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The effect of Ash from Burning Industrial Waste on the Physical and Mechanical Properties of Ordinary Portland concrete

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ABSTRACT

One of the ways to dispose of urban waste is to burn it in incinerators. In this research, it was tried to use the ash obtained from the waste incineration plant of Saveh city (Iran) as a substitute for part of the consumed cement in concrete production. To achieve this goal, the effects of waste ash on compressive strength, abrasion resistance, flexural strength, water absorption and unit weight of concrete were investigated using experimental methods. The concrete used was made with a compressive strength of 30 MPa. The results obtained from the laboratory tests showed that the addition of waste ash as a partial substitute of the cement in the amounts of 10, 20, and 30% in the tested concrete samples caused to decrease the compressive strength by 21, 42, and 49%, the flexural strength by 5, 15 and 22%, and the unit weight of concrete by 3, 5 and 7% respectively, and to increase the water absorption by 3, 6 and 12% respectively, compared to the control sample. Also, there is a slight decrease in the abrasion resistance of concrete including waste ash. However, the obtained strengths were still acceptable for the construction of concretes that require less strength. On the other hand, the use of this ash as a part of the cement used in concrete not only removes the concern of waste incineration plants to dispose of this pollution, but also reduces the consumption of cement and consequently reduces greenhouse gases caused by cement production.

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1. Introduction

Every year, thousands of tons of waste are produced from industries and cities, so the disposal of produced waste has become one of the main problems in developing countries. In other words, the increase in waste production has imposed huge costs on these countries. Also, the lack of landfills and high costs in this matter have increased the concern of many municipalities. All types of waste such as municipal, hospital, industrial waste and etc. are dangerous wastes that if get disposed improperly, will surely cause air, soil, surface and ground water pollution. One of the ways to prevent such pollution is to use waste incinerators.

On the other hand, concrete is the most widely used construction material in the world today [1-3]. The most polluting part of the concrete industry is the cement production process [4-7]. The annual consumption of natural resources for cement production is also significant

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[8-10]. In addition to the consumption of huge resources, a significant amount of air, water and soil pollution is also created due to cement production [11-14]. In addition to consuming large amounts of energy, this huge production of cement causes the release of large amounts of carbon dioxide gas [15-17]. Therefore, it is necessary to reduce the amount of cement used in concrete as much as possible.

One of these solutions can be replacing waste ash instead of part of the cement used in concrete. The main issue is that the concrete produced using ash obtained from waste burning has the required reliability and strengths and is economically justified. The effect of adding incinerated waste as a substitute for part of the aggregate on some characteristics of concrete has been investigated by different researchers [18-25].

The effect of incorporation of incinerated municipal waste materials as partial cement replacement in concrete has been also investigated in literature [26-32].

Different parameters such as the type, temperature and capacity of incinerator furnace as well as waste input can influence on the final compositions and as a result the characteristics of ashes obtained from burning industrial waste [32]. On the other hand, different compositions of ashes from such a complex combustion process with various reactions will result in different effects on the properties of concrete. Therefore, it seems to be necessary to investigate much further the effect of waste ash composition and its implications on the produced concrete. As an instance, the findings of Matos and Coutinho [26] indicate that the significant content of aluminum in the composition of waste ash may react with the alkaline media of cement paste and thus result in further pores and cracks in concrete because of hydrogen gas formation. Tyrer [29] stated that the existence of free aluminum in the composition of waste ash can disrupt the reactions of the cement paste due to the hydrolysis reactions at high pH.

Considering that the results obtained so far are exclusively related to the ashes used in those researches and it is possible that the wastes and the ashes obtained from their burning may have different compositions and so have different effects on the properties of produced concrete, in the current research the effect of replacing the different percentages of the ash obtained from industrial waste burned in Saveh Waste Technology Complex as a partial replacement of cement has been investigated on the physical and mechanical properties of ordinary concrete.

