggregates, air-entraining admixture, and water-reducing admixture were obtained from Blue Circle CBM from typical materials currently used in municipal sidewalk concrete mixtures in London, Ontario. Various samples of WLP from the City of London's waste collection site were obtained and analysed. Their properties are summarized in Table 1. Generally, the latex polymers represent about 15% of WLP, water is around 59%, and other extender solid pigments including TiO_2 are around 25%. These proportions vary significantly in time, but considering that the material is a noncontrolled by-product, the variation shown in Table 1 was considered acceptable. However, the material is expected to have more uniform properties if larger container mixing is implemented to average out any variability. The virgin latex used was a styrene–butadiene with a density of 1025 kg/m^3, a non-volatile content of 47%, which generally corresponds to the solid latex polymer content.

3. Experimental and test methods

To investigate the partial replacement of virgin latex by recycled latex paint, a reference concrete mixture with a water/cement ratio (w/c ratio) of 0.40 and a latex-modified mixture with similar w/c ratio were made. In addition, mixtures containing 100%, 75%, and 25% replacement of the virgin latex by recycled latex paint were prepared and their proportions are shown in Table 2. Although the polymer/cement ratio will not be maintained when recycled latex paint is used as partial replacement for virgin latex on a mass basis, this option was adopted to make the replacement procedure simpler. The mixing water was adjusted to account for the additional water in the latex and recycled paint.

Table 1
Typical compositions of WLP

Date sampled	Density (kg/m^3)	Nonvolatile content (%)	Ethylene glycol (%)	Water (%)	Latex polymers (%)	TiO_2 (%)	Extender pigments (%)
12/02/00	1.528	47.4	1.0	52.6	16.5	15.5	15.5
12/02/00	1.432	37.6	1.0	62.4	14.2	11.7	11.7
01/27/01	1.510	42.5	1.2	57.5	12.9	14.8	14.8
01/27/01	1.462	40.6	1.4	59.4	14.7	12.9	12.9
02/03/01	1.469	44.5	1.4	55.5	18.1	13.2	13.2
02/24/01	1.463	40.2	1.0	59.8	14.2	13.0	13.0
02/24/01	1.414	38.2	1.1	61.8	16.3	10.9	10.9
03/03/01	1.378	35.8	0.8	64.2	17.1	9.4	9.4
03/03/01	1.414	39.4	0.9	60.6	17.5	10.9	10.9
Average	1.452	40.7	1.1	59.3	15.7	12.5	12.5
S.D.	0.045	3.406	0.197	3.406	1.676	1.843	1.843

Table 2
Mixture proportions for replacing virgin latex with WLP

	Reference mixture	100% Virgin latex	75% Latex–25% paint	25% Latex–75% paint	100% Paint
Cement (kg/m^3)	390	390	390	390	390
Water (kg/m^3)	155	90	90	85	80
Coarse aggregate (kg/m^3)	890	890	890	890	890
Fine aggregate (kg/ m^3)	820	820	820	820	820
Virgin latex (kg/m^3)	–	125	95	30	–
Recycled paint (kg/m^3)	–	–	30	95	125
Slump (mm)	75	105	110	115	120
Air content (%)	6.5	8.5	9.5	8.0	9.0
Polymer/cement ratio (%)	–	15.0	12.7	7.4	5.0
w/c ratio (%)	0.40	0.40	0.41	0.40	0.39

Moreover, to investigate the effect of using WLP in municipal sidewalk concrete mixtures that are normally not intended to be modified with polymer, a reference sidewalk concrete mixture and mixtures having 10%, 20%, 30%, 40%, and 60% replacement of mixing water with recycled latex paint were made and their proportions are shown in Table 3.

Water and WLP and/or virgin latex were manually mixed. The saturated surface-dry coarse aggregates were mixed with part of the mixing water (with WLP and/or latex). The fine aggregates and cementitious material were subsequently added and mixing resumed for 2 min with the remaining mixing water and chemical admixtures being added over the first minute of mixing. After a 2-min rest period, a 3-min mixing sequence was conducted, and the mixer was covered with a plastic sheet.

