Production of Artificial Aggregate by Utilizing Quarry Waste Material

H. Ozkan [1,2] **N. Miyan** [3] **T. Omur** [2] **N. Kabay** [2]

ABSTRACT

The dynamism of the construction industry is responsible for two main environmental problems: the significant increase in the amount of waste materials and the significant consumption of natural resources. Therefore, it is essential to find innovative solutions that can minimize cement use or reserve natural resources. Since aggregates cover approximately 60-80% of the concrete volume, the use of artificial aggregate (AA) in concrete has been investigated in recent years by utilizing waste materials at considerably high ratios, and these studies have generally used fly ash as the major component. Washing aggregate sludge (WAS) is a waste material generated during the production and classification of aggregates, without being properly utilized. Therefore, the primary purpose of this study is to efficiently use WAS to manufacture AA and to evaluate its effect on the concrete properties. The sintering method was employed for the AA production. The dried and ground WAS (<100 μm) was blended with ground granulated blast furnace slag (GGBFS) to manufacture sintered aggregate (SA). The manufactured aggregate properties were characterized by physical, mechanical, chemical, and microstructural tests and the optimum sintering duration and temperature were found as 15 min and 1150 °C, respectively. Concrete specimens were also produced by introducing SA in replacement with the coarse aggregate. The concrete test results showed the possibility of producing SA using WAS and its efficient utilization in concrete production. Considering the mechanical properties of concrete, the optimum SA ratio was found as 30%.

Keywords: Artificial aggregate; Washing aggregate sludge; Waste material; Sintering

1. INTRODUCTION

The construction industry is considered a critical indicator of the national economy [1] and the development of sectoral activities requires a high rate of concrete production. Concrete is the most widely used building material in the construction industry [2] and concrete production requires approximately 1.6 billion tons of cement, 10 billion tons of aggregate, and 1 billion tons of water per year. Therefore, concrete production is one of the activities that cause significant depletion of natural resources [3]. It is important to investigate the applicability of alternative and sustainable materials as a replacement of natural resources in concrete production.

In the last few years, the use of industrial by-products through blending or partial replacement of ordinary Portland cement (OPC) has become popular [4]. Since the volume of aggregate used in concrete occupies approximately 65-75% of the total volume of concrete, the utilization of industrial

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[1] Betão Liz, CIMPOR Group, Lisbon, Portugal. hozkan@cimpor.com
[2] Yildiz Technical University, Istanbul, Turkey.
[3] University of Rhode Island, Civil and Environmental Engineering, Kingston, RI, United States.

by-products in the production of artificial aggregate (AA) is seen as a more efficient solution in terms of high consumption of waste materials.

AAs are man-made materials whose properties mainly depend on the production process (granulation and hardening) and the type of primary raw material [5]. Three major production techniques are preferred to improve the mechanical properties of AAs, including sintering, cold bonding, and autoclaving [5]. In the past, mining waste [6], sewage sludge [7], aggregate washing sludge [7], different types of ashes [8], and natural materials [9] have been used for the production of AAs. However, in most of these investigations, waste material was not used as a primary material in the production of AAs.

Washing aggregate sludge, one of the main waste materials of aggregate quarry operations is a silty clay material [10] that is generated during the classification of aggregates [11]. WAS is usually sent to landfills without evaluation, where it is stockpiled. However, the inadequacy of disposal sites and European Union regulations have increased attention towards the development of new approaches that enable the recycling of this type of waste [12].

In the literature, there are limited studies on the utilization of WAS as AA and its use in concrete. This study aims to present a methodology to produce sintered aggregate (SA) with the utilization of WAS obtained from a sandstone quarry located in Istanbul, Cendere, and its valorization in conventional concrete.

2. EXPERIMENTAL STUDY

2.1 Materials

In the production of SA, WAS and ground blast furnace slag (GGBFS) were used as raw materials. WAS was obtained from the sandstone aggregate quarry of OYAK Cement Concrete and Paper Group in Cendere, Istanbul, which produces crushed sand for concrete (Figure 1). The chemical composition and physical properties of the binders used in this study are presented in Table 1. While WAS consists mainly of SiO_2, Al_2O_3, and Fe_2O_3, GGBFS obtained from the OYAK Cement Bolu Plant consists of main components such as CaO, SiO_2, and Al_2O_3. The particle size distribution of the binders is presented in Figure 2. The median particle size (d50) of WAS and GGBFS were close to each other and were 10.70 and 9.93 µm, respectively. X-ray diffraction (XRD) results of WAS and GGBFS are shown in Figure 3.

Figure 1. (a) Washing system and (b) Aggregate washing sludge pile

Table 1. Properties of binders

Compound and Tests [%]	*Washing Aggregate Sludge*	*Ground Granulated Blast Furnace Slag*	*Ordinary Portland Cement*
CaO	4.45	37.50	63.50
SiO_2	52.56	39.00	19.70
Al_2O_3	16.69	12.50	4.95
Fe_2O_3	8.41	1.00	3.50
MgO	3.76	5.00	1.50
Na_2O	1.63	0.60	0.25
K_2O	3.95	0.20	0.60
SO_3	0.60	0.20	2.85
Specific gravity (g/cm^3)	2.85	2.90	3.16
Specific surface area (cm^2/g)	5420	5300	4000

