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Modification of cement mortar with recycled ABS

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Abstract

Cement mortar was modified using recycled acrylonitrile butadiene styrene (ABS) in powder form. Mixtures with polymer–cement ratios of 8, 15, and 25 wt.% were investigated for changes in compressive properties and adhesion to steel rebar. Compressive tests indicated an increase in Young's modulus for samples with 8% and 15% ABS. Adhesion strength to the steel rebar decreased on adding the ABS. However, when the ABS was treated with maleic anhydride, an increase in adhesion strength was obtained. The decrease in adhesion of the untreated ABS-modified cement to steel was attributed to the disruption of the interface between the cement mortar and steel rebar. Scanning electron microscopy (SEM) indicated changes in the cured cement with addition of ABS. Gas adsorption measurements of pore size distribution indicated an increase in pore volume of the 8 and 15 wt.%-containing cement mortar.

Keywords: Recycled polymers; Mortar; Mechanical properties; Bond strength

1. Introduction

The demand for high-quality cement concrete and mortar is related to the need to increase the long-term durability of concrete structures. Deficiencies in concrete are damage tolerance and the interface between the cement and inserts. Polymer-modified Portland cement mortar has increased tensile strength, reduced drying shrinkage, increased durability, greater fatigue strength, and improved adhesion (bond strength) over conventional mortar and concrete [1,2]. Recent investigations have given insight to the effects of polymer modification on the adhesion strength of cement paste to aggregates [3]. Increased bond strength between cementitious materials and steel is of practical importance in the application of repair materials to damaged surfaces, and in the design and use of steel fiber-reinforced cement composites and grouts for structural purposes. Adding polymer dispersions to Portland cement mortar during mixing produces polymer-modified mortar and concrete [4]. The utility of polymers as fillers (nonreactive admixture) has also been investigated. Concrete reinforced with short fibers such as carbon, nylon, or PP have shown high flexural toughness and low drying shrinkage [5–10].

Acrylonitrile butadiene styrene (ABS) is a common component in consumer electronic housings and automobiles. There is consequently a greater need to develop applications using recycled polymers such as ABS. ABS has shown dramatic improvements in toughness when added to brittle polymers [11]. In addition, the low specific gravity of ABS would also lower the weight of the cement matrix. Here, we examine its potential for improving the properties of cement mortar. Compression properties and adhesion (bond) strength to steel are measured. Polymer-modified mortars using recycled ABS powder were prepared with 8, 15, and 25 wt.% polymers.

2. Experimental

2.1. Materials

Type I Portland cement was used in accordance to ASTM C 150-92, which is a general-purpose hydraulic cement and is most commonly used [12]. Natural silica

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Table 1
Compression test results

ABS (%)	Modulus (GPa)	Strength (MPa)	Peak strain ($\times 10^{-2}$)
0	6.15 ± 0.15	557 ± 38.9	9.74 ± 1.31
8	7.84 ± 0.17	464 ± 40.56	8.26 ± 0.65
15	7.43 ± 0.18	314 ± 54.7	6.33 ± 0.55
25	5.39 ± 0.33	106.83 ± 22.9	5 ± 0.2

sand was employed, which conformed to the requirements for graded standard sand. The steel substrate consisted of standard 12.7-mm (1/2-in.) diameter corrugated steel rebar. Recycled ABS obtained from GE Plastics in form of regrind powder that had no cross contamination and sieved to 375 μm to maintain a quality control was used.