Table 3
Mixture proportions for replacing mixing water with WLP

	Reference mix	Paint (%)				
		10	20	30	40	60
Cement (kg/m^3)	285	285	285	285	285	285
Slag (kg/m^3)	70	70	70	70	70	70
Coarse aggregate (kg/m^3)	1070	1070	1070	1070	1070	1070
Fine aggregate (kg/m^3)	750	750	750	750	750	750
Water (kg/m^3)	135	125	110	95	82	55
Latex paint (kg/m^3)	–	14	27	40	55	82
Water-reducing admixture (ml/100 kg of binder)	220	220	220	220	0	0
Air-entraining admixture (ml/100 kg of binder)	10	10	10	5	5	5
Slump (mm)	58	160	180	180	120	110
Air content (%)	9	11	16	12	7	4
Polymer/cement ratio (%)	–	0.6	1.2	1.8	2.4	3.6
w/c ratio (%)	0.38	0.38	0.35	0.33	0.32	0.29

The slump (ASTM C 143) and air content (ASTM C 231) of fresh concrete were measured. Cylindrical specimens 100 × 200 mm, beams 100 × 100 × 350 mm and slabs 200 × 230 × 75 mm were prepared using a vibrating table. Specimens without latex were covered by wet burlap for 24 h, and then cured in a moist curing room at 23 °C and more than 95% RH. Specimens containing latex and/or WLP were covered with wet burlap for 48 h then air-cured under lab conditions at around 23 °C until testing. For each mixture, the compressive strength was measured on three cylindrical specimens at 1 day and 28 days according to ASTM C 39 specifications. The flexural strength was obtained on three beam specimens as per ASTM C 78. In addition, the rapid chloride penetrability was obtained at 28 days on three disks 50 × 100 mm cut from cylindrical specimens 100 × 200 mm for each mixture as per the ASTM C 1202 guidelines. After curing the slabs (14 days in the moist chamber and 14 days in lab conditions for slabs with no latex; 1 day moist curing and 27 days in lab conditions for slabs with latex), strips of high-density expanded polystyrene were attached to the sides of the slabs with an exterior grade adhesive in order to create a watertight brine pond with a 6-mm thickness and a concentration of 4% $CaCl_2$. Starting at an age of 28 days, the slabs were subjected to 50 cycles of freezing–thawing strictly following the ASTM C 672 guidelines. The amount of scaled-off material was measured after each five cycles, and scaling was given a visual rating. The results are average values obtained on two identical slabs for each mixture.

4. Results and discussion

The air content and slump results for mixtures using WLP as partial replacement for virgin latex and mixing water are shown in Tables 2 and 3, respectively. It is observed that the air content of fresh concrete increased

Table 4
Experimental results: replacement of virgin latex with WLP

Mixture	Compressive strength (MPa)		Flexural strength (MPa)		Chloride penetrability (C)
	1 Day	28 Days	1 Day	28 Days	
Reference	13.7	44.5	6.1	8.6	1880
100% Virgin latex	17.2	53.3	7.8	10.2	850
75% Latex–25% WLP	16.4	51.6	5.4	10.5	470
25% Latex–75% WLP	11.2	48.9	5.6	9.8	1350
100% WLP	8.7	44.7	5.8	9.2	1040

with the level of replacement of mixing water with WLP. This behaviour is usually observed with virgin latexes, and is believed to be due to surfactants contained as emulsifiers and stabilizers in polymer latexes [2]. Commercial latexes intended for use in concrete often contain antifoaming agents to reduce air entrainment. It was decided to reduce the dosage of the air-entraining admixture and add an antifoaming agent in the recycled paint (mixtures with 30–60% WLP), which decreased the air content, but this effect was unpredictable and difficult to control. When the latex paint was used for partial replacement of virgin latex, it was coupled with an antifoaming agent and the air entrainment was better controlled.

It is also observed that as the paint replacement level increased, the slump of the mixtures increased (Table 3), especially when coupled with a high air content. This effect allowed eliminating the water-reducer in sidewalk concrete mixtures, which could yield significant cost savings. It could also allow reducing the w/c ratio, thereby enhancing strength and durability of concrete. Improvements in workability due to WLP addition can be attributed to the ball-bearing effect of polymeric materials [2], the increased entrained air content, the dispersing effect of surfactants present in WLP, and the effect of ultrafine pigments used as extenders.