2. Specifications of Consumed Materials

The cement used in concrete is type 2 cement produced in the cement factory of Joveyn city with a relative specific gravity of 3.1 and a cement strength class (CSC) of 31.5 MPa. The water used is the drinking water of Sabzevar city, which has a suitable pH. The aggregates used in concrete, including sand and two types of gravel, were prepared from the construction materials of Rivand village, Sabzevar city, grading chart of which is shown in Figure 1. The ash needed to replace part of the cement was obtained from Saveh Waste Technology Complex. Due to the presence of some impurities in the ash to be used in concrete, the ash was passed through an 18 grade (1 mm) sieve before being used in concrete. Table 1 shows the components of waste ash obtained from the XRD test.

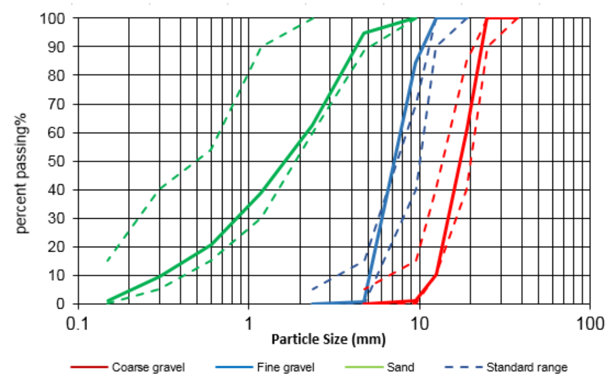

Figure 1. Particle size distribution curves

Table 1:
Chemical composition of waste ash

Chemical Analysis	*Sodium-Calcium-Aluminium (Na-Ca-Al)*	*Carbon disulfide (CS_2)*	*Carbon (C)*
(%)	*28*	*17*	*55*

3. Concrete Mixture Design

Concrete samples were made based on Iran's National Concrete Mixing Plant, Publication 479 [33]. After preparing the construction materials and mixing them for 5 minutes, a standard cube mold of 150 x 150 x 150 mm was used to make the samples. Also, the compaction of fresh concrete was done using a standard rod in three layers and each layer with 25 hits. Grading has been modified based on the regulations of Iran's National Mixing Plant and the modified grading chart is shown in Figure 2. All the samples were removed from the mold after 24 hours and placed in the lime water pool with a temperature of 25°C. The specifications of the tested samples are presented in Table 2. In all designs, all the conditions (cement type, water to cement ratio, granulation type, etc.) have been kept constant and only the amount of ash replacement has been changed.

Water to cement ratio (w/c): Using the Iran's National Mixing Plant Regulations and considering the compressive strength assumed in this research (equal to 30 MPa) for normal concrete (without ash) and also the standard deviation equal to 10.5 (obtained according to section 2-3-

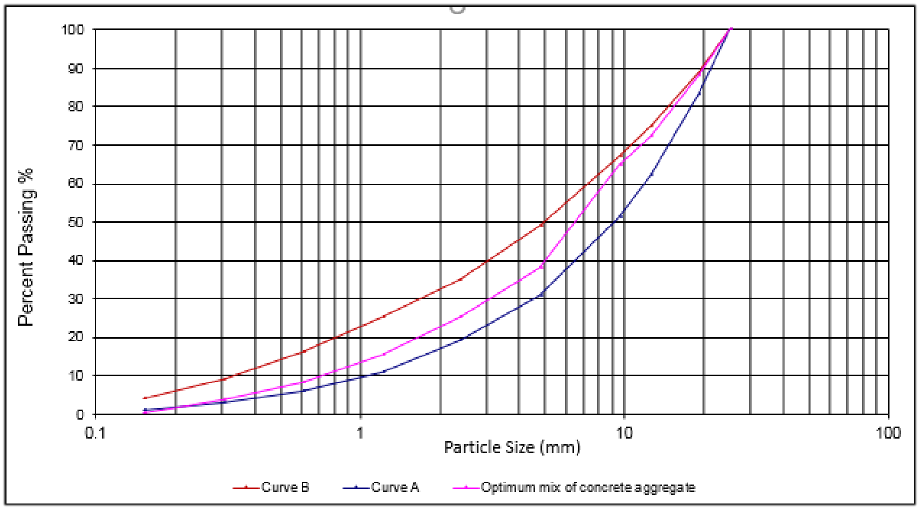

Figure 2: Modified granulation diagram

Table 2

concrete mixture design (For 1 m^3 of concrete)

