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Effect of gelatin powder, almond shell, and recycled aggregates on chemical and mechanical properties of conventional concrete

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Abstract. The objective of the research is to study the effect of different additives on the conventional concrete. In this term, three types of materials have been added to the concrete: gelatin powder as the binder, recycled aggregates, and almond shell as the fine and coarse aggregates. Several experiments have been made to determine physical and mechanical properties, such as test for compressive and tensile strengths, for impact loading strength, durability test (water absorption) and deep penetration tests. Moreover, the microstructure results for the new type of concrete have been studied by means of scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDXS). The results show that when 70 kg of gelatin powder is added to 1 m^3 of concrete, the concrete's compressive strength and tensile strength are improved more than 22%; during impact loading the first and ultimate cracks are 11 and 129 by numbers, and the first and ultimate cracks' strength is more than 223 and 2346 J respectively. The durability of sample from concrete with additional gelatin has been improved. SEM results illustrate that the weakness of almond shell concrete is related to cracks and voids between the cement matrix and almond shell. The voids of gelatin concrete are higher than that of conventional concrete. The conventional concrete has smooth crystals, and gelatin concrete has sharp and cubic crystals. EDXS results show that chemical content of these two types of concrete is different: conventional concrete contains silicon, while EDXS results show that chemical content of these two types of concrete is different: conventional concrete contains silicon, while gelatin concrete contains calcium and also C-S-H gel is generated in it.

Keywords: conventional concrete, gelatin powder, almond shell, recycled aggregates, impact loading

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Влияние порошка желатина, миндальной скорлупы и вторичных заполнителей на химические и механические свойства обычного бетона

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Аннотация. Цель исследования – определить влияние различных добавок на свойства обычного бетона. В бетонную смесь внесены три вида добавок: желатиновый порошок в качестве связующего, вторичные заполнители и миндальная скорлупа в качестве мелкого и крупного заполнителей. Проведено исследование по определению физико-механических свойств бетона с указанными добавками: прочности на сжатие и растяжение, испытания на ударную нагрузку, на долговечность (водопоглощение) и на глубину проникновения влаги в бетон. Микроструктура бетона изучена с помощью сканирующей электронной микроскопии (SEM) и энергодисперсионной рентгеновской спектроскопии (EDXS). Установлено, что при добавлении 70 кг желатинового порошка на 1 м^3 бетона его прочность на сжатие и растяжение увеличилась более чем на 22 %; под действием ударной нагрузки начальное и предельное количество трещин составляет 11 и 129, а начальная и предельная прочность трещинообразования – более 223 и 2346 Дж соответственно. Кроме того, показатели долговечности лучше у бетона с добавлением желатина. Результаты, полученные при помощи SEM, демонстрируют, что пониженная прочность бетона с добавлением миндальной скорлупы связана с трещинами и пустотами между цементной матрицей и миндальной скорлупой. Пустоты в бетоне с желатином выше, чем в обычном бетоне. Структура обычного бетона имеет вид гладких кристаллов, а бетона с желатином – острые и кубические кристаллы. Результаты, полученные с помощью EDXS, показали различие в химическом составе: обычный бетон содержит кремний, тогда как бетон с добавкой желатина в вышеуказанных пропорциях содержит кальций и в нем образуется гель C-S-H.

Ключевые слова: обычный бетон, желатиновый порошок, миндальная скорлупа, переработанные заполнители, ударная нагрузка

1. Introduction

After water, concrete is the most widely used material in the construction industry. Mechanical properties and durability of concrete are among the most important properties related to performance. Many researchers tried to add different materials to concrete for improve the mechanical and chemical properties of concrete [1–3]. In this term the effect of some materials on the concrete are important for researcher [4–5]. For example, many researchers have been studied on the effect of recycled aggregates on the concrete [6–9].

Many researchers have been preferring to use alter materials as alternative aggregates in the concrete. For example, Gunasekaran et al. [10–11] investigated on the mechanical properties of reinforced concrete with additional coconut shell. Their results shows that coconut shell aggregates concrete beam shear force at the yielding moment was more than 20 MPa, while control concrete sample yielding shear force was more than 19 MPa. In another example, Gunsekaran et al. [12] found the mechanical properties of coconut shell con-

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crete. Their results shows that the compressive strength of coconut shell concrete was more than 26 MPa. Hilal et al. [13] used walnut as the alternative material with coarse aggregates. They understood that adding walnut instead of coarse aggregates decrease the compressive strength. The conventional concrete compressive concrete was more than 56 MPa, while the walnut concrete compressive strength decreased to 26 MPa. Alaneme, and Mbadike [14] investigated on the Bambara nutshell ash as mixture of concrete mortar. Their results show that the compressive strength increased more than 20–46% with adding different percentages of Bambara nutshell ash. Kong et al. [15] investigated adding the waste oyster shell on the recycled aggregates concrete. They examined the compressive, and flexural strength. Their results have been shown that the compressive strengths were than 21 MPa, and 47 MPa for 3 and 28-days curing periods respectively. The flexural strength was more than 7.5 MPa for 28 days curing periods. Raja et al. [16] investigated on the coconut shell, and the foundry sand as replacement aggregates with fine, and coarse aggregates. They replaced more than 10, 20 and 30% of foundry sand, and 10 and 20% of coconut shell to concrete. As a result, the compressive strength increased more than 32 MPa. Their results shows that the effect of foundry sand was more than coconut shell on the compressive strength of concrete. The tensile, and flexural strengths were 4.2 and 2.88 MPa respectively. In another example, Soriano et al. [17] added almonds shell ash (ABA) to cement. They examined the mechanical properties of concrete with adding ABA. They found that the compressive strength of concrete increased more than 44 MPa when 25% of ABA has been added. Moreover, some researchers added sustainable powder to cement to find the effect of mechanical properties. For example, Bigi et al. [18] added more than 18 and 82% of gelatin powder to cement. They understood that the final setting time of cement increased more than 45 min, and compressive strength enhanced up to 10.7–14 MPa.

Many researchers investigated on the recycled aggregated as a greener method, and a viable concrete. For example, Nuaklong et al. [19] find the mechanical properties of concrete with recycled aggregates and adding different type's fly ash. According to the results, different fly ash types was not effective on the compressive strength. The compressive strength results were between 44 and 46 MPa. He et al. [5] studied the effect shrinkage, and creep on the recycled aggregated concrete. In their study, the results of compressive strengths were between 32 and 48 MPa with different mixture designs.

The morphology analysis is an important analysis which related to understanding the reaction of material in micro scale of materials. Scanning electron microscopy (SEM) is a method which can display the morphology of the materials. Chaudhary et al. [20] analyzed the almond shell via SEM method with 10μm as a reinforcement in composite. The SEM results shows that almond shell has pure particle size between 1.020 to 1.253μm. For example, recycled aggregates microstructure is important to understand the mechanical properties of concrete. In this regard, Guedes et al. [6] investigated the microstructural characterization of concrete with recycled aggregates. Results shows that, the replacement of natural aggregates by recycled crushed concrete did not change any morphology of the Cementous structure and hydration.

