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The Experimental Assessment of the Effect of Paper Waste Ash and Silica Fume on Improvement of Concrete Behavior

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Abstract

In this research, the results of experiments achieved on some mixtures of concrete comprising silica fume and paper waste ash as a substitute to Portland cement have been presented. The Portland cement was substituted with various ratios (namely 0, 2.5, 5, 7.5 and 10 percent by weight of cement) of both silica fume and paper waste ash. In all mixtures of concrete, the ratio of cement to water was regarded to be persistent (with an amount of 0.4). The experiments' findings demonstrate that the 28-days tensile, flexural and compressive strengths of concrete specimens of this study are more than the results obtained from the relationship given by both the American (ACI) and Concrete Code of Iran for normal concrete due to adding paper waste ash and Silica fume to some mixes, which indicates their positive effect in increasing mechanical properties. According to our findings, empirical relationships have been proposed for the relationship of indirect tensile strength and 28-days concrete's compressive strength, flexural tensile strength and concrete's 28-days compressive strength, compressive strength and specific weight, the estimation of elasticity modulus in regard to specific weight of mix designs, the growing movement of compressive strength of normal concretes by increase in the amount of cement. So that these equations can be useful to predict the behavior of the concrete containing the Silica fume and paper waste ash. The electrical resistance of mix with 10% paper waste ash was a little lower, compared to the witness concrete mix at all ages.

Keywords: *paper wastes, silica fume, strength, concrete permeability, modulus of elasticity*

1. Introduction

Increasing the generation of various types of wastes in different quantities and qualities become popular. Consequently, the importance of controlling and protecting the environmental health of human beings in urban communities and the necessity of increasing the level of systematic productivity in all stages of waste management have led to use new management systems for solid wastes to develop the effective plans for collection, transportation and processing systems according to the scientific and practical strategies. The idea of using paper wastes in concrete for the purpose of reducing environmental pollution and the application of silica fume to improve the properties of concrete is employed in the building industry. The purpose of this research is to present the necessary bases for providing an appropriate and economical plan to produce concrete with residual additives, with the intention of providing a foundation for elevating the safety and economy of structures. Recent studies show that some of paper waste ash and cardboard industry trashes can be exploited as raw material in the industry of building, Seyyed Alipour *et al.* (2013), Carmen *et al*. (2012), Mucahit and Sedat (2010), Mohammad *et al.* (2010), BS 6073-2 (2008). Produced by paper recycling industry, Paper sludge ash (PSA) is a type of waste generated after waste paper sludge, which is a consequence of the de-inking and re-pulping of paper, is dewatered and burnt to decrease the volume of waste and generate energy. Normally applying fluidized bed combustion at ~850 – 1,100°C, the procedure of combustion is controlled in the EU. According to reports, ~125,000 tons/year of PSA are generated in the UK, 30% of which is naturally delivered to landfill and 70% is exploited in low value areas (e.g., land spreading). Despite the dependence of variation of PSA's properties and composition on combustion conditions and the feedstock (dewatered waste paper sludge delivered to the fluidized bed combustion unit), this compound has a high level of alkaline (pH = 12–13) and mostly includes oxides of aluminum, silicon, and calcium. According to Hong *et al.* (2015), evaluation of the advantageous re-application of PSA has been encouraged by the effort towards reduced landfill and efficiency of resource.

Previous researches related to paper ash waste were conducted

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on hydraulic characteristics, reactivity and the possible application of them as cement materials. For instance, Pera and Amrouz (1998), demonstrated that paper waste ash can be converted to sticky lime materials at temperatures between 700 and 750°C which was confirmed by subsequent studies. The impacts of reprocessed cardboard factory trashes on the properties of non-load bearing concrete were investigated in a laboratory study. Two types of cardboard factory wastes were used: type I containing cardboard and sand and type II containing nylon, expanded polystyrene (EPS) and cardboard, which constitute the highest volume of waste, Bai *et al.* (2003), Banfill and Frias. (2007), Frias *et al*. (2008), Segui *et al.* (2012). Hong *et al.* (2015), evaluated the hydrophobic concretes containing paper waste ash in a laboratory study. Aylesford Newsprint Ltd delivered the applied paper sludge ash (PSA), which is a foremost newsprint producer in the UK, generating 400,000 tons of recycled newsprint from 500,000 tons of waste paper fiber every year. This leads to the production of approximately 70,000 tons of PSA in a year. As demonstrated by X-ray fluorescence spectroscopy, the PSA is mostly calcium aluminosilicate with a combination of 0.1% SrO, 0.4% K_2O, 0.1% P_2O_5, 61.2% CaO, 0.9% Fe_2O_3, 0.2% SO_3, 21.2% SiO_2, 0.3% TiO_2, 2.8% MgO, and 12.6% Al_2O_3. Mayenite ($Ca1_2Al_4O_{33}$), gehlenite ($Ca_2Al(AlSiO_7)$), lime (CaO), and calcite ($CaCO_3$) are the key crystalline phases determined by XRD. In addition to encompassing moveable balls of smaller particles, PSA is extremely absorbent, as demonstrated by scanning electron microscopy. For this purpose, they put provided paper waste ash from paper mills in powder form and evaluated their effect on the performance, strength and transitional properties of concrete including water absorption, penetrability and electrical resistance of concrete. The studied specimens had a cement/water ratio of 0.38 and were maintained at a temperature of 50°C and were tested after 28 days. Ahmad *et al.* (2013) examined laboratory studies to investigate the probability of applying paper waste ash in concrete. To this end, they used 5, 10, 15 and 25% paper waste ash by weight of cement as an alternative to a part of cement in concrete. They conducted water absorption, tensile strength, dry density, and compressive strength tests on specimens at the age of 28 days and compared them with ordinary concrete. Their results showed that the use of 5% of paper waste ash by weight of cement and particles smaller than 90 μm can be effective without reducing the workability of concrete. According to a study by Spathi (2013), we can change PSA into a super-hydrophobic powder with the application of a cost-effective and easy procedure that includes dry milling with stearic acid, acting as a surface functionalizing agent. Succeeding paper has enhanced the quantity and type of surface functionalizing agent exploiting a variety of milling circumstances and fatty acids (Young, 2013), and optimum procedure shaped a super-hydrophobic powder with a water contact angle of 153° (Spathi *et al*., 2015). The micro-particulate texture prompted by milling and the generation of calcium stearate self-assembling monolayer coating the fractured PSA surfaces create hydrophobicity. Considering the increasing use of recycled concrete and the urgent need to know the full specifications of this type of concrete and the studies in this field, the topic of waste additives is a novel one which this research will be based on it. Less attention has been paid to the application of composition of paper waste ash with Silica fume in concrete.

This research investigated the effect of adding paper waste ash on the level of absorption of water, permeability, electrical resistance and mechanical properties of concrete. The effect of adding paper waste ash along with silica fume on physical, chemical and mechanical features (of concrete) was also studied experimentally. One of the most important practical purposes of this research is to achieve a concrete with low water absorption and appropriate strength to increase the durability of concrete in hydraulic structures.

2. Methodology

The Methodology of this research is experimental. In this research, the compressive strength and permeability of concrete were investigated on 15 cm cubic specimens. 30 cm × 15 cm cylindrical specimens (15 cm in cross-sectional diameter and 30 cm in height) and 120 cm × 20 cm × 20 cm beams (120 cm in span length) were used in indirect tensile strength (Brazilian) and flexural tests of concrete respectively. In order to increase the quality and reduce the error, at first, the aggregate grading and testing of materials are repeated 3 times, and the mix design is presented after the elimination of errors and achieving acceptable answers. Flexural tensile strength, indirect tensile strength, compressive strength, determination of elasticity modulus and permeability coefficients and electrical resistance are performed for all concrete specimens at different ages. The experiments have been performed on 25 concrete mixtures encompassing silica fume and paper waste ash as a substitute to Portland cement. The Portland cement was substituted by various ratios (namely 0, 2.5, 5, 7.5 and 10 percent by weight of cement) of both silica fume and paper waste ash. On the other hand, obtained from the mentioned experiments, equations for concretes containing paper waste ash and Silica fume are presented based on existing equations, so that the behavior of concretes containing paper waste ash and Silica fume can be predicted.