Specimen Name	Ash (%)	Ash (kg/m^3)	Water (kg/m^3)	Cement (kg/m^3)	Coarse Gravel (kg/m^3)	Fine Gravel (kg/m^3)	Sand (kg/m^3)
A28	0	0	173	402.0	563	526	726
B28	10	40.2	173	361.8	563	526	726
C28	20	80.4	173	321.6	563	526	726
D28	30	120.6	173	281.4	563	526	726

-2, table 3-3 of the aforementioned regulations) and also consumed cement with CSC of 32.5 (the CSC of Portland cement type II is 31.5, which according to the regulations of the Iran's National mixing plant, it can be considered 32.5 when using the mentioned diagram) and finally, due to the angular aggregates, the ratio of water to cement was determined as 0.43.

4. Results and discussion

4.1. Compressive strength

The compressive strength of the samples was measured using a compressive test jack (Figure 3). These tests have been determined based on ASTM C39. In the compressive strength tests, the samples reach the ultimate strength by applying axial compressive force at a certain speed. The compressive strength has been then obtained by dividing the maximum force supported by the sample by the cross-sectional area of the sample.

Looking at the previous studies shows that the incorporation of waste ash as the partial replacement of cement might be successful, up to 30% of the binder mass (Kumar and Chandak (0-30%) [30], Kim et al. (0-30%) [34]). Some other researchers have even tested only one replacement level of waste ash (Tang et al. (30%) [35], Caprai et al. (25%) [28] and Alderete et al. (20%) [27]). Therefore, in the current research, in order to investigate the effect of waste ash on the compressive strength of ordinary concrete, the samples have been made with different percentages of waste ash, including 0 (as a control sample), 10, 20, and 30 percent ash as a substitute for cement. The number of samples for each replacement percentage was 3, and the average compressive strength of these three samples was reported as the corresponding concrete compressive strength.

Figure 3. Compressive strength measuring device

Figure 4 shows the compressive strength results of 7, 14, and 28-day concrete samples with zero, 10, 20, and 30 percent of ash replaced with cement. It can be seen carefully in the graph that the increase in the amount of ash causes a decrease in the compressive strength of concrete, and this decrease for 28-day samples (compared to the control sample without ash) for 10, 20 and 30% ash is 21%, 42% and 49% respectively. It is worth noting that despite the decrease in compressive strength with the increase of waste ash, the produced concrete can still be used to make concrete that needs less compressive strength, such as filler concrete or light concrete in building floors. The results also indicate that the effect of curing time on the compressive strength of the samples made with 20 and 30% ash is less compared to the other two types of samples.

Figure 5 shows the curvature created on the surface of different concrete samples. It can be seen carefully in the figure that there is no curvature in the concrete sample without ash. In other words, it can be seen that the amount of curvature increases in concrete samples including ash, which indicates an increase in concrete volume after initial setting probably due to the undesirable increase of Al (Table 1) by adding ash in concrete [30].

The existence of Al in waste ash can produce H2 (hydrogen gas) as described by the chemical reaction (1) [24, 25]. The hydrogen gas can be entrapped within the concrete and so can cause cracking of concrete and eventually reduce the strength [30, 31]:

$$2Al + 4OH + 2H_2O \rightarrow 2Al(OH)_3 + H_2 \uparrow \quad (1)$$

During the construction of concrete samples with ash compared to the control samples, some fat stains were observed in the concrete; The presence of these fat elements might be another reason for the reduction of compressive strength in concrete samples containing ash. Considering the increase in volume observed in concrete with the increase in the amount of replaced ash, perhaps this ash can be used in making concrete to fill cracks and repair concrete surfaces that do not need high strength.