The mechanical properties and durability of recycled aggregate concrete (RAC) are currently the subject of extensive research. A comprehensive examination of the RAC's mechanical properties was carried out. The findings indicate that the high-water absorption of the aggregates and the weak areas created by the mortar adhering to the old interface is primarily responsible for the RAC's deterioration in terms of its mechanical properties. The sturdiness of RAC likewise was explored, and the outcomes show that the higher the reused total (RA) content, the mortar content appended to the RA, and the W/C (water-to-ash ratio), the more regrettable the strength of RAC [21–23]. The use of almond shell and gelatin powder to mix with concrete lacks sufficient information regarding the properties of the fresh and hardened shell and gelatin powder, as can be seen from earlier literature. Therefore, in order to introduce a new type of conventional concrete with high-strength properties, this research examined the use of shell and gelatin powder as a substitute.

The current study has applied different materials, such as almond shell powder, gelatin powder, and recycled aggregates, to a mixture with concrete. **This study aims** to introduce a new type of conventional concrete with high-strength properties. In this regard, the materials were mixed with concrete to find the compressive and tensile strengths. Moreover, microanalysis was applied. In this term, scanning electron microscopy and energy-dispersive x-ray spectroscopy (EDXS) were applied to find the microstructure and chemical properties.

2. Materials and methods

2.1. Materials. The current study has been used almonds shell, gelatin powders, recycled aggregates as the sustainable, and natural material in concrete. The original concrete has been inspired by the high-performance concrete (HPC) in previous study. To prepare concrete, portland cement (Table 1), gravel, and sand aggregates, superplasticizer (Table 2), almond shell, gelatin powder, and recycled aggregates have been used. The gravel size range was between 20 mm, and 5 mm with specific gravity (2650 Kg/m^3) granulometric curves of coarse aggregates is shown in Figure 1. The sand with a particle size range of 0.6 to 2.0 mm is mixed with concrete and both are collected from the Semnan region, Semnan, Iran. The fine aggregates specific gravity was 2384 Kg/m^3, and the granulometric curves is illustrated in the Figure 2.

Table 1

Chemical properties of ordinary portland cement (OPC)

Oxide, %								Fineness, m^2/kg	Relative density
SiO_2	Fe_2O_3	MgO	SO_3	Al_2O_3	CaO	K_2O	LOI		
19.52	4.04	4.36	2.89	4.81	62.18	0.6	1.62	387	3.14

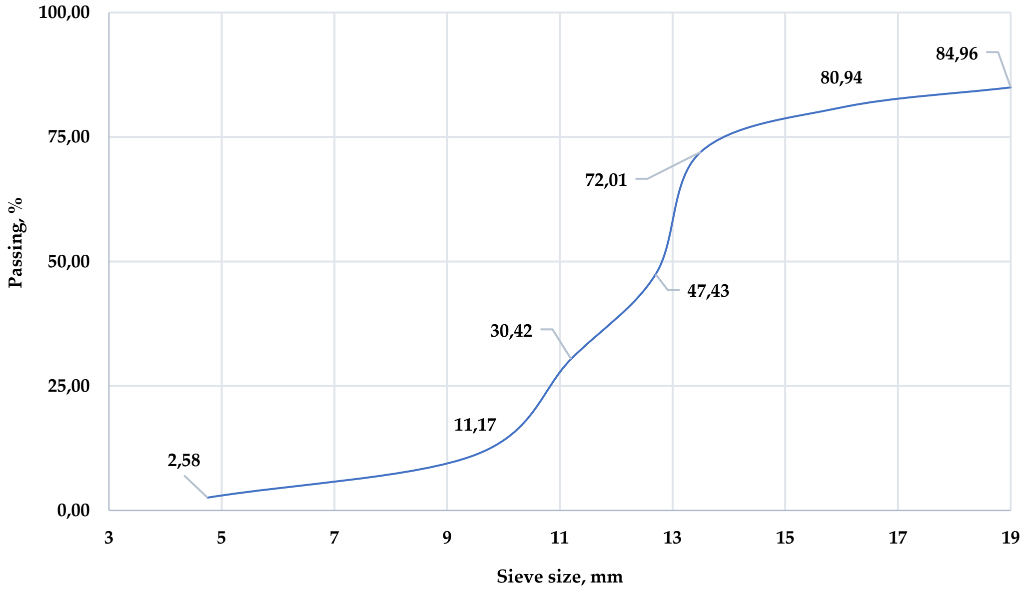


Figure 1. Granulometric curves of coarse aggregates

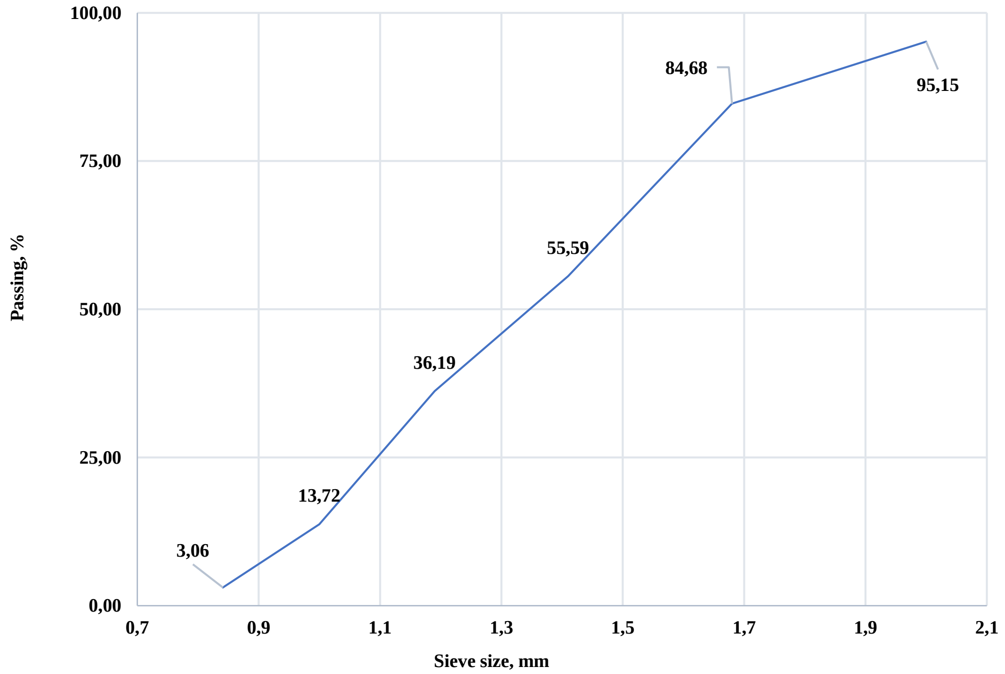


Figure 2. Granulometric curves of fine aggregates

The almond shell was used as an alternative material with coarse aggregates. The size of the almond shell was between 50 and 20 mm. The positive aspect of adding an almond shell was the lightweight and the shell form structure of the almond. Figure 3 shows the almond shell. Gelatin powder was added to concrete to find the ability to improve compressive strength and the cementious matrix. In this case, the gelatin powder was melted at 100°C water temperature. Next, normal-temperature water was added to cement. $C_{102}H_{151}N_{31}O_{39}$ illustrates the chemical properties of gelatin powder as shown in Figure 3, *b* [24].