2.1 Materials

Grading is one of the most important characteristics of aggregates. Grading is specified by the aggregates size separation using sieves and based on the size range of aggregates. Aggregate grading test is performed using a laboratory "sieve shaker" machine. The sieves should meet the requirements of the CGSB

Table 1. Features of Aggregate in Concrete Mixtures

Properties	Coarse aggregates	Fine aggregates
Relative density SSD	2.83	2.67
Apparent relative density	2.91	2.78
Relative density oven-dry	2.79	2.61
Water absorption (%)	1.29	2.44

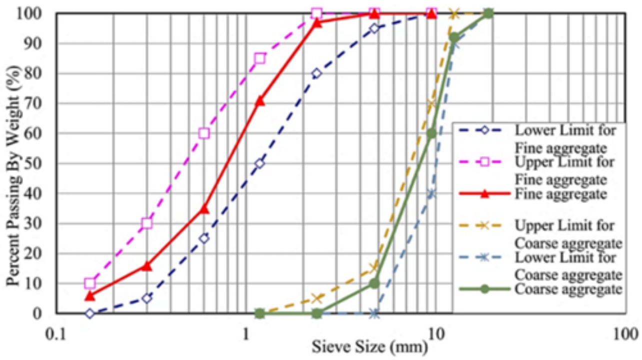


Fig. 1. Fine and Coarse Aggregates' Distribution of Size

(Canadian General Standards Board) for woven wire sieves Chen *et al*. (1982). Satisfactory aggregate has fineness modulus of 2.7. Coarse aggregates had nominal maximum aggregate with a size of 12.5 mm. The physical characteristics of the aggregate are shown in Table 1. In addition, Fig. 1 shows the coarse and fine aggregates' gradation distributions.

2.1.1 Paper Waste Ash

The remaining trash must be de-watered before the procedure because of the paper sludge's high water content (40 – 70%), which might cause problems in the fields of management, burning and delivery. The composition and amount the of paper sludge waste (PSW) is different with a great dependence on the processing techniques, the raw materials, the percentage and characteristics of the recycled paper and the grade of paper produced Monte *et al*. (2009). Typically applied as loadings in the production of paper, inorganic materials (mainly, kaolinite and limestone), and organic material (non-recovered cellulose) are the compounds of paper waste, which are its feature composition. Table 2 contains an example of mineralogical and chemical composition of this type of paper waste. Iran paper manufacturer Shomal, which applies 100% recycled paper as the raw material, provides the characterization of this dry material.

Table 2. Chemical and Physical Composition of Paper Waste Ash and Ordinary Portland Cement

Chemical components		Chemical composition (% w/w)	
Chemical constituents	Empirical formula	WSA	OPC
Calcium oxide (lime)	CaO	25.43	61.17
Silicon dioxide (silica)	SiO_2	10.79	20.8
Aluminium trioxide	Al_2O_3	6.83	4.2
Ferric trioxide	Fe_2O_3	0.46	4.9
Magnesium oxide	MgO	0.87	0.6
Sulphate	SO_3	0.32	1.85
Potassium oxide	K_2O	0.22	0.6
Sodium oxide	Na_2O	0.15	0.1
Loss of ignition	LOI	54.34	1.6
Bulk density (g/cm^3)	-	-	3.11
Particle density (g/cm^3)	-	-	1.65

With a sum exceeding 43% of the whole mass, principal oxides are Al_2O_3, SiO_2, and CaO. Because organic material is present and calcite undergoes the de-carbonation procedure, high loss on ignition (LOI) in these waste products (approximately 54%) must be emphasized. Depending on the origin and type of paper, the level of recycled paper applied as the raw material, the type of process, and loading, there is a wide range of these values used only for guidance (Bin Mohd Sani, 2011).

2.1.2 Ordinary Portland Cement

The physical and chemical features of the ordinary Portland cement (OPC) were determined by comparing it with that waste paper sludge ash (WSA). As an outcome of testing, it demonstrates that that paper waste ash is comparable to the chemical features of ordinary Portland cement. The physical and chemical characteristics of the ordinary Portland cement have been shown in Table 2.

2.1.3 Super-Plasticizer

Superplasticizer reduces the surface tension of water and greatly increases the consistency. In this research, GLENIUM 110P, the product of O-BASF has been used which is a polycarboxylic ether based superplasticizer. According to the manufacturer's recommendation, the appropriate amount of this superplasticizer in concrete mix is between 0. 5% and 2.5%, by weight of cement. In this research, we used 2% for all mixes constantly where required. Also, to achieve the maximum attainability, it is suggested to add this super-plasticizer to the concrete mix after the addition of the first 50% to 70% of the mixing water as a solution in the remaining mixing water of concrete mix and continue the mixing operation for at least 60 seconds after adding.

2.2 Mix Proportion

Concrete mix design specifies the ratio of concrete components (cement, water, sand, gravel and additives) to achieve specific properties. The standard of ACI 211.1 was applied to project concrete mixture sizes of recycled concrete aggregate (RAC) with cement/water (w/c) ratio of 0.4. The advantage of using this method is that in the final stages of design, by constructing a laboratory specimen and performing some simple tests on it, the results of previous steps are corrected and the effect of special properties of regional materials are properly involved in design results. For each mix design, 45 cubic and cylindrical specimens are made. Compressive strength, indirect tensile strength, abrasion resistance, water permeability, water absorption and impact tests are performed for two specimens of each mix design at the age of 7, 28 and 90 days. One sample of each test, so-called control sample, is maintained for future testing in the case of large differences in the results of tested standard samples (scattered results) and also to create a strength-age association for the concrete under job situations as a control for construction operations or the start of the work. The concrete mix design results is shown in Table 3 presenting volumetric ratios but it was

Table 3. Mix Proportions (by Weight of Cement)

Mix design No.	Cement	Sand	Gravel	Water cement ratio	Paper waste ash (%)	Silica fume (%)
1	1	1.51	2.93	0.4	0	0
2	1	1.51	2.93	0.4	0	2.5
3	1	1.51	2.93	0.4	0	5
4	1	1.51	2.93	0.4	0	7.5
5	1	1.51	2.93	0.4	0	10
6	1	1.51	2.93	0.4	2.5	0
7	1	1.51	2.93	0.4	2.5	2.5
8	1	1.51	2.93	0.4	2.5	5
9	1	1.51	2.93	0.4	2.5	7.5
10	1	1.51	2.93	0.4	2.5	10
11	1	1.51	2.93	0.4	5	0
12	1	1.51	2.93	0.4	5	2.5
13	1	1.51	2.93	0.4	5	5
14	1	1.51	2.93	0.4	5	7.5
15	1	1.51	2.93	0.4	5	10
16	1	1.51	2.93	0.4	7.5	0
17	1	1.51	2.93	0.4	7.5	2.5
18	1	1.51	2.93	0.4	7.5	5
19	1	1.51	2.93	0.4	7.5	7.5
20	1	1.51	2.93	0.4	7.5	10
21	1	1.51	2.93	0.4	10	0
22	1	1.51	2.93	0.4	10	2.5
23	1	1.51	2.93	0.4	10	5
24	1	1.51	2.93	0.4	10	7.5
25	1	1.51	2.93	0.4	10	10

Table 4. The First Mixture Design Proportions

Gravel (Kg/m^3)	Sand (Kg/m^3)	Cement (Kg/m^3)	Water (Lit/m^3)	(W/C)
1,172	604	400	160	0.4

also been conducted with weight method and the result of first mix design is shown in Table 4. It should be noted that additives are added to the mix designs based on the percentage of cement weight. The substances applied to generate the 25 concrete mixtures included:

1. Crushed gravel, produced by Beton Kaco;
2. River sand, created by Beton Kaco;
3. Waste paper sludge ash, generated by Gillan;
4. Silica fume, Iran Ferroalloy Industries Co;
5. Type I cement, produced by Urmia Cement Co;
6. Polycarboxylate-ether superplasticizer, supplied by Fabir Co;
7. Tap water

3. Testing Methodology

3.1 Test of Compressive Strength

The compressive strength test of concrete or mortar is performed by locating a cube or cylinder specimen under compressive load which is expressed in terms of force per unit of cross section. This test has been performed based on BS EN 12390-1 (2000) standard. Totally, the compressive strength test carried out on 25 mix designs at the age of 7, 28 and 90 days. The force is read and recorded from the jack monitor after it remains fixed, and the compressive strength of specimen is obtained from dividing this force by the cross section.

