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Use of Post-Consumer Waste Plastics in Cement-Based Composites

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ABSTRACT

This paper describes an innovative use of post-consumer waste HDPE plastic in concrete as a soft filler. A reference concrete was proportioned to have the 28-day compressive strength of 5000 psi (35MPa). A high-density plastic was shredded into small particles for use in the concrete. These particles were subjected to three chemical treatments (water, bleach, bleach + NaOH) to improve their bonding with the cementitious matrix. The plastic particles were added to the concrete in the range of 0 - 5% of total mixture by weight. Compressive strength and splitting tensile strength were measured for each test mixture. The results showed that chemical treatment has a significant effect on performance of the plastic filler in concrete. Of the three treatments used on the plastic, the best performance was observed with the alkaline bleach treatment (bleach + NaOH) with respect to compressive strength and tensile strength of concrete.

INTRODUCTION

Approximately 16.4 million tons of plastic wastes are generated in the USA [1]. Although plastic wastes constitutes over 8% of total waste streams discarded in municipal solid waste by weight, they constitute nearly 20% of the total municipal wastes by volume [1]. Less than 2.5% of the total plastic wastes are recycled/reused.

Naik et al. [2] evaluated the literature concerning use of polymers and used plastics in cement-based materials. Their study revealed that little work had been directed toward the use of discarded plastics in advanced cement-based materials. Rebiez et al. [3] used unsaturated polyester resin containing discarded polyethylene terephthalate (PET) derived from soda bottles in manufacture of polymer concrete. The PET was chemically modified to produce a liquid resin using facilities available at a commercial chemical company. The resulting resin was used in manufacture of polymer concrete. This process is not developed for other types of discarded plastics. Additionally it is not economically attractive at the present time for PET. Therefore, a need exists to find high-volume uses of post-consumer plastics, especially in cementitious matrix composites which could consume most of the plastic wastes generated in the country.

Cement-based materials are inherently brittle in nature and have low fracture toughness due to cracking at low strain levels (1,4). Increased ductility in concrete can be introduced through addition of more ductile materials, such as plastics. Ductility in a material is characterized by high tensile strain capability before fracture.

Inclusion of plastic particles/fibers in concrete should improve its fracture resistance, but will have negative impact on compressive strength and creep behavior. Therefore, there is an urgent need to develop the technology to employ substantial amounts of discarded plastics in portland cement concrete without compromising its performance for particular

applications. Extensive research is in progress at the Center for By-Products Utilization at the University of Wisconsin-Milwaukee for finding best uses of post-consumer plastics in concrete and concrete making materials. The present study was mainly oriented toward establishing a technology for use of high-density polyethylene (HDPE) plastic as a flexible particulate filler (reinforcement) in concrete.

THEORETICAL CONSIDERATIONS

Concrete is prone to have micro and macrocracks during production and curing, especially in the interface region between the mortar matrix and filler (aggregates). In general, mechanical and durability properties of composite materials are greatly affected by properties of the interface region between the matrix and the filler, such as internal structure, and bond between the filler and matrix. The cracks/flaws present in the interface region become nuclei for further crack growth and propagation during loading. The rate of crack development can be determined through the use of fracture mechanics models.

The crack growth and propagation characteristics of a composite can be altered by inclusion of a flexible filler such as plastic particles/fibers. Due to flexibility of the plastic particles, stresses will be relaxed due to deformations that will occur during various modes of loadings. Thus the stresses produced during the loading will result in a lower defects at the crack tips with plastic particles than without plastic particles. As a result, there will be lower crack growth, and increased amount of energy will be required to cause failure in the material,

especially in the tensile mode of loading. Thus, addition of appropriate amount and size of particles/fibers of plastic should increase fracture toughness, tensile strength, and impact resistance of concrete, provided adequate bond exists between the cementitious matrix and plastic particles.

In general, plastics do not achieve chemical bonds with cementitious materials. Therefore, chemical treatments of plastics are needed to enhance bonding characteristics with the cementitious matrix for developing plastic containing cement-based materials with improved properties.