Recycled aggregates were added to the concrete mixture to find mechanical properties. In this term, recycled aggregates with sizes between 50 and 20 mm as coarse aggregate were added to the concrete (Figure 4).

a *b*

Figure 3. Almond shells as the coarse aggregates (*a*) and gelatin powder to add to concrete (*b*)

Figure 4. Recycled aggregates as the coarse aggregates

In the current study, ten different mixture designs were examined one by one. Table 2 shows the mixture design. According to earlier research, basalt fibre high-performance concrete (BFHPC) served as an inspiration for the original concrete[1] [25].

[1] ASTM C109/C109M. *Standard test method for comprehensive strength of hydraulic cement mortars*. ASTM International; 2009; ASTM C496. *Standard test method for splitting tensile strength of cylindrical concrete specimens*. ASTM International; 2017; ACI Committee 544.2R. *Measurement of properties of fiber reinforced concrete*. Detroit: American Concrete Institute; 1989.

Table 2

The mixture design of the current study

Specimens	Cement	Water	Coarse aggregates	Almond shell	Recycled aggregates	Fine aggregates	Gelatin powder	Super-plastiziter
OC	500	190	450	–	–	600	–	10
AS	500	190	360	200	–	600	–	10
AS1	500	259	450	270	–	480	–	10
AS2	550	259	450	225	–	600	–	10
AS3	550	259	540	279	–	720	–	10
GC	500	190	450	–	–	600	70	10
GC1	500	210	250	–	–	800	105	10
GC2	500	210	–	–	–	1300	140	10
RC1	450	210	–	–	450	600	–	10
RC2	450	210	–	–	450	600	140	10

2.2. Experiment methods. The current study investigates the compressive and tensile strengths according to ASTM C109[2] and ASTM C496.[3] The dimensions of samples for compression, tension, and flexural tests were 10×10×10 cm^3, and 10 (radius)×20 cm^3 (Figure 5). The materials were mixed in the laboratory pan mixer at a steady speed of 48 rpm. The aggregates were mixed for 1–2 minutes, the water was quartered for 1 minute, and the binders were added and mixed for 2 minutes (Figure 5). Before loading concrete, the frameworks are polished with oil. The concrete is loading on the frameworks. The cube and cylinder concrete specimens are molded to water. The cube water molded samples were held at 35°C for 48 hours, while the cylinder water molded samples were kept at 35 °C for 72 hours. The samples were then cured for 28 days molded with 35 °C water (Figure 6).

The cube samples were tested in the compression machine (Figure 7). The compressive test is done according to ASTM C109.[4] The cube specimens sample was 10×10×10 cm^3. The loading speed was 600 Kg/second. Refereeing to Figure 8 an analog loading speed check, a cement surface was put under the cube to load stabile.

a *b*

Figure 5. Cube (*a*) and cylinder (*b*) samples

[2] ASTM C109/C109M. *Standard test method for comprehensive strength of hydraulic cement mortars*. ASTM International; 2009.
[3] ASTM C496. *Standard test method for splitting tensile strength of cylindrical concrete specimens*. ASTM International; 2017.
[4] ASTM C109/C109M. *Standard test method for comprehensive strength of hydraulic cement mortars*. ASTM International; 2009.

a *b*

Figure 6. The pan mixture of laboratory (*a*) and molded concrete samples under water (*b*)

Figure 7. Cube simples under compression machine

Figure 8. Compression machine

The tensile test was established according to ASTM C496.[5] Furthermore, the cylinder diameter was 10 (radius)×20 cm^3. The loading test speed is shown in Figure 9 as equal to 200 Kg/second. According to the test method, certain devices must surround the cylinder. The tension machine is loaded on top of the samples, and finally, the sample is divided into two parts (Figure 10).

The falling mass impact resistance test is in the category of tests that determine the mechanical properties of concrete. The projectile impact test, Sharpie test, drop weight test, and Hopkinson bar test are consecutive tests suggested by ACI committee 544 to check the impact behavior of concrete. With the drop weight test device with repeated blows, the number of blows to create a certain level of rupture is obtained, which is a measure of the material's energy absorption capacity. This test is performed by dropping a 4.54 kg weight from a height

[5] ASTM C496. *Standard test method for splitting tensile strength of cylindrical concrete specimens*. ASTM International; 2017.

of 457 mm and repeated blows until certain cracking levels (first cracking and final cracking) continue [25–28].[6] This test was carried out on concrete samples with disk dimensions of 15×16.36 cm obtained from concrete based on blast furnace slag treated at ambient temperatures of 25 and 90 °C at the age of 28 days and also based on equation (1) The impact energy absorption capacity E was calculated as

$$E = N(WH), \quad (1)$$

where N – the number of blows to cause the initial crack; W – the hammer's weight; H – the height of the fall.

Figure 9. Cylinder loading test speed

a *b*

Figure 10. Tension test:
a – tension test method; *b* – cylinder simples under compression machine

Concrete's ability to absorb water is one of its most important defenses against the elements and issues with durability. Concrete has a lower capacity for water absorption, which reduces the likelihood of harmful ions entering the material and reduces reinforcement corrosion or destruction. According to the ASTM C642 stan-

[6] ACI Committee 544.2R. *Measurement of properties of fiber reinforced concrete*. Detroit: American Concrete Institute; 1989.

dard,[7] after 28 days of processing, cubic samples of concrete measuring 100×100×100 mm were first dried for 72 hours in a heater at 105 °C was measured after this time period and cooling of the samples in the laboratory environment. Then the samples were immersed in water. Their wet weight was measured after half an hour and 24 hours. The water absorption of the samples is calculated within the specified timeframes. The water absorption equation was determined as

$$W_A = \frac{W_W + W_D}{W_W}, \tag{2}$$

where W_A – water absorption; W_W – saturated weight of the sample; W_D – dry weight of the sample.

After 28 days of processing, cubic samples measuring 150×150×150 mm were placed in the testing machine following the standard DIN 1048-part 5.[8] The samples inside the machine are subjected to a pressure of 5 atmospheres for 72 hours. After this time, the samples were removed from the machine, broken with a pressure jack, and the depth to which water penetrates the concrete was measured.

3. Results and discussion

3.1. Mechanical properties: compressive strength. Concrete structure behavior in the utility phase is called compressive strength. The addictive chemical powder, replacement cement with other materials, and curing environment affect the compressive strength. The concrete with the addition of almond shells was lighter, and the compressive strength was lower than other types of concrete. Figure 11 shows that the compressive strength of concrete with additional gelatin powder was better than conventional concrete. The compressive strength of GC (additional concrete with gelatin powder) was 50.7 MPa for 28 days curing periods, while for conventional concrete, the compressive strength was 39 MPa. On the other hand, the concrete with almond shells had less compressive strength than other types. For example, AS has 10.9 MPa compressive strength, and AS1 has 14.6 MPa for 28 days curing periods.