2.2. Sample preparation

The polymer-modified cements were prepared by pouring cement powder into an empty dry mixer bowl and then adding the water and polymer admixture gradually. This was followed by mechanical stirring using a Kitchen Aid Ultra Power Mixer for 120 s. Polymer–cement ratios were 8, 15, and 25 wt.% [13]. Sand–cement ratio was 3:1. The cement pastes were prepared with a water/cement (w/c) ratio of 0.60 due to the recycled ABS powder's low workability at w/c = 0.40 and 0.50 [14]. The fresh polymer-modified mortar was poured into a PVC plastic pipe and a 6-in. corrugated no. 4 steel rebar was placed in the center during the pouring and set. Curing was conducted at laboratory room conditions of 20°C and 65% RH for 24 h. The samples for the adhesion tests were demolded and subsequently cured by immersing in water for 7 days. Additional curing was done at laboratory room conditions of 20°C and 65% RH prior to mechanical testing. Both untreated and maleic anhydride-treated recycled ABS was used in the adhesion tests.

2.3. Compressive testing

Compression tests were done in accordance with ASTM C-109, utilizing 2-in. (50-mm) cubes.

2.4. Adhesion tests

Bond strength between polymer-modified cement paste and steel was determined using a pullout technique. Fiber pullout methods were developed in the early stages of composite research consisting of a fiber or filament embedded in a matrix block. A steadily increasing force is applied to the free end of the fiber in order to pull it out of the matrix. The stiffness of the reinforcing fiber, the steel rebar, is greater than the matrix, the polymer-modified mortar cement. The pullout process is governed by at least five different variables: interfacial pressure (p_I), friction coefficient (μ) along the embedded length, work of fracture of the interface (G_i), the embedded fiber length (L), and free fiber length (l_f). The route to failure during a pull out test occurs at some value of stress (τ), in which a constant shear stress distribution is assumed along the embedded fiber length, therefore [Eq. (1)]:

$$F_d = 2\pi r L \tau \quad (1)$$

where F_d is the debonding force, L is the embedded length, τ is the interfacial shear stress, and r is the radius of corrugated rebar.

The joint effect of adhesion bonding and friction resistance that occurs in a pullout test specimen depends on the length of the embedded fiber. Adhesional bonding increased with embedded fiber length, whereas the frictional resistance to pullout due to friction decreases. A pullout fixture was designed that would allow measurement of the adhesional bonding strength by pulling out the steel rebar from the polymer-modified mortar matrix coupon [15]. Data were

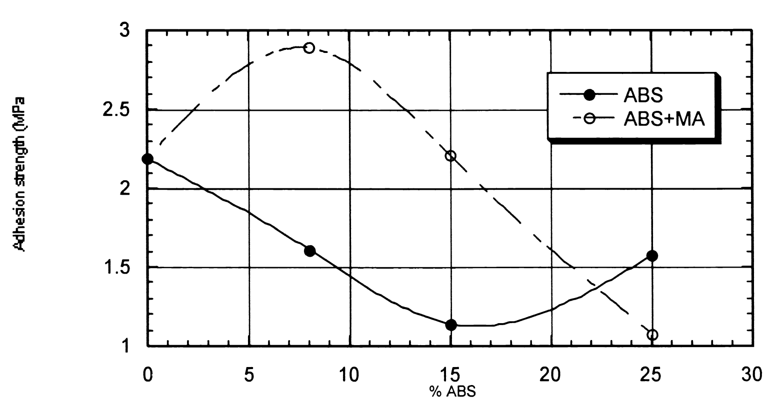

Fig. 1. Adhesion strength to steel rebar.

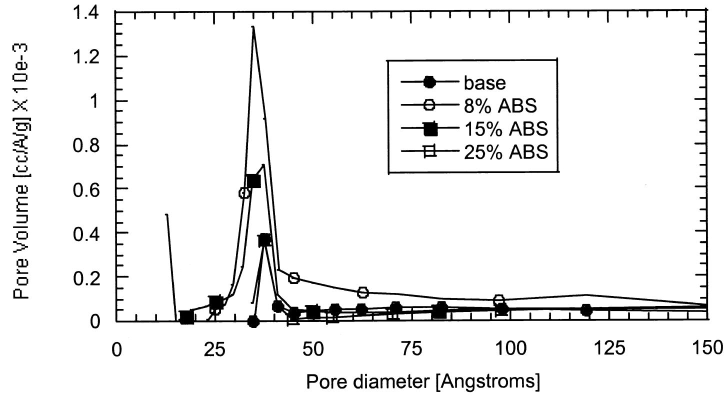

Fig. 2. Pore size distribution as a function of ABS (wt.%).

analyzed corresponding to samples showing split fracture of the matrix coupon [16].

