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Experimental evaluation of replacement of recycled mineral aggregate on the green pavement specifications using the non-destructive testing method

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Abstract

In recent years, utilizing concrete pavement in construction roads' pavement has been very popular. Concrete pavement is a compressed concrete which has distinctive features including high durability, low construction costs, and fewer efforts for repair and maintenance. Since that about 75-85% of concrete pavement is composed of stone materials, so utilizing recycled mineral aggregate can have positive environmental effects and enhancing the properties of concrete pavement. The present research addressed the investigation of utilizing five different types of queries' recycled aggregate obtained from Farshe Raahe Mehriz mines, Choghart and dolomite of large farm on the concrete pavement's strength. The types of these aggregates include Lime, Calcite, Albite Quartz, Amphibolite and Delomite. Some mechanical tests have been performed to determine the strength specifications of recycled mineral aggregate. Then, the concrete samples were made using compression test, and some non-destructive strength tests, including electrical resistance, Schmidt stiffness, and uniaxial compression strength have been performed on the samples. The results show that utilizing quartz aggregates prepared from tectonic blocks of Choghart mine pit, due to the high contents of silica, will lead to an increase in stiffness of concrete samples than the other aggregates used. Besides, the water absorption rate and stiffness of recycled mineral aggregate can be used as a reasonable index for determining the electrical resistance and stiffness of concrete samples.

Keywords: recycled mineral aggregate, concrete pavement, natural environment, non-destructive test.

Introduction

Safety in transportation is important from the perspective of the human environment[1], and the use of aggregates with good friction and low wear is very important for pavement construction.Concrete pavement mixture is a rigid and relatively dry mixture of aggregates, cement and water. Compared to ordinary concrete, this concrete has a higher density and durability, no need for rebar, higher execution speed and lower cost. This concrete mix should be used as a suitable pavement for parking lots, ports, military areas, roadsides and highways [1]. The resistance of this type of pavement to abrasion is satisfactory. Taken samples from properly executed pavements usually show high strength. For low-speed traffic, concrete pavement can be a good choice in many countries because it leads to significant cost savings, especially when special equipment is not required for the construction process [2]. Choosing the right source of aggregate is one of the essential factors in the quality and cost of pavement concrete [3]. Aggregates make up about 75% to 85% of the volume of concrete pavement mixtures and therefore have a significant effect on the properties of hardened and fresh concrete. Selecting the right aggregate will lead to more economic efficiency and better exploitation of road pavement. Aggregate properties affect the efficiency, detachment potential and compaction of fresh concrete. The strength, modulus of elasticity, thermal properties and durability of hardened concrete are also affected by the properties of the aggregate. Aggregates used in pavement concrete mixtures include fine-grained (aggregate finer than 4.75 mm) and coarse-grained (aggregate coarser than 4.75 mm). Coarse grains usually contain crushed or natural sand, or a combination of these. Fine-grained may also contain natural sand, crushed sand, or a combination of the two [4]. Nowadays a significant amount of waste or recyclable materials is produced in various mining factories due to industries development that happened as a result of economic growth and increasing the amount of mineral and industrial production, in addition to the extraction of the desired metal. Waste from mining industry includes rocks that are left behind and usually discarded after separating minerals and valuable materials from the ore. If these recycled mineral aggregates can be substituted for stone materials in pavement concrete, its destructive effects can be reduced. The effect of stabilized construction wastes usage on Reduction of the pavement grooves depth was investigated in other studies. For this purpose, construction material wastes were mixed with different percentages of lime and then treated for seven days. The final mixture subjected to a uniaxial compressive strength test. The results showed that the use of construction materials waste and its stabilization with lime on average 20% leads to a reduction in the depth of the grooves and increases the service life of asphalt pavement [5]. Researchers studied the effect of coal waste powder on the strength characteristics of pavement concrete. In this study, coal waste (Central Alborz Coal Washing Plant of Mazandaran) after pulverizing and bringing the grain size to the regulatory range, was replaced 5, 10, 20 and 30% of the cement weight in the pavement concrete mixture. Pavement concrete mixtures containing mixed cement (a combination of cement and coal waste powder) were investigated for mechanical properties (compressive and tensile strength) in 7, 28 and 90 day processing periods. The results show that 5% replacement of waste powder improves the strength properties of a concrete mix up to 90 days, but 10% and 20% replacement of this powder reduces the compressive and tensile strength of pavement concrete mixture at different ages. Also, with increasing the percentage of waste powder replacement, the mixing time was decreased [6]. Other researchers examined the use of coal tailings and ash in roller-compacted concrete pavement (RCCP) as well as a combination of limestone powder (LS) in coal tail ash (CWA). The main tests included compressive strength, hardness, toxicity Characteristic Leaching Procedure (TCLP) and microstructure analysis. The results showed that the use of LS mixture as a CWA supplement increases the mechanical properties, including compressive strength and hardness. It can also be concluded that the use of coal waste and its ash reduces the volume of hazardous waste in nature [7].In a recent study, zinc waste was investigated as a substitute for Portland cement in roller-compacted concrete mixtures containing RAP aggregates[8]. For this purpose, Jarosite (the second product of the zinc purification process, which is considered hazardous waste in the zinc industry) was used in roller-compacted concrete pavement (RCCP) as a substitute for Portland cement that was mixed with modified reclaimed asphalt pavement (RAP)[9]. Portland cement was mixed with Jarosite in proportions of 5%, 10%, 15%, 20% and 25% and replaced in mixtures containing 50% RAP aggregate and tested for mechanical properties, durability and microstructure. 5% of portland cement in mixture showed the best result and also the use of Jarosite in RAP-RCCP mixtures could provide environmental benefits such as reducing the load on landfill, reducing cement consumption and reducing the effect of carbon. Due to the large volume of mineral tailings near the mines, in addition to occupying a large volume, in many cases leads to damage and environmental problems that need special attention[10]. The possibility of using this waste in various industries, including the construction industry, is important. The use of these wastes reduces costs and energy consumption. It will also be an important step towards preserving the environment. The main purpose of this study is to investigate the use of recycled mineral aggregates in concrete pavement and its strength. Therefore, the physical properties of recycled mineral aggregates (moisture content, specific gravity, water absorption percentage) and their mechanical properties (Schmidt hardness, compressive strength, Young's modulus) were determined. Then mixing the aggregates and making concrete samples using compaction tests were done to determine mechanical properties (Schmidt hardness, electrical resistance, compressive sound wave velocity, longitudinal sound wave velocity, tensile strength, compressive strength and Young's modulus of 40%). To achieve these goals, five types of stone materials were used, all of which were broken and one material was used to make concrete. Consumables materials were from wastes and surplus stones that are produced during the ore production process. The type of used aggregates included limestone, dolomite, calcite, amphibolite and Quartz abiotrophy. In this study, based on the obtained data and statistical methods, the relationship between the characteristics of recycled mineral aggregates and concrete made of these stone materials is investigated.