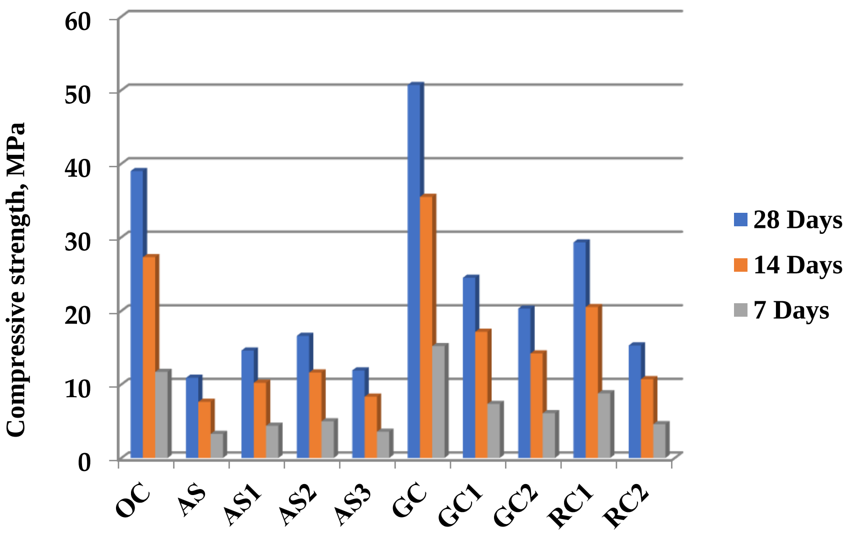


Figure 11. The compressive strength of each concrete types

The GC concrete type results show that gelatin powder's curing period is directly related to compressive strength, and compressive strength will frequently increase with time. Meanwhile, in the compressive strength experimental test, the concrete with additional almond shells and recycled aggregates showed harsh and sudden failure. In contrast, the concrete with gelatin powder showed soft failure (Figures 12 and 13). The test results show that coarse aggregates' compressive strength was better than almond shells and recycled aggregates.

[7] ASTM C642. *Standard test method for density, absorption, and voids in hardened concrete*. ASTM International; 2021. p. 1–3.
[8] DIN 1048-part 5. *Concrete harden determination of the depth of penetration of water under pressure*. 2016.

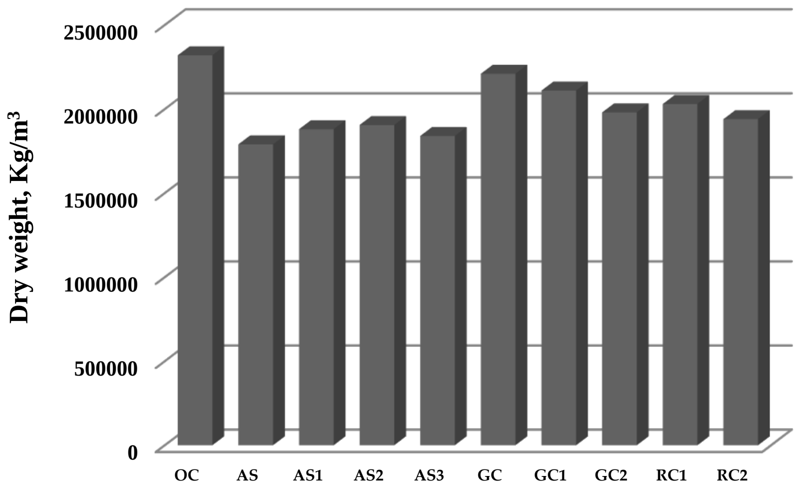
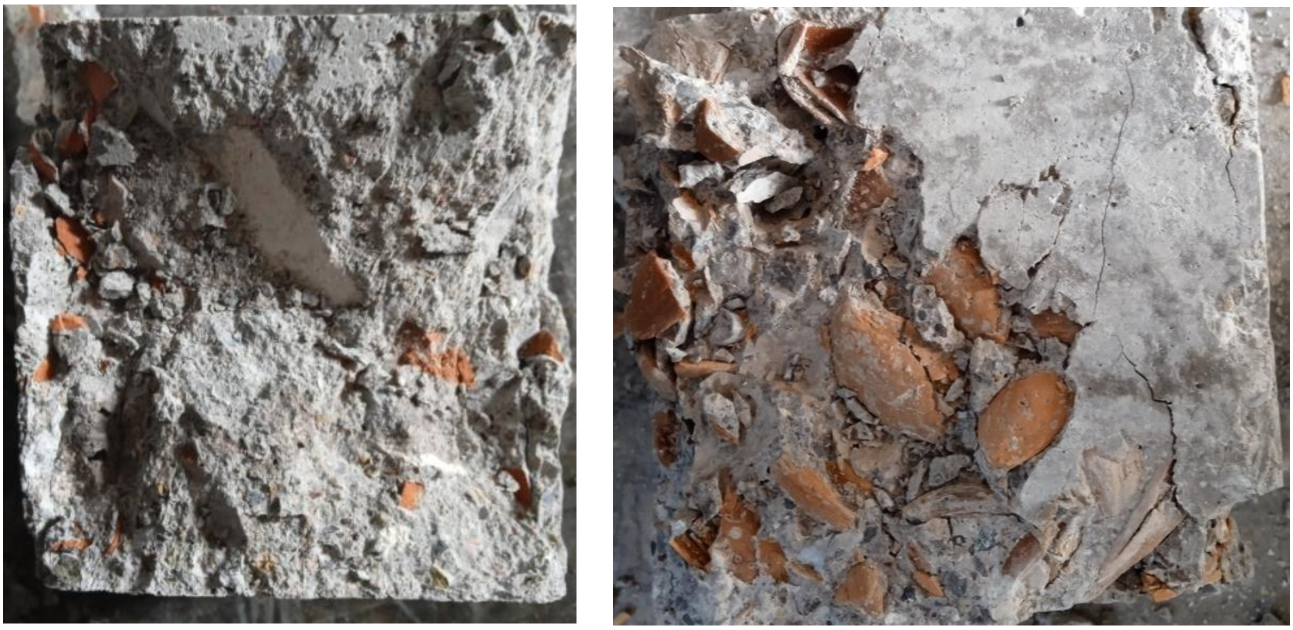


Figure 12. The dry weight of each concrete types



a *b*

Figure 13. The failure mechanism of each concrete type:
a – recycled aggregates; *b* – almond shell

3.2. Tensile strength. The nature of concrete is brittle and does not allow it to withstand tensile load; therefore, the tensile strength of concrete is low. The lowest tensile strength was for the AS3 28 days, and the biggest was for the GC concrete types. According to the results, the GC has maximum tensile strength with 3.7 MPa for 28 days and 2.6 for 14 days curing periods (Figure 14).