3.2 Tensile Strength Test

Indirect tensile strength (Brazilian) test was performed according to CSA/ACI (A23.2-13C) standard. The tensile strength of specimens is calculated from the following equation according to ASTM C496 standard. ASTM C496 / C496M (2017).

$$T = \frac{2P}{\pi LD} \tag{1}$$

Where, D is diameter of specimen (mm), T is Tensile strength (MPa), L is length of specimen (mm), and P is maximum applied load on specimens by machine (KN).

3.3 Flexural Tensile Strength Test

Flexural tensile strength test is carried out according to BS EN 12390–5:2000 standard. Place a simple concrete beam on two supports and place two point loads at $\frac{L}{3}$ distance from the supports on it and increase the load P until the cracking of beam. The tensile strength of specimen is obtained by using the flexural tensile strength relationship. The flexural tensile strength is shown by f_r.

$$f_r = \frac{2PL}{bh^2} \tag{2}$$

Where: h, M_{max} and b are beam height, maximum bending moment and beam width respectively.

3.4 Determination of Elastic Modulus

In this test, the 15 × 30 cm, cylindrical specimen is located vertically between two metal strips of jack with a vertical spacing of 15 cm where a strain gauge is placed and then the required force in the linear range of concrete is calculated. Then the concrete crusher machine is fixed on that force. After applying the force, the number of strain gauge rounds is multiplied by 0.002 and the change of length is obtained in millimeters (Figs. 2(a) and 2(b)). The calculation method for elasticity modulus is as follows:

1. Determination of the linear stress range of concrete (In this research, it was considered that $F_c = 0.25f_c'$). F_c must be less than $0.5f_c'$.
2. Determination of the applied force on cylindrical specimen
3. Determination of strain

$$\varepsilon = \frac{x \times 0.002}{150} \tag{3}$$

4. Determination of elasticity modulus

$$E = \frac{F_c}{\varepsilon} \tag{4}$$

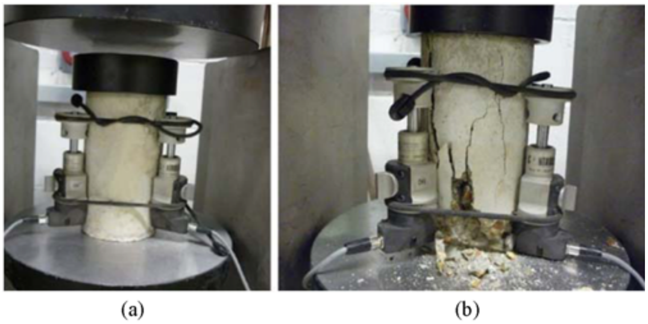


Fig. 2. Elasticity Modulus Testing Device: (a) Cylindrical Compression Test Set Up, (b) Concrete Sample after the Test

In the above equations:

Fc: Stress in linear range of concrete, f_c': Compressive strength of concrete, A: Cross section of specimen, E: Elasticity modulus of concrete and x: Gauge reading.

3.5 Electrical Resistance

One of the nondestructive tests on concrete was determination of electrical resistance test to specify the electrical resistance. This test gives the designers and experts the ability to decide on retrofit and reinforcement plans or operation validation by providing the electrical resistance of concrete. The ISCRM (Impedance Spectroscopy Concrete resistance Meter) electrical resistance measuring device. Choi *et al.* (2018), has been used in this study. The average of three readings for each mix has been reported. The test method was as follows: we place two brass or copper plates in full contact with two opposite surfaces of concrete and obtain the electrical resistance by a special ohmmeter with high-accuracy and high-speed estimation of resistance in a manufacturing space, including contact resistance measurements. It is factory calibrated from 20.000 ohm to 500.00 kohm. However, this electrical resistance must be reported according to dimensional effects. This means that the specific electrical resistance must be determined and reported, so that it can be compared with other concretes. For this purpose, the following equation is used:

$$\rho_c = \frac{RA}{L} \quad (5)$$

Where:

A = The surface of specimen (The contact surface of brass plate with concrete)

L = The distance between two contact plates (Length of specimen)

R = The electrical resistance that have read from the machine

ρ_c = Precise electrical resistance of concrete (Ω.m)

As we know, concrete with a higher electrical resistance will be more durable and more favorable. For proper connection between the brass plate and concrete, a thin layer of relatively loose cement paste is usually used. The plate was bonded to the cement paste and concrete surface under pressure and the measurement was done. In this test, at first, a cement mortar (not loose and not stiff) was rubbed on two opposite surfaces of concrete. Then one of the brass plates was placed on the table and the concrete specimen was placed on it. The second brass plate was placed on the opposite surface of specimen. Now, we can read the resistance. The device used in determination of electrical resistance test was shown in Fig. 3.

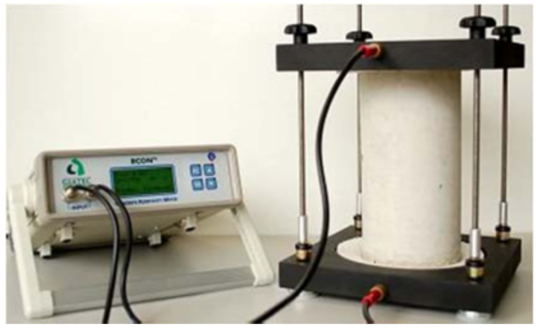


Fig. 3. Electrical Resistance Measurement Testing Device

4. Results and Discussions

The recent research assesses the impacts of various levels of paper waste ash and silica fume on the durability and mechanical features of concrete. In whole, 943 concrete specimens were generated in 25 various test groups, for which the parameters of

Table 5. The Findings of the Experiments

No. Mixes	Specific weight (Kg/m^3)	Average of strength in 28 days (Kg/cm^2)		
		Compressive	Tensile	Flexural tensile
1	2400.3	205	29.43	36.22
2	2369.25	194	28.63	35.24
3	2295	174	27.11	33.37
4	2390.85	194	28.63	35.24
5	2354.4	186	28.03	34.50
6	2281.5	167	26.56	32.69
7	2366.55	187	28.11	34.59
8	2311.2	176	27.27	33.56
9	2261.25	156	25.67	31.60
10	2443.5	259	33.08	40.71
11	2436.75	246	32.24	39.68
12	2388.15	234	31.44	38.70
13	2419.2	239	31.78	39.11
14	2397.6	235	31.51	38.78
15	2327.4	228	31.04	38.20
16	2362.5	240	31.84	39.19
17	2357.1	235	31.51	38.78
18	2322	222	30.63	37.69
19	2490.75	345	38.18	46.99
20	2461.05	338	37.79	46.51
21	2444.85	330	37.34	45.96
22	2473.2	339	37.85	46.58
23	2430	328	37.23	45.82
24	2389.5	312	36.31	44.69
25	2413.8	321	36.83	45.33

tensile strength, modulus of elasticity, and compressive strength, specific weight, and the electrical resistance. The results of experiments indirect tensile strength and compressive strength of concrete, a flexural tensile strength in regard to the specific weight of mix designs, presented in Table 5.

4.1 Compressive Test Results

Concrete specimens (dried in the air) usually have a specific weight between 2,398 and 2,440 kg/m^3 at the ages of 7, 28 and 90 days. Following the breaking of the samples, it was observed that the concrete has a completely smooth surface with less porosity. Smooth surface reflects the hydrophobicity of concrete that repels water and has the waterproof property. There are various methods to change a consistent concrete mix to generate hydrophobic concrete, all of which include somehow filling the porous concrete mixture. Some of the most applied techniques are crystalline formations (with the highest level of application, such as the current research), small speck infusion, and polymer formation. So, it can be concluded that Silica fume can be applied as a suitable material instead of a percentage of cement to create a continuous texture and reduce porosity. Samples encompassing Silica fume have a better compressive and flexural strength, compared to the same specimens without Silica fume because of the removal of pores and it has chemical pozolanic reactions producing Calcium Silicate Hydrate. Fig. 4 demonstrates the changes in compressive strength of all specimens with 25 mix designs. According to the results shown in Fig. 8, the compressive strength ratio of 28 days to 90 days is between 0.67 and 0.81. The ratio of compressive strength to tensile strength of ordinary concrete is about 10. However, this ratio is between 13.55 and 17.79 in the selected and optimal concrete specimens in this research due to the proper indirect tensile strength of structural concrete. Also, it can be observed that in all mix designs, increase in specific weight increases the compressive strength proportionally.

