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Disposing waste latex paints in cement-based materials – Effect on flow and rheological properties

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ABSTRACT

The effect of waste latex paints (WLPs) on fresh and hardened properties of cement-based materials is not well understood. In this project, WLPs were not randomly collected from waste collection sites; rather produced to ensure full traceability of composition, then stored in sealed or opened pail conditions to get expired. Test results have shown that rheological properties of cement pastes are directly affected by WLP constituents, substitution rates, and storage conditions. A series of charts were proposed to predict the variations in flow, yield stress, and plastic viscosity of pastes containing 4%, 8%, 12%, and 16% substitution rates of mixing water by WLPs. The indicative measures used for prediction included the gloss unit of paints and their pigment volume concentrations. The compressive strength slightly increased at relatively low WLP rates, but then dropped sharply at higher substitutions.

1. Introduction

The disposal of waste latex paints (WLPs) raises major environmental and economical concerns to municipalities and state agencies. The American Environmental Protection Agency estimated that every homeowner in the United States has 10 to 15 l of leftover paints, among which around 10% ends up in landfills [1]. In Ontario, Canada, it is estimated that about 30 million liters of paints are sold each year, with 5% to 10% ends up as waste [2]. If improperly disposed, paints can be toxic to the environment as these can contaminate water, harm fish and wildlife, and cause sewage systems to be less effective [3].

Limited studies investigated the possibility of disposing WLPs in the concrete construction industry. In 2008, Mohammed et al. [4] evaluated the effect of substituting mixing water by 5% to 25% WLP on fresh and hardened properties of concrete containing 280 kg/m^3 cement and 0.4 water-to-cement ratio (w/c). Tested WLP had 45% solid content and viscosity of 90 mPa s. The authors observed a gradual improvement in slump and compressive strength up to around 10% WLP, while higher substitution rates led to reduction in both workability and strength. The addition of WLP led to increased flexural strength at all substitution rates, which was attributed to the high tensile strength of latex films and bond improvement at the hydrated paste-aggregate interfacial transition zone [4]. Similar conclusions were drawn by Nehdi and Sumner [5] when testing WLP having 30% solid content composed of 15% polymers, 12.5% titanium dioxide pigment, and 12.5% extenders. The drop in compressive strength at relatively high WLP rates was attributed to a set-retarding effect along with increased air content. The authors believed that pigments and extenders in WLPs could fill additional porosity and act as nucleation sites for the growth of hydration compounds [4,5]. The leaching tests on aged concrete incorporating WLP indicated negligible emissions of toxic metals and glycol substances such as diethylene glycol and propylene glycol [4].

Almesfer et al. [6] found that the substitution of mixing water by up to 12% WLP leads to improved workability and almost unaffected flexural strength of masonry blockfill materials. The tested WLP had around 50% solid content composed by 25% polymers and 25% pigments. Regardless of WLP concentration, rheological tests have shown an increase in yield stress and decrease in viscosity of cementitious materials. The former phenomenon was related to the presence of thickeners that enhances stability of matrix, whereas the decrease in viscosity was attributed to the dispersing agent. Concurrent with other findings [4,5], Almesfer et al. [6] noticed a decrease in compressive strength due to WLP additions, which was attributed to increased air content associated with reduced density. The authors suggested the existence of a threshold polymer content, beyond which the WLP begins having greater effect on material visco-plastic behavior [6].

The partial replacement of mixing water by WLPs during concrete production requires thorough assessment of the various

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implications that could result from such additions on fresh and hardened properties. In fact, latex-based paints are made of numerous constituents (i.e., binder latex, pigment, extender, dispersant, thickener, and specialty additives) that could lead to synergetic effects on cement aptitude to flow and hydration processes. Additionally, WLPs are non-controlled products whose chemical composition and physical properties vary between manufacturers and types of application. In other words, it is not clear whether the results published in literature would still be valid if, for example, WLPs containing different types of polymeric binders and/or possessing different viscosity levels or solid contents were collected and used for concrete production. This fact was admitted by various researchers [4–6] who recommended additional investigations to evaluate variability of WLPs on concrete properties.

This paper is part of a comprehensive research project undertaken to assess the effect of WLP composition, storage condition, and substitution rate on fresh and hardened properties of cement-based materials. Its main objective is to develop useful and practical charts that enable the prediction of WLP additions on variations in flow and rheological properties of cement pastes. Twelve paint formulations containing different types of latexes to cover a wide range of commercially available paints are produced, then stored under different conditions (i.e., sealed vs. opened pail) to expire. Other aspects dealing with WLP effects on durability and bond to embedded steel bars will be investigated in follow-up paper. Such data can be of particular interest to concrete producers, municipalities, state agencies, and environmental organizations to economically and efficiently manage the disposal of WLPs.