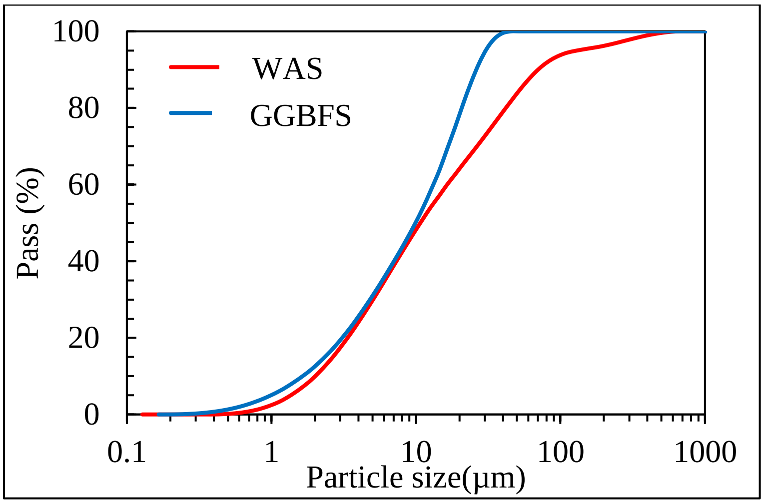

Figure 2. Particle size distribution of raw materials

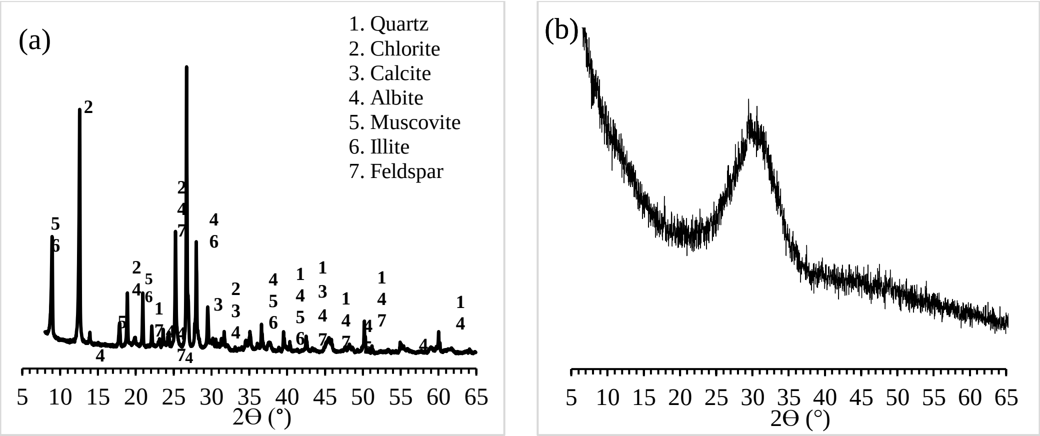

Figure 3. XRD results of a) WAS and b) GGBFS

2.2 Aggregate production

Artificial aggregates (AAs) were produced using equal proportions of WAS and GGBFS, each 50% by mass. GGBFS and WAS were initially mechanically mixed in a mixer to ensure homogeneity, then gradually added to the pelletizer to initiate agglomeration, and water was continuously sprayed on the mixed powder to obtain fresh pellets (Figure 4). The disk angle and rotation speed of the rotating drum of the pelletizer were set at 70° and 42 rpm, respectively, after several trials, taking into account the efficiency of aggregate yield. The agglomerated aggregates were collected from the disk, stored under closed conditions for 24 hours, and dried in an oven at 105 °C before sintering. The oven-dried pellets were sintered at target temperatures of 1100 °C and 1150 °C for 15, 30, and 60 minutes at a heating rate of 25 °C/min. The target temperatures were selected after several preliminary trials, as lower temperatures (<1100 °C) do not provide sufficient strength, and higher temperatures (> 1150 °C) cause softening and sticking of the pellets. Mixture compositions and sintering parameters are presented in Table 2.

Figure 4. The appearance of a) Pelletization machine, and b) Fresh pellets

Table 2. Artificial aggregates curing conditions

WAS (%)	*GGBFS (%)*	*Sintering Temperature (°C)*	*Sintering Time (min)*
50	50	1100	60
50	50	1150	60
50	50	1150	30
50	50	1150	15

2.3 Concrete production

Sintered aggregates (SAs) were substituted with coarse aggregate in certain proportions and their effect on the properties of conventional concrete was investigated. In the reference concrete, coarse aggregate, crushed sand (0–4 mm), and natural sand (0–2 mm) were used in proportions of 45%, 35%, and 20% respectively. SA was substituted with coarse aggregate (4–11.2 mm) inc three different proportions of 15, 30, and 45% by volume. The produced WAS-containing aggregates were sieved before use in concrete mixes to comply with the coarse aggregate size range (4–11.2 mm). CEM I 42.5R type OPC was used as a binder in concrete production. A commercially available polycarboxylate formaldehyde-based superplasticizer was used in a fixed proportion to adjust the workability of the concrete. The water/cement ratio by mass was kept constant at 0.50 for all mixes. Table 3 shows the mix proportions of the concrete designs and in total four different concrete mixes were prepared.

Table 3. Concrete mix proportions

Material	*Ref*	*Mix 1*	*Mix 2*	*Mix 3*
Cement	360	360	360	360
Water	180	180	180	180
Chemical admixture	7	7	7	7
Natural sand	355	355	355	355
Crushed sand	640	640	640	640
Coarse aggregate	826	702	579	455
Sintered aggregate	0	91	183	274

2.4 Tests

Mechanical and physical tests were carried out in order to characterize the SAs. Particle crushing strength (PCS) was determined by placing aggregate particles between two parallel plates and axially loading each particle until failure using a compression machine with a capacity of 28 kN. A total of 15 aggregate particles were used for the testing of each mix and PCS values were calculated using the following equation (Eq.1)

$$PCS = (2.8F/\pi D^2) \tag{1}$$

The compressive strength of the concrete specimens was determined at 28 days on three 150x150x150 mm^3 cube specimens according to EN 12390-3 and the average values were reported. The water absorption and oven dry density of the concretes were determined according to ASTM C 642 standard using cylinder specimens with 100 mm diameter and 50 mm height.