It can also be seen from Figure 5 that the ash has an effect on the color of fresh concrete and as the amount of ash increases, the color of concrete becomes darker. But during drying, the color difference is reduced and almost all of them are close to the color of the control sample.

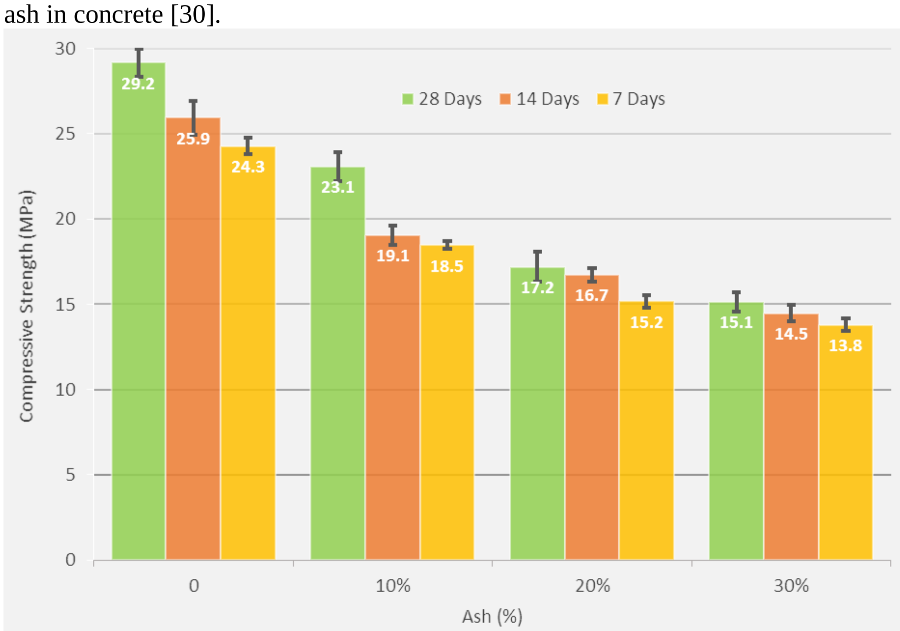

Figure 4. Compressive strength of concrete samples

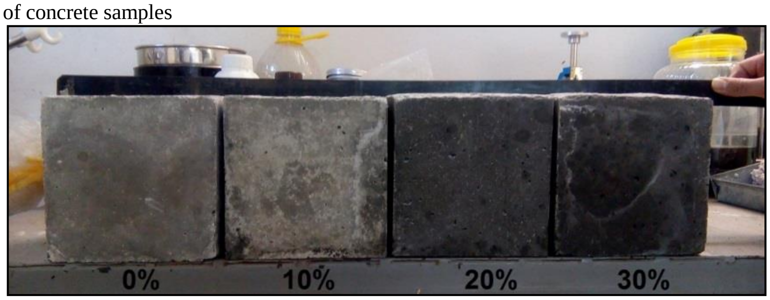

Figure 5. The curvature created on the concrete surface

4.2. Abrasion resistance

In this research, testing the abrasion resistance of concrete on 75x150x150 mm cube samples using the wide wheel abrasion test according to Iranian National Standardization Organization, INSO 12728 (Appendix C, Abrasion resistance measurement) [36] (taken from the European Standards, EN 1340 [37]) related to requirements and tests of concrete kerb units has been carried out. The grinding machine as shown in Figure 6 consists of a wide grinding wheel, a storage hopper with one or two control valves to regulate the output abrasive, a flow guide hopper, a clamped moving table or plate, and a weight. If two control valves are used, one of them should be used to adjust the flow rate and the other valve to turn off and on the flow.

Figure 6. Abrasion resistance testing device

The wide grinding wheel must be made of a steel conforming to EN 10083-2 with a hardness between HB 203 and HB 245. The diameter of the wheel should be (200±1) mm and its width (70±1) mm. The wheel must rotate 75 times in (3±60) seconds. In order to make the groove created on the samples easier to see, the samples were spray painted before testing as shown in Figure 7.

