Mechanical properties and durability of concrete with fine recycled asphalt and silica fume

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ABSTRACT

Recently, there has been an increasing trend toward the use of sustainable materials. Sustainability helps the environment by reducing the consumption of non-renewable natural resources. Concrete – the second most consumed material in the world after water – uses a significant amount of non-renewable resources. As a result, an experimental investigation was conducted to study the durability and mechanical properties of concrete constructed with 10% and 15% recycled Asphalt pavement aggregate (RAP) (fine) as well as 6% silica fume. This experimental program consisted of three mix designs. The compressive strength, tensile strength, electrical resistivity and chloride ion penetration of RAP mixes were compared with the conventional concrete. To overcome inferior durability of RAP mixes, silica fume (6%) has been added to the RAP mixes. Results of the mixes including both RAP and silica fume show superior mechanical properties (both compressive and tensile strength) and durability (both electrical resistivity and chloride ion penetration) compared with the conventional concrete.

KEY WORDS :

Silica fume, Concrete, Mechanical properties, Durability, Recycled asphalt

1. INTRODUCTION

Today, concrete is suitable for a variety of construction projects, from sidewalks to high rise buildings, roads, bridges, water supply tanks and even railways. Concrete plays an important role in promoting social development in countries. However, it's worth mentioning that the concrete industry consumes a large amount of natural materials including cement and aggregate. Therefore, there is an urgent need to find and present an appropriate alternative to natural materials [1]. According to Sunny et al. a well-known alternative for aggregate is the use of construction waste for the production of recycled materials [2].

1.1. Silica fume

Silica fume is a byproduct of industrial silicon. Silica fume is a very soft material with extremely small particles. It has a non-crystalline material with a diameter of about 0.1 to 0.2 microns (about 100 times smaller than cement), with a specific gravity of 2.2 gr/cm^3 and a specific surface area of approximately 20 m^2/gr and the apparent density is 200 kg/m^3 [3].

The use of silica fume with different percentages of replacement, improves mechanical properties and durability of concrete because of their high density and low permeability [4-5]. Valipour et al. (2013) replaced 5, 10 and 15 percent of cement by silica fume for mix with w/c=0.4. They investigated effect of chloride penetration in concrete for the age of 28 days based on the RCMT method. Their results showed that the replacement of 5, 10 and 15 percent of cement with silica fume, reduced chloride penetration in concrete 74, 81 and 73 percent, respectively [6]. Stack et al. (2013) also replaced 10 and 20 percent of cement with silica fume in their research, and measured the chloride in concrete for 90 days by the RCMT method for a mix with w/c ratio of 0.32. Their research showed that the replacement of 5% and 10% of cement with silica fume reduced the chloride penetration in concrete 72%. [7]. Gupta et al. (2016) replaced 5 and 10% cement with silica fume and measured the chloride permeation in concrete for a 28-day age using the RCMT for a mix with water to cement ratio of 0.35. Their results showed that the replacement of 5% and 10% of cement with silica fume reduced the chloride penetration in concrete 12% and 82%, respectively. [8]

Rafia used concrete mixes containing 10, 15 and 20% silica fume instead of cement and concluded that 15% replacement of silica fume with cement had the highest strength and 20% silica fume had the least strength. According to his experiments, the optimal percentage of silica fume replacement was 15%, and with increasing the replacement, resistance was reduced [4]. Kirti used 10, 15, 20 and 25% silica fume as a cement replacement and reported 29, 40, 59 and 44 increase of compressive strength, respectively [5]. Patil et al. also used concrete containing 5, 10 and 15% of silica fume and found that 15% of silica fume is the optimal percentage of cement replacement. According to their investigations, in concrete containing 5, 10 and 15% silica fume, 12, 27 and 34% increase was observed in compressive strength and, 12, 13 and 16% increase in tensile strength, respectively [9]. Iskissi investigated effect of silica fume on compressive strength and concluded that adding 5 to 15 percent of silica fume as a cement replacement in concrete would increase the strength of concrete 20% to 100% [10]. By investigating the different percentages of silica fume with cement, the researchers concluded that this material is very effective to increase mechanical properties and durability of concrete [9].