It was anticipated that reaction of plastics with oxidizing chemicals would produce reactive chemical species on the surface of polymers which could participate in cementitious reactions. Such a reaction will produce concrete like product, but at an improved ductility due to the presence of polymeric substances. For example treatment of high-density polyethylene (HPDE) with hypochlorite could be expected to lead to reactions such as:

$$CH_3 - (CH_2 - CH_2 - CH_2)_n - CH_3 + OCl^{\Gamma} + H_2O \; 6 \; CH_3 - (CHOH - CH_2 - CHOH)_n - + Cl^- \quad (1)$$

$$CH_3 - (CH_2 - CH_2) - CH_3 + 3OCl^- + OH^- \; 6 \; CH_3 - (CH_2 - CH_2) - COO^- + 3Cl^- + 2H_2O \quad (2)$$

The R-OH and R-COOH species are much more reactive with cementitious materials than the polymeric hydrocarbons, ie. HC - $(CH_2 - CH_2 - CH_2)_n$-. For example, electrostatic

bonding can yield species such as:

$$--(CH_2CH_2)_n\text{-}COO^{-}\text{A } Ca^{++}\text{A } OH^{-}\text{A } (SiO_2\text{A } H_2O)-- \qquad (3)$$

This research was carried out to validate the above concepts concerning addition of plastics, and the effect of chemical treatment of the plastic surface on resulting concrete performance.

EXPERIMENTAL PROGRAM

An experimental investigation was planned to determine the effects of inclusion of post-consumer plastics in concrete as a filler. A HDPE plastic was shredded to small particles for use in manufacture of plastic containing concrete.

MATERIALS

The materials used were portland cement, plastic (HDPE), water, 6 mm natural sand, and 19 mm coarse aggregate. An ASTM Type I cement meeting the requirements of ASTM C-150 was used (Table 1). The properties of the aggregates are shown in Tables 2 and 3. Both the aggregates met the ASTM C-33 requirements. The shredded HDPE plastic particles were obtained from a local recycling company. The plastic was shredded into irregular shaped flat particles of varying sizes. An average thickness of plastic particles wad about 1 mm. The particle size analysis revealed that the shredded particles were out of the

ASTM C 33 limits for fine aggregates. However, the material passing through 3/8 in. sieve and retained on #4 sieve was used in this investigation.

MIXTURE PROPORTIONS

A reference concrete without plastic was proportioned to obtain the 28-day compressive strength of 5000 psi (35 MPa). Other mixtures with plastics were also proportioned. The plastics were added to the reference mixture in various amounts ranging between 0.5 and 5% of total weight of the mixture. The details of the mixture proportions are given in Table 4.

CHEMICAL TREATMENTS

The plastic samples were treated by soaking them in water, bleach, and bleach plus NaOH (alkaline bleach) per Table 5. Some plastic samples were subjected to water pretreatment in order to separate impurities (nonplastic particles) from plastic particles. This treatment also caused dissolution of detergent and surfactant from polymer surfaces. Other samples were subjected to bleach, and alkaline bleach treatment in accordance with Table 5.

RESULTS AND DISCUSSION

The effects of chemical pretreatment and amount of HDPE plastics on compressive and splitting tensile strengths of portland cement concrete are described in the following sections. The mixtures P_0 through P_3 were used to study the effect of chemical pretreatment on the above properties. While the mixtures P_4 through P_7 were employed for studying the effects of concentrations of the plastic particles on concrete properties.

Compressive Strength

As could be anticipated the effect of soft plastic as "aggregates" on all concrete mixtures containing 4.5% post consumer plastic showed lower compressive strength than the reference mixture without plastic (Fig. 1). This was attributed to lower compressive strength of the plastic particles compared to cementitious matrix as well as natural fine and coarse aggregates. Among the various treated samples (P_1, P_2, and P_3) the sample treated with bleach oxidant plus NaOH gave the best results (Table 6 and Fig. 1). The sample soaked in water showed better results than the sample treated with bleach alone.

The improved performance of plastic treated with alkaline bleach was probably due to increased coverage of the polymer surface with $-O^-$ and $-COO^-$ sites produced by the alkaline oxidizing conditions, as follows, with surface species underlined:

$$--\underline{CH6_2}-- + 2OH^- \; 6 \; --\underline{CHOH}- + H_2O+ 2e^- \qquad (4)$$

$$--\underline{CH_3} + 7OH^- \; 6 \; -\underline{COO}^- + 5H_2O + 6e^- \qquad (5)$$

Equations (4) and (5) illustrate the fact that the oxidation potential for such heterogeneous reactions are enhanced by high pH on the solution side of the interface.

