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Effects of latex modification on fresh state consistency, short term strength and long term transport properties of cement mortars

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HIGHLIGHTS

- Strength and long term transport properties of latex modified mortars investigated.
- SBR latex found more effective from the view point of long term gas transportation.
- SBR latex emulsions was found more advantageous compared to SAR latex emulsions.

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ABSTRACT

In this study, two different types of latexes (Styrene Acrylate Rubber and Styrene Butadiene Rubber) at five different dosages by weight of cement have been employed in the preparation of latex modified mortars. Two sets of cement mortars have been designed at constant water/cement ratio and consistency, respectively. Densities at fresh state, flexural and compressive strengths at 28 days were measured for each mortar. Capillary water absorption and carbonation depth values were determined from the cylindrical specimens after 7 years. Also, the total porosities of selected specimens were measured with a mercury porosimeter in order to compare the effect of porosity on long term transportation properties of cement mortars.

Results showed that it is possible to improve the fresh state and mechanical performances of cement mortars with SBR latex addition. SBR modified cement mortars also exhibited an improved impermeability in terms of both water and CO_2 gas penetration at the long term. The most important advantage of SBR latex addition was the improvement in CO_2 gas penetration resistance compared to SAR latex modified mortars. The mechanism behind this improvement is discussed with the aid of porosity analysis.

1. Introduction

Polymer additives such as latexes, redispersible polymer powders, water-soluble polymers, liquid resins, and monomers have been introduced into cement mortar to reduce the brittleness and durability shortcomings of cement mortar and concrete [1–3]. Among these additives, latex emulsions are the most frequently used type due to application easiness. Since latex emulsions are introduced into cement mortar as liquid form, more homogeneous polymer dispersion is usually obtained [4].

Polymer latexes are usually produced by emulsion polymerization technique and emulsion consist of very small (0.05–5 pm in diameter) polymer particles dispersed in water [5]. After mixing with cement, the drainage of water from the cement paste-latex emulsion system along with the cement hydration leads to film or membrane formation. This three dimensional polymer film network inside the capillary pores of matrix may improve the flexural strength, crack resistance and impermeability of cement mortar depending on the type and amount of latex emulsion used. On the other hand, some side effects such as excessive air entrainment, set retardation and mechanical strength loss may also be observed in the presence of high amounts of latex emulsion. It should be noted that the type of emulsifier, presence or absence of an anti-foaming admixture may significantly affect the latex emulsion performance in cement mortar [6,7]. Therefore, the dosage of latex emulsion should be optimized by both taking the potential advantages and side effects into account.

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Styrene-butadiene rubber (SBR) and styrene-acrylate rubber (SAR) are most widely used latex emulsions for modifying the mechanical and transport properties of cement mortars [1,8,9]. These latexes have been used for many years, primarily in tile adhesives, floor overlayments, stuccos, exterior insulation finish systems (EIFS), overlayment of bridge and parking-garage decks to reduce the penetration of water-soluble salt, and repair of concretes [10]. Blended use of these latex emulsions may show synergistic effects for cement mortars in terms of mechanical performance [11]. Wang et al. [9] reported that at the same water/cement mass ratio, the apparent bulk density, compressive and flexural strengths of the polymer-modified mortars rise slightly when a little SBR emulsion is added (up to 4–5%), and then all of mechanical properties decline with increasing polymer/cement (P/C) ratio. Wang et al. [12] also showed that the toughness of the modified mortars can be improved markedly and the higher the P/C, the higher the toughness at P/C below 10%. On the other hand, SBR latex may reduce water requirement, by this way, both flexural strength and tensile bond strength can be enhanced up to a specific P/C ratio [13,14]. Barluenga and Hernandez-Olivares [15] showed that SBR latex could increase the entrained air content and decrease the water requirement of cement mortar for a specific consistency at the same time. The resultant compressive and flexural strength increased with increasing latex content. However, if SBR latex is used at a fixed W/C ratio, the compressive strength values significantly decrease due to excessive air entraining effect at high latex ratios [15,16]. SBR latex may also be used to prepare self-leveling and crack free cement based flooring mortar applications [17]. Concrete road overlay material comprised of polyester fiber and SBR latex was reported as another application of SBR latex to improve the toughness and flexibility of concrete [18]. An improvement in the ductility of cement mortar is also reported by Bureau et al. [19] with SBR latex addition. Furthermore, SBR latex modification significantly improve the chloride ion transportation resistance of concrete [11]. Aggarwal et al. [8] conducted an extensive experimental study to determine the role of SAR latex on cement mortar fresh and hardened properties. They concluded that the addition of SAR latex improved the workability and hence reduced the water requirement of cement mortar for a fixed consistency. Lower water absorption values, carbonation and chloride ion penetration depths compared to unmodified mortar were reported with higher flexural and compressive strengths at the same time. Similar durability advantages were also reported for SBR latex modified concretes due to improved impermeability properties [20,21]. However, Wu et al. [22], reported that SAR latex did not have any water-reducing ability. W/C could be decreased by the addition of a superplasticizer. Conflicting results may arise from the other minor chemical constituents present in the commercial SAR latex products.