3. RESULTS AND DISCUSSION

Table 4 shows the mechanical and physical properties of the SAs. Increasing the sintering temperature from 1100 °C to 1150 °C increased the PCS value by about 67%, indicating the optimum sintering temperature, and yielded PCS values around 10 MPa. In the next step, the sintering time was reduced from 60 minutes to 15 minutes to observe its effect on PCS. It was observed that reducing the sintering time did not make a significant difference in the PCS values. On the other hand, the 24-hour water absorption of the SAs was reduced to 22.8%, when the sintering temperature down to 15 min. The physical, mechanical, and environmental performance of artifical aggregates are considered as the criterias for utilization in concrete. The observation that sintering at 1100 °C resulted in markedly inferior mechanical performance relative to sintering at 1150 °C underscored the preference for 1150 °C as the optimal temperature. Additionally, the enhancement of physical properties without substantial compromise in strength and density, despite the reduction of sintering duration from 60 minutes to 15 minutes, along with the considerable decrease in environmental impact, significantly influenced the choice of aggregate for concrete production. The oven-dry and SSD density of the SA were 1640 and 2010 kg/m^3, respectively, and the loose bulk density was 940 kg/m^3. Thus, the 4 coded artifical aggregate was selected to use in the preperation of concrete samples. The results indicated that the SAs could be classified as lightweight aggregates according to EN 206. It was also found that the water absorption of the SA was significantly high depending on various properties such as binder compositions and sintering temperature.

Fig. 5 shows the physical properties of the concrete specimens. The oven-dry density of the concrete mixtures ranged from 2315 to 2159 kg/m^3 and it was found that the addition of SA consistently reduced the density of the concrete, which is due to the lower particle densities of Sas compared to natural coarse aggregates. On the other hand, the water absorption and permeable voids of the concrete specimens increased with increasing SA replacement ratio. This can be attributed to the porous nature of the SA compared to the coarse aggregate it replaced. Water absorption and permeable voids were about 40% and 33% higher in the Mix 3 compared to the reference concrete, respectively.

Fig. 6 shows the mechanical properties of the concrete specimens. The results show that up to 45% replacement of coarse aggregate with the SA reduces the 28-day compressive strength from 55.3 MPa to 46.6 MPa. On the other hand, the concrete mixes containing 15% and 30% sintered WAS aggregates (Mix 1 and Mix 2) showed similar or comparable compressive strength with REF concrete. As such, the compressive strength of Mix 1 was only 4.7% lower than REF concrete and achieved up to 52.7 MPa at 28 days curing age.

Table 4. Physical and mechanical test results of sinter aggregates

Aggregate Code	*Sintering Temperature (°C)*	*Sintering Time (min)*	*PCS (MPa)*	*Water Absorption (%)*	*Loose Unit Weight (kg/m³)*	*Dry-oven Density (kg/m³)*
1	1100	60	6.4 ± 1.7	25.1 ±1.3	920 ±40.1	1615 ±53.5
2	1150	60	10.7 ± 2.5	24.0 ±1.7	930 ±52.5	1630 ±62.4
3	1150	30	10.0 ± 3.1	23.6 ±1.5	950 ±35.3	1630 ±44.6
4	1150	15	10.0 ± 2.1	22.8 ±1.0	940 ±62.5	1640 ±75.0