3.3. Impact resistance results. According to the results, the GC had the maximum impact resistance rather than other than samples. The first crack was 11 joules, the second sample was 129 joules, the first crack impact strength joules was 223.85 joules, and the second impact strength was 2641.43 joules (Tables 3 and 4). The OC first and ultimate cracks were 9 and 106 joules respectively. Moreover, the first and ultimate crack impact strength in joules were 183.15 and 2161.17 joules (Figure 15).

3.4. Durability, water absorption and penetration depth. The durability of any structural component includes the ability to withstand weather conditions, chemical attacks, abrasion, or any other destructive process. The durability of concretes is determined by their characteristics, such as absorption and water absorption.

Concrete with more gelatin and recycled aggregates absorbs less water than concrete with more almond shells, according to the results of the water absorption test. Water penetrates the cube specimens through the substantial pores of the concrete samples with the addition of bead shells. In contrast, water cannot penetrate the concrete specimens through the effect of gelatin on cement. According to Figure 16, the GC had the best results with 0.5%, and AS had the maximum absorption with 2.1%. The RC1, and RC2 had good results, while RC1 results were better with 0.7% (Figure 16).

Almond shell concrete had the highest porosity; the results indicate that the almond shell concrete series had the highest penetration depth. These results indicate that the penetration depth is related to concrete pore percentages (Figure 17).

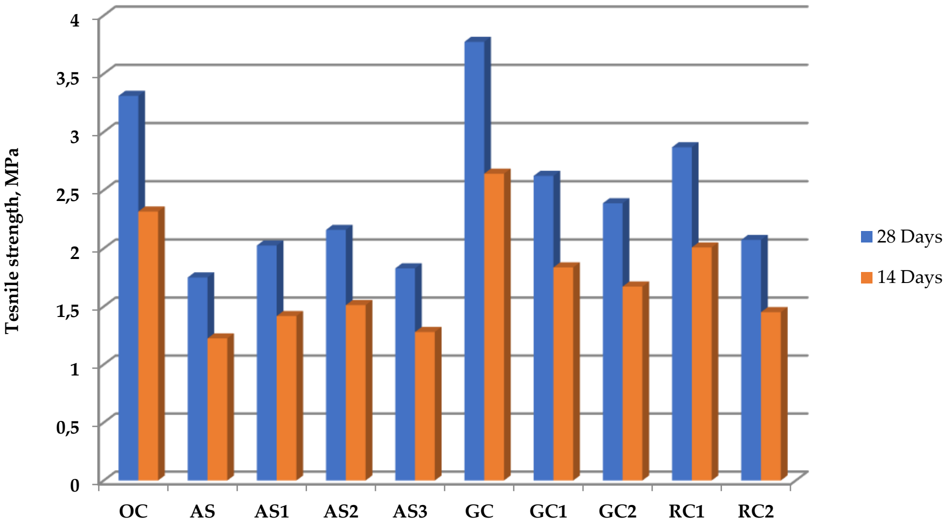


Figure 14. The tensile strength of each concrete types

Table 3

First crack impact energy of samples

Sample	First crack	First crack impact strength, joules
OC	9	183.15
AS	2	46.5021
AS1	3	62.28721
AS2	3	70.81971
AS3	2	50.76834
GC	11	223.85
GC1	5	104.5231
GC2	4	86.60482
RC1	6	125.001
RC2	3	65.27358

Table 4

Ultimate crack impact energy of samples

Sample	First crack	First crack impact strength, joules
OC	106	2161.17
AS	26	548.7247
AS1	36	734.9891
AS2	41	835.6725
AS3	29	599.0665
GC	129	2641.43
GC1	60	1233.372
GC2	50	1021.937
RC1	72	1475.012
RC2	37	770.2283