2. Geographical location and material of recycled mineral aggregates

In this study, five types of recycled mineral aggregates (made of lime, calcite, abiotrophy quartz, amphibolite and dolomite) obtained from Farshe Raahe Mehriz mines, Choghart and dolomite of large farm were investigated (Fig. 1). The limestone prepared from Farshe Raahe Mehriz mine is a sedimentary rock that is used by Farshe Raahe factory of city Mehriz to make concrete and asphalt mixture (Fig. 1b). This mine is located 20 km southwest of Yazd, in the Yazd-Ardakan plain (Fig. 1a). Yazd-Ardakan plain is a tectonic hole that is located between Khoranagh Mountains in the east to north and Shirkuh in the south to southwest. The incline of Khoranagh Mountains is towards the north and Shirkuh Mountains towards the west. Between these two chain mountains, the remnants of the Third Age features are protruding in the form of low conglomerate-sandstone hills, which have changed the local topography and created special geomorphological conditions. Important and high mountains of this region are mostly made of Cretaceous calcareous formations [11]. Calcite rock was prepared from the tailings of the Farsh Rah

Mehriz limestone mine, which is a sedimentary rock (Fig. 1b). This stone is a wastes of this mine and the company does not used in the concrete and asphalt pavement by this company. It is present in the amount of one to thirty or less in the aggregate used by this company. Albitophy quartz rock is prepared from tailings of the area of tectonic block 1 (Fig. 1c) and Choghart iron mine.