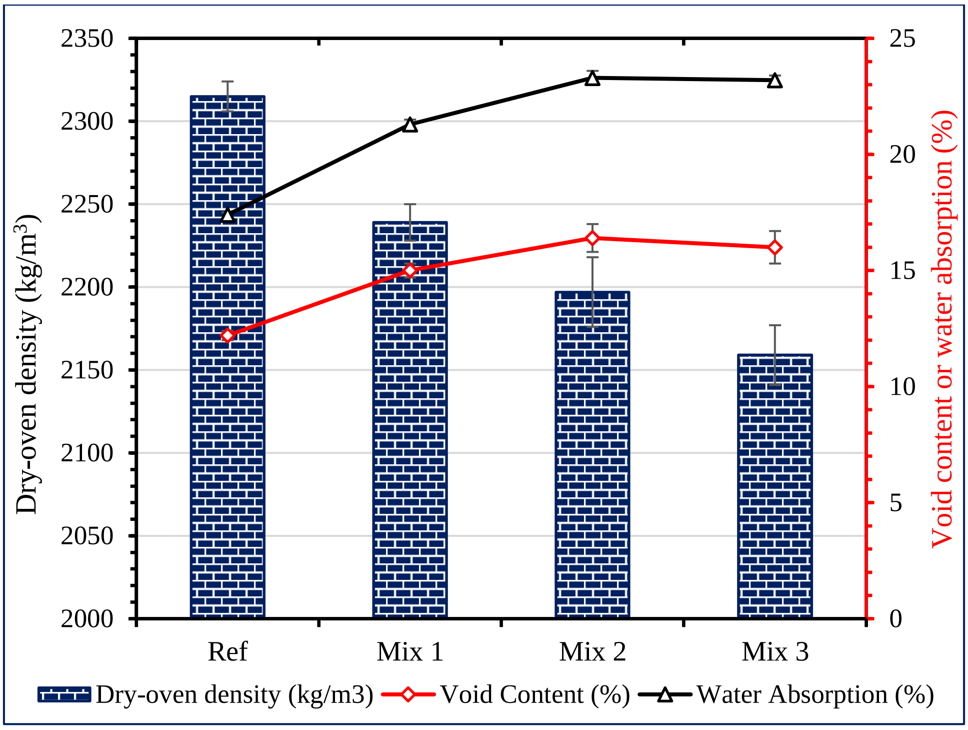

Fig. 5. Physical properties of concretes

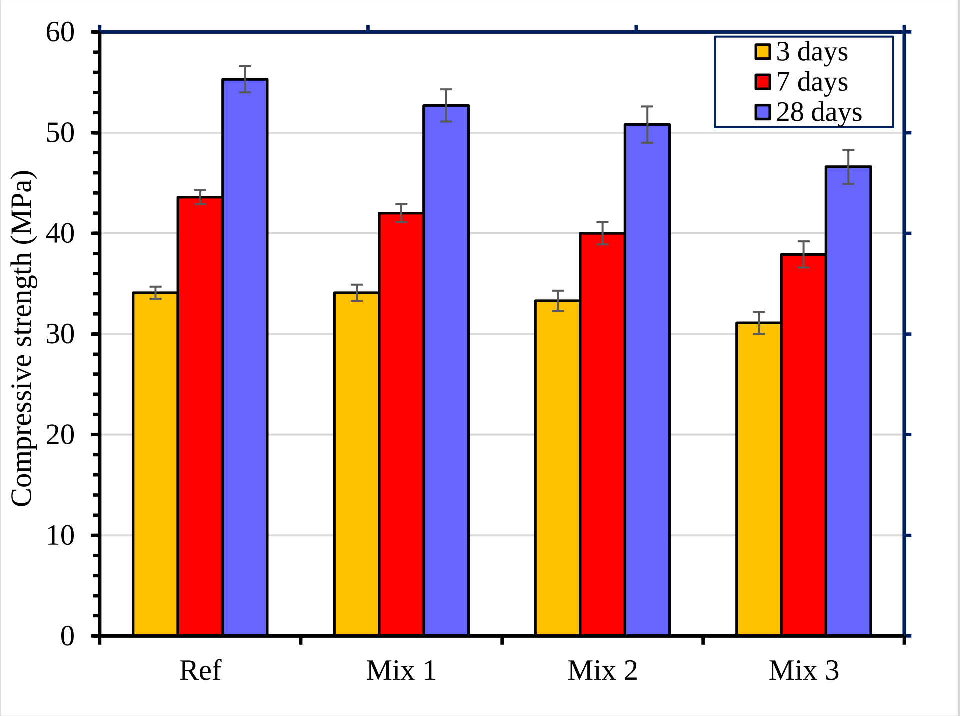

Fig. 6. Mechanical properties of concretes

CONCLUSION

This study presents the use of WAS as an alternative raw material in the production of artificial aggregates. The properties of the sintered aggregate were characterized and also used in concrete by substituting with coarse aggregate to investigate its effect on the physical and mechanical properties of concrete. Based on the experimental results the following conclusions can be drawn:

- It was determined that the aggregates produced using WAS by the sintering method were classified as lightweight aggregates.
- Increasing the sintering temperature from 1100 °C to 1150 °C increased the particle strength of the sintered aggregate by more than 50%. However, the sintering time did not cause a significant change in strength, and 15 min of sintering was found as optimal sintering duration considering the physicomechanical and ecological performance of SAs.
- Substitution of sintered aggregate up to 30% reduced the strength of concrete by 8%. However, even concrete produced by substituting 45% of sintered aggregates achieved the same concrete class.
- The oven-dry density of the concrete decreased with increasing sintered aggregate content, while water absorption and permeable voids increased.
- The proposed methodology offers an alternative approach to environmentally friendly, sustainable production. It also provides a solution to efficiently utilize the WAS waste produced by the washing plant of aggregate quarries, which can help conserve the natural resources used to produce aggregates.

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The Effect of Fines Content on Durability of Concrete Produced with Two Different Water/Cement Ratios

H. Ozkan [1,2]

ABSTRACT

In this study, the effect of fine material content (<63 μm) of crushed sand provided from limestone quarry on the mechanical and durability properties of concrete was investigated. Two series of concrete mixes were prepared with water-to-cement ratios of 0.38 (L mix) and 0.58 (H mix), respectively. Blast furnace slag cement (type CEM III-B 32,5N) was used in the concrete mix design to enhance the service life of concrete (100 years of durability). The dosage of slag cement used in the concrete mixtures was 380 kg/m^3 in the L mix, while it was 280 kg/m^3 in the H mix. The mechanical and durability properties of concretes were assessed by conducting compressive strength, ultrasonic pulse velocity, rapid chloride migration, and electrical resistivity tests. The results showed that for the L mix concretes, the increment of fines content from 0% to 15% did not have a clear effect on compressive strength. On the other hand, for the H mix, compressive strength increased with the addition of limestone fines (LSF). Furthermore, the rapid chloride migration resistance decreased with the increment of LSF for both mixes. Ultrasonic pulse velocity and electrical resistivity tests also supported the durability test results. It can be concluded that durable concretes can be produced from CS with around 10% LSF.

Keywords: Fine material; Limestone; Durability

1. INTRODUCTION

Concrete is one of the main materials used in the construction industry which also has a great impact on the service life of the structures. Concrete basically consists of coarse and fine aggregates, water, cement, mineral, and chemical admixtures. A large portion of the concrete volume consists of aggregates [1]. For this reason, aggregate properties have a significant effect on the concrete properties. The effect of aggregates on concrete performance varies depending on their physical, mechanical, and chemical properties.

The production of crushed sand has increased recently due to the scarcity of natural sand resources, to meet the demand for concrete. It has been observed that between 5% and 20% of fine material below 75 μm occurs during the crushed sand production in aggregate quarries [2]. The utilization of fine materials below 75 μm in concrete is restricted by the ASTM C 33. The main reason for this restriction is the clay and silt content of these fine aggregates. However, at the point where aggregate production has evolved today, clay and silt contents in aggregates can be minimized by selecting the appropriate rock structure and appropriate crushing methods [3] which has contributed to the widespread use of crushed sand in concrete [5].

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[1] Betão Liz, CIMPOR Group, Lisbon, Portugal. hozkan@cimpor.com)
[2] Yildiz Technical University, Istanbul, Turkey. hozkan@cimpor.com)

To ensure that future generations have enough resources to meet their requirements, the consumption of natural resources should be carefully monitored. The decline in natural sand resources has raised the demand for crushed sand for use in concrete. Over the last decade, researchers have focused on the effect of fines content in crushed sand on concrete performance. However, a limited number of these studies comprise their effects on the durability performance of concrete. Therefore, detailed research has been carried out to experimentally study the effect of fine content obtained from a limestone quarry on the durability performance of concrete.

