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EXPERIMENTAL STUDY ON CHLORIDE RESISTANCE OF CONCRETE CONTAINING RECYCLED PLASTIC AS FINE AGGREGATE

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ABSTRACT: Plastic waste is one of the most factors with a negative impact on the environment. The goal of many researchers is to use plastic waste in concrete while taking advantage of its properties to improve the properties of concrete in some applications. This study aims to investigate the concrete resistance to chloride attacks by using plastic waste as a partial replacement for sand in the concrete. The effects of the plastic fine aggregate (PFA) on the mechanical and physical properties of concrete were studied. Four concrete mixes (normal concrete, concrete with superplasticizer or/and micro-silica) were prepared as control specimens. In addition, three concrete mixes were prepared with 10%, 20%, and 30% replacement of sand by PFA. The experimental results showed a slight decrease in the unit weight and the mechanical properties of concrete until the ratio of 20% PFA. However, the results showed significant improvements in the resistance of PFA concrete to chloride attack under normal, cyclic, and aggressive chloride attack conditions compared to the concrete with reliable protection methods.

Keywords: Recycled plastic, Chloride resistance, Plastic fine aggregate, Plastic concrete

1. INTRODUCTION

The percentage of recycled plastic is small compared with waste generated annually [1-3]. Recycling of various types of plastic waste has attention because of the high cost of dumping and reducing land for landfills [4]. Using plastic waste in concrete is one of the effective solutions to get rid of and use it simultaneously. Therefore, many researchers studied the effect of plastic waste on concrete as a partial replacement for aggregate. It is found that the workability decreased with increasing the replacement, while the slump increased [5-9]. Most studies showed that a reduction in compressive strength, flexural strength, and splitting strength depends on the replacement level [10-15]. Also, the unit weight of concrete decreases significantly as the replacement ratio is increased [16-20].

Protection of concrete from chloride attacks is very important to prevent corrosion in steel reinforcement [21-22], where this corrosion leads to cracking of the concrete cover and decreases the life service of the structure [23-24]. Some researchers showed that using plastic in concrete will improve the chlorides resistance of concrete because plastic works as a physical obstacle to repel chlorides [25-26]. On the other hand, other researchers showed a decrease in chlorides resistance without explaining it [27-29]. This decrease in chlorides resistance may be because of using granule plastic of the same size which increases the void content.

2. RESEARCH SIGNIFICANCE

Most research on recycled plastic in concrete focused on the mechanical properties of concrete and showed little attention to the chloride resistance of concrete. Therefore, this study aims to investigate the resistance of concrete to plastic waste as a partial replacement of sand to chloride attacks under hard conditions at different ages. Also, the study goal is to determine the suitable percentage of thermoplastic waste as sand replacement in concrete to balance between strengths reduction in concrete and the advantage of concrete chloride protection.

In this study, thermoplastic waste was recycled and graded as a partial replacement for fine aggregate in the concrete. Besides the properties of concrete, the concrete resistance against chloride attacks was investigated under normal and hard attack conditions. Three different plastic fine aggregate (PFA) replacement ratios (10%, 20%, and 30%) of the sand weight were compared to normal concrete and concrete with typical protection methods by using micro-silica or/and a water reduction superplasticizer.

3. RESEARCH PROGRESS

Material, preparation, and required tests for specimens are covered in this section.

3.1 Cement

Ordinary Portland cement, Type I, was used in this study for concrete specimens. The physical properties are presented in Table 1 and the chemical properties are presented in Table 2.

3.2 Aggregate

Natural aggregate was used in this study. The specific gravity of sand and gravel was 2.61 and 2.56, respectively, with a sulphate content of 0.04%.

Plastic waste was collected from various sources such as boxes and toys. The plastic wastes were crushed to produce plastic fine aggregate (PFA) as shown in (Fig.1). Crushed PFA was prepared by using appropriate sieves and mixed to meet the grading of fine aggregate according to ASTM C33-03 specifications. The produced PFA has a density of 950 kg/m3. Grading PFA produces homogenous distribution and avoids increasing air content.