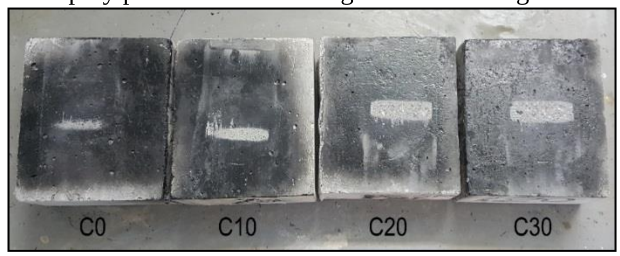

Figure 7. Preparing the sample to perform the abrasion resistance test

In order to choose the best amount of waste ash consumption, concrete samples with 0% ash as control samples and 10, 20, and 30% ash substitute for cement were examined for 30 MPa compressive strength with 50-90 mm slump. Abrasion resistance of the samples was measured after 28 days of curing using an abrasion resistance measuring device and measuring the groove created on the sample. The results obtained for each of the ash percentages are the average of three values obtained from three test samples.

4.2.1. Measurement of created groove

After creating the groove by the wide wheel machine, first, using a pencil, the outer boundary of the groove was marked and a line was drawn (l1 and l2 as shown in Figure 8). Then the line AB, from the middle of the created groove, was drawn perpendicular to the middle line. At the end, a caliper was placed on points A and B on the inner edge of the length of l1 and l2 of the groove, and measurements were made and recorded with an approximation of ±1 mm.

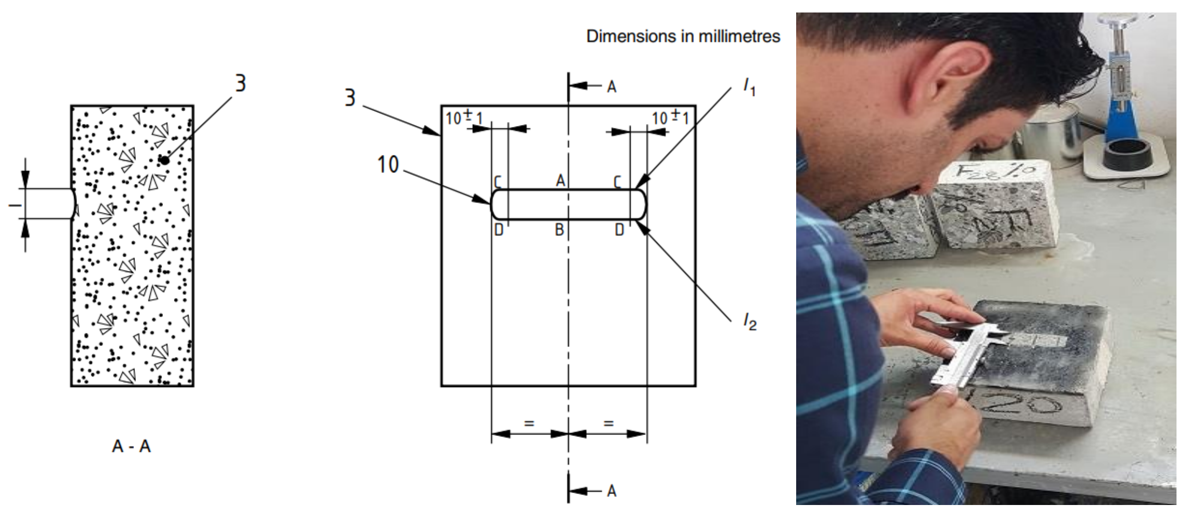

Figure 8. Groove measurement of samples

Table 3.
Size of grooves obtained from wear resistance

Specimen Name	Ash (%)	AB (mm)	CD1 (mm)	CD2 (mm)	Δ	Calibration factor	Final dimension (mm)
C0	0	8.8	8.2	7.3	8.1	11.9	20.5
C10	10	12.4	11.6	10.8	11.6	8.4	21
C20	20	17.9	17.1	16.3	17.1	2.9	21
C30	30	21.3	20.3	19.5	20.4	-0.4	21