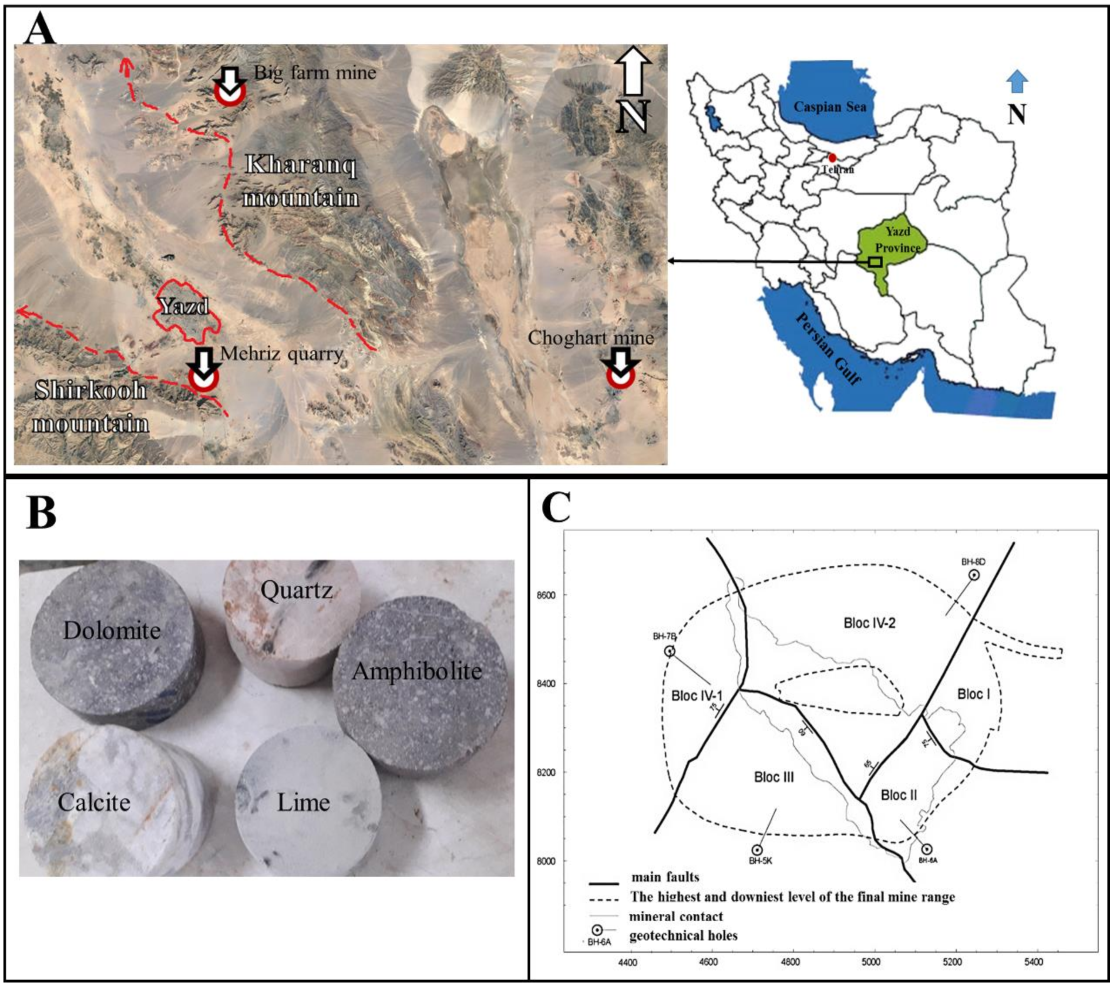


Fig. 1. (a) Geographical location of the studied mines; (b) the aggregates used; and (c) Tectonic blocking of Choghart mine area

This rock is an igneous rock. One of the characteristics of this stone is its high quartz content, which is very suitable to use in paving (Fig. 1b). Choghart mine is located 130 km east-southeast of Yazd and 13 km from Bafgh. Choghart deposit is a mass with a northwest-southeast trend, about 600 meters long and nearly 200 meters wide, which is exposed at the ground level. A wide variety of different sediments, both intrusive and deformed, can be seen around this deposit. The complex that forms the embedded rock of the mine has two completely different faces. Stones with a high percentage of quartz and feldspar, which have been named by geologists as quartzite, porphyry quartz, granophyre, keratofir and Quartz albitofir, and rocks with a high percentage of actinolite amphibole and altered parts as amphibolite, amphibole pyroxenite, hornblendite and metasomatites with different combinations of them have been mentioned [8]. This mine has phosphorous iron, and its deposit is magnetite. Choghart iron mine is formed inside metamorphic and igneous Precambrian igneous rocks [9] (Figure A-1).Amphibolite rock is also prepared from the tailings of the four-two tectonic block area (Figure C-1) of Choghart iron mine, which is an amphibolite igneous rock. Existence of iron and silica in its texture, is a characteristic of this stone . Dolomite ore from the large farm dolomite mine is a sedimentary rock (Figure B-1). The rocks of this mine are used to produce sponge iron. The stone is prepared from the surplus of the mine. This mine is located 55 km northeast of Yazd in the Yazd-Ardakan plain (Figure A-1).