2. EXPERIMENTAL STUDY

The experimental study was carried out focusing on the items as follows:

- Effect of various fines content on the mechanical properties of concrete,
- The effect of fines content on the durability performance of concrete,
- Non-destructive tests (NDT) to support durability results

2.1 Materials and methodology

In this study, the effect of varying amounts of fine material (below 63 μm sieve) on concrete performance was researched on concrete mixes produced with two different water-to-cement (w/c) ratios. Blast furnace slag cement (CEM III/B (S) 32.5 N) with slag content of 68% was used in the production of the concretes to obtain high durability performance. The chemical composition of the cement, which conforms the EN 197-1 standard requirements are shown in Table 1. Two coarse aggregates and crushed limestone sand from the same mineralogical sources were used in concrete mixes and their properties are given in Table 2. The crushed sand was made from pre-washed crushed limestone obtained from a quarry. The key steps were obtaining pre-washed crushed limestone sand, performing wet sieve analysis to isolate and control the fines content, and carefully grading/proportioning the sand to achieve the target fines percentages for each concrete mix. The controlled gradation data using different proportions of limestone fines in addition to the aggregates are given in Table 3. In addition, the gradation curves of crushed sand aggregates with different sizes of fine contents is depicted in Figure 1. This clearly shows the effect of fines on the gradation curve of crushed sand, in which the higher fines affected the gradation curve to 1 mm sieve sizes. A new generation phosphonate-based superplasticizing concrete admixture, which conforms the EN 934-2 was used in all concrete mixes to adjust workability. To produce the concrete mixes, initially, the solid materials were poured into a mixer and mixed at a dry state for 1 minute. Then water and high-range water reducer were added gradually and the mixing continued for another 2 minutes. The fresh concrete was poured into relevant moulds, and cured in water at a temperature of 20 ± 5 ° C until 28 days.

Table 1. Oxide composition of CEM III B 32.5 N cement

Compounds and Tests [%]	*Measurement Values*
SiO_2	32.59
Al_2O_3	8.68
Fe_2O_3	1.97
CaO	48.18
MgO	3.58
SO_3	1.76
Na_2O	0.35
K_2O	0.81
Na_2O Equivalent Total Alkali	0.88
Cl-	0.02

Table 2. Aggregate properties

Property	*Crushed Sand*	*4-12 mm*	*12-22 mm*
Specific Gravity	2.69	2.71	2.72
Water Absorption (%)	0.9	0.4	0.3
Fine Material Amount (%)	9	1	0.4
Water Soluble Chloride Content (%)	<0.001	<0.001	<0.001
Water Soluble Alkali Content (%)	<0.01	<0.01	<0.01
Acid Soluble Sulfate Content (%)	0.06	0.06	0.06
Methylene Blue Value	**0.25**	-	-

Table 3. Controlled gradation of crushed sand

Sieve Size (mm)	***Controlled Aggregate Gradation with Targeted Fines Content (<0.063 mm)***					
4	100	100	100	100	100	100
2	60	60	60	60	60	60
1	29	29	29	29	29	29
0.5	21	21	21	21	21	21
0.25	6	8	11	13	16	18
0.125	1	4	8	11	14	18
0.063	**0**	**3**	**6**	**9**	**12**	**15**

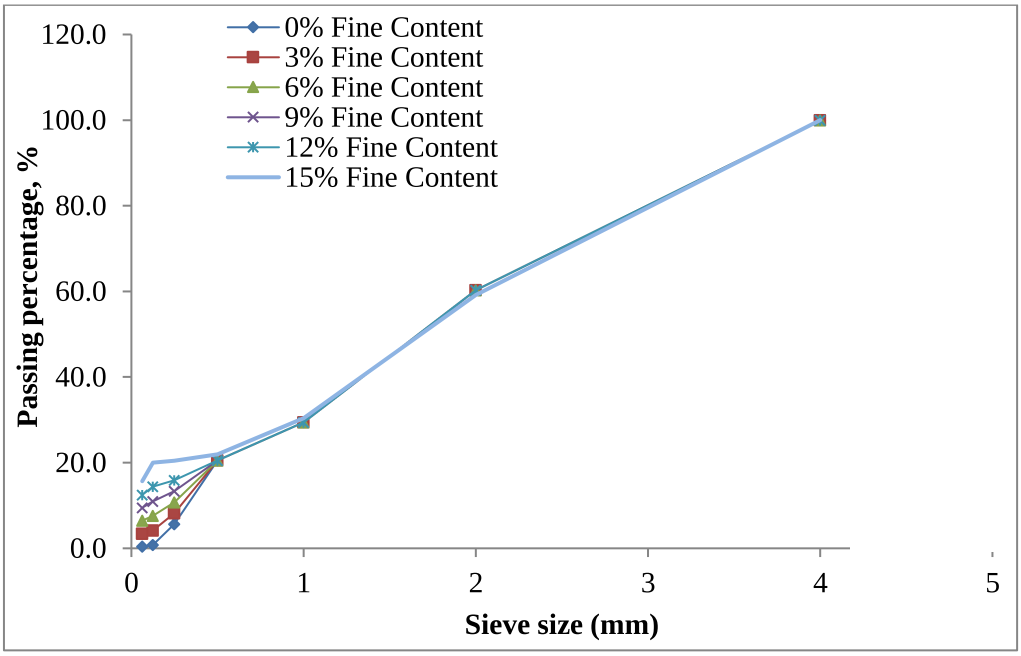

Figure 1. The gradation curves of crushed sand aggregates used in concrete

2.2 Concrete mix design

Two different series of concrete designs were made with w/c ratios of 0.58 (H mix) and 0.38 (L mix), where H and L indicate high w/c ratio and low w/c ratio, respectively. The cement dosages for the H and L mix designs were determined as 280 kg/m^3 and 380 kg/m^3, respectively. In the concrete designs, a total of six different ratios of fine materials were used as 0%, 3%, 6%, 9%, 12%, and 15% by mass compared to the aggregate. Detailed information about the concrete designs is given in Table 4. The fine content is adjusted via modifying the crushed sand aggregate gradation (see Table 3 and Figure 1). The 180±30 mm slump value was achieved by adjusting the dosage of chemical admixture.