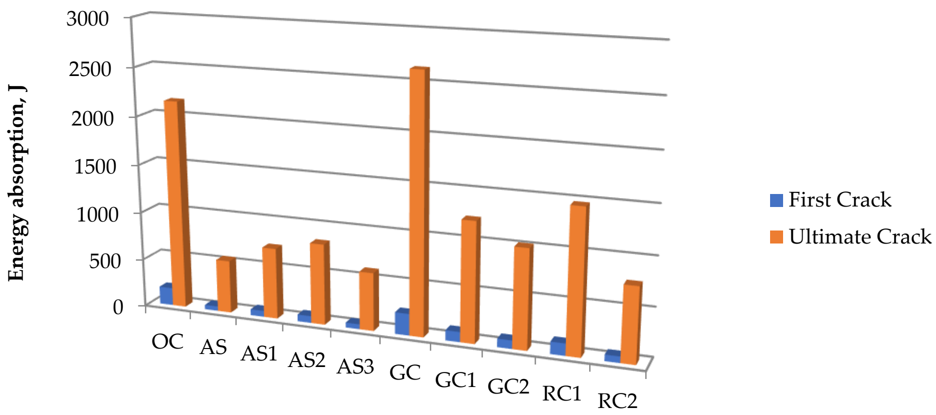


Figure 15. First and ultimate crack impact strengths

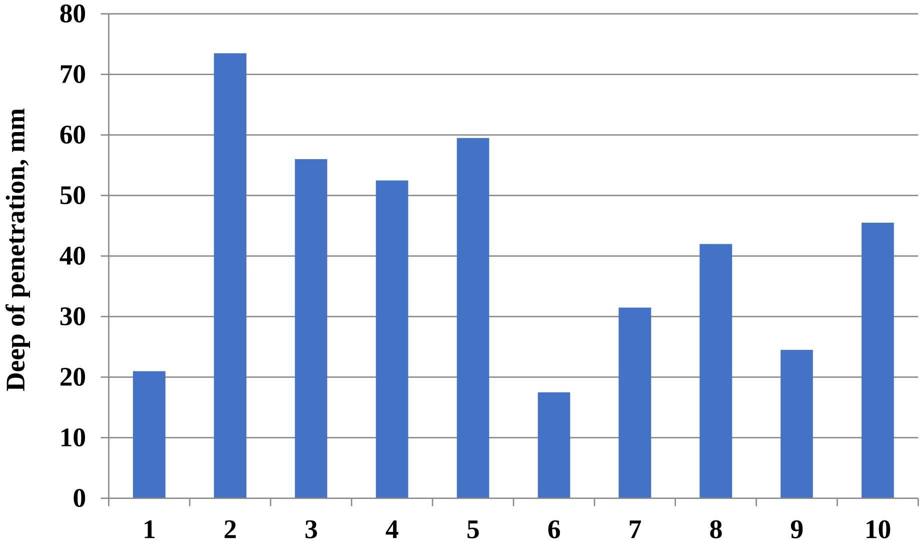


Figure 16. Water absorption results of concrete

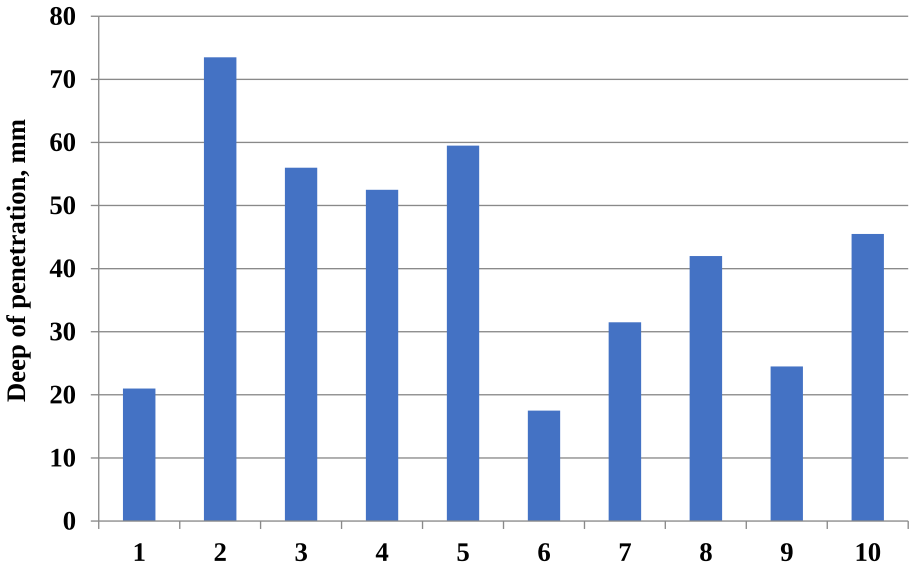


Figure 17. Deep of penetration results

3.5. Microstructure results. The current study applied scanning electron microscopy and energy dispersive x-ray spectroscopy for all types of samples. Figure 18 displays almond shell concrete SEM. Figure 18 shows the crack region between the almond shell and concrete (Figure 18, *b*). In addition, the crystallization of concrete is shown in Figure 18, *d*. Cracks and voids between the almond shell and concrete were an important reason for not improving the compressive strength of concrete. Figure 18, *f* shows that the crack depth of 10 micrometers and almond shell and concrete, the crack depth is an important reason for reducing concrete's mechanical and chemical properties.

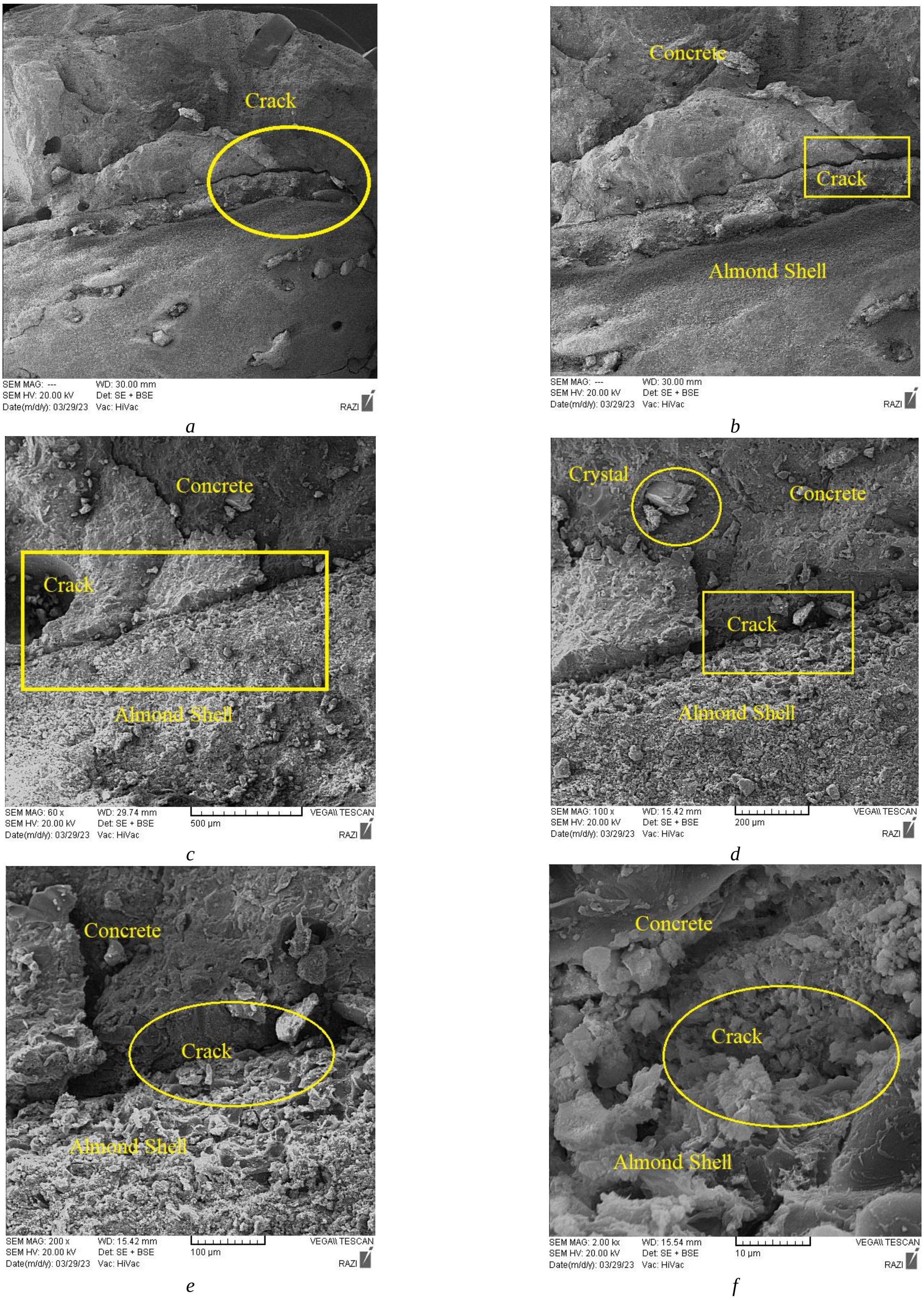


Figure 18. The SEM of almond shell concrete

Figure 19 shows the conventional concrete (OC) SEM results. Figure 19, *b* shows the voids and crystallization process (at a 100-micrometre scale). With the focus on one crystal, the type was heterogeneous with a round shape and round edges (Figure 19, *c*). The EDXS analysis of the crystal reveals that the value of unnormalized concentration(Unn) in weight percentage of element silicon, at 26.01 according to Figure 20 and Table 6. After silicon, aluminium and potassium with 9.11 and 4.23 had the maximum percentages of element (Table 5, Figure 20).