The sieve analysis of sand, PFA, and gravel is presented in Tables 3 and 4 and (Fig.2).

3.3 Water, micro silica, and superplasticizer

Clean and typical tap water was used for mixing concrete compounds and curing specimens. Micro-silica is a dry silica fume powder that was used according to ASTM C 1240. Further, hyperplastic PC200 as a reduction water superplasticizer was used. Micro silica and superplasticizer were used to increase durability and resistance to aggressive atmospheric conditions by reducing permeability.

Table 1 Physical properties of cement

Properties	Result	ASTM C150-04 limits
Fineness (m^2/Kg)	295	≥ 280
Setting time (min.)		
Initial	185	≥ 45
Final	315	≤ 375
Compressive strength (N/mm^2)		
3 days	11.7	≥ 8
7 days	18.5	≥ 15

Table 2 Chemical composition of cement

Composition	Result Weight (%)	ASTM C150-04 Limits (%)
Lime (CaO)	63.12	-
Silica (SiO2)	18.68	-
Alumina (Al2O3)	5.17	-
Iron oxide (Fe2O3)	3.18	-
Magnesia (MgO)	2.43	≤ 2.8
Sulfur trioxide (SO3)	4.12	≤ 5
Loss on Ignition	2.72	≤ 3

Fig.1 Plastic fine aggregate (PFA)

Table 3 Grading of sand and PFA

Sieve Size (mm)	Test Result Passing (%)		ASTM C33-03 Limits (%)
	Sand	PFA	
9.5	100	100	100
4.75	98	99	95-100
2.36	91	96	80-100
1.18	75	80	50-85
0.600	56	58	25-60
0.300	16	25	5-30
0.150	0	6	0-10

Table 4 Grading of gravel

Sieve Size (mm)	Test Result Passing (%)	ASTM C33-03 Limits (%)
25	100	100
19	95	90- 100
9.5	46	20- 55
4.75	4	0- 10
2.36	0	0- 5

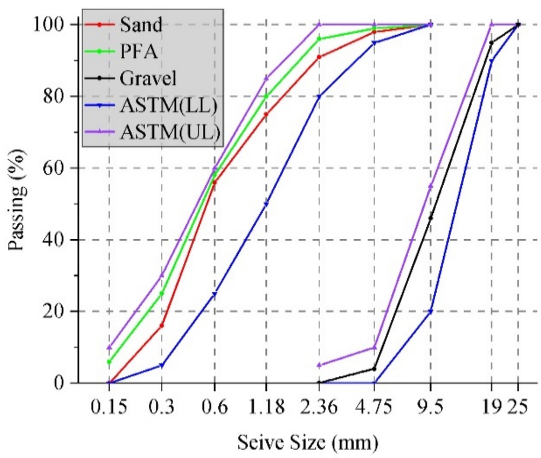


Fig.2 Particle size analysis curves of aggregates.

Table 5 The mix proportions of concrete materials

Specimens	Cement (kg)	Sand (kg)	PFA %	PFA (Kg)	Gravel (kg)	W/C	Water (kg)	SF (kg)	SP (kg)
CN	420	650	0	0	1146	0.45	189	0	0
CSF	420	607	0	0	1146	0.45	189	42	0
CSP	420	650	0	0	1146	0.35	147	0	6
CSPSF	420	607	0	0	1146	0.35	147	42	6
P10	420	585	10	25	1146	0.45	189	0	0
P20	420	520	20	50	1146	0.45	189	0	0
P30	420	455	30	75	1146	0.45	189	0	0

3.4 Concrete Specimens Preparation

Three percentages of PFA were used to determine the concrete properties and chloride resistance. The test results of PFA concrete were compared with control specimens. Control specimens include normal concrete and concrete with additives (micro-silica (SF), or/and superplasticizer (SP)). The PFA replacement ratios used in mixtures are 10%, 20%, and 30% of the sand weight.