1.2. Recycled asphalt aggregates

Environmental control is a growing problem in the construction industry. Natural resources are used extensively in every day. Therefore, construction activities have a significant environmental impacts on the environmental cycle. On the other hand, waste management has not been successful in the construction industry, which has made construction waste a major threat to the environment. Therefore, it is thought to be an effective tool to reduce the effects of landfill and improve waste management to improve this challenge is reusing and recycling of construction materials [9-11].

Recycled asphalt chips, which are waste from the reconstruction and processing of asphalt pavements, constitute a large part of the waste material. [12]. Asphalt has a key feature that can be recycled 100% without reducing its capabilities, and currently has the largest recycling capacity in the world. Many other building materials can claim to be recovered, but most of them have shown a reduced ability and properties [13].

Hand and colleagues reported that the concrete's strength to recycled asphalt is systematically reduced, regardless of whether aggregate is a coarse-grained or fine-grained recycled asphalt. And this drop in strength is probably the result of a poor bond between asphalt and cement mortar [2]. By replacing of 20% and 50% of recycled aggregates in the concrete, they concluded that the use of recycled aggregates with low replacement rates in concrete is possible. They reported 14% and 16% decrease in compressive strength [14]. Tebesh and colleagues examined several recycling effects on the strength of concrete containing recycled asphalt aggregate, and it was found that the tensile strength of concrete produced with recycled concrete was lower than that of natural-made concrete [12].

The purpose of this study was to investigate the effect of silica fume and recycled fine asphalt as a replacement of cement and aggregate, respectively, on the durability and mechanical properties of concrete. For this purpose, the experimental study developed to compare mechanical properties (compressive and tensile strength) and durability (accelerated penetration of chlorine ion and electrical resistance) of concrete.

2. Experimental Study

The following section discusses details of materials, mixture proportions, specimen designs, test set up, and test procedures.

2.1. Materials

2.2. Cementitious Materials

Type I Portland cement and silica fume in accordance with ASTM C150 [15] and ASTM C1240 [16] were used for this study. The chemical and physical properties of these cementitious materials are shown in Table 1.

2.3. Aggregate

Aggregate for this study consisted of natural river sand (Homaei Quarry, Qom), crushed gravel (Venarch Quarry, Qom). Table 2 shows physical properties of aggregates.

Recycled asphalt aggregate: Recycled asphalt waste from the city of Qom (20 years old) without processing was used as a fine aggregate replacement. The characteristics of recycled aggregates are presented in Table 2. The water used in this research is drinking water in Qom. The superplasticizer was used for the concrete mixtures with silica fume to achieve the necessary workability.

Table 1. Physical and chemical properties of cement and silica fume

Physical and chemical component (%)	Cement	Silica fume
SiO_2	20.66	93.6
AL_2O_3	4.69	1.32
Fe_2O_3	4.15	0.87
CaO	63.80	0.49
SO_3	2.33	0.1
MgO	1.32	0.97
Na_2O_3	0.36	0.31
K_2O	0.63	1.01
LOi	2.20	-
Special Weight (Kg/m^3)	3100	200
Blaine (g/cm^2)	3080	-

Table 2. Physical properties of aggregates

Type of aggregate	Water absorption percentage	Saturated density with dry surface (kg/m^3)	Maximum diameter of aggregate (mm)
Natural sand	2.19	2467	4.75
Natural gravel	1	2700	19
Recycled sand	3.62	2278	4.75

2.4. Mixture proportions

The design of concrete mixes tested in this study was in accordance with ACI 211.1-91 [17]. Table 3 summarizes the three mix and fresh properties of the mixes designs S0R0 as a control mix, S6R10 and S6R15 means mix with 6% silica fume and 10% and 15% recycled asphalt as a cement and aggregate replacement, respectively.