One difficulty associated with using WLP is that the surfactants used in its manufacturing are generally different from those used in making latex supplied for LMC. Thus, predicting its effect on air entrainment properties and workability is difficult and needs careful assessment. For industrial-scale implementation, it is recommended that WLP be collected in large containers that are equipped with a pump circulating system. The continuous mixing action will reduce the variability of the material and prevent settlement of the solid phase of the paint, which may otherwise introduce unacceptable variability in concrete mixtures. Quality control tests on WLP could be regularly conducted, which allow adjusting concrete mixtures' design accordingly.

Table 4 shows compressive strength, flexural strength, and rapid chloride penetrability test results for concrete mixtures incorporating various proportions of WLP as partial replacement for virgin latex. The compressive strength at 1 day and 28 days increased by around 15% and 20%, respectively, compared to those of a reference mixture when virgin latex was used at a polymer/cement ratio of 15%. As the proportion of WLP replacement of virgin latex increased from 0% to 100%, the compressive strengths decreased both at 1 day and at 28 days (Table 4), but generally remained higher or comparable to that of the reference mixture except the 1-day strength results of mixtures with 75% to 100% of WLP, which were lower due likely to a set-retarding effect of the WLP. An increase in compressive strength of concrete due to polymer modification is usually not noticeable [2], and that observed in this study may be due to an improvement in workability, and the filler effect and/or pozzolanic activity of the pigments used in WLP. A decrease in the strength of some mixtures containing WLP may also be attributed to an increase in the air content measured at high WLP dosages.

Table 4 also shows that the flexural strengths at 1 day and 28 days increased by around 27% and 17%, respectively, compared to those of a reference mixture when virgin latex was used at a polymer/cement ratio of 15%. These improvements are usually due to the polymer itself and to an overall enhancement of the aggregate–cement paste bond [2]. The flexural strength of mixtures incorporating WLP was lower than that of the reference mixture at 1 day, but exceeded the 28-day flexural strength of the reference mixture when set-retarding effects were overcome.

Fig. 1 shows the 28-day rapid chloride penetrability test results for mixtures incorporating virgin latex and/or WLP relative to that of a reference mixture along with the corresponding rating ranges of ASTM C 1202. Using virgin latex in concrete at a polymer/cement ratio of 15% decreased the rapid chloride penetrability of concrete by around 55% from a moderate to a low rating. Although replacing virgin latex with WLP would decrease the polymer/cement ratio (WLP contains only one third of polymer compared to virgin latex), it decreased the rapid chloride penetrability by 45%, a value comparable to that achieved by virgin latex. Furthermore, a 75% virgin latex–25% WLP was optimal, and reduced the rapid chloride penetrability of concrete by 65%. The reduction of chloride ion penetrability

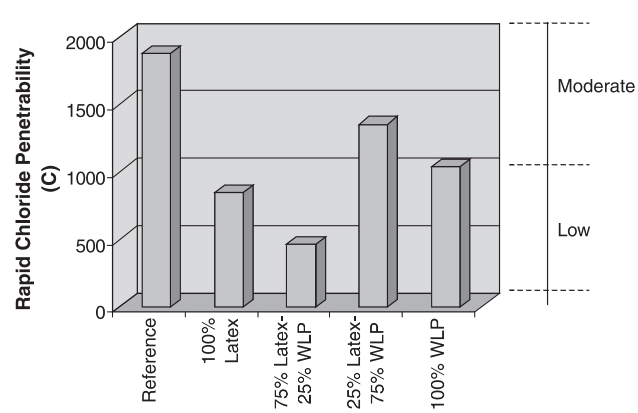

Fig. 1. Rapid chloride penetrability of concrete mixtures incorporating WLP as partial replacement for virgin latex.

Table 5
Experimental results: replacement of mixing water with WLP

Mixture	Compressive strength (MPa)		28 days flexural strength (MPa)	Chloride penetrability (C)
	1 Day	28 Days		
Reference	15.4	35.8	5.8	2130
10% WLP	11.4	27.6	5.6	1750
20% WLP	6.6	17.0	5.0	1900
30% WLP	9.5	22.0	5.3	1250
40% WLP	8.6	41.1	6.1	990
60% WLP	7.5	44.3	6.4	750

because of virgin latex is due to the pore-blocking effect of polymers. However, WLP contains only one third of the polymers in virgin latex. It is believed that the extender pigments used in latex paints played a significant role in this regard. These extender pigments are often present at around 25% by mass, and contain a blend of titanium dioxide, calcium carbonate, calcinated clays, diatomaceous earth, metakaolin, etc. [3]. Some of these mineral pigments significantly decrease chloride ion penetrability through mechanisms similar to those of silica fume.