Table 4. Concrete mix designs

Code	*Fine Content of 0-4 mm (%)*	*w/c Ratio (%)*	*Cement (kg/m^3)*	*0-4 mm (Crushed sand) (kg/m^3)*	*4-12 mm (kg/m^3)*	*12-22 mm (kg/m^3)*	*Chemical (kg/m^3)*
H-00	0	0.58	280	915	519	517	2.61
H-03	3	0.58	280	915	519	517	2.61
H-06	6	0.58	280	915	519	517	2.61
H-09	9	0.58	280	915	519	517	2.61
H-12	12	0.58	280	915	519	517	2.61
H-15	15	0.58	280	915	519	517	2.80
L-00	0	0.38	380	915	495	492	3.57
L-03	3	0.38	380	915	495	492	3.57
L-06	6	0.38	380	915	495	492	3.57
L-09	9	0.38	380	915	495	492	3.57
L-12	12	0.38	380	915	495	492	5.32
L-15	15	0.38	380	915	495	492	5.32

2.3 Experimental methods

In order to determine the workability of concretes, the slump test was performed following the EN 12350-2 standard for all mixes. Unit weight and the temperature of the fresh concrete were also measured. Table 6 shows the slump value of concretes. The compressive strength of the concrete samples was determined on 150×150×150 mm cubes at 28 days as shown in Table 6, in accordance with the TS EN 12390-3.

Ultrasonic pulse velocity (UPV) was determined in accordance with TS EN 12504-4 on cube specimens with a diameter of 150x150x150 mm at 28 days. The measurements were taken three times for each sample, and the average of the three readings was reported.

The non-steady state migration technique was used to determine the resistance of concrete against chloride ion migration following NT Build 492. Initially, the samples with a height of 50 mm and a diameter of 100 mm were covered with plastic tape and then saturated with lime water in the vacuum chamber. Then, 60 V (DC) was applied, and the new voltage with the test duration was determined according to the resistance of the samples to the chloride ion migration. After the test, the samples were split into two, and silver nitrate solution ($AgNO_3$) was sprayed over the surfaces. The part exposed to chloride ions appeared as a white color, and the chloride ion penetration depths were measured from 7 points.

Wenner probe resistivity was measured on the diametral line of 100 mm diameter x 200 mm high cylindrical specimens. In Wenner probe resistivity technique, four equally spaced electrical probes were used with the two applying low-frequency alternating current while the voltage drop between the two inner probes was measured.

3. RESULTS AND DISCUSSION

3.1 Effect of fines content on compressive strength

The effects of fines content on the compressive strength of concrete mixes are shown in Table 5 and Figure 2. The 28-days compressive strength of the H mixes varied between 34 MPa and 46 MPa, while the compressive strength of the L mixes varied between 65 MPa and 75 MPa. Considering the H mixes, the increase in fines content improved the compressive strength, and the highest strength was achieved in H-15 mix as 46.1 MPa. On the other hand, the fines content had no significant affect on the compressive strength of L mixes. The results indicate that the increase in fines content modifies the pore structure and provides nucleation sites for the cement hydration products which results in improved mechanical strength of H mixes.

Table 5. Compressive strength and slump values of concrete mixes

Code	*Fines Content (%)*	*Slump (mm)*	*Compressive Strength (MPa)*
H-00	0	190	34.0
H-03	3	190	39.2
H-06	6	200	40.2
H-09	9	200	42.5
H-12	12	190	41.6
H-15	15	180	46.0
L-00	0	180	72.1
L-03	3	190	73.7
L-06	6	190	65.3
L-09	9	150	71.0
L-12	12	200	67.8
L-15	15	200	74.7

