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An experimental investigation on the erosion resistance of concrete containing various PET particles percentages against sulfuric acid attack

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HIGHLIGHTS

- PET particles were used as an alternative aggregate against erosion caused by sulfuric acid in concrete.
- Concretes included PET particles more retain their load bearing capacity under sulfuric acid attack.
- Under sulfuric acid attack, changes in crushing load are nearly similar to ultrasonic wave velocities.
- Concretes included PET particles are able to utilize in environments under sulfuric acid attack.

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ABSTRACT

PET (Polyethylene Terephthalate) is one of the most common plastics for various productions. The rapid increase in the use of these products causes increment in solid waste problems. Eventually, management and prevention of solid waste resulted by urban and industrial waste are dramatically important. On the other hand, deterioration of sewage purification structures, part of industrial structures and concrete sewer pipes attacked by sulfuric acid is an important issue of the world that has communicated with substantial financial need in all countries. Thus, not so many researches has been investigated the effect of sulfuric acid erosion on concrete containing PET particles, this study represents the laboratory investigation of different values of 0%, 5%, 10%, and 15% of PET particles as an alternative aggregate on erosion caused by sulfuric acid in concrete. All samples were cured during 28 days, 3 samples from each mix design were tested, finally. In intervals of 15, 30, and 60 days of immersion in 5% sulfuric acid, 3 specimens were taken out from sulfuric acid solution. Then, after drying these specimens and measuring their dimensions, crushing load, weight and ultrasonic wave velocity values were obtained. The results showed that by increasing in amount of PET particles as an alternative aggregates in concrete, there is less reduction in values of crushing load, weight loss and ultrasonic wave velocity. Also, it could be seen that ratios of crushing load reduction to weight loss for specimens attacked by 5% sulfuric acid solution were increased by increasing in percentage of PET particles, which illustrates that in a particular range of crushing load, less weight loss was occurred in concretes included more PET particles.

1. Introduction

1.1. PET concrete

PET (Polyethylene Terephthalate) is a usual plastics which is used as a raw material for making products like blown bottle which is used to produce soft drinks, food containers, etc. In recent decade due to rapid increment in the use of PET bottles, the problem of solid waste is increased. Therefore, management and prevention of solid waste due to residential and industrial wastes has become very important [1]. In Beijing more than 150 tons of PET is wasted in a year [2]. This issue is known clearly that waste PET bottles need too long time to decompose in the nature [3]. Also destroying PET bottles improperly, causes lots of environmental problems in the nature. For example, burning PET as fuel, releases toxic gases in environment and contributes to produce acid rains which cause to concerns about air pollution and public Health. Therefore, investigations on proper and economical recycling methods in this field is significantly needed. Investigations on conversion of PET bottle

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wastes in structural industry due to its many environmental and economic benefits, have conducted globally.

Laboratory investigations indicate that use of PET as resin in production of polymer concrete, not only has positive environmental effects but also causes decrease in production cost of polymer concrete [1].

Recently significant growth in use of waste materials as substitute for proportion of concrete admixture materials has been done. Researchers used materials like sintered sludge pellets, rubber wastes, waste plastics, fiber glass waste materials, blast furnace slag, and granulated coal ash in concrete and investigated its effects on different properties of concrete [4].

According to this, usage of PET waste in concrete as an aggregate could be one of its extensive usage, has disposal of waste advantages and causes decrease in environmental damages due to less use of natural aggregate resources [4].

Generally, aggregate consists 65–80 percent of concrete proportion and has the main role in concrete behavior such as durability, dimensional stability and workability which could improve some of mechanical and durability properties of concrete due to low thermal conductivity, good abrasion behavior, high toughness and high heat capacity [5–7].

Akcaozoglu et al. [1] research has shown that use of PET in concrete due to lower specific gravity in comparison with ordinary aggregate causes decrease in concrete weight which is valuable advantage in design of structures.

Since, water absorption of mortars made by PET is very low, researchers suggest that due to its high resistance against erosion, it could be used in aggressive environments as a proportion of concrete [8]. Also, Won et al. and Sehaj et al. [9,10] showed that use of PET in concrete could increase ductility and decrease plastic shrinkage cracks which are related with concrete durability. Another investigations conducted by Akcaozoglu et al. [1] indicated that in concrete with PET particles, permeability and resistance against carbonation are improved.