Figure 5 illustrates the increasing trend of mean compressive strength with specific weight in all mix designs. Based on the findings obtained for specific weight and their analysis, it is evident that the specific weight of all mix designs is in good agreement with each other. However, there is less consistency in some mix designs such as mix design No. 10. The reason for this phenomenon may be the impossibility of sufficient compaction of mix designs with a high amount of paper waste. Figs. 5 and 6 show the increasing trend of compressive and indirect tensile

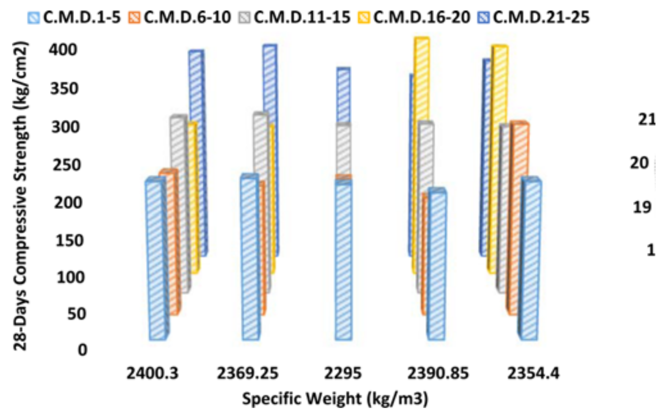


Fig. 5. Compressive Strength vs. Specific Weight in Mix

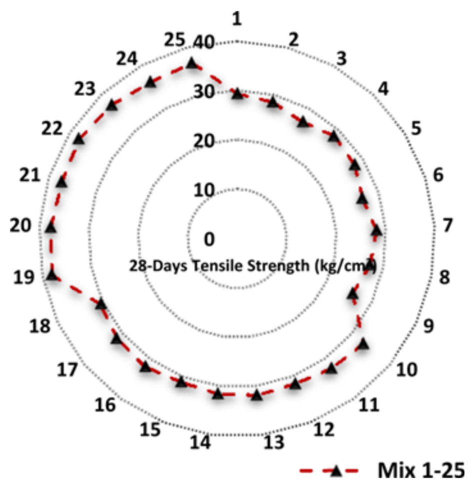


Fig. 6. Tensile Strength of Concrete Specimens in Mix

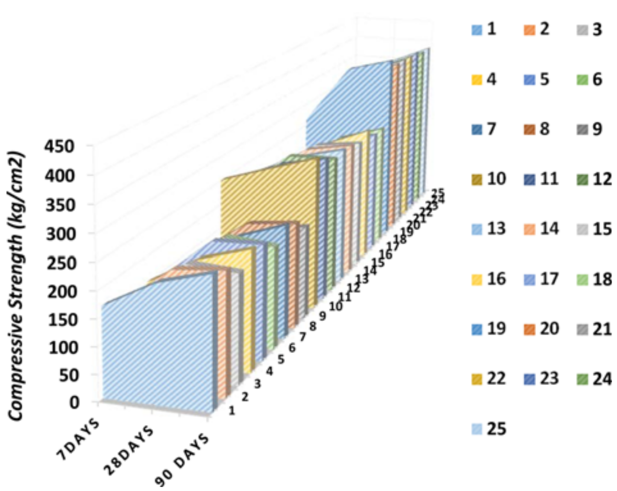


Fig. 4. Change in Compressive Strength of All Mix Designs

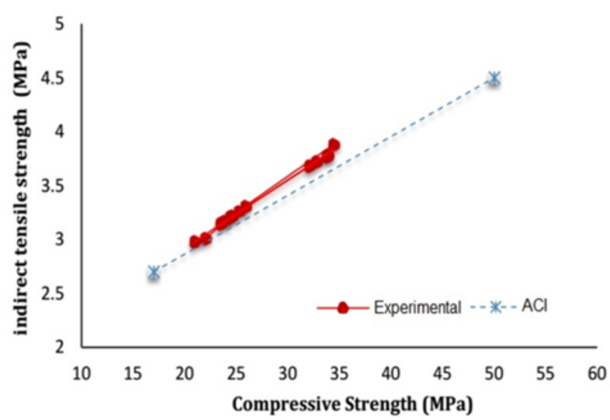


Fig. 7. The Relationship between Indirect Tensile Strength and 28-Days Compressive Strength of Concrete and the Comparison with ACI

strengths of concrete specimens respectively. The results show that increase in specific weight increases the tensile strength like compressive strength because of the relation between the tensile and compressive strength.

Figure 7 shows the association between indirect tensile strength and 28-days compressive strength of concrete. We also compared our findings to ACI standard.

Considering the obtained results and using the regression method, the following equation can be proposed to predict the indirect tensile strength according to 28-days compressive strength for mix designs containing Silica fume and paper waste additives in this study:

$$f_t = 0.612\sqrt{f_c'} \quad (6)$$

f_c' is 28-days compressive strength of cubic specimens of size 15 cm × 15 cm × 15 cm. This relationship results in higher indirect tensile strength compared to the proposed relationship by ACI ($f_t = 0.59\sqrt{f_c'}$) due to the use of Silica fume in all mix.

4.2 Tensile Test Results due to Flexural

The flexural tensile strength changes trend in all mix design is shown in Fig. 8.

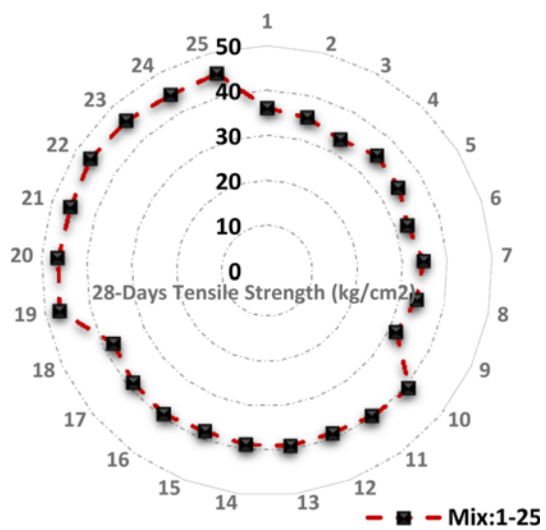


Fig. 8. Concrete Samples' Flexural Tensile Strength in Mix

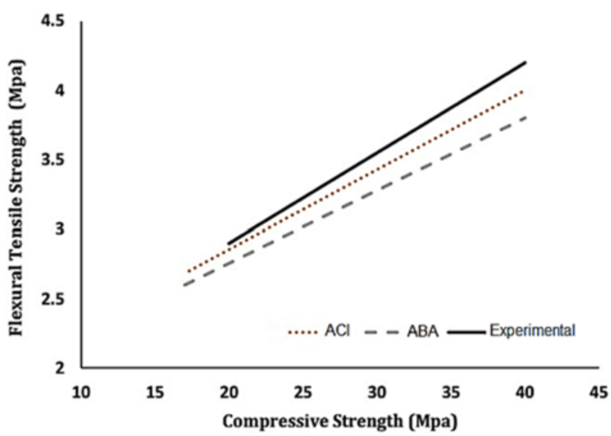


Fig. 9. Flexural Tensile Strength vs. Compressive Strength

Figure 9 demonstrates the correlation between flexural tensile strength and 28-days compressive strength of concrete. The results were also compared with ACI and Concrete Code of Iran, ACI 211.1. (2009) and Management and Planning Organization of I.R (1999).

Considering the obtained results and using the regression method, the following equation can be proposed to predict the flexural tensile strength according to 28-days compressive strength for lightweight structural concrete:

$$f_r = 0.633\sqrt{f_c'} \quad (7)$$

f_c' is 28-days compressive strength of cubic specimens of size 15 cm × 15 cm × 15 cm. This relationship results in higher flexural tensile strength compared to the proposed relationships by ACI ($f_t = 0.63\sqrt{f_c'}$) and Concrete Code of Iran ($f_t = 0.6\sqrt{f_c'}$). It was observed that the application of 10% Silica fume in all mix designs significantly increases the indirect tensile strength and flexural tensile strength.