3. Materials and Methods

3.1. Tests of recycled mineral aggregates

After preparation of mineral recycled aggregates, various types of physical and mechanical tests were performed on them, including moisture content (BS812) and water absorption percentage of coarse aggregates (ASTM C131)[12]. Studies have shown that the rock stiffness is related to uniaxial compressive strength and their modulus of elasticity. In fact, stiffness is one of the common concepts used to describe the behavior of rocks. Stiffness is related to intrinsic factors such as type of minerals, grain size, boundary adhesion of minerals, strength and elastic and plastic behavior of rock. Several methods have been proposed to determine the hardness of the rock. One of these methods is the use of a device called a Schmidt hammer, known as a vibratory or dynamic test. This method is used to determine the hardness of a rock using a Schmidt hammer in the desert or laboratory. Other properties of stone and concrete, such as its compressive strength, can be estimated, using this hardness. This method is standardized by the International Society of Rock Mechanics (ISRM). This test was performed on both aggregates and prepared concrete according to the standard (ASTM C805).

Another experiment performed to determine the mechanical properties of mineral recycled aggregates is the uniaxial compressive strength test of rock. This experiment is used to measure the uniaxial compressive strength of cylindrical specimens and to draw stress-strain curves, as well as to calculate Young's modulus and Poisson's ratio. This test is the most common laboratory test for mechanical studies of pure rock. Uniaxial compressive strength test performed using the standard (ASTM D2938, 2005). In addition to obtaining the compressive strength of each sample, the Young E modulus (the ratio of axial stress to the corresponding axial strain under uniaxial load) was also determined. The rock high-frequency sound wave velocity test was used to determine the transmission speed of high-frequency pressure (P) and shear (S) waves in the rock. These waves' speed depends on the compressive and tensile strength of the rock or the rock's quality of the in general. This test was performed by an ultrasonic device according to the standard (EN12504-4) [?].3.2. Preparation method and non-destructive testing of concrete samples In this research, the mixing plan and the method of making concrete samples are based on the soil compaction method. The maximum size of stone materials is 19 mm according to the concrete pavement design guide and according to ACI211 standard. In this method, the optimal humidity was determined according to ASTM D1557 standard. The cylindrical specimens with a diameter of 100 and a height of 200 mm were made in accordance with the standard -14 ASTM C39 to determine the compressive strength. Also, the indirect tensile strength was measured based on the standards ASTM C 49-11-11. Acoustic wave velocity tests on concrete samples were used to determine the transmission speed of high-frequency longitudinal (P) and transverse (S) waves in concrete. Ultrasonic pulse velocity is affected by the elastic and mechanical properties of concrete. In the high-frequency sound wave speed test, two transducers are used which are connected to both ends of the sample using a paraffin-like material. The transmitter converter generates a mechanical pulse, which is propagated along with the sample and received in the receiver converter. The tester measures the travel time of the wave from the transmitter to the receiver. By knowing the length of the sample, and the time of wave movement, the speed of sound in the tested sample can be calculated. This test was performed according to the standard (ASTM C597) on concrete samples. This experiment was performed by an ultrasonic device (Fig. 2).

Fig. 2. High-frequency audio wave speed device.

Another practical test for determining the strength of concrete was the electrical resistance test in accordance with the standard (ASTM C1760). In this test, water-saturated concrete is used, and the ease or difficulty of passing an electric current through saturated concrete can be a sign of its permeability to water. The main reasons for the disintegration of concrete are: sulfate attack, the alkaline reaction of aggregate, melting and freezing, reinforcement wear and corrosion, which is an electrochemical process that requires moisture and oxygen. Therefore, the presence of moisture and its ability to enter concrete and move in it are essential features because both sulfates and chlorides need moisture for alkaline reactions of aggregates and cannot occur in dry concrete. Another aspect of water infiltration is the increase in water volume at temperatures below 4 ° C, which increases the pressure on the adjacent concrete and leads to degradation. This test was performed on concrete samples to determine the amount of chloride ion, two weeks after treatment. The samples were first saturated in water for 24 hours and then tested by a laboratory electrical resistance apparatus (Figure 3). Then the electrical resistance was calculated according to Eq. (1).

$$\rho = \frac{V.A}{I.L} \qquad (1).$$

where, ρ, A, I, V, and L denote the electrical resistance (Ωm), the cross-section of the sample (m2), the current (A), the voltage (v), sample length (m), respectively.