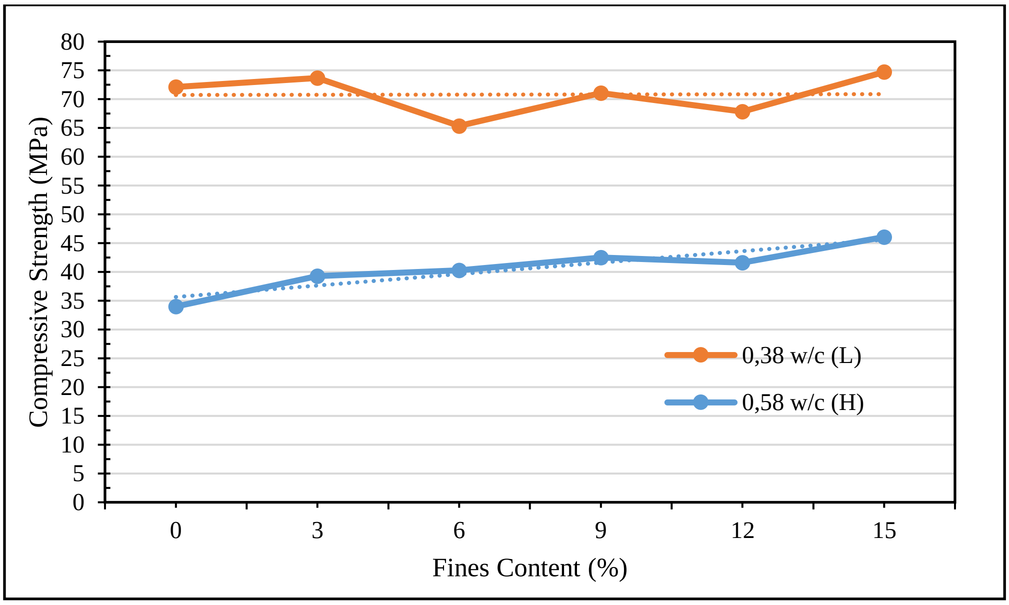

Figure 2. Compressive strength of samples

3.2 Effect of fines content on the durability properties of concrete

Rapid chloride permeability, ultrasonic pulse velocity, and electrical resistivity tests were carried out to determine the durability properties of concrete mixtures, and the results are shown in Table 6. The effect of fine material utilization rates on the rapid chloride permeability of concrete specimens is shown in Figure 3.

For L mixes, an increase in the fine material content had a significant effect on the chloride permeability coefficient. This is mainly due to fewer interconnected capillary pores as a result of higher strength achieved by high cement content and a low water/cement ratio. A similar trend was also observed for the H mixes, the increase in fine material content decreased the chloride permeability coefficient. The reduced permeability of the mixtures in both batches containing fines is due to the filler effect of the fines blocking the capillary passages formed during the hydration of the cement.

The results obtained from the electrical resistance tests are shown in Figure 4. The electrical resistance values ranged from 823 to 1168 Ohm.m for the L mixes, while for the H mixes, these values varied within a narrower range and ranged from 612 to 821 Ohm.m. It was observed that the electrical resistance decreased as the s/w ratio increased. In addition, with the substitution of fine material, the electrical resistance values showed a fluctuating trend for the L mixes, while the H series showed a flat trend.

Ultrasonic pulse velocity results are presented in Figure 5. It can be noticed that the pulse velocity of concrete samples generally increases with increasing fines content.

Both electrical resistivity results and ultrasonic pulse velocity results are consistent with the results of the rapid chloride permeability test. The relationship between chloride permeability and electrical resistivity values is given in Figure 6. The increasing electrical resistivity value in response to the decrease in the chloride permeability coefficient value supports well the results.

Table 6. Durability test results

Code	*Chloride Permeability Coefficient (10^{-12} m^2/s)*	*Electrical Resistance (Ohm.m)*	*Ultrasonic Pulse Velocity*
H-00	4.70	612	6784
H-03	4.13	616	6834
H-06	3.09	626	6713
H-09	3.25	739	6902
H-12	3.34	679	6913
H-15	2.95	821	6944
L-00	2.29	902	6969
L-03	2.17	823	7015
L-06	1.69	1069	7093
L-09	1.57	1006	7181
L-12	1.58	1015	7067
L-15	1.27	1168	7225