In order to calibrate the created groove, measurements were recorded at a distance of (10±1) mm from each end of the groove (C and D) to obtain three results. The calibration value (Δ) is equal to the average of three measured values and is obtained from equation (1). The test result, which is the corrected dimension after applying calibration factor, is calculated from equation (2) and is reported after rounding with approximately 0.5 mm. It is worth mentioning that if two grooves are created in one test, the larger value should be reported as the desired result. The calibration factor according to equation (3) is the arithmetic difference between 20.0 and the recorded calibration value (Δ).

$$\Delta = \frac{(AB + CD_1 + CD_2)}{3} \quad (1)$$

$$\text{Corrected dimension} = AB + (20.0 - \Delta) \quad (2)$$

$$\text{Calibration factor} = 20.0 - \Delta \quad (3)$$

Table 3 and Figure 9 show the final dimension (corrected dimension) of the grooves resulting from the abrasion resistance test. According to the results obtained from the test and the grooves created on the samples with different percentages of waste ashes, it can be seen that with the increase in the amount of ash, the dimensions of the grooves created due to wear on the samples have slightly increased, which indicates a very little decrease in wear resistance with adding waste ash to concrete. Table 4 shows the requirements for abrasion resistance of concrete kerb units according to EN 1340 [37]. It is worth noting that the abrasion resistance of all concrete samples containing waste ash is in the H category (class 3) which is acceptable based on EN 1340.

4.3. Flexural

In concrete structures, the absence of cracks is an important factor in maintaining the stability of the structure due to the protection of steel rebars against corrosion. Since applying axial tensile force to concrete samples is a difficult task, the tensile strength of concrete is determined by indirect methods such as flexural and Brazilian (cracking) tests. These methods lead to strengths that are higher than the actual strength under axial tensile load. In the flexural test, the rupture modulus is the maximum theoretical tensile stress that occurs in the lower strands of the tested beam. The purpose of this test is to determine the flexural strength based on the ASTM C78, which was performed on prismatic samples of 50 x 10 x 10 cm by the flexural strength determination device (Figure 10) at a speed of 0.5 min/mm.

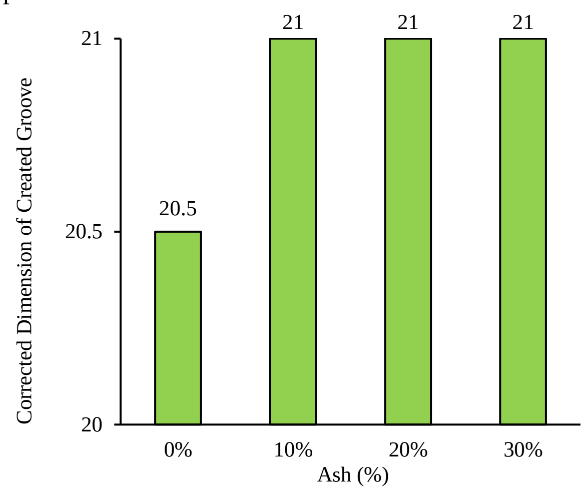

Figure 9. Abrasion resistance test results

Table 4.
Abrasion resistance classes [37]

Class	Maximum abrasion (mm) (wide wheel test)	Marking
1	No performance measured	F
3	≤ 23	H
4	≤ 20	I

Figure 10. Flexural strength testing device

If the crack is created outside the distance between two loads, provided that the distance to the loading point does not exceed 5% of the length of the sample, the flexural strength of the sample is obtained from equation (4).

$$f_b = \frac{\mathrm{My}}{\mathrm{I}} = \frac{3Pa}{d^3} \quad (4)$$

where f_b is the rupture modulus of the section, M is the second moment of area, y is the maximum distance to the neutral beam, I is the second moment of area around the neutral axis, P is the maximum applied force, a is the distance between the cracked section and the nearest support (this distance is measured along the longitudinal axis of the bottom surface of the sample) and d is the height of the beam. It is reminded that if the crack is outside the distance between two loading points and the distance to the loading point is more than 5% of the length of the sample, the test must be repeated. ASTM allows rupture to occur outside the middle third of the beam at a distance of $a < 1/3$ from the nearest support.