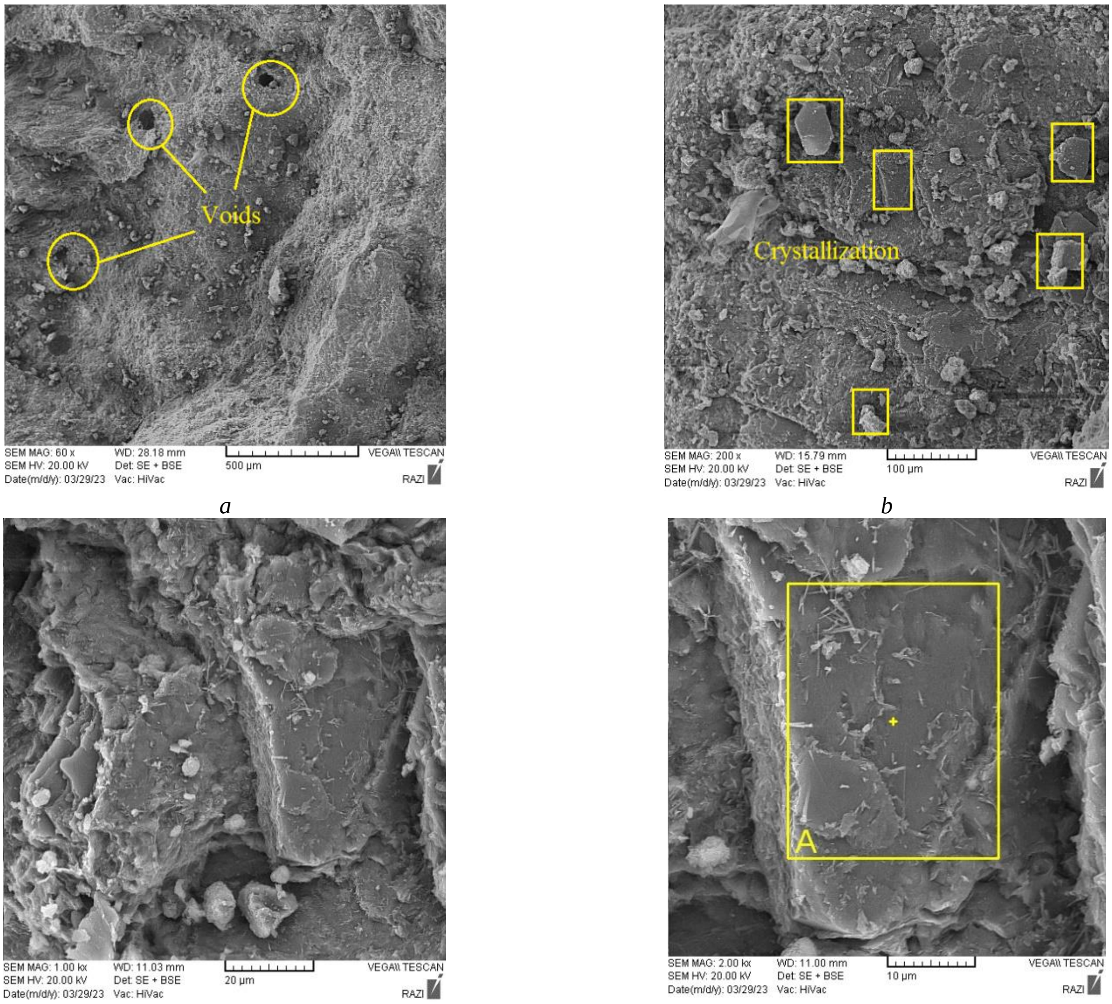


Figure 19. The SEM of OC sample

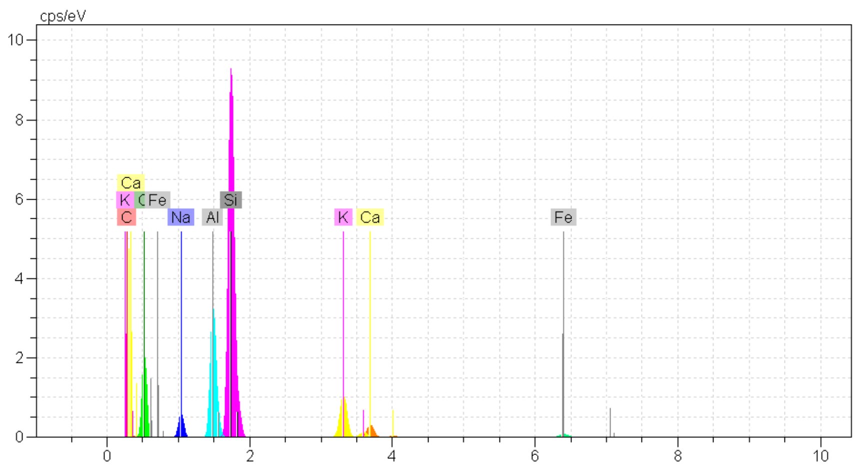


Figure 20. The EDXS of OC sample

Table 5

The EDXS of OC sample

Element	Unn wt, %
Carbon	0.92
Oxygen	38.03
Sodium	2.47
Aluminium	9.11
Silicon	26.01
Potassium	4.22
Calcium	1.23
Iron	0.77