4.3 The Association between Specific Weight and Compressive Strength

As it was mentioned before and according to the results, it was observed that the highest compressive strength is associated with the highest specific weight. Usually increase in concrete specific weight increases the compressive strength. This can be represented as an equation, which indicates a linear relationship between compressive strength and specific weight as shown in Fig. 10. One of the advantages of knowing the relationship between specific weight and compressive strength is that one of the assumptions for designing concrete structures is knowing the specific weight of concrete. Structural lightweight concrete can have different specific weights. So, having an equation that describes the relationship between specific weight and compressive strength for a lightweight mix design, the concrete specific weight could be guessed with an acceptable approximation according to the compressive strength considered in design of structure. Also, the relationship between 90-days and 28-days compressive strength of concrete might be shown by the linear equation of Fig. 11.

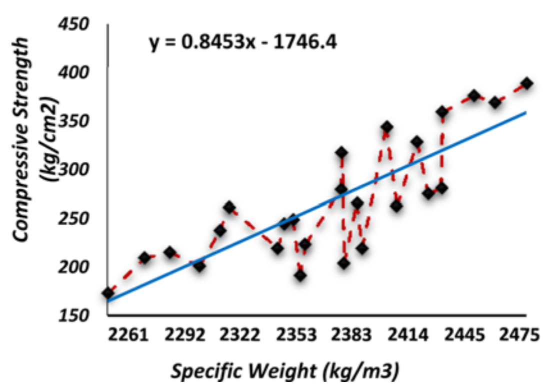


Fig. 10. Compressive Strength vs. Specific Weight

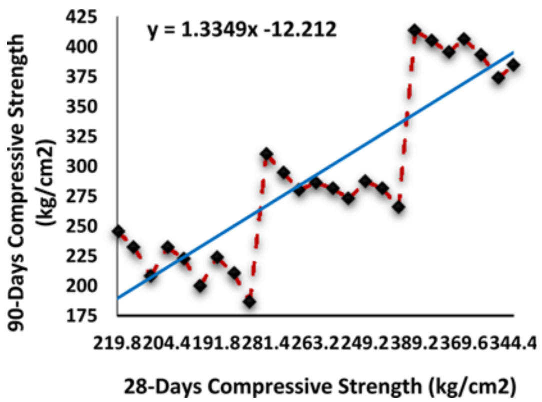


Fig. 11. Compressive Strength (90 vs. 28-days)

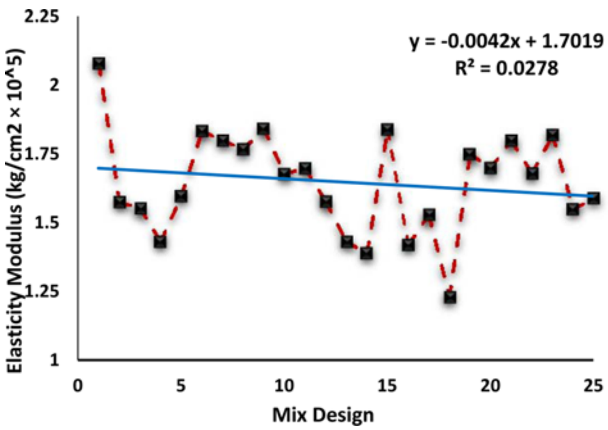


Fig. 12. Elasticity Modulus in Mix

4.4 Modulus of Elasticity

The results of this test are shown in Fig. 12. This figure shows that specimens made with 7.5% and 10% of paper waste have lower elasticity modulus compared to other specimens. Fig. 13 shows the estimation of elasticity modulus from specific weight of mix designs.

According to the ACI 318-83 Standard (2002) standard, the elasticity modulus of concrete can be calculated from Eq. (8) in terms of specific weight and compressive strength:

$$E = 43\rho^{1.5}\sqrt{f'} \times 10^{-6} \quad (8)$$

Where ρ is the specific weight (kg/m^3) and f' is the compressive strength of cylindrical sample (MPa). Considering this equation, it seems that the elasticity modulus of concrete containing silica fume is about 0 to 8% more than the predicted value in the standard.

The results of elasticity modulus test and Fig. 13 show that increase in concrete specific weight increases the elasticity modulus.

4.5 Cement Content

Investigations show that elevation in the level of cement upsurges the compressive strength proportionally. Table 6 shows the variation of cement content from 320 to 400 kg/m^3 in mix design with 0.4 of water cement ratio.

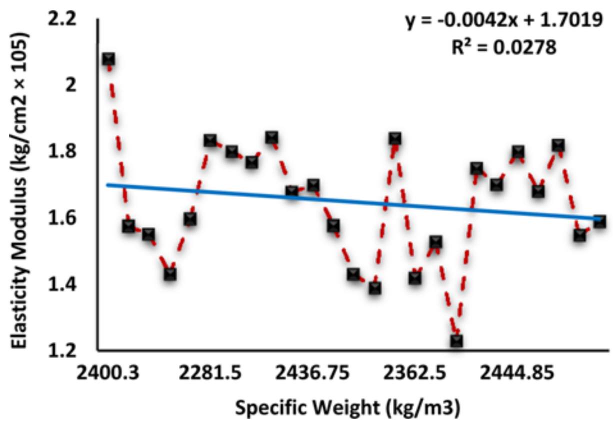


Fig. 13. Elasticity Modulus vs. Specific Weight in Mix

Table 6. Cement with Paper Waste and Silica Fume in All Mix

Mix design NO.	Paper waste ash (%)	Silica fume (%)	Cement (kg/m^3)	Paper waste ash (kg/m^3)	Silica fume (kg/m^3)
1	0	0	400	0	0
2	0	2.5	390	0	10
3	0	5	380	0	20
4	0	7.5	370	0	30
5	0	10	360	0	40
6	2.5	0	390	10	0
7	2.5	2.5	380	10	10
8	2.5	5	370	10	20
9	2.5	7.5	360	10	30
10	2.5	10	350	10	40
11	5	0	380	20	0
12	5	2.5	370	20	10
13	5	5	360	20	20
14	5	7.5	350	20	30
15	5	10	340	20	40
16	7.5	0	370	30	0
17	7.5	2.5	360	30	10
18	7.5	5	350	30	20
19	7.5	7.5	340	30	30
20	7.5	10	330	30	40
21	10	0	360	40	0
22	10	2.5	350	40	10
23	10	5	340	40	20
24	10	7.5	330	40	30
25	10	10	320	40	40

4.6 Electrical Resistance Test of Concrete Specimens

In this study, 25 mix designs are considered and compared with each other to assess the impact of silica fume and paper waste ash on concrete. According to the results of mix designs in Table 7, the 0 to 10% increase in silica fume increases the electrical resistance significantly. This considerable increase in electrical resistance is due to the higher density and higher mobility of ions in concrete containing silica fume. Generally, the electrical resistance of concrete has an increasing trend with

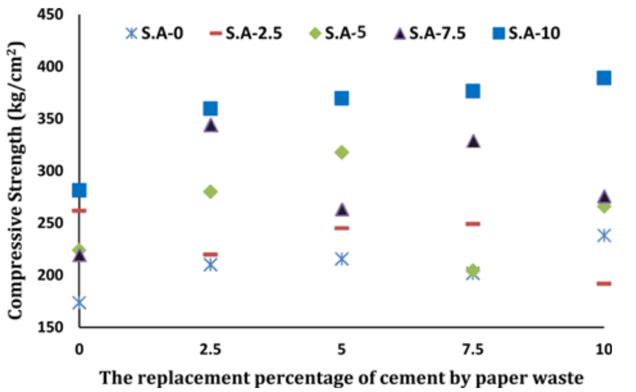


Fig. 14. The Association between Compressive Strength and the Replacement of Cement by Paper Waste and Silica Fume