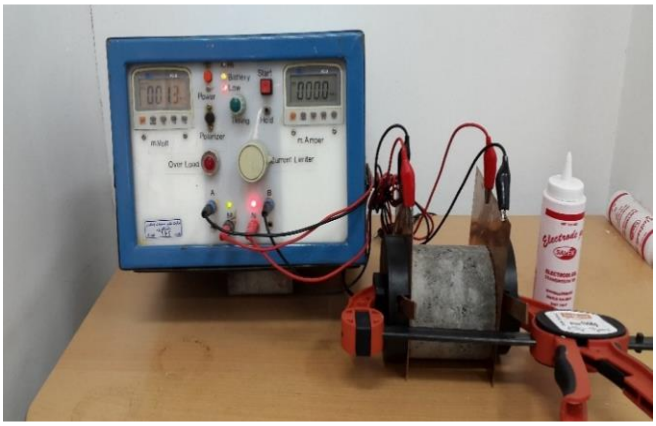


Fig. 3. Electrical resistance test device.

4. Results and discussion

4.1. Test results of recycled mineral aggregates Results of physical and mechanical experiments on recycled mineral aggregates can be seen in Table 1 and Fig. (4). Schmidt hardness of the stone is directly related to its compressive strength. Calcite rock has the lowest hardness (3) due to the presence of calcite mineral the highest Young modulus due to its crystalline structure. Quartz stone has the highest hardness of 7 due to silica (Table 1). Amphibolite has the highest specific gravity (more than 11% of control materials) for the iron in the rock composition. Dolomite also has a high specific gravity due to the presence of 20% magnesium in it. Moisture content is within the allowable range (maximum allowable 25% based on (BS 812)). The water absorption percentage of all samples is less than 2.5% (According to the standard, maximum water absorption of materials is 2.5%). Dolomite had the highest percentage of water absorption compared to other stone materials. Also, the results of a high-frequency sound wave velocity test (Fig. 4) showed that the quartz sample has the highest sound wave velocity. The reason is the high hardness of this sample.

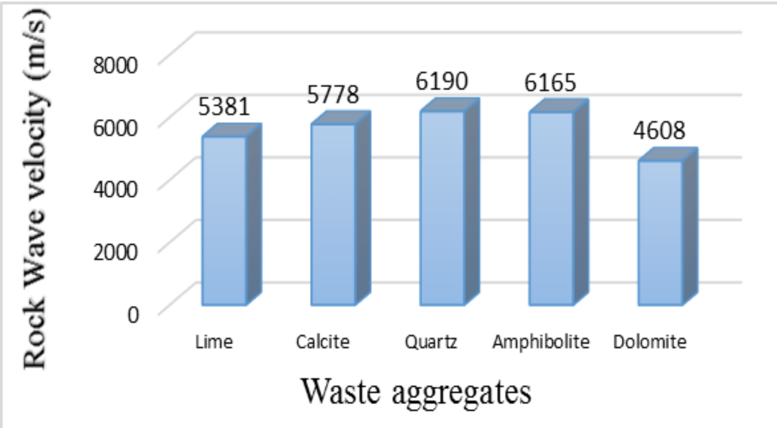


Fig. 4. Results of high-frequency sound wave speed experiments

Table 1. Summary of test results of recycled mineral aggregates

Water absorption percentage	Moisture Content	Specific gravity (gr/cm^3)	Young's modulus (Gpa)	Compressive Strength (Mpa)	Schmidt hardness (Mpa)	Aggregates type
0.469	0.137	2.73	7.69	34.70	5.3	Lime
0.646	0.047	2.72	74.27	26.49	5.1	Calcite
0.482	0.154	2.65	13.48	62.17	6.99	Quartz
0.367	0.067	3.32	10.34	50.23	6.55	Amphibolite
0.843	0.033	2.89	9.65	32.19	6.18	Dolomit

4.2. Concrete sample test

Maximum dry density shows the lowest percentage of air cavity and the optimal amount of water. The amphibolite has the highest maximum dry specific gravity (Fig. 5). Besides, Quartz has the highest Schmidt hardness (Fig. 6) and compressive strength (Fig. 7). Amphibolite has the highest sound wave velocity (Fig. 8) and electrical resistance (Table 2).