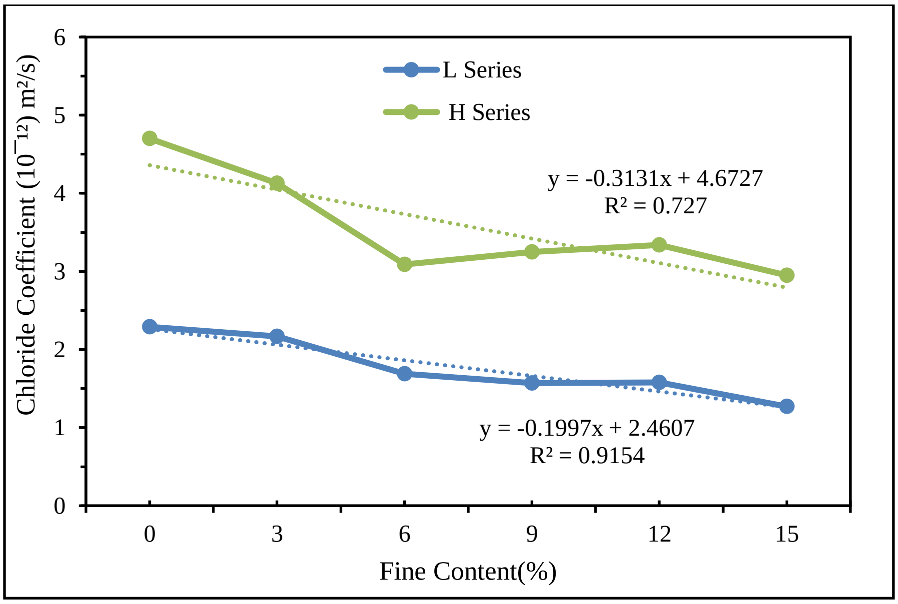

Figure 3. Rapid chloride permeability

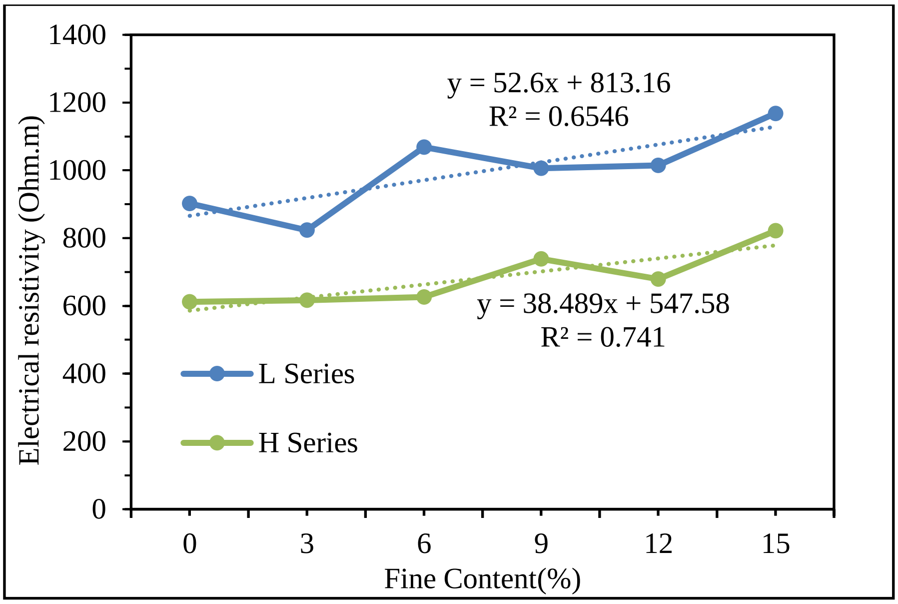

Figure 4. Electrical resistance result

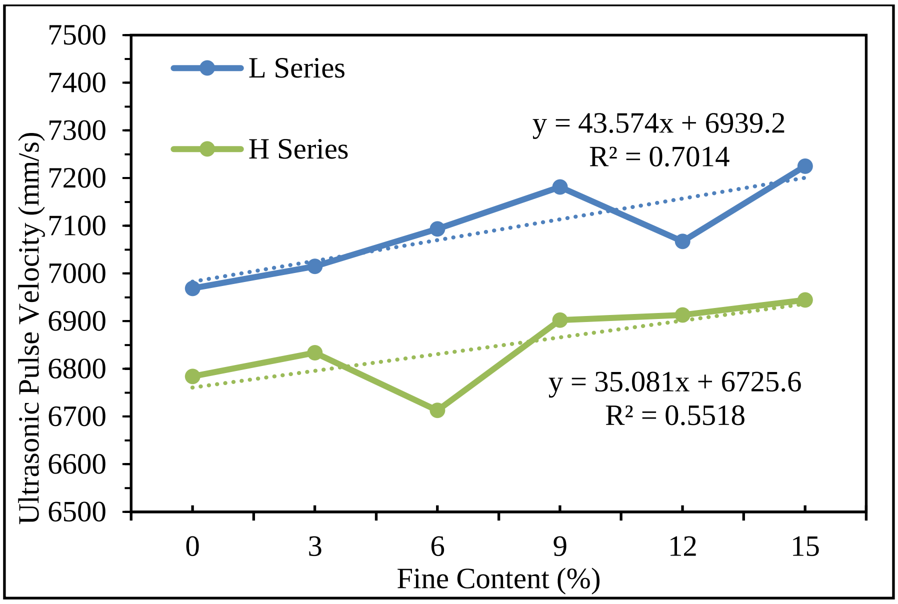

Figure 5. Ultrasonic pulse velocity result

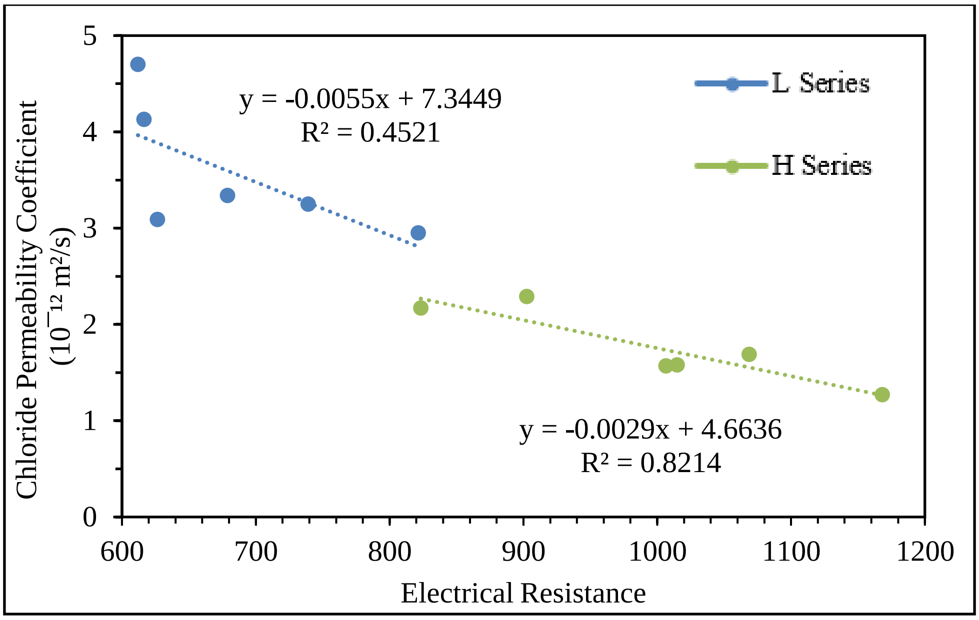

Figure 6. The relationship between chloride permeability coefficient and electrical resistance

CONCLUSION

In this study, the effect of limestone fines up to 15% on concrete strength and durability properties was investigated. The main conclusions drawn from the study are listed below:

- The utilization of crushed sand with fines content up to 15% improved the compressive strength of concrete mixes (H mixes) produced with relatively low cement content and high w/c ratio. On the other hand, the compressive strength was not significantly affected in L mixes where higher cement dosage and lower w/c ratio were used.
- The chloride permeability was significantly reduced with an increase in the fines content for both types of concrete mixes. The rate of decrease was higher for the H mixes.
- The electrical resistivity of the concrete mixes increased with an increase in the fines content. The highest values were achieved for both mixes when the fines content was 15%.
- The ultrasonic pulse velocity results indicate that the pore structures of concrete mixes are modified and more compact structures with less voids and flaws were achieved with an increase in the fines content.
- Crushed limestone, abundantly available, demonstrates effective performance, particularly in combinations with concrete containing elevated water/cement ratios (low strength), through a straightforward gradation adjustment method. Research indicates that utilizing crushed limestone with adjusted fine content, without the need for specialized filler material, which require further grinding operations, can enhance the workability, strength, and durability of low-performance concrete for in-situ applications.

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