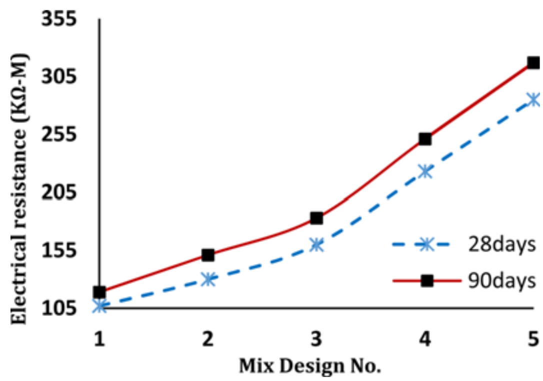


Fig. 15. Electrical Resistance (Mix Design 1 to 5)

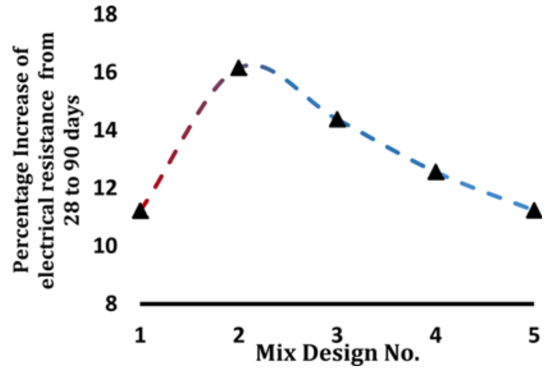


Fig. 16. Percentage Increase of Electrical Resistance of Specimens (Mix Design 1 to 5)

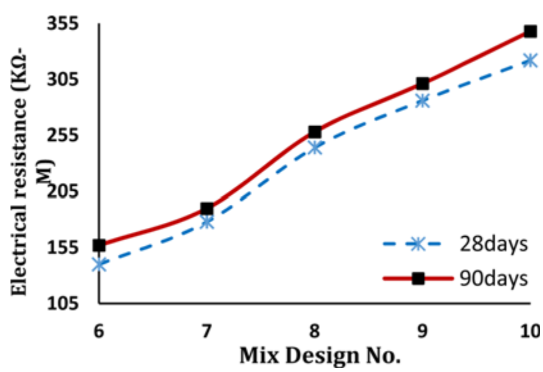


Fig. 17. Electrical Resistance (Mix Design 6 to 10)

Table 7. Electrical Resistance Test Results for 25 Mix Designs

Mix design No.	The average of 28-days (KΩ-M)	The average of 90-days (KΩ-M)	Increment percentage of electrical resistance from 28 to 90 days
1	107	119	11.21
2	130	151	16.15
3	160	183	14.38
4	223	251	12.56
5	285	317	11.23
6	140	157	12.14
7	178	190	6.74
8	244	258	5.74
9	286	301.3	5.35
10	322	348	8.07
11	147	156.3	6.33
12	172.8	189	9.37
13	235.7	254	7.76
14	246	271.5	10.37
15	318	337.6	6.16
16	146.6	159	8.46
17	183	196.3	7.27
18	273	255.9	7.97
19	254.3	275.1	8.18
20	324	349.6	7.90
21	158.2	174	9.99
22	191	208	8.90
23	243	263	8.23
24	270	296.3	9.74
25	344.5	378.4	9.84

increase in the age of concrete specimens. It is also observed that in a constant water cement ratio, and for all ages, increase in Silica fume and paper waste ash, increases the electrical resistance. Increase in the amount of additives, increases the volume of paste in the concrete mix, and considering the high electrical resistance of cement paste along with Silica fume and paper waste in comparison to aggregates, an increase in electrical resistance is observed in the mix. On average, electrical resistance of concrete increases by about 8% between the ages of 28 and 90 days.

Figures 15 to 24 present that adding of Silica fume and paper waste ash has increased the electrical resistance. This increase in higher percentages of additive has occurred more quickly in all mix designs. In some mix designs, the increase in electrical resistance has occurred at a lower rate which can be attributed to the inappropriate and non-uniform distribution of Silica fume and paper waste ash in concrete. In other words, non-uniform distribution makes parts of the concrete more susceptible to passage of ions which increases the electrical resistance of ions.

By elevating the level of Silica fume in the mixture, the pozzolanic properties of silica also affect the concrete. If the amount of waste paper ash is high in the mixture and Silica fume exhibits its pozzolanic properties, the amount of Silica fume that

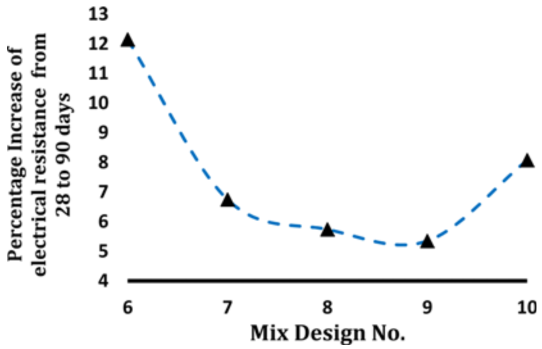


Fig. 18. Percentage Increase of Electrical Resistance of Specimens (Mix Design 6 to 10)

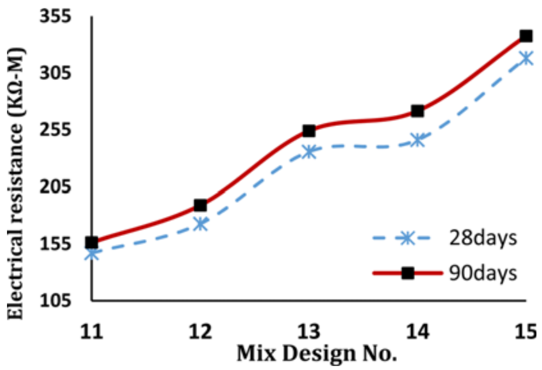


Fig. 19. Electrical Resistance (Mix Design 11 to 15)

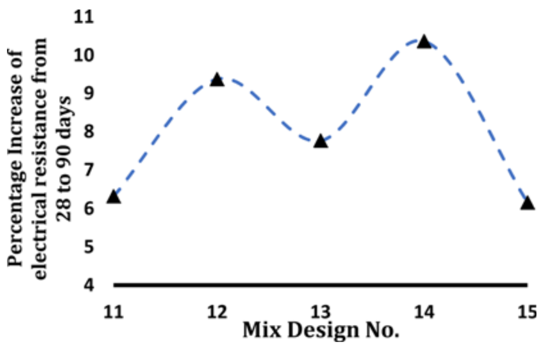


Fig. 20. Percentage Increase of Electrical Resistance of Specimens (Mix Design 11 to 15)

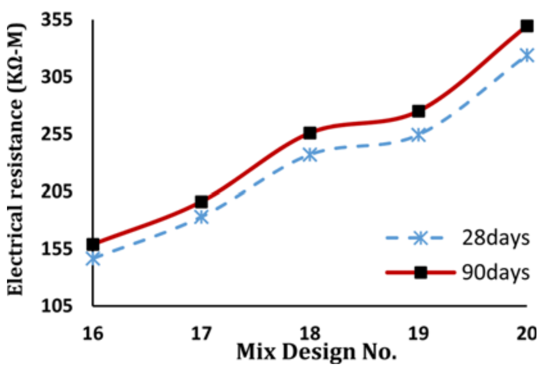


Fig. 21. Electrical Resistance (Mix Design 16 to 20)

is needed for proper distribution of waste paper ash will decrease and as a result, due to the formation of a more irregular structure in concrete, the electrical resistance of concrete increases. Electrical

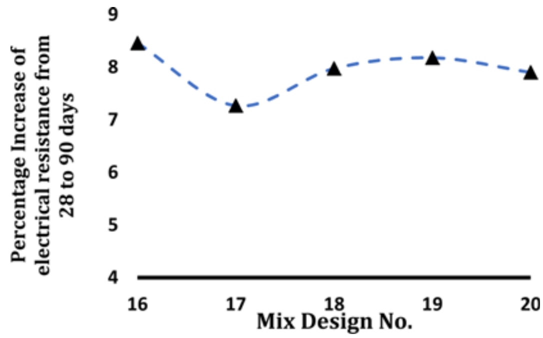


Fig. 22. Percentage Increase of Electrical Resistance of Specimens (Mix Design 16 to 20)