Table 3. Mix proportions

Concrete mixes	Cement (Kg/m^3)	Water (Kg/m^3)	Silica fume (Kg/m^3)	Super lubricant (Kg/m^3)	Fine aggregates (Kg/m^3)	Coarse aggregates (Kg/m^3)	Recycled Fine aggregates (Kg/m^3)	Slump (mm)	Specific gravity for fresh concrete (Kg/m^3)
S0R0	425	205	0	0	1036	690	0	91	2356
S6R10	400	213	26	0.9	914	679	100	100	2330

3. Test Results Analysis

The following section discusses about mechanical properties as well as durability of mixtures.

3.1. Mechanical Properties

In terms of mechanical properties, compressive and splitting tensile strength are discussed in the following section.

3.1.1. Compressive strength

The compressive strength test were carried out in accordance with ASTM C39 [18], at 7, 28 and 56 days. Figure 1 shows test results of compressive strength. Results of this study show that mixes with both silica fume and recycled asphalt had higher compressive strength (except S6R15 at 28 and 56 days). S6R10 showed 44%, 14%, 7% increase in compressive strength compared to control mix at 7, 28 and 56 days, respectively. S6R15 showed 19% increase at 7 day, but 5% and 3% decrease at 28 and 56 days test results.

The addition of 6% silica fume to aggregates containing recovered asphalt, which improves the resistance of concrete samples. The addition of this pozzolanic material contributes to the growth of the resistance of all designs to the sample of concrete, which makes the use of recycled aggregate economically justifiable and more applicable to the structural part.

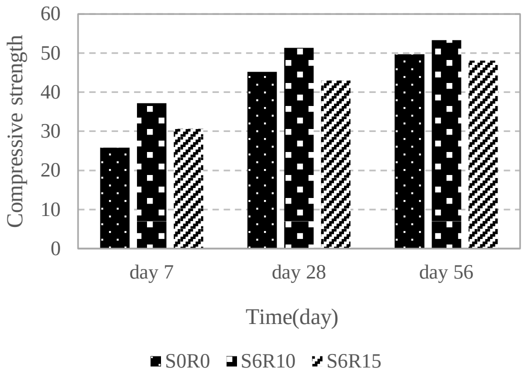

Figure 1. Compressive strength

3.1.2. Tensile Splitting Strength

Tensile splitting strength test were based on ASTM C496 [19] and the results of the tests are shown in Fig. 2 at the age of 7, 28 and 56 days.

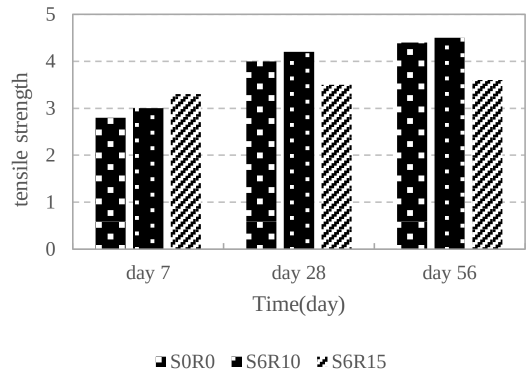

Figure 2.Splitting tensile strength

Similar trend was observed in tensile splitting strength. Figure 2 shows S0R10 had higher tensile strength compared to control mix, 7%, 5% and 3% at 7, 28 and 56 days, respectively. S6R15 showed 18% increase at 7 day, but 13% and 18% decrease at 28 and 56 days.

3.2. Durability

In the following sections, electrical resistivity and chloride ion penetration tests were performed to evaluate durability of mixtures.

3.2.1. Electrical resistivity of concrete

In this study, an electrical resistance test was carried out on cylindrical samples (100 × 200 mm) at the age of 7, 14, 28 and 56 days, and the results are presented in Table 4.