2. Overview on composition of latex-based paints

Latex-based paints are often commercialized in five categories including gloss, semi-gloss, satin, eggshell, and matt whereby gloss units can range from larger than 75, 25–75, 10–25, 5–15, and less than 10, respectively [7]. The predominant type of binder includes acrylic copolymers such as VA and pure acrylic (PA). These latexes consist of very small polymer particles (0.05–5 μm) formed by emulsion polymerization and stabilized in water with the aid of anionic and/or nonionic surfactants [8]. The PA is typically used for producing glossy paints and/or whenever enhanced resistance against scrubbing and water adsorption are required. The VA is cheaper than PA when polymerization is realized at given solid content, and mostly used in eggshell and matt products.

Powders in latex-based paints can broadly be divided into two categories including pigments (0.1–1 μm) and extenders (0.5–15 μm) [7]. The titanium dioxide (TiO_2) is the pigment that provides whiteness and constitutes the main source of hiding (or, opacity) for paints. Its concentration typically varies from as low as 2.5% for colored pigmented paints up to 15% for white paints. Extenders such as calcium carbonate ($CaCO_3$), clay, silica, talc, and chalk are incorporated to ensure the bulk material at relatively low cost. It is to be noted that the paint chemist often uses a figure called PVC (i.e., pigment volume concentration) to indicate the relative volume proportions in the formulation; it is given as:

$$\text{PVC,\%} = \frac{\text{Volume of (pigment and extender)}}{\text{Volume of (pigment and extender)} + \text{Volume of binder}} \times 100 \quad (1)$$

Typical PVC for gloss, semi-gloss, satin, eggshell, and matt paints can vary from less than 20%, 15–30%, 25–40%, 30–45%, and 40–80%, respectively [7].

Dispersing agents and thickeners are essential components in latex-based paints. The former additive is incorporated to lower the interfacial solid/liquid tension, thus ensuring efficient dispersion and stability of pigment and extender powders in the liquid solution [7,9]. The concentration of dispersing agent is adjusted by paint producers depending on powder surface area (i.e., PVC) of the formulation. From the other hand, thickeners are incorporated to regulate viscosity, thus ensuring smooth flow and thicker film layers necessary to hide imperfections with minimum spoilage. Their chemicals basis mostly includes cellulose ethers, urethanes of various grades, as well as cross-linked acrylic emulsions [7]. Unlike dispersants, the concentration of thickeners added in paints varies between manufacturers depending on the desired viscosity and type of application.

3. Experimental program

3.1. Composition and properties of WLPs used in this project

As already noted, the tested WLPs were not randomly collected; rather, produced and then stored under different conditions to expire. The raw materials used for paint production and storage conditions are presented below.

3.1.1. Raw materials for paint production

Two types of binder latexes were used, depending on the gloss desired. The VA is water-dispersion copolymer of vinyl acetate and butyl acrylate commonly used for producing matt, eggshell, and satin paints. It had a white milky appearance with solid content, specific gravity, viscosity, and pH equal to 51.5%, 1.1, 0.085 Pa s, and 4.5, respectively. The PA emulsion polymer is designed for gloss and semi-gloss enamels. It had a white milky appearance with solid content, specific gravity, viscosity, and pH equal to 47.3%, 1.07, 0.027 Pa s, and 8.5, respectively.

A rutile grade TiO_2 pigment having a specific gravity of 4.05, whiteness larger than 97%, and median particle size of 0.18 μm was used. The extender consisted of a $CaCO_3$ having specific gravity of 2.7 and median particle size of 3.4 μm. The VA, PA, TiO_2, and $CaCO_3$ particle size distributions determined using laser diffraction analyzer are plotted in Fig. 1 (the cement is also shown in this figure).

A modified polyacrylic acid polymer compatible with VA and PA latexes was used as dispersing agent [7]. It had a molecular weight, specific gravity, active materials, and pH of 2000 g/mole, 1.01, 55%, and 7, respectively. The manufacturer's recommended dosage in latex-based paint formulations varies from 0.2% to 1%.

Two types of thickeners including powder hydroxyethyl cellulose (HEC) and liquid non-ionic hydrophobically-modified urethane (HMU) were used. The former thickener is compatible with VA latex; its pH in 2% solution is 6.6. When mixed with water, HEC

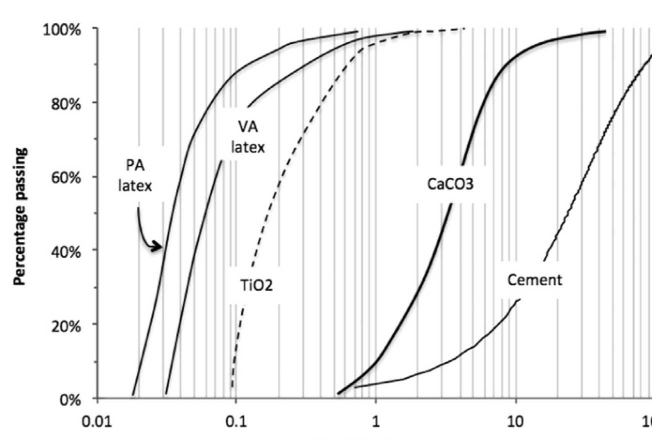

Fig. 1. Particle size distribution of PA, VA, TiO_2, $CaCO_3$, and cement materials.