A drum mixer of 0.1 m^3 size was used for making the concrete mix. The materials were mixed for about 2 minutes; then, water was added and for the concrete mixture with superplasticizer, the superplasticizer solution is added to water and the mixing continued for 2 minutes.

The control concrete mix was designed according to the British method for f_{cu} of 35 MPa. Table 5 shows the mixed proportions of materials used in this work.

3.5 Test Specimens

3.5.1 Slump

According to ASTM C 143-03, the test was conducted.

3.5.2 Compressive Strength

This test was conducted with (150*150*150) mm cubes according to B.S.1881 part 116 with a machine capacity of (1900) kN. The average compressive strength of three cubes per test age was recorded.

3.5.3 Flexural Strength

According to ASTM C78-02, concrete prisms of (150*150*500) mm dimensions were utilized, and a four-point load test was performed. The average flexural strength results of two prisms were obtained.

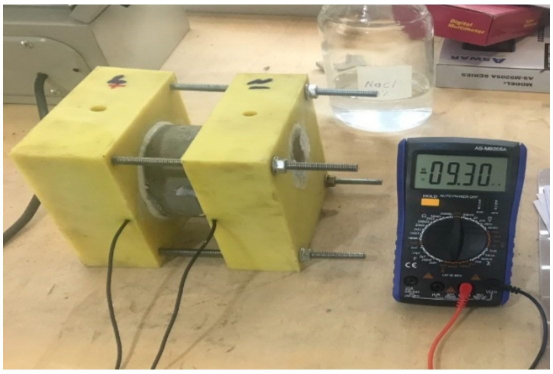
3.5.4 Tensile Strength

According to ASTM C496-04, concrete cylinder specimens with 150 mm diameter and 300 mm height were used. For each test age, the average strength of two cylinders was recorded.

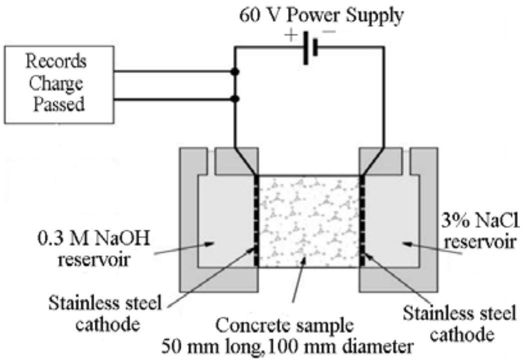
3.5.5 Rapid Chloride Permeability

Concrete specimens were disc with a diameter of 100 mm and height of 50 mm were used according to AASHTO T277 and ASTM C1202 as illustrated in (Fig.3). The concrete specimens are water-saturated and exposed to a 60 DC voltage for 6 hours as illustrated in (Fig.4). On one face of the specimen is a 3.0 % NaCl solution and on the other face is a 0.3 M NaOH solution. The full charge moved is measured in terms of coulombs (Eq. (1)) and this is used to calculate the concrete chloride resistance according to the criteria shown in (Fig.5). The average of the two specimens' results was indicated for each test.

Fig.3 Specimens of Rapid Chloride Permeability Test



(a) Chloride Permeability device



(b) Chloride Permeability test diagram

Fig.4 Rapid Chloride Permeability Test

$$C_f = 900\,(A_0 + 2\,A_{30} + 2\,A_{60} + 2\,A_{90} + 2\,A_{120} + \ldots\ldots + 2\,A_{330} + 2\,A_{360}) \quad (1)$$

Where C_f represents the current flowing through the concrete cell (coulombs) and A_t is the current reading in amperes at time t (min) for applied voltage (60 DC).