2.5. Nitrogen gas adsorption analysis

A gas sorption analysis method was used to determine the porosity of the polymer-modified mortar. The limitations of this technique are analysis time, which can last several hours, and the size of the sample, which is limited by the size of the sample tube. Total pore volume and pore size distribution are two common techniques used to describe the porosity of materials. The pore size distribution is a distribution of pore volume with respect to pore size [Eq. (2)]. In pore size analysis, the desorption isotherm is used in calculations because the desorption curve of the isotherm defines a more thermodynamically stable absorbent condition than the absorption isotherm curve. The desorption curve on the isotherm displays a lower relative pressure that leads to a lower free energy state in the system, therefore, in the pore size analysis [17]. The isotherm data are best represented by a Type B hysteresis curve indicating slit-shaped pores.

The average radius ($\bar{r}_p$) is calculated from Eq. (3) using only the upper and lower values of (P_0/P) in the desorption curve, and $t_{\bar{r}}$ is the thickness of the adsorbed layer at the average radius ($\bar{r}_p$).

$$V_{\rm pn} = \left(\frac{r_{\rm pn}}{r_{\rm Kn} + \frac{\Delta t_n}{2}}\right)^2 \left(\Delta V_{\rm n} - \Delta t_{\rm n} \sum_{j=1}^{n-1} Ac_j\right) \quad (2)$$

$$r_p = \frac{2V_{\rm liq}}{S} \quad (3)$$

where N is Avogadro's number, M is the molecular weight of the adsorbate, nitrogen, and $A_{\rm cs}$ is the cross-sectional area of nitrogen, which is 16.2 $\mathring{A}^2$.

$$W_{\rm m} = \frac{1}{s+i}$$

where s is the slope of the BET plot and i is the corresponding intercept.

Samples were outgassed at 100°C for 2 h under vacuum to drive off moisture. After outgassing the sample is reweighed and placed in the analysis port. A user program is then selected that will take a 25-point isotherm. A Quantachrome NOVA 2200 gas adsorption analyzer was utilized for seven-point BET and 25-point isotherm measurements. The maximum size of a sample tube employed in these experiments was 12 mm in diameter.

2.6. Scanning electronic microscopy

Scanning electronic microscopy (SEM) was used to examine the phase interaction of the ABS and cement hydrates.

3. Results and discussion

As tabulated in Table 1, the compression modulus increased on addition of the ABS to the cement mortar at 8% and 15% but decreased at 25%. The compressive strength however decreased together with the strain to failure as the percentage of ABS increased. This indicates that the addition of ABS made the cement stronger but less ductile, acting as a rigid reinforcing filler. The adhesion strength to the steel rebar decreased with increasing ABS

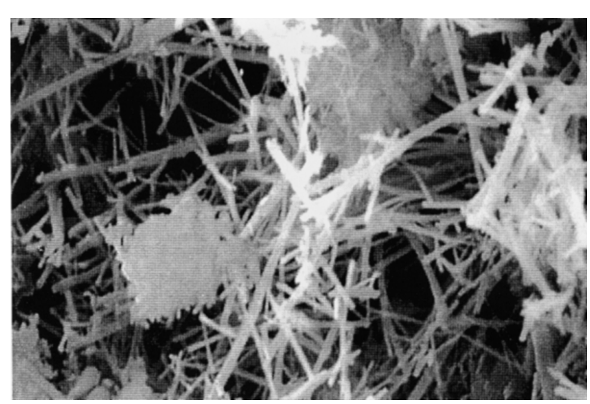

Fig. 3. SEM of 0% ABS polymer-modified mortar at $\times$ 3500.