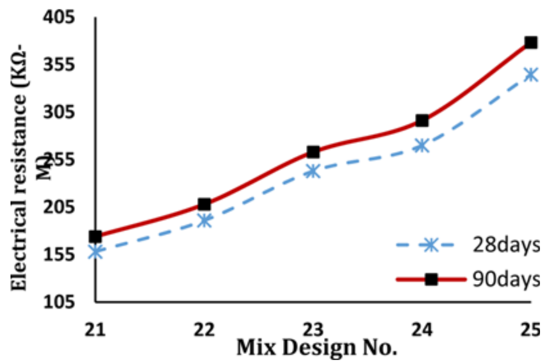


Fig. 23. Electrical Resistance (Mix Designs21 to 25)

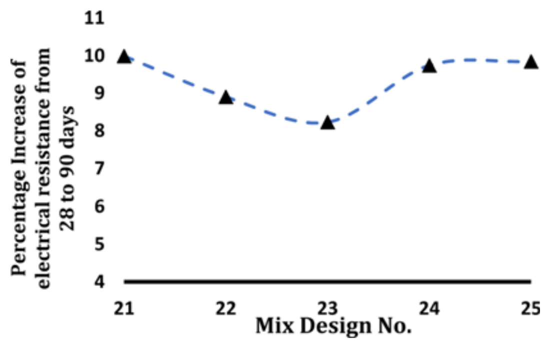


Fig. 24. Percentage Increase of Electrical Resistance of Specimens (Mix Designs 21 to 25)

resistivity as one of the characteristics of concrete indicates some of its important properties including permeability and the amount of chloride ion penetration in it. Increase in electrical resistance decreases the permeability. The electrical resistance measurement test is a non-destructive test. Therefore, without destruction of concrete, it is possible to carry out successive experiments on a special concrete specimen. The impact of Silica fume on electrical resistance includes the filling feature of Silica fume, the proper distribution of paper waste ash and its pozzolanic property. The first one is decisive in small amounts of silica fume. In the second one, there is an optimal ratio for simultaneous consumption of waste paper ash and silica fume which can be achieved by trial and error of mix design. The pozzolanic property reveals in large amounts of silica fume.

4.7 Micro Structures

Studying the microstructure of cement paste and concrete using scanning electron microscope (SEM) images has revealed a new horizon in concrete technology in recent years. Concrete characteristics including specific gravity and all kinds of chemical reactions and hydration that are created in the primary and last setting process of concrete have a direct and close relationship with the concrete microscopic structure. Therefore, studying the microstructure of concrete in the process of cement hydration and the placement state of concrete besides the various admixtures; materials added to concrete, including various types of waste paper ash and silica fume using scanning electron microscope (SEM) which are very important. In this investigation, waste paper ash and silica fume were added to concrete and detailed studies were done on their arrangement in the concrete structure. Scanning electron microscope (SEM) was used for (studying) 25 concrete mixes encompassing paper waste ash and silica fume as a substitute to Portland cement have been

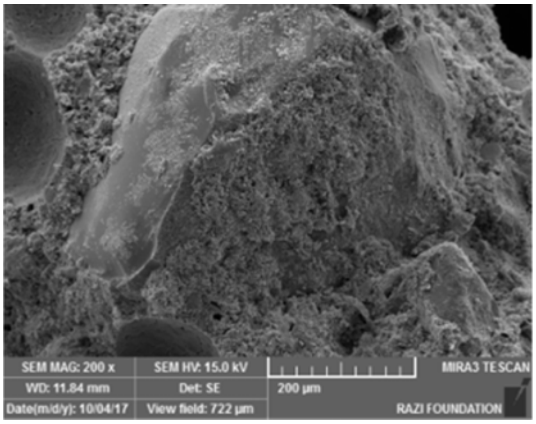


Fig. 25. SEM Images of Concrete with Paper Waste

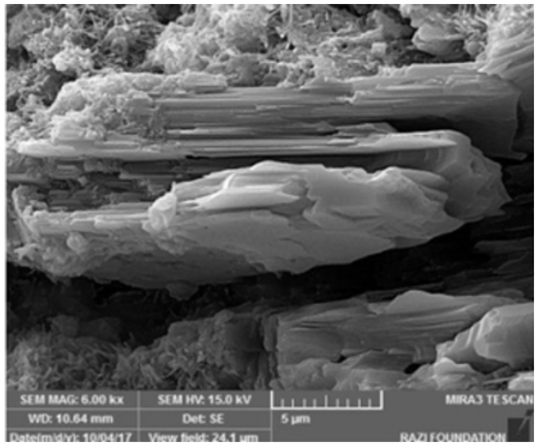
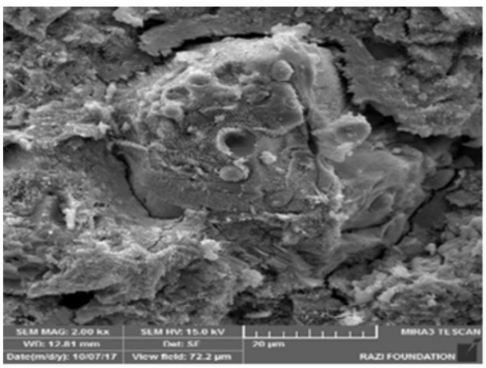
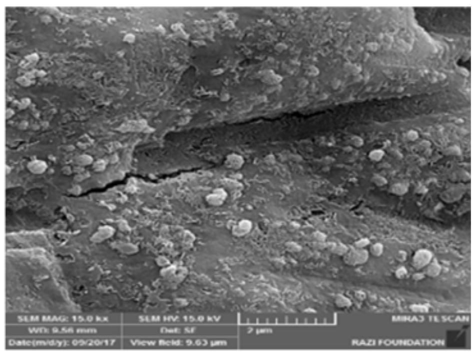


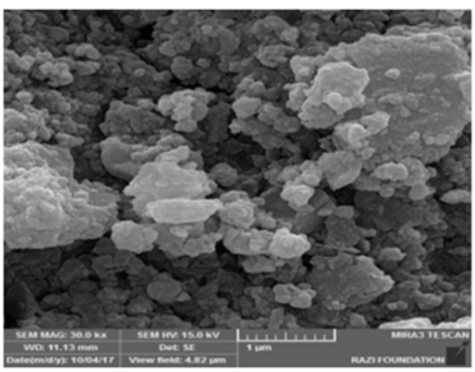
Fig. 26. SEM Images of Concrete with Silica Fume



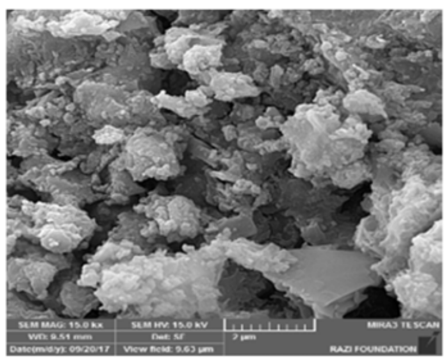
(a)



(b)



(c)



(d)

Fig. 27. SEM Images of Concrete with Different Paper Waste and Silica Fume Contents: (a) Normal Concrete, (b) Concrete with Paper Waste (10% by Weight of Cement), (c) Concrete with Silica Fume (10% by Weight of Cement), (d) Concrete with Paper Waste and Silica Fume (10% by Weight of Cement)

presented. The Portland cement was substituted by various ratios (namely 0, 2.5, 5, 7.5 and 10 percent by weight of cement) of both silica fume and paper waste ash. In all mixes of concrete, the water-cement ratio was considered persistent (with an amount of 0.4); whose hydration reaction was stopped using acetone at the age of 7 days. The taken images (by scanning electron microscope) are divided into two groups: the fracture surface and the modeled transition zone (region) between the paste and the waste paper ash. The results of tests and microscopic photos and their comparison with the voucher sample (Fig. 25) show that the addition of paper waste ash to concrete (10% by weight of cement) reduces the volume of cavities and creates a smooth surface with less porosity. Also, adding silica fume (10% by volume) improved the concrete integrity (Fig. 26). The difference between the density of control sample and paper waste ash containing sample is clearly obvious (evident), shown in Fig. 27. The SEM micrograph of concrete particles revealed its sub-angular to round shape (Figs. 25 – 27). Application of both silica fume and paper ash enhances the microstructure of the concrete. They have chemical reactions with crystallic calcium hydro-oxide. In fact, they cause the finer the size of crystal calcium hydro-oxide particles in the transition zone between paste and aggregate and strengthening this zone.