Figure 11 shows the results of flexural strength of concrete samples with different percentages of waste ash. The results indicate that the addition of waste ash as a partial replacement of cement in the amount of 10, 20 and 30% in the tested concrete samples reduces the flexural strength by 5, 15 and 22% respectively compared to the control sample. The reason for the decrease in flexural strength can be related to the less cohesion of waste ash compared to cement and also the creation of more pores in concrete.

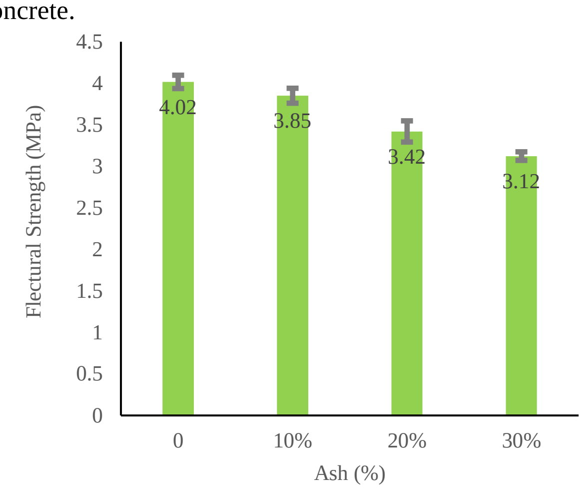

Figure 11. Flexural strength test results

4.4. Water absorption test

The purpose of this test is to determine the amount of water absorption based on to Iranian National Standardization Organization, INSO 12728 [36] (derived from the European Standards, EN 1340 [37]) related to the requirements and tests of concrete kerb units. The samples were immersed in a container containing drinking water with a temperature of 20+5 °C until it reached a constant mass (M1); Then the samples were placed at a distance of at least 15 mm from each other so that at least 20 mm of water was placed on the samples. The samples must be in water for at least 72 hours, and when the difference in mass of the samples after weighing 2 times within 24 hours is less than 0.1%, it means that the samples have reached constant mass.

Before each weighing, the samples were dried with a damp cloth so that their surface did not shine. Then, the samples were placed in a oven for at least 72 hours at a temperature of 105 ± 5 °C, so that there was a distance of at least 15 mm between them, and they were dried until they reached a constant mass. Before weighing the dried samples, they should be cooled in the laboratory environment. The water absorption percentage of the samples was calculated using equation (5):

$$W_a = \frac{(M_1 - M_2)}{M_2} \times 100 \quad (5)$$

In which W_a is the water absorption percentage of each sample, M1 is the mass of the saturated sample in grams, and M2 is the mass of the dry sample in grams.

As can be seen in Figure 12, adding waste ash by 10, 20 and 30% increases the water absorption of concrete by 3, 6 and 12%, respectively, compared to the control sample