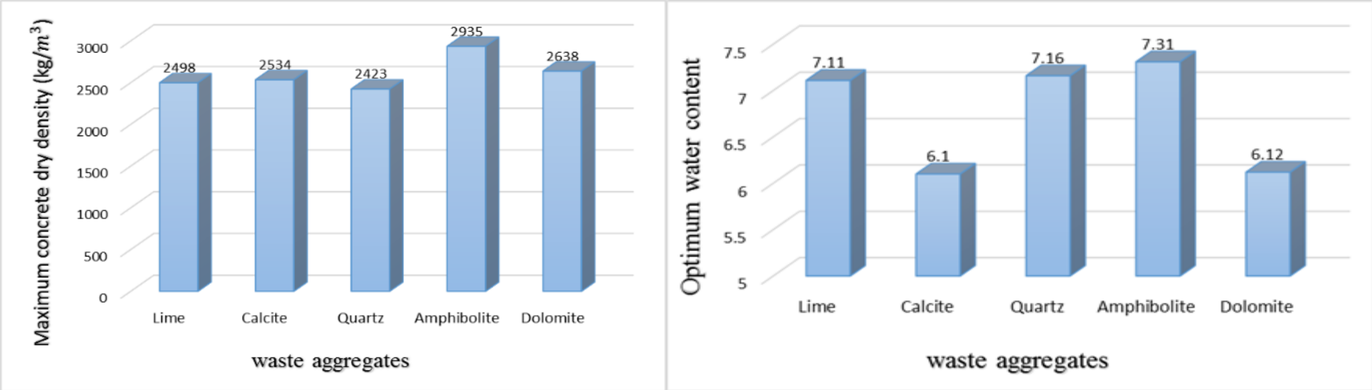


Fig. 5. Concrete compression test results

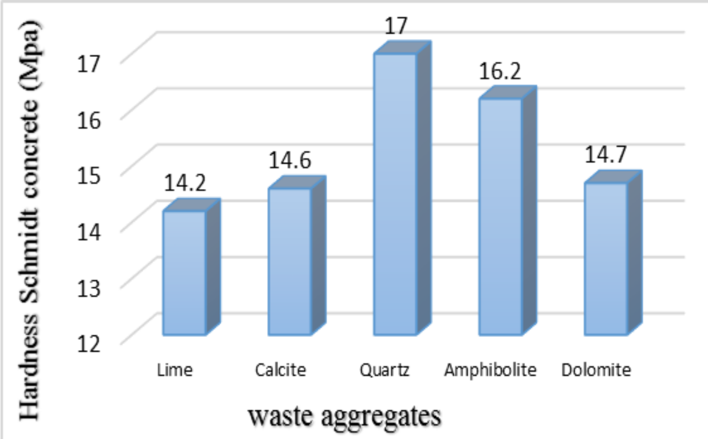


Fig. 6. Schmidt concrete hardness test results.

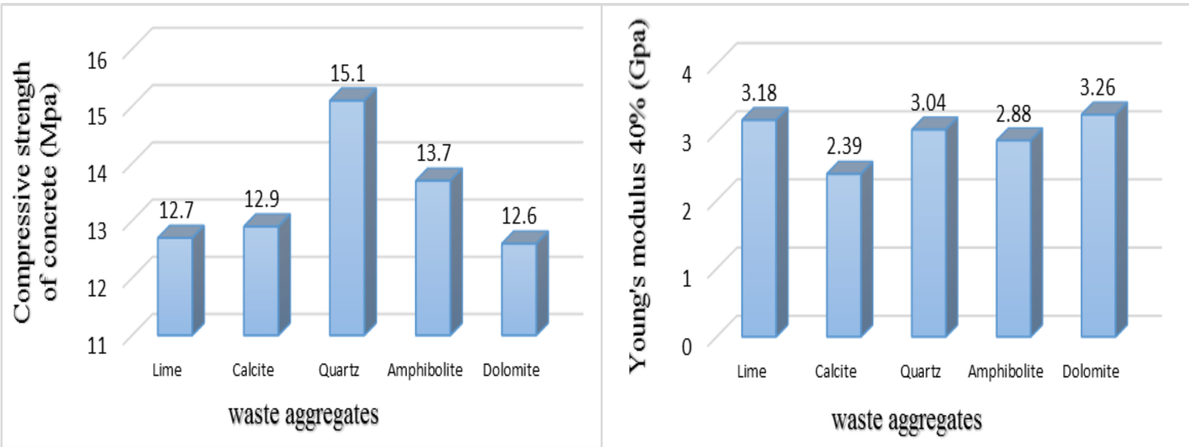


Fig. 7. Compressive strength and 'young's modulus of concrete.

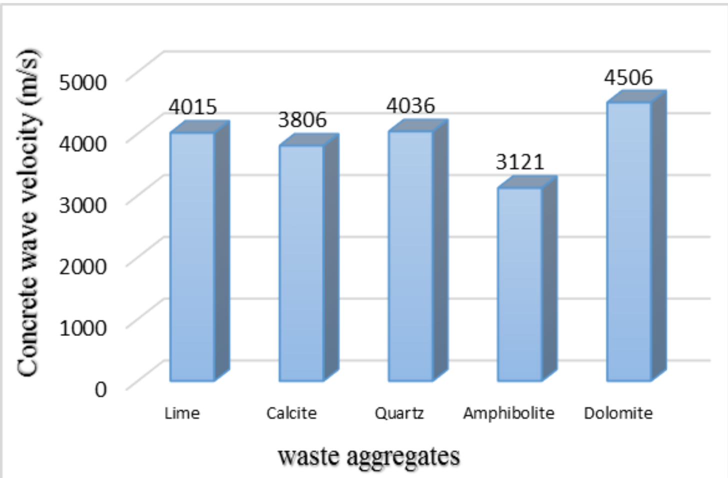


Fig. 8. Results of the sound wave velocity test on the concrete sample.