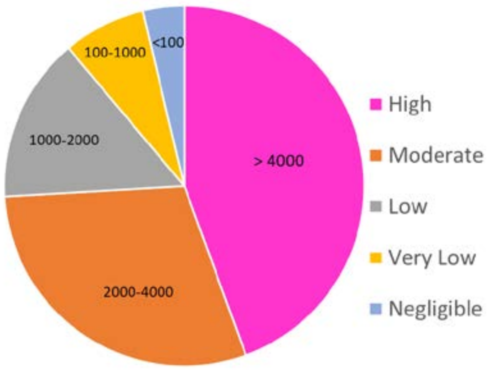


Fig.5 RCPT ratings (coulombs) per ASTM C1202

4. RESULTS AND DISCUSSION

4.1 Concrete Unit Weight

Figure 6 shows the percentage change in a dry unit weight of concrete with PFA, superplasticizer, or/and micro-silica concerning normal concrete. The results show that the percentage reduction is proportional to the PFA replacement ratio and using micro-silica increases the unit weight of concrete. This trend is clearly due to the light density of PFA and the high density of micro-silica.

4.2 Slump Test

Figure 7 shows that the slump is increased with the increased rate of PFA. This proportional increase is returned to plastic surface properties which make the concrete flow easy.

4.3 Concrete Strength

As expected from many previous researchers, the results show that the compressive, flexural, and splitting strengths decrease with the increased rate of PFA as shown in (Figs.8, 9, and 10) respectively. These strengths decrease due to weak adhesive between cement paste and plastic and also because of the decrease in PFA concrete density. The strength of concrete specimens with silica fume and reduction water superplasticizer is higher than that of other specimens. The results show that the reduction in strength of PFA concrete till 20% replacement is slight compared to normal concrete. For 30% PFA replacement, the reduction in strength is significant and it is about 12%.

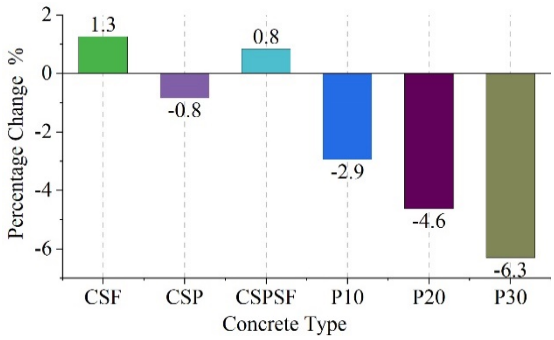


Fig.6 Change in a dry unit weight of concrete specimens w.r.t normal concrete.