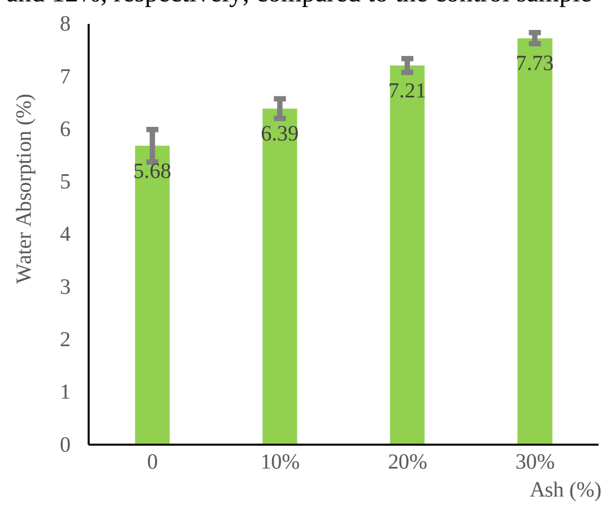

Figure 12. Water absorption test results

4.5. Unit weight test

This test is performed according to ASTM C138. The minimum volume of the container for the maximum nominal size of the aggregate of 25 mm, is about 5.5 liters, and for the maximum nominal size of 38 mm is about 11 liters. The volume of the container should be obtained by filling the container with distilled water and weighing it carefully. The upper level should be adjusted by placing a glass on top of the container (cup) so that it does not remain empty or has excess water. By controlling the temperature of distilled water and having the density of distilled water at this temperature, the volume of distilled water inside the container and as a result the volume of the container is obtained.

Concrete should be poured in standard forms in three layers with approximately equal height and compacted with a rod or vibrator. 25 hits are made in each layer. After each layer is compacted, the body of the mold containing concrete is hit 10 to 15 times with a rubber hammer or other suitable device, and then the next layer is compacted. Each layer is compacted by hitting the rod in such a way that about 25 mm descends in the bottom layer. The concrete of the last layer should be poured in such a way that after compaction, there is no shortage of concrete, and the excess concrete is removed with a sharp ruler and the said surface is smoothed. Additional concrete should not exceed 5 mm. As can be easily seen in Figure 13, the results indicate a decrease in unit weight with an increase in the amount of waste ash due to the creation of more pores in concrete including ash. This decrease in unit weight for adding waste ash to the amount of 10, 20 and 30% is equal to 3, 5 and 7%, respectively, compared to the control sample.

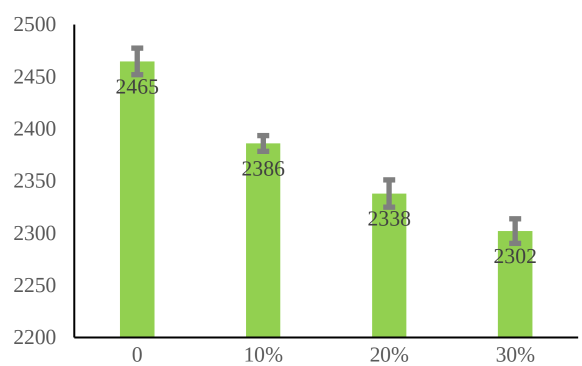

Figure 13. The results of the concrete unit weight test

5. Conclusion

Based on the laboratory results obtained from the present research, the following can be concluded:

- Based on the tests, it was found that the addition of waste ash as a partial replacement of the cement in the amount of 10, 20 and 30% in the tested concrete samples reduces the compressive strength by 21, 42 and 49%, reduces the flexural strength by 5, 15 and 22%, increases the water absorption by 3, 6 and 12% and reduces the unit weight by 3, 5 and 7%, respectively compared to the control sample and also a slight decrease in abrasion resistance in concrete.
- Despite the decrease in strength with the increase of waste ash, the produced concrete can still be used to make concrete that needs less strength, such as filler concrete or light concrete in building floors.
- Due to the increase in the volume of concrete with the increase in the amount of replaced ash, perhaps this ash can be used in making concrete to fill cracks and repair concrete surfaces that do not need much strength.
- It is also useful to remember that considering that the results obtained are exclusively related to the available ash and the methods used in this laboratory research and it is possible that each time the waste is burned, it has different compositions and have different effects on the results, so in order to express a more definite and accurate opinion, a wider laboratory program will be needed.

The suggestions for future research could include as:

1. Focus on Investigating the durability (such as thawing and freezing, shrinkage, creep, corrosion, and chloride infiltration of concrete) of concrete made with waste ash (from burning industrial waste).
2. Investigating the methods for improving the properties of concrete made with waste ash, such as increasing the strength and durability (for example, by adding pozzolans or suitable additives).

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