Table 5 shows compressive strength, flexural strength, and rapid chloride penetrability test results for sidewalk concrete mixtures incorporating various proportions of WLP used as partial replacement for mixing water. The 1-day compressive strength decreased with higher WLP dosage due to an increased air content and a set-retarding effect. It is known that the setting of polymer-modified concrete is somewhat delayed compared to normal concrete [2], and this effect is dependent on the polymer type and polymer/cement ratio. However, the 28-day compressive strength of mixtures having air contents comparable to that of the reference mixture reached or exceeded the strength of the reference mixture. Also, such mixtures achieved higher 28-day flexural strength results than the reference mixture. As shown in Fig. 2, WLP achieved substantial decreases in chloride ion penetrability of concrete mixtures, and this effect was higher the higher the dosage. At 60% replacement of mixing water by WLP, the chloride ion penetrability decreased by 65% from a high rating to a low rating (ASTM C 1202). It is worth mentioning that as the replacement level of mixing water by WLP on a mass basis increases, the effective w/c ratio decreases (WLP contains 59% water), which helps decreasing chloride penetrability, in addition to the polymer and extender-pigment effect mentioned earlier. It is also worth mentioning in this context that the WLP

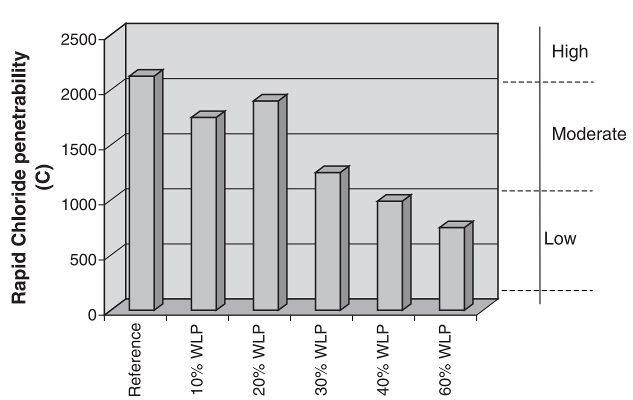

Fig. 2. Rapid chloride penetrability in sidewalk concrete mixtures incorporating various proportions of WLP as partial replacement for mixing water.

Table 6
Results of deicing salt surface scaling tests

Mixture	Visual rating ASTM C672	Total scaling residue (kg/m^2)
Control (no latex), w/c ratio = 0.40	2	0.85
Virgin latex polymer/cement ratio = 15%, w/c ratio = 0.40	1	0.55
40% Replacement of mixing water with WLP polymer/cementitious material ratio = 2.4%, w/c ratio = 0.36	1	0.60
25% Virgin latex – 75% WLP polymer/cement ratio = 7.4%, w/c ratio = 0.40	1	0.45

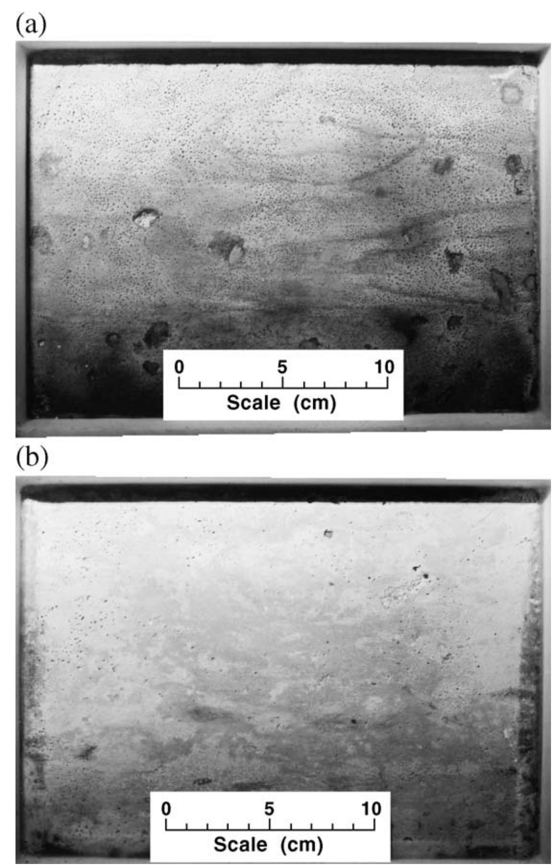

Fig. 3. Deicing salt surface scaling of a reference concrete slab and a slab from a concrete incorporating 40% replacement of mixing water with WLP after 50 freezing–thawing cycles.