The oxidative (i.e. hypochlorite) pretreatment of the polymer particles in neutral pH

solution was expected to enhance the concrete strength compared to water washing, but the enhancement was anticipated to be less than that for the alkaline oxidation with the same oxidant. The results, however, were a slight decrease in strength of the concrete as compared to the case with water washed polymer. It might be speculated that the untreated plastics surfaces contain a relatively small surface coverage by -OH sites, which were chlorinated, to yield a surface less reactive to calcium and other cationic concrete mix reactants than was the case for the water washed material.

The results further show that the relative strength enhancement during the first week is similar for water-washed and alkaline hypochlorite treated PE as compared to the control concrete (Fig. 1). It is noteworthy that the neutral hypochlorite treated PE did not appear to undergo rapid curing strength enhancement after the third day, in contrast to all other cases. This observation correlates with the hypothesis that residual polar sites on water-washed PE are reacted to yield non-polar groups by the neutral chlorinating agent.

In a related study in our laboratories, polyethylene terephthalate was treated with alkaline hypochlorite under similar conditions and the same period of time. Surface tension measurements showed a shift of 8.0 dynes for a 5.0 cm length interface. Calculations using assumptions of 100 kj/mole bond strength, 1.0 nm^2 area per site, and a surface roughness factor of unity, resulted in an estimate of 1 - 10% coverage by ionic functional groups. Similar studies are underway for the polyethylene material for which the above concrete strengths are reported.

The effect of amount of the plastic particles are shown in Fig. 2. At the 0.5% plastic level (P_5) , compressive strength of the concrete was either comparable or superior to that of the reference mixture without plastic (P4). However, beyond 0.5% plastic addition, compressive strength of concrete decreased significantly.

Splitting Tensile Strength

The effect of various chemical treatment on tensile strength of the mixtures is shown in Table 6 and Fig.3. In general, the effect of the treatment on tensile strength of the mixtures followed the similar general trend as observed for the compressive strength. The plastic treated with bleach plus NaOH showed the highest tensile strength, and the plastic treated with bleach alone exhibited the lowest tensile strength.

The observed tensile strength as a function of plastic addition is shown in Fig. 4. The splitting strength increased with age, and with plastic addition up to 0.5%. Beyond the 0.5% plastic addition tensile strength decreased.

CONCLUSION

1. **In general, effect of chemical treatment of the plastic particles produced significant influence on compressive and tensile strengths of concrete at a plastic concentration 4.5%. This was presumably due to the introduction of chemical bonding between the plastic and cementitious matrix of concrete resulting from the treatments used.**
2. **Of the three treatments used (water, bleach, and alkaline bleach) used, the highest**

compressive strength was achieved when the plastic was treated with alkaline bleach, and the lowest when treated with bleach alone.

3. **The tensile strength results exhibited the same trends as observed in the compressive strength data.**

4. **As expected, compressive strength decreased with increase in the amount of the plastic in concrete, particularly above 0.5% plastic addition. Therefore, in order to maintain a particular compressive strength level, plastic concentration in concrete must be controlled. However, the amount of plastic addition can be increased substantially if particles are further processed to improve the bond area and stress transfer capacity of the particles.**

5. **The tensile strength decreased as plastic content increased, especially beyond 0.5% which was contrary to the expected trend. This suggest that the effectiveness of the plastic filler must be improved. This could be improved through physical processing as well as chemical treatment for obtaining the best results.**

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REFERENCES

1. **FHWA, "A Study of the Use of Recycled Paving Material - Report to Congress",**

Report No. FHWA-RD-93-147, June 1993, 34 pages.