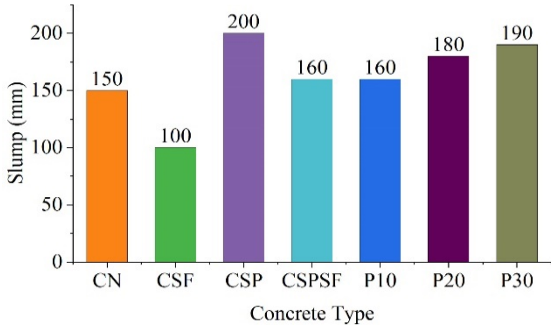


Fig.7 Slump test results for concrete specimens

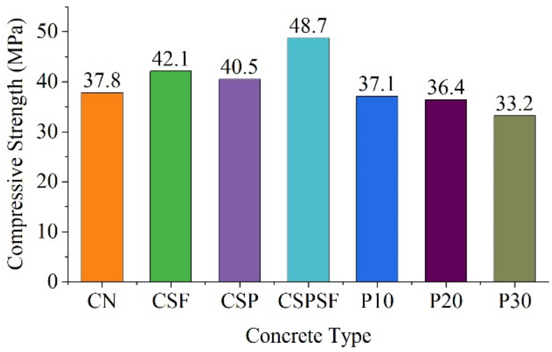


Fig.8 Compressive strength of concrete specimens

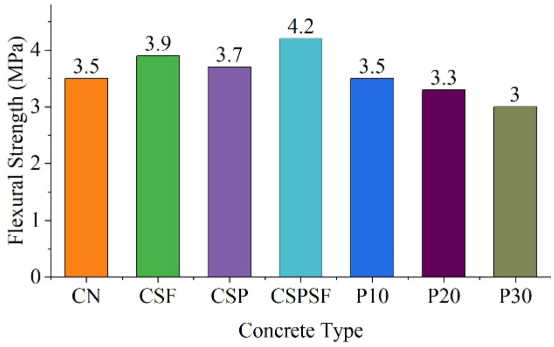


Fig.9 Flexural strength of concrete specimens

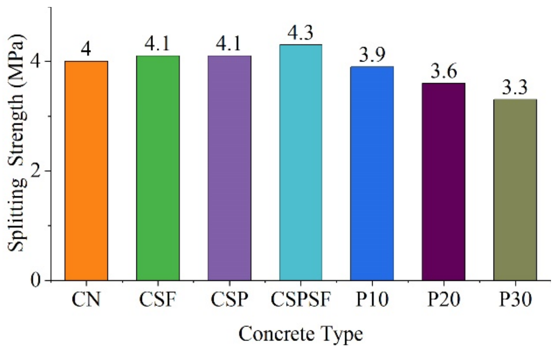


Fig.10 Splitting strength of concrete specimens

4.4 Chloride resistance

Three PFA concrete mixes are considered by replacing 10%, 20%, and 30% of sand weight with PFA. PFA specimens are compared with specimens of normal concrete and concrete with typical methods of improving the durability by adding micro-silica or/and superplasticizer to the concrete mix (Table 5).

Forty-two chloride resistance specimens were divided equally into three groups. The three groups of specimens were tested under different chloride attack conditions. In the first one (normal test), the 14 specimens were tested normally at different ages of 28, 60, 120, 180, and 350 days. In the second group (cyclic test), the 14 specimens were tested and then retested every 7 days for 50 cycles by drying and water saturating the specimens and then testing them again. In the third group (aggressive test), the 14 specimens were tested at age 28 days and retested at ages 60, 120, 180, and 350 days with keeping the specimens exposed to the 3.0% NaCl solution on the same side the chloride attack at the first test. The first chloride test for all specimens was carried out with concrete age of 28 days.

The three series results are shown in (Figs.11, 12, and 13). The results show an improvement in the resistance of PFA concrete to chloride attack compared with control specimens. Also, the results show that the concrete resistance to chloride is proportional to the replacement rate of PFA. In the normal test, the PFA specimens showed stability of their resistance with age. In the cyclic and aggressive tests, the PFA specimens showed the highest resistance with time to prevent the current flowing rate of the test compared with control specimens. This chloride resistance improvement is returned to the use of graded PFA, which produces homogenous distributions in all fine aggregate levels. Thus, the voids content decreases and it works as a physical obstacle to the chlorides path.

The PFA specimens showed excellent corrosion resistance compared with other types of concrete, especially with normal concrete which showed large corrosion at chloride exposed face as shown in (Fig.14). This indicates that chlorides attack affects the concrete, especially when it is exposed for a long time [30,31].

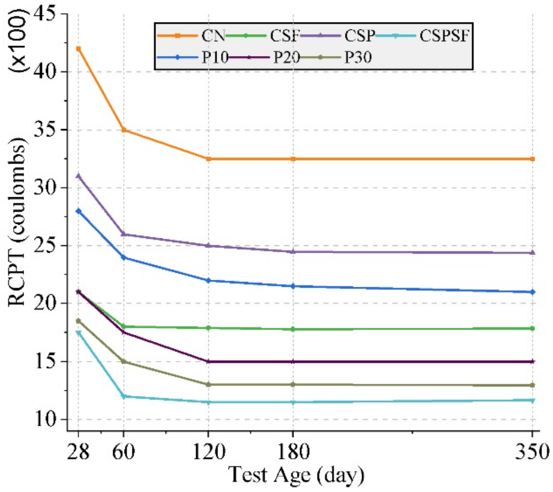


Fig.11 RCPT at different ages (Normal test)