used as partial replacement for virgin latex and that used as partial replacement for mixing water were sampled at different dates. Thus, their effects on workability, air content, strength, and other properties cannot be directly compared.

The results of deicing salt surface scaling tests are summarized in Table 6. Using virgin latex at a polymer/cement ratio of 15% enhanced the surface scaling rating of concrete slabs from 2 (*no latex*) to 1 (*with latex*). Replacing 40% of the mixing water by WLP achieved comparable results. This could be beneficial, for instance, when WLP is used in municipal sidewalk concrete mixtures. Fig. 3 shows the deicing salt scaling behaviour after 50 freezing–thawing cycles of a reference concrete slab and a slab incorporating 40% replacement of mixing water with WLP. It is shown that unlike the slab made from the reference mixture, the one made from the WLP-modified mixture did not exhibit aggregate exposure.

The above results indicate that positive effects can be expected when WLP is used for partial replacement of mixing water in sidewalk concrete mixtures. An experimental section of a municipal sidewalk was constructed in 1998 at the City of London's waste collection site, and its performance is being monitored (Fig. 4). The mixture contained 375 kg/m^3 of CSA Type 10 cement, 715 kg/m^3 of natural sand, 1080 kg/m^3 of limestone coarse aggregate, and 50% replacement of mixing water with recycled WLP. Its air content was 6% and its 28-day compressive strength reached 35 MPa. The experimental section included a 5.0×1.7-m concrete sidewalk with a regular finish, a 2.0×1.7-m sidewalk with an impressed concrete finish, and a 15-m long concrete curb and gutter. In addition to the ease of construction observed when WLP was added to concrete, the sidewalk had a distinctly lighter and more reflective colour compared to a reference sidewalk, which could be an advantage for night vision. It also did not exhibit coarse aggregate popouts present in the reference sidewalk. Although deicing salts have been used on the experimental sidewalk, no signs of surface scaling have been observed to date. The demonstration WLP-modified sidewalk had a much higher quality finish, and the impressed concrete sidewalk showed much sharper details at the edges of patterns, indicating substantial gains in the finishing process.

Fig. 4. Section of an experimental concrete sidewalk incorporating 50% WLP as partial replacement for mixing water.

Various issues need more research before recommending a large-scale industrial use of WLP in concrete. The conventional generic polymers used in virgin latexes supplied for LMC are often acrylic or styrene–butadiene rubber, which are known to reduce permeability and resist alkaline breakdown. The mixture of polymers found in WLP is predominantly copolymers of acrylics and vinyl acetate. The long-term performance of these polymers in alkaline environments needs further investigation. In addition, the effect of surfactants and antifoaming agents present in WLP on the spacing factor of air bubbles in air-entrained concrete can be critical for its freezing–thawing and surface scaling durability, and needs laboratory and field examination. No measurements of the alkali content in recycled paints have been conducted, and their effect on the expansion of concrete due to alkali–silica reaction needs clarification. Technological issues related to quality control, limiting effects of contaminants, and variability in time of WLP need further investigation. In addition, the concrete industry may need special equipment or special maintenance procedures to handle concrete incorporating large amounts of recycled paint. Leaching tests are also needed to investigate whether solvents present in WLP are fixed in concrete or can migrate to the outside environment. Such issues will be addressed in future research.

5. Conclusions

This study investigated the use of WLP as partial replacement for virgin latex in LMC and as partial replacement for mixing water in municipal sidewalk concrete mixtures. This work was motivated by the fact that WLP represents around 12% of the total HZW collected by municipalities in Ontario, its proportions are on the rise and the cost of its disposal is escalating. It was found that WLP contributes a significant part of the advantages imparted by virgin latexes in concrete, 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 popouts. However, more research is 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 the recycled paint.

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