2. **Naik, T.R., Singh, S.S., and Brodersen, B.S., "Construction Materials Containing Polymeric Substances and Used Plastics," A CBU technical report, UWM Center for By-Products Utilization, UW-Milwaukee, Wisconsin, March, 1994.**

3. **Rebiez, K.S., Fowler, D.W., and Paul, D.R., "Mechanical Properties of Polymer Concrete Systems Made with Recycled Plastic," ACI Materials Journal, Vol. 91, No. 1, January -February, 1994, pp. 40-45.**

4. **Soroushian, P, Alhozaimy, A., and Eldaruish, A.I., "Recycling of Plastics in Concrete to Enhance Toughness Characteristics and Resistance to Shrinkage Cracking," Proceedings of the Symposium on Recovery and Effective Reuse of Discarded Materials and By-Products for Construction of Highway Facilities sponsored by Federal Highway Administration and EPA, Denver, Colorado, October 19-22, 1993, pp. 5-4, to 5-53.**

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Table 1: Chemical and Physical Properties of Cement

CHEMICALS	Lafarge, Type I	ASTM C-150 TYPE I
Silicon Oxide, SiO_2	21.1	-
Aluminum Oxide, Al_2O_3	4.9	-
Iron Oxide, Fe_2O_3	2.9	-
Sulfur Trioxide, SO_3	3.7	3.0 Max.
Calcium Oxide, CaO	74.7	-
Magnesium Oxide, MgO	2.0	6.0 Max.
Titanium Dioxide, TiO_2	0.0	-
Potassium Oxide, K_2O	0.6	-
Sodium Oxide, Na_2O	0	-
Loss on Ignition	1.0	3.0 Max.
PHYSICAL TESTS	**Lafarge, Type 1**	**ASTM C-150 TYPE I**
Air Content (%)	8	12
Fineness (m^2/kg)	385	280
Autoclave Expansion (%)	-0.02	0.8
Specific Gravity	3.11	-
Compressive Strength, psi 1-day 3-day 7-day 28-day	1395 3450 4455 5315	- 1800 2800 -
Vicat Time of Initial Set (min)	230	45 Min. 375 Max.

Table 2: Gradation of Aggregates

Fine Aggregates			Coarse Aggregates		
Sieve Number	% Passing	ASTM C-33 % Passing	Sieve Size	% Passing	ASTM C-33 % Passing
4	99.7	95-100	1"	99.5	100
8	86.6	80-100	3/4"	87.1	90-100
16	73.2	50-85	1/2"	50.5	-
30	54.3	25-60	3/8"	17.2	20-55
50	11.2	10-30	#4	1.4	0-10
100	5.1	2-10	#8	0.5	0-5

Table 3: Physical Properties of Aggregates

Aggregates	Bulk Specific Gravity	Bulk Specific Gravity (SSD)	Apparent Specific Gravity	SSD Absorption (%)	Dry Rodded Unit Weight (lb/ft^3)	Percent Voids (%)	Fineness Modulus
Sand	2.66	2.70	2.76	1.4	110	34	2.70
Coarse Aggregate	2.55	2.56	2.58	0.5	95	41	3.44

Table 4: Mixture Proportion Data

Mix No.	P0	P1	P2	P3	P4	P5	P6	P7
Treatment	None	Water	Bleach	Bleach + NaOH	None	Water	Water	Water
Specified Design Strength, psi	5000	-	-	-	5000	-	-	-
Cement, lbs	22.6	22.6	22.6	22.6	22.6	22.6	22.6	22.6
Plastic, lbs	0	6	6	6	0	1	2	3
Water, lbs	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7
Sand, SSD, lbs	53.7	53.7	53.7	53.7	53.7	53.7	53.7	53.7
:" Aggregate, SSD, lbs	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0
Slump, in	3	1.5	0	0	3.25	1	1.25	2
Concrete Density, pcf	152.2	135.8	131.6	131.4	154.7	150.1	145.9	141.9

Table 5: Chemical Treatment of Plastics

Mix No.	P1	P2	P3	P4
Plastic, lbs	7	7	7	7
Water	Yes	No	No	Yes
5% Hypochlorite Solution, L	0	15	15	0
5% Hypochlorite Bleach + 4% Sodium Hydroxide (NaOH), lb	0	0	1.32	0
Total Soak Time	16 hrs*	7 days**	6 days**	23 hrs*
Drying Time	1 hr	1 hr	12 hrs	1 hr

* The degree of cleanness was about the same in both the cases.