In this study, SAR and SBR modified cement mortars have been prepared. The fresh state consistencies and densities of latex modified mortars have been determined. Mechanical properties of mortars have been compared within themselves and with unmodified cement mortar at 28 days. Furthermore, first experimental studies on the long term transport properties of latex modified mortars (after a waiting period of 7 years) have been investigated in terms of capillary water absorption and carbonation depth.

2. Experimental study

2.1. Materials

CEM I 42.5R type Ordinary Portland cement providing the requirements of EN 197-1 [23] was used for all mixtures. The Blaine surface area and specific gravity of cement were 370 m^2/kg and 3.12 respectively. Standard fine aggregate conforming to the requirements of EN 196-1 [24] was used. The physical and chemical properties of Styrene Acrylate Rubber (SAR) and Styrene Butadiene Rubber (SBR) latexes are presented in Table 1. These polymer emulsions are usually employed to improve the consistency of mortar and concrete at fresh state and improve the flexibility of brittle concrete at hardened state [4,9]. Additionally, both SAR & SBR improve the crack bridging ability and water resistance of concrete by film forming at hardened state [25,26]. Low glassy transition and film forming temperatures make these latexes ideal for use in cementitious materials at ambient temperature conditions. The maximum dosage of latexes can be increased up to 30% for special applications.

2.2. Mixture proportions, specimen preparation and test methods

Two different types of latexes (Styrene Acrylate Rubber – SAR (Acronal S400) and Styrene Butadiene Rubber – SBR (Lipaton) have been employed in the preparation of latex modified mortars. The cement-fine aggregate ratio (by weight) was kept constant as 1/3 for all mixtures. Latex emulsions were added to cement mortar mixtures at five different dosages (5%, 10%, 15%, 20% and 30% by weight of cement respectively). Two sets of cement mortars have been designed for this purpose. At the first set (Set A), water/cement ratio (W/C) is kept constant and at the second set (Set B) consistency of mortar (flow-spread diameter of 130 mm) is kept constant by adjusting W/C ratio. In this study, in order to obtain constant consistency (constant flow-spread diameter), the water demands of fresh mortars were decreased due to addition amount of latex emulsions. The solid content of latex emulsions was taken into account in order to quantify the mixing water content of each mixture. For each set, a control mortar without latex addition was also prepared for comparison. Since the target W/C is 0.50 for Set A and target consistency is 130 mm for Set B, control mortar was used for both sets of cement mortars.

Mortar mixtures have been prepared with a Hobart mixer following the same mixing procedure: First, cement and sand mixed for 2 min. Mixing water and latex emulsions (SAR or SBR) were then added to the dry mix. Total mixing time was 5 min to ensure homogeneous mixing. Flow spread values have been determined by using a flow table conforming ASTM C230 [27] standard. Fresh mortar was casted into $40 \times 40 \times 160$ mm prismatic molds and compacted with an external vibrator. Fresh densities were determined and specimens were demolded one day after casting. Theoretical air contents have been determined by taking the difference between theoretical density and measured fresh density values. Mixed curing method has been performed and all specimens kept in 20 °C water for 7 days and then cured in air conditions. Flexural and compressive strength values have been determined at 28 days by using ASTM C348 & C349 [28,29] standards, respectively.

Table 1
The physical and chemical properties of polymer latex emulsions.

Emulsion code	SAR	SBR
Solid content (% by weight)	57 ± 1	48.5
pH value	7.0–8.5	8.0
Viscosity of emulsion (mPa·s) (ISO 3219 – shear rate: 25 s^{-1} at 23 °C)	140–200	30
Glassy transition temperature (°C)	−6	−5
Emulsion density (g/cm^3)	1.04	1.01
Emulsifier type	Anionic	Mixture of anionic & non-ionic
Average particle diameter (micron)	0.2	0.15
Min. film forming temperature (°C)	<1	<3
Tension strength of polymer film (N/mm^2)	0.3	6
Elongation% of polymer film	>2500	1000