Table 2. Geometric characteristics and results of concrete electrical strength test.

Saturated unit weight	Water absorption percentage	electrical resistivity (Ω.m)	Voltage (v)	Flow (ma)	Sample surface (mm^2)	Sample height (mm)	Sample number	Waste Aggregates type
2.47	3.81	89.62	103.2	236.8	8328	40.5	AL	Lime
2.41	2.06	73.52	172.4	188.9	8007	99.4	BL	
2.44	2.94	81.57	average					
0.0009	0.76	64.8	Variance					
2.384	2.43	89.12	101.7	237.6	8328	40.0	AC	Calcit
2.382	1.33	100.41	175.6	184.6	8328	78.9	BC	
2.38	1.88	94.77	average					
0.00001	0.3	31.86	Variance					
2.35	2.56	77.02	92.8	240.0	8167	41.0	AQ	Quartz
2.36	1.52	100.15	185.5	161.4	8295	95.2	BQ	
2.36	2.04	88.59	average					
0.00005	0.27	133.74	Variance					
2.79	2.30	63.65	76.7	241.5	8167	40.8	AA	Amphibolite
2.77	2.35	55.59	106.8	229.2	8279	69.4	BA	
2.78	2.33	59.62	average					
0.0001	0.0006	16.24	Variance					
2.48	2.49	93.84	104.3	232.5	8409	40.2	AD	Dolomit
2.51	1.36	104.32	164.2	196.4	8247	66.1	BD	
2.50	1.93	99.04	average					
0.00025	0.32	27.45	Variance					

5. Relationship between strength properties of concrete and recycled mineral aggregates

Statistical regression models were used to investigate the relationship between the strength properties of concrete (electrical resistance, hardness, acoustic wave velocity) and recycled mineral aggregates (hardness, water absorption percentage, Young's modulus) (Fig. 9). The water absorption percentage of recycled mineral aggregates with the coefficient values of R^2 = 0.7 has a significant relationship with the electrical strength of concrete, as mentioned previously [13,14]. While the Schmidt hardness and Young's modulus of recycled mineral aggregates with coefficient values of R^2 = 0.07 and R^2 = 0.12, respectively, are unrelated to the electrical resistance of concrete. Also, the Schmidt hardness of recycled mineral aggregates with a coefficient of determination of R^2 = 0.79 has a significant relationship with the Schmidt hardness of concrete.