** The soaking time between 5-7 days have been found to have the same effect.

Table 6: Strength Properties Data*

Mix No.	P0	P1	P2	P3	P4	P5	P6	P7
Specified Strength, psi	5000	-	-	-	5000	-	-	-
Plastic Per Cubic Foot of Concrete, lb	0	6	6	6	0	1	2	3
% Plastic by Total Weight of Concrete	0	4.5	4.5	4.5	0	0.5	1.5	2
Treatment	No Treatment	Water	Bleach	Bleach+ NaOH	No Treatment	Water	Water	Water

Table 6 (cont.): Strength Properties Data*

Mix. No.	P0	P1	P2	P3	P4	P5	P6	P7
Test Age, Days	Compressive Strength, psi							
3	2890	1010	870	1400		2600	2070	1560
7	4140	1270	960	1880	3120	3210	2620	1870
28	4940	-	1070	1870	4080	4150	3170	2200
Test Age, Days	Splitting Tensile Strength, psi							
3	585	260	235	295	480	500	435	335
7	790	330	235	500	670	555	520	400
28	960	-	275	550	795	710	580	490

*Each value is an average of three readings.

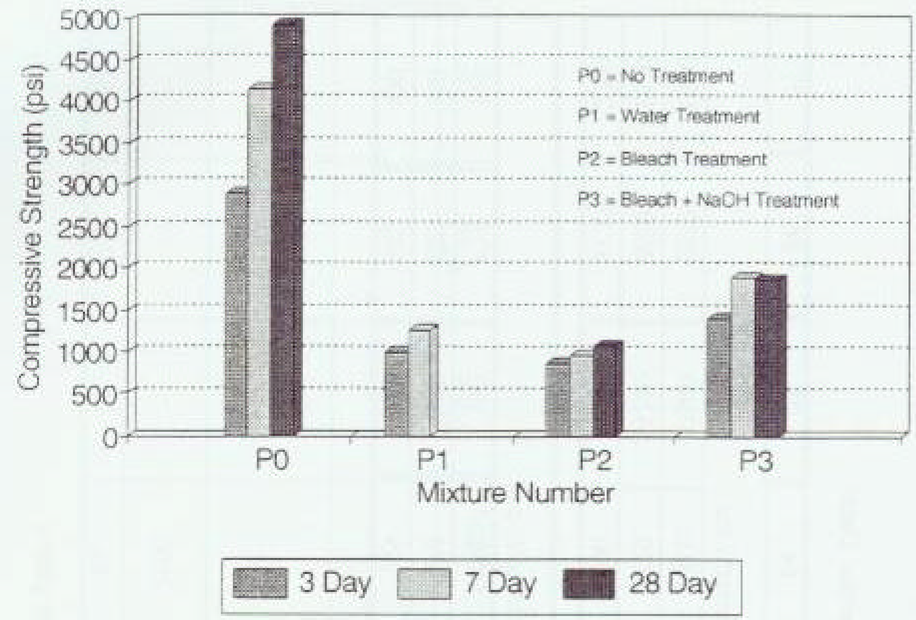

FIG. 1 Effect of Treatment on Compressive Strength of Concrete

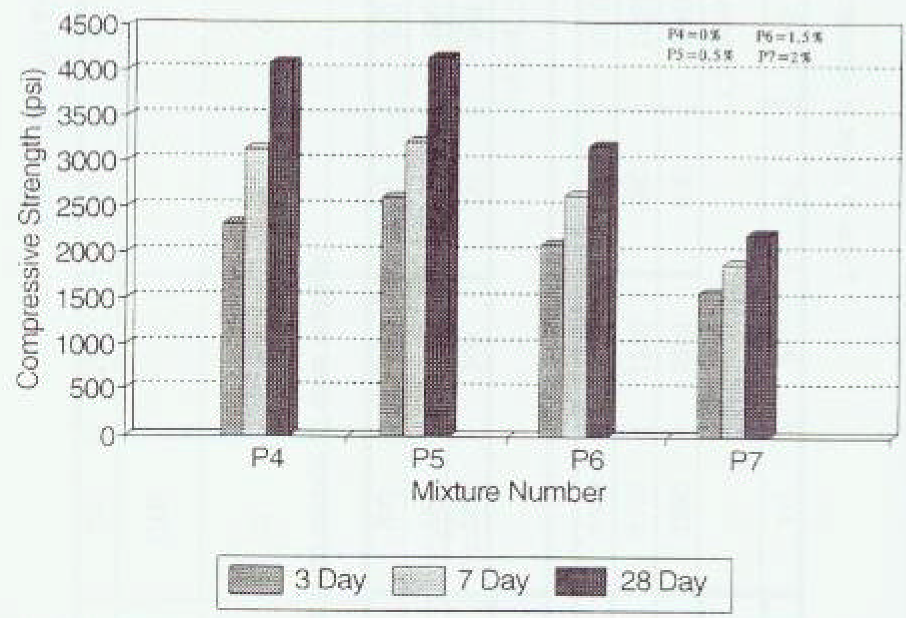

FIG. 2 Effect of HDPE Quantity on Compressive Strength of Concrete

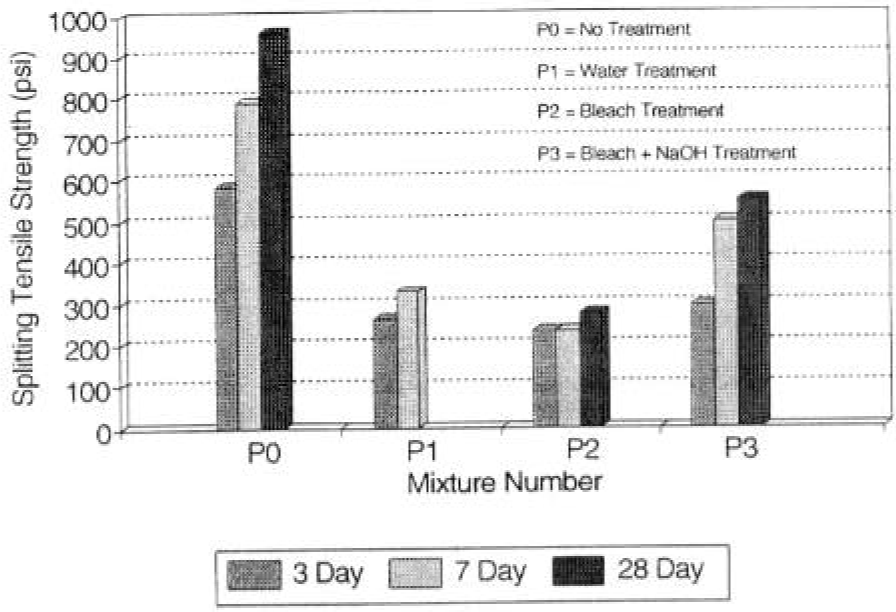

FIG. 3 Effect of Treatment on Splitting Tensile Strength of Concrete

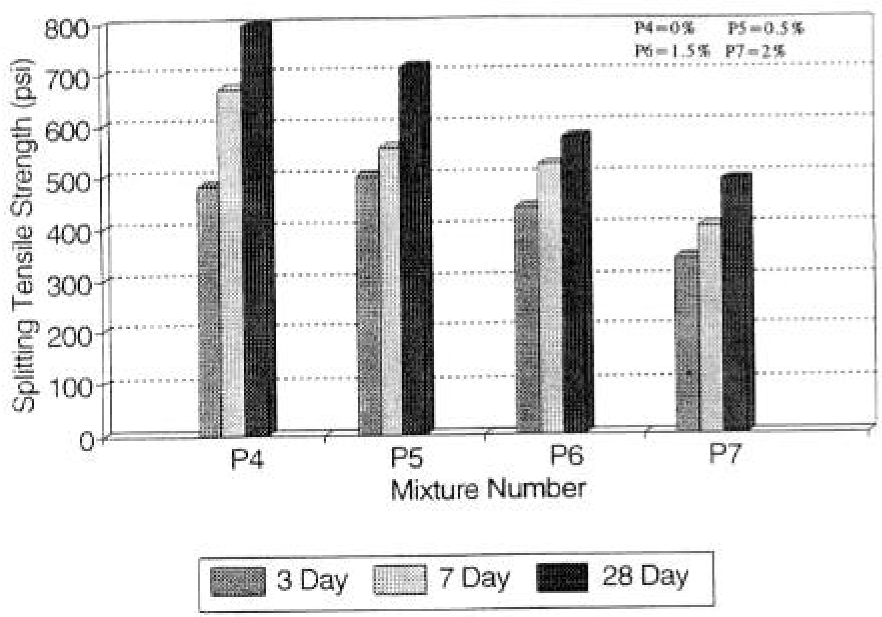

FIG. 4 Effect of HDPE Quantity on Splitting Tensile Strength of Concrete