Table 4. Results of electrical resistance test at different ages

Concrete mixes	Electric resistance at different ages (KΩcm)			
	7 days	14 days	28 days	56 days
S0R0	7	7.5	8.1	9
S6R10	6.1	13.4	27.4	38.6
S6R15	6.1	15.4	32.7	39.8

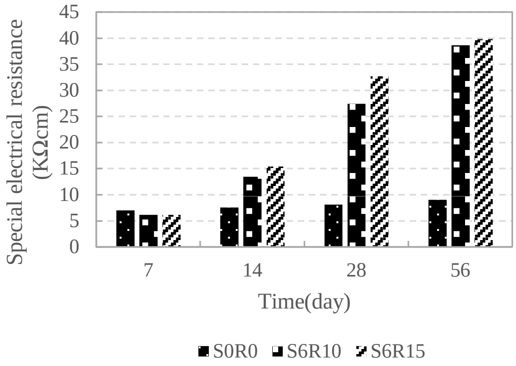

Figure 3. Electric Resistivity of Concrete Mixes

As shown in Fig. 3, for three-component concrete containing 15% recycled asphalt aggregates, at all ages, increased electrical resistance due to the application of 6% silica fume was very significant. This concrete mixture increased by 19% and 3%, respectively, to S6R10 concrete at the age of 28 and 56 days, and compared to the S0R0 control concrete, it increased 4 times the electrical resistance.

3.2.2. Rapid Chloride Migration Test (RCMT)

The RCMT test was based on AASHTO TP 64-03 [20] and NT-BUILD492 [21] to measure the chloride ion penetration depth. The higher level of chloride ion penetration means lower durability of concrete. The RCMT tests were carried out at 28 and 56 days. As shown in Figure 4, S6R10 showed 3 and 4 times less penetration compared to control mix respectively on days 28 and 56 days. The RCMT test results for concrete mixes of different ages are presented in Table 5.

Table 5. Results of the chlorine ion penetration test (RCMT)

Concrete mixes	The rate of chlorine ion penetration in concrete ($10^{-12}m^3/s$)	
	28 days	56 days
S0R0	17.9	15
S6R10	6.4	4.1

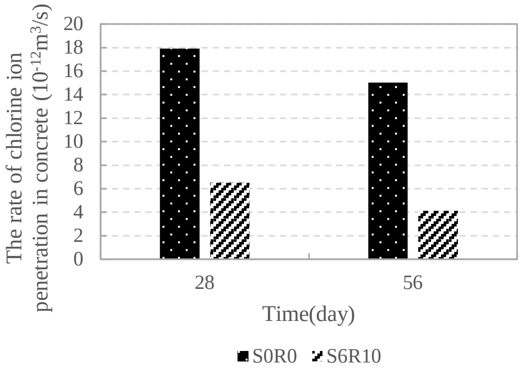

Figure 4. The RCMT test results

Comment [M1]:

According to the above figure, the addition of 6% silica fume to concrete containing 10% recycled asphalt aggregate has had a significant impact on the reduction of chloride ion penetration. So that S6R10 concrete at the age of 28 and 56 days reduced the penetration of the S0R10 concrete by 64% and 72%, respectively. Results of this study confirms the effectiveness of silica fume on durability of RAP.

Conclusions

Based on test results of this study the following conclusions can be summarized.

1. Adding silica fume compensate inferior mechanical properties of recycled asphalt mix.
2. Using 10% recycled asphalt and 6% silica fume, showed higher compressive and tensile splitting strength compared to the control mix.
3. Using 15% recycled asphalt even with 6% silica fume showed 4% and 13% decrease in compressive strength and tensile splitting strength of concrete, respectively.
4. Mixes with 10% recycled asphalt and 6% silica fume showed and 4 times lower chloride ion penetration compared to control concrete.
5. In term of electrical resistivity of the mixes, the three-component S6R10 and S6R15 concretes compared to the control mix showed four times higher electrical resistivity.

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