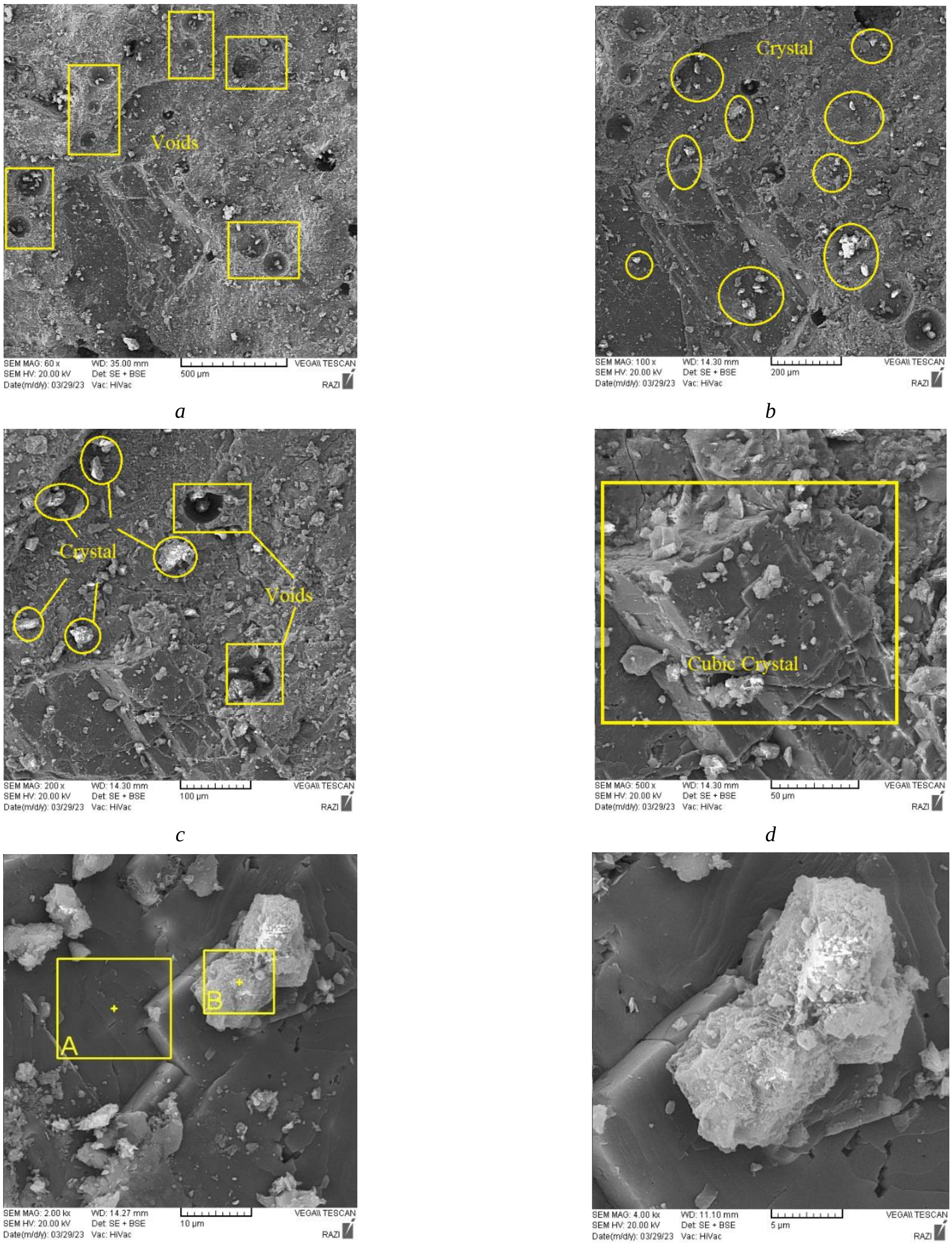


Figure 21. The SEM of gelatin concrete

Gelatin concrete had more voids and more crystals than normal concrete (Figure 21, *a*, *b*). 500 μm SEM results show that gelatin concrete has many voids on the surface, while normal concrete has fewer. There are two types of crystals in gelatin concrete: the pointed crystal and the white crystal, and the cubic crystal (Figure 21, *b*, *c*). Cubic crystal contains sharp crystal. The EDXS results show that the sharp crystal contains more calcium and silicon, while the cubic crystal contains more carbon and magnesium. The chemical properties of conventional concrete crystals include silicon and gelatin, including carbon and calcium. In fact, the gelatin powder can form C-S-H gel in the concrete. The sharp crystal has more silicon in C-S-H gel and the cubic crystal has more carbon in C-S-H gel (Figures 22 and 23, Table 7).

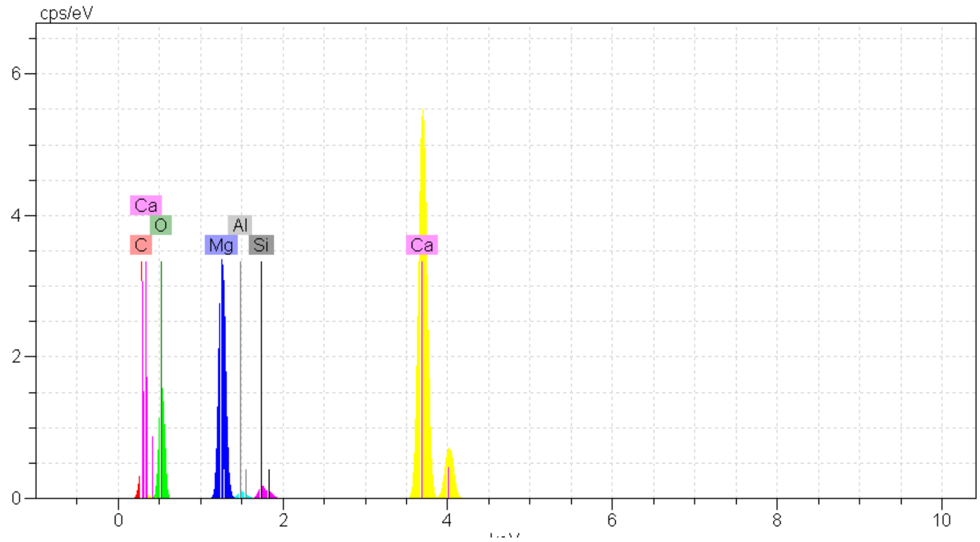


Figure 22. The EDXS of B place of gelatin concrete

Table 6

The EDXS of A place of gelatin concrete

Element	Unn wt, %
Carbon	6.27
Oxygen	40.14
Magnesium	12.38
Aluminum	0.43
Silicon	0.77
Calcium	20.33

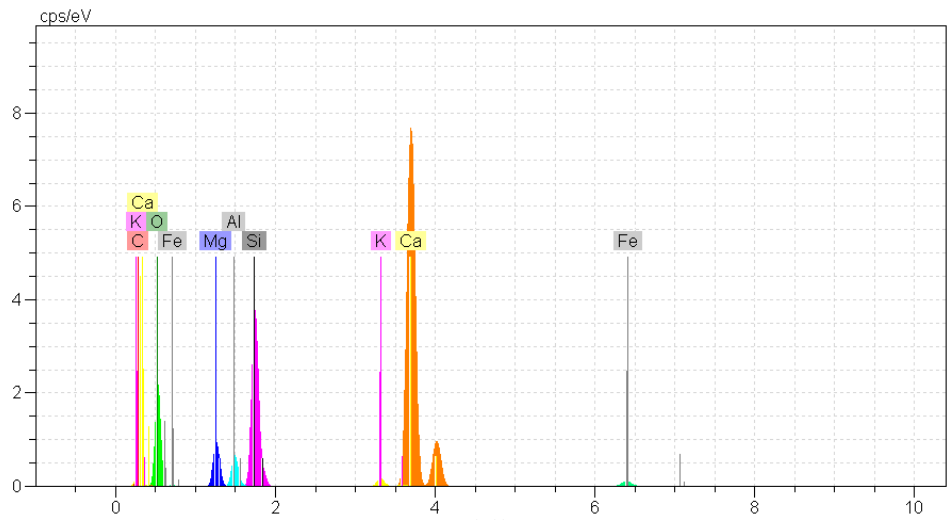


Figure 23. The EDXS of B place of gelatin concrete

Table 7

The EDXS of A place of gelatin concrete

Element	Unn wt [%]
Carbon	2.19
Oxygen	45.12
Magnesium	2.14
Aluminum	1.12
Silicon	6.37
Calcium	26.87

4. Conclusion

The current study investigated the effect of almond shells, gelatin powder, and recycled aggregates on concrete. According to the results, the gelatin powder had the maximum effect on the concrete's mechanical and durability properties. The mechanical test, such as compressive and tensile strengths and impact loading resistance, were applied. Water absorption and deep penetration were applied based on chemical resistance. The main conclusions and relevant suggestions are as follows:

1. GC had the best compressive strength and tensile strength, and the almond shell aggregates lost the weight of concrete samples.
2. The impact resistance was better for OC and GC. This show that the effect of gelatin powder is on the impact resistance of concrete.
3. The SEM results show that the crack between the almond shell and concrete was the reason of the weakness of almond shell concrete.
4. SEM of conventional concrete shows that the crystals are smooth, and EDXS results show silicon in the chemical properties of concrete.
5. Sharp and cubic crystals of two different types can be seen in gelatin concrete. Gelatin concrete had more open space than regular concrete, and sharps crystals outnumbered cubes crystals. While the cubic crystal has more carbon in its C-S-H gel, the sharp crystal has more silicon.

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