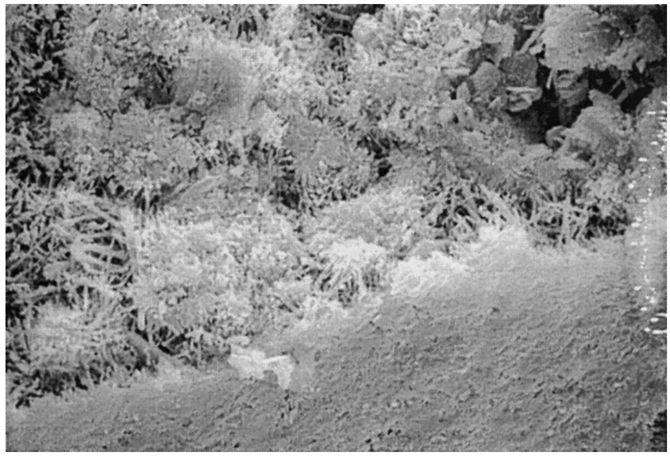

Fig. 4. SEM of 15% ABS-modified mortar at $\times 3500$.

content (Fig. 1). This is indicative of disruption in bonding to the steel rebar due to ABS presence. On treating the ABS with a reactive component (maleic anhydride), the adhesion strength showed a dramatic improvement at 8% ABS. This can be related to the enhanced hydrogen bonding of the inert ABS to the cement on the rebar. Examining the pore size distribution in Fig. 2, it can be seen that the addition of ABS results in higher level of porosity, which then decreases with increasing ABS content. The results are similar to that encountered by PP fiber introduction into the cement matrix [6–8]. The increased porosity serves to decrease the adhesion strength. However, the ABS acting as a load-bearing filler is able to sustain the compressive load.

SEM pictures of the ABS-modified and -unmodified mortars are shown at $\times 3500$ in Figs. 3–5. In Fig. 3, the base material at $\times 3500$, one can see the fibrils that cement form because of the hydration, and this is what gives high strength to cement. Figs. 4 and 5, where ABS is at higher percentages, one is able to view the distinct phases of the ABS and the cement hydrates. The presence of the ABS particles serves to distribute the cement fibrils around each particle. As seen in Fig. 5, the interface at the steel rebar shows that cement film formation is inhibited by the ABS presence.

4. Conclusions

Recycled ABS can be used to increase the compressive modulus of cement mortars. However, the presence of ABS increases the porosity in the mortar resulting in decreased adhesion strength to steel rebar. By treating the ABS with maleic anhydride, a substantial increase in adhesive strength is obtained. The results show a potential use for recycled ABS materials in cement.

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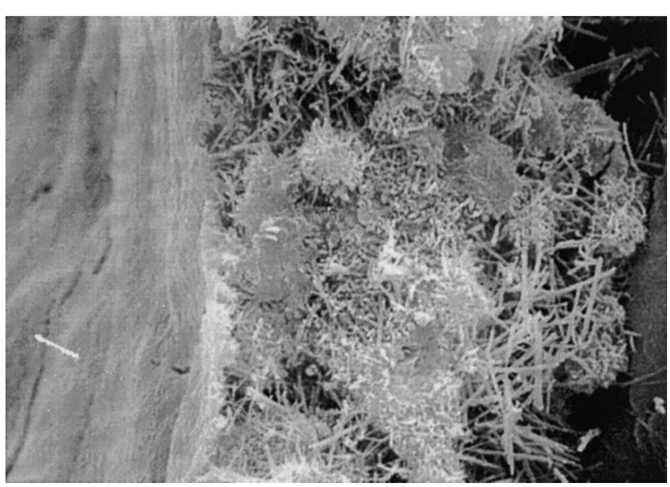

Fig. 5. SEM of 25% ABS-modified mortar at $\times 3500$.

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