5. Conclusions

In this research, we experimentally evaluated the impact of waste paper ash along with silica fume on concrete's mechanical features. Compressive strength, indirect tensile strength, flexural tensile strength, abrasion resistance (Los Angeles), determination of elasticity modulus and permeability coefficients, water permeability, slump, ultrasonic pulse velocity (UPV), electrical resistance and impact examinations are carried out for all concrete specimens at different ages. Also, equations have been presented for concrete containing waste paper ash and silica fume based on existing equations and were compared with the ACI and concrete code of Iran. This equations are suggested to predict the behavior of concrete containing waste paper ash and silica fume. The research results are presented as follows:

1. In order to keep the workability level, it was not necessary to modify the w/c ratio of the various mixes significantly.
2. The adverse impact of waste paper ash and silica fume on workability was reduced as there was an increase in the superplasticizer content.
3. There was no significant adjustment to bulk density by the incorporation of waste paper ash and silica fume maximum changes of 2% were obtained. At 10% silica fume content, the density of the mix was higher, because of the better particle size distribution provided by the incorporation of the waste paper ash powder.
4. The tensile strength/compressive strength ratio of ordinary concrete is about 10. However, this ratio is between 13.55 and 17.79 in concrete specimens containing waste paper ash and silica fume.
5. The compressive strength ratio of 28 days to 90 days is between 0.67 and 0.81. However, this ratio is between 0.55 and 0.65 in ordinary concrete, which indicates a higher initial strength in specimens containing waste paper ash and silica fume.
6. The elasticity modulus of concrete containing Silica fume is about 0 to 8% more than the predicted value in the ACI standard. The results show that increase in concrete specific weight increases the elasticity modulus.
7. Elevation in the level of cement increases the compressive strength in all mix designs.
8. 0 to 10% increase in silica fume increases the electrical resistance and mobility of ions significantly. Generally, the electrical resistance of concrete has an increasing trend with increase in the age of concrete specimens. On average, electrical resistance of concrete increases by about 8% between the ages of 28 and 90 days.
9. The electrical resistance of paper waste ash mixes was slightly lower than that of the control mix at all ages. The replacement of 2.5%, 5%, 7.5% and 10% Silica fume amplified the electrical resistance of the concrete mixes comprising Silica fume. There was a satisfactory relationship between the electrical resistance and compressive strength of all samples.

Acknowledgements

Not Applicable

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References

ACI 211.1 (2009). *Standard practice for selecting proportions for normal*, ACI 211.1, American Concrete Institute, Farmington Hills, MI, USA.

ACI 318-83 (2002). *Building code requirements for reinforced concrete*, American Concrete Institute. Farmington Hills, MI, USA.

Ahmad, S., Malik, M. I., Wani, M. B., and Ahmad, R. (2013). "Study of concrete involving use of waste paper sludge ash as partial replacement of cement." *IOSR J. of Eng.*, Vol. 3, No. 11, pp. 6-15.

ASTM C496 / C496M (2017). *Standard test method for splitting tensile strength of cylindrical concrete specimens*, ASTM C496 / C496M, ASTM International, West Conshohocken, PA, USA.

Bai, J., Chaipanich, A., Kinuthia, J. M., O'Farrell, M., Sabir, B. B., Wild, S., and Lewis, M. H. (2003). "Compressive strength and hydration of wastepaper sludge ash-ground granulated blast furnace slag blended pastes." *Cem. Concr. Res.*, Vol. 33, pp. 1189-1202, DOI: 10.1016/S0008-8846(03)00042-5.

Banfill, P. and Frias, M. (2007). "Rheology and conduction calorimetry of cement modified withcalcined paper sludge." *Cem. Concr. Res.*, Vol. 37, No. 2, pp. 184-190, DOI: 10.1016/j.cemconres.2006.11.013.

Bin Mohd Sani, M. S. H., bt Muftah, F., and Ab Rahman, M. (2011). "Properties of waste paper sludge ash (WPSA) as cement replacement in mortar to support green technology material." *3rd International Symposium & Exhibition in Sustainable Energy & Environment (ISESEE)*, Malacca, Malaysia, DOI: 10.1109/isesee.2011.5977117.

BS 6073-2 (2008). *Precast concrete masonry units guide for specifying precast concrete masonry units*, BS 6073-2, British Standards Institution, British Standards Institution, London, UK.

BS EN 12390-1 (2000). *Testing hardened concrete: Shape, dimensions and other requirements for specimens and moulds*, BS EN 12390-1, British Standards Institution, London, UK.

Carmen, M., Teresa, C. A., and Francisco, C. (2012). "Recovering wastes from the paper industry: Development of ceramic materials." *Fuel Processing Technology*, Vol. 103, No. 102, pp. 115-181.

Chen, W. F. (1982). *Plasticity in reinforced concrete*, McGraw-Hill, New York, US, DOI: 10.1016/0045-7825(82)90016-0.

Choi, S. G., Ki, C., Najeebullah, T., Junkyeong, K., Seunghee, P., and Innjoon, P. (2018). "Real-Time strength monitoring for concrete structures using EMI technique incorporating with fuzzy logic." *Applied Sciences,* Vol. 8, No. 75, DOI: 10.3390/app8010075.

Frias, M., Sanchez de Rojas, M. I., Rodriguez, O., Jimenez, R. G., and de la Villa, R. V. (2008). "Characterisation of calcined paper sludge as an environmentally friendly source of metakaolin for manufacture of cementitious materials." *Adv. Cem. Res.*, Vol. 20, No. 1, pp. 23-30, DOI: 10.1680/adcr.2008.20.1.23.

Hong, S. W., Barakat, R., Alhilali, A., Saleh, M., and Cheeseman, C. R. (2015). "Hydrophobic concrete using waste paper sludge ash." *Cem. and Conc. Res.*, Vol. 70, pp. 9-20, DOI: 10.1016/j.cemconres.2015.01.005.

Management and Planning Organization of I. R. Iran, Technical Activities and Code Development Section (1999). *Iranian concrete code (ABA)*, MPOrg Press, Iran.

Mohammad, I., Ismail, M. A., Lau, S. K, Bala, M., and Zaiton, M. (2010). "Fabrication of bricks: From paper sludge and palm oil fuel ash." *Conc. Res. Let.*, Vol. 1, No. 8, pp. 70-77.

Monte, M. C., Fuente, E., Blanco, A., and Negro C. (2009). "Waste management from pulp and paper production in the European Union." *Waste Manage*., Vol. 29, No. 1, pp. 293-308, DOI: 10.1016/j.wasman.2008.02.002.

Mucahit, S. and Sedat, A. (2010). "Utilization of recycled paper processing residues and clay of different sources for the production of porous anorthite ceramics." *J. of the Eur. Ceramic Soc.*, Vol. 30, No. 8, pp. 1785-1793, DOI: 10.1016/j.jeurceramsoc.2010.01.038.

Pera, J. and Amrouz, A. (1998). "Development of highly reactive metakaolin from paper sludge." *Adv. Cem. Based Mater.,* Vol. 7, No. 2, pp. 49-56, DOI: 10.1016/S1065-7355(97)00016-3.

Segui, P., Aubert, J. E., Husson, B., and Measson, M. (2012). "Characterisation of wastepaper sludge ash for its valorisation as a component of hydraulic binders." *Appl. Clay Sci.*, Vol. 57, pp. 79-85, DOI: 10.1016/j.clay.2012.01.007.

Seyyed Alipour, F., Yousefi, K. D., and Dehestani, M. (2013). "Application of paper making industry wastes in construction materials." *7th Nati. Cong. on Civil Eng.*, University of Sistan and Baluchestan, Zahedan, Iran.

Spathi, C. (2013). *Resource efficient reuse applications for paper sludge ash*, PhD Thesis, Imperial College, London, UK.

Spathi, C., Young. N., Heng, J. Y. Y., Vandeperre, L. J. M., and Cheeseman, C. R. (2015). "A simple method for the preparation of super-hydrophobic powder using paper sludge ash." *Mater. Lett.*, No. 142, pp. 80-83.

Young, N. (2013). *Development of hydrophobic coatings from paper sludge ash*, MSc Thesis, Imperial College, London, UK.