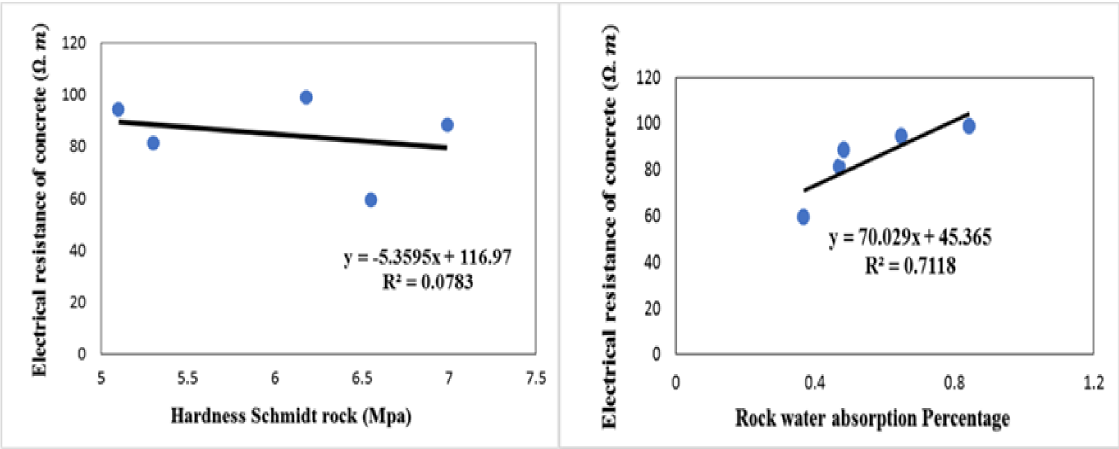
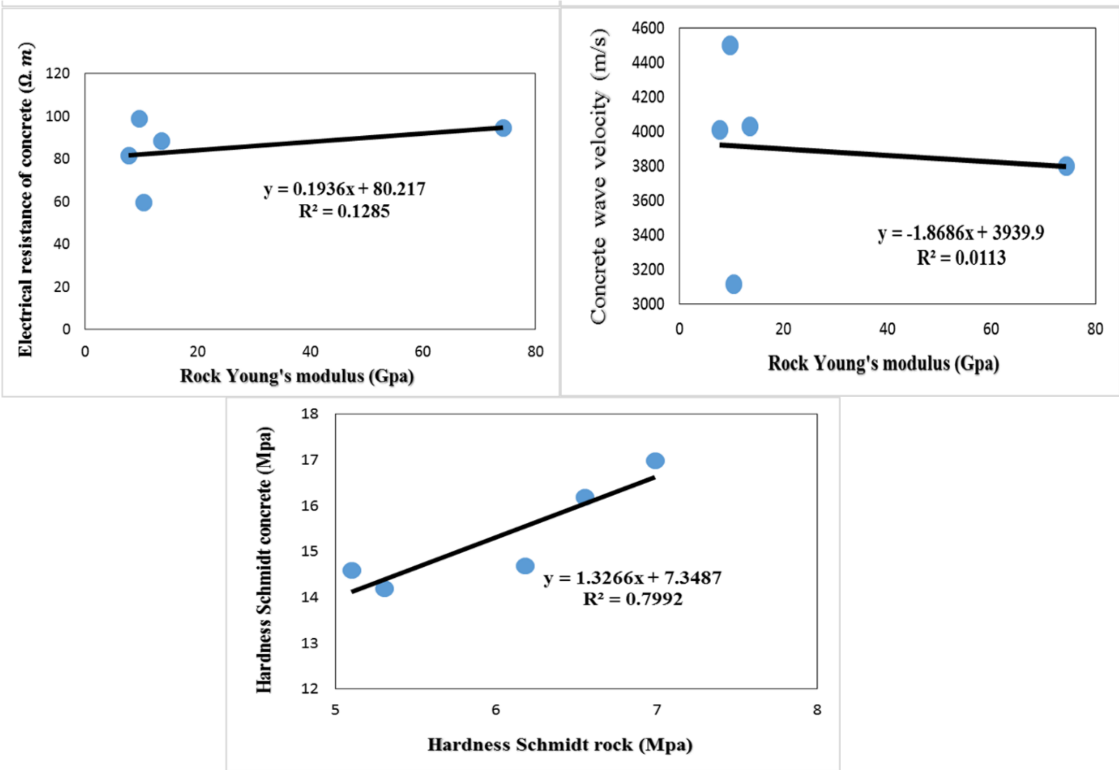


Fig. 9. Results of statistical methods to investigate the relationship between the strength properties of concrete and mineral recycled aggregates.



Continuation of Fig. 9. Results of statistical methods to investigate the relationship between the strength properties of concrete and mineral recycled aggregates.

6. Conclusion

In this research, the effect of recycled mineral aggregates on the concrete pavement's strength has been investigated. For this purpose, five types of aggregates were prepared from wastes of limestone mines, Choghart and dolomite of large farm. Then, the mechanical tests, including Schmidt stiffness, uniaxial compression strength, and sound wave speed, were performed to determine their mechanical specifications. The concrete samples' design mix using recycled mineral aggregates was done by the compression test. The non-destructive rests, including electrical resistance, wave speed, Schmidt stiffness, and uniaxial compression strength were performed to determine mechanical specifications. The results show that utilizing Quartz aggregates prepared from tectonic blocks of Choghart mine pit, due to the high contents of silica, will lead to an increase in stiffness of concrete samples than the other aggregates used. This is appropriate in points where the concrete pavement exposed to high stress. The statistical results of the relationship between strength properties of concrete and aggregates reveal that the percentage of water absorption of recycled mineral aggregates, with the determination factor of R^2=0.7, with concrete's electrical strength. On the other hand, Schmidt stiffness and Young's module of the aggregates with determination factor of R^2=0.7 and R^2=0.7, respectively, have no meaningful relationship with concrete's electrical resistance. Besides, it can be concluded that despite utilizing these wastes prevents the accumulation of large volumes of tailings near mines, it will reduce the costs and environmental issues too. Eventually, using such wastes mixtures recycled with recycled mineral aggregates is an action toward preserving natural resources and achieving a more environmentally friendly process.

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