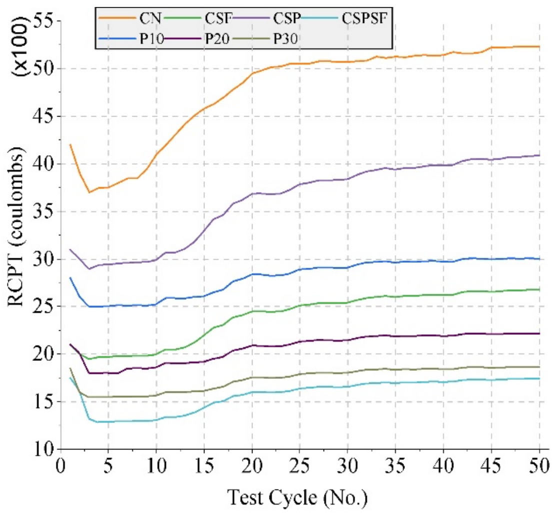


Fig.12 Cyclic RCPT every 7 days (Cyclic test)

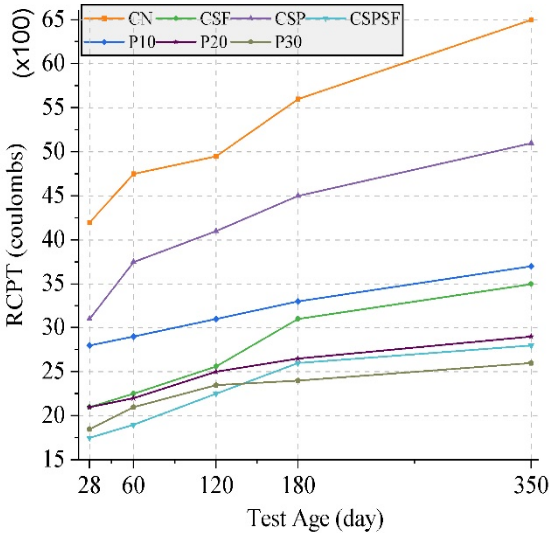


Fig.13 RCPT at different ages with chloride exposed situation (Aggressive test)

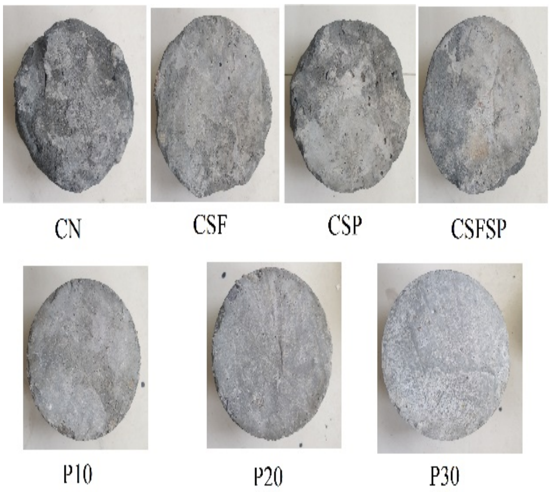


Fig.14 specimens' condition at end of the aggressive test

5. CONCLUSIONS

Thermoplastic waste was recycled as a partial replacement of fine aggregate in concrete. The concrete resistance to chloride was examined under different exposure conditions to chloride solution. Also, the physical and mechanical properties of concrete were tested. The main points can be concluded as followings.

1. The slump of concrete containing recycled plastic as fine aggregate is increased compared to normal concrete.
2. The PFA reduces the dry unit weight of the PFA concrete.
3. The reduction in compressive, flexural, and splitting strength of concrete with a replacement level of PFA up to 20% is slight. However, the reduction is significant at a replacement level of 30% PFA.
4. Concrete with PFA shows an improvement against chloride attacks and the concrete chloride resistance is proportional to the PFA ratio.
5. PFA specimens showed excellent corrosion resistance compared with other types of concrete.

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