However adding waste PET to concrete could have negative effects in quality of concrete such as decrease in compressive strength, tensile strength and modulus of elasticity due to low surface energy because of its weak mechanical bond [11–13]. Recent researches generally indicate that use of plastic wastes in concrete as substitute of aggregate could affect some of its properties.

1.2. Sulfuric acid erosion

In recent decade, durability of concrete in design of structures especially in infrastructures has become so important. Significant improvements in our knowledge about chemical processes of different concrete deteriorations have been achieved. Anyway our knowledge about interactions of this processes in final mechanical properties of concrete is limited yet.

Generally, exposing concrete in acid environments is the main debate about durability of concrete structures which affect performance, life time and maintenance cost of vital structural infrastructures. In fact, previous researches have illustrated that acids in ground water, chemical waste water or acids resulted by oxidation of sulfur compounds in backfill could attack concrete substructure members and influence their durability [14,15]. In addition, lots of concrete structures especially in industrial regions that often included sulfuric acid are exposed to acid rain erosion [14]. On the other hand, deterioration of sewer pipes and waste water purification structures attacked by sulfuric acid is global challenge which already have lots of economic necessities all around the world. Deterioration of sewer systems lead to serious problems such as reduction of ability in waste water transfer, pollutions of soil and ground water and excessive ground settlement cave-in [16]. Therefore, supplying high quality wastewater infrastructure needs significant expenditure on concrete with expected quality. For example only in U.S, annual control and maintenance expenditures are even more than investing in construction of new wastewater structures [17].

Hewayde et al. [18] estimated that costs of maintenance and repair due to biogenic sulfuric acid attack on sewer systems are almost 100 billion U.S dollars. Therefore, motivation of researches in field of concrete sewage systems durability exposed to erosion is increasing.

Olmstead et al. [19] were first one who reported erosion in sewer systems. In 1920, hydrogen sulfide (HS) was known as erosion factor in Cairo sewer systems too. Initially it was believed that HS is produced by reduction of sulfate in sewage flow, and then is changed to sulfuric acid by breaking out to sewer atmosphere and oxidation [20].

In 1945 Parker [21] attributed this phenomena to chemical-microbial interactions in sewage systems and expressed that influence of sulfuric acid in concrete is more destructive than sulfate attack. Because in this situation there is dissolution effects consequent of hydrogen ions beside of sulfate ions attacks.

In fact, sulfuric acid reacts with calcium hydroxide (CH) existence in concrete and produce gypsum. Creation of gypsum in concrete causes volume to increase by factor of nearly 2, although some researchers mentioned that this reaction plays a secondary role in erosion procedure. Indeed, reaction between gypsum and calcium aluminate hydrate (C_3A) and consequently creating ettringite, leads to much more deterioration. Volume of ettringite is greater than initial compounds (nearly 7 times) [22]. These voluminous compounds cause inner pressure in concrete that lead to formation of cracks [23]. While the erosion continues, cracked surface is become soft and white and the corroded concrete loses its mechanical strength that contributes to more cracking, spalling and finally leads to completely destruction [24–28]. The findings of the present investigations are not used in many of common constructions yet. Lack of enough researches on presenting a proper relation for designing a durable structure, expresses that mechanisms related to concrete deterioration are not widely accepted and understood yet.

Furthermore, erosion of water and wastewater infrastructures is on the top of dissensions during last decades. There are many opinions about designing and characteristic of a proper infrastructures to deal with corrosive environment during service life [29–34]. Some of these researches on the one hand illustrate improvement of concrete properties by use of various admixtures and innovative materials compounds and at last introduce a modern concrete, and on the other hand prevent growing sulfuric acid-producing bacteria [35,36].

So far, various researches have been done on effects of cement type, water to cement ratio (W/C) [14,37,38], supplementary cementitious materials [18,35,39,40], polymer materials and type of aggregates [16], to improve normal concrete and mortar resistance against acid attacks.

In spite of many accomplished researches, previous data on influence of various materials in normal concrete resistance against sulfuric acid attack are contradictory. As it was mentioned, nowadays use of concretes included PET particles around the world are increasing because of their economic and environmental useful aspects. Therefore, utilizing this kind of concrete in a more appropriate way in structural industry needs more researches concentrating on their properties and durability. In recent decades, concrete mechanical properties consisted of PET particles have been investigated in various points of view. Investigations on durability of this kind of concrete are the main factor in designing and constructing infrastructures. As regards, a few studies have been conducted in field of sulfuric acid effect on PET concretes erosion, it is likely that durability of PET concretes be different with normal