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Research Article

Research on micro limestone for concrete pavements produced with natural aggregates in the Erzurum region

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ABSTRACT

The use of naturally formed aggregates in concrete pavements is an innovative and sustainable solution both environmentally and economically. This study investigates the usability of fine and coarse aggregates formed spontaneously in Oltu, Narman, Pasinler and Uzundere in concrete pavements by improving the mechanical properties of concrete. In the study, the compressive strength, flexural strength, water absorption capacity and capillarity permeability of the concrete samples planned to be used on concrete pavements were obtained by considering the contribution of these aggregates. In addition, microscopic electron scanning analyzes (SEM) were applied to visualize the internal cracks that may occur in the concrete. The test results showed that the concrete formed with aggregates from Oltu and Pasinler regions had the highest compressive, flexural and hardened unit weights. It has been concluded that the concrete produced from Uzundere region, which gives results below 35 MPa in terms of compressive strength, is not applicable on concrete pavements. In addition, considering the high compressive, flexural, unit weight and capillary permeability, it is predicted that the most suitable concrete design for the construction of concrete pavements is the P_0 (concrete formed with aggregates from Pasinler region) concrete sample.

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1. Introduction

Today, concrete pavements, formed with cement as a binding material, are a type of coating used on pavements exposed to medium and heavy traffic loads. Concrete pavements are examined in joint-free concrete pavement, joint-reinforced concrete pavement, and joint-free reinforced concrete pavement. In addition, concrete pavements can be formed as pre-stressed concrete, compacted with rollers and composite (Budak et al. 2009). Concrete pavements have advantages such as long structural life, being economical, being stiffness and having high strength, being applicable in all conditions, providing fuel savings and being costly (Kozak 2011). With innovations and rapid developments in concrete pavement technology such as ready-mixed concrete, slip form, permeable concrete, fiber concrete, pre-stressed concrete, and continuously reinforced concrete, concrete pavements have become an indispensable option against asphalt pavements for today's modern roads (Şengün et al. 2020). Generally, as an alternative to asphalt pavements, roller compacted concrete pavement is preferred because of its stiffness and non-collapsing, fast construction and efficiency (Nanni et al. 1996). Concrete, which forms the formation of roller-compacted concrete pavements, has a high volume of fine aggregate, low volume of binder, coarse aggregate and water (Lam et al. 2018).

Population growth, rapid urbanization and continuous economic developments create some basic needs in transportation (Strieder et al. 2022). To meet these needs, it is necessary to put forward innovative approaches in the transportation sector by using naturally occurring components. Bitumen, a product of petroleum decomposition, is used in the transportation field to reduce the decomposition of aggregates by interlocking

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and to reduce the water permeability of asphalt coatings (Airey 2002). However, bitumen that undergoes age-hardening has lower penetration and higher viscosity. As a result, bituminous pavement layers may deteriorate because the bituminous binder hardens and becomes more brittle and its adhesion with the aggregate decreases (Isacsson and Lu 1995; Suo and Wong 2009). In addition, considering that bitumen is a more costly material, concrete coatings have been considered a new alternative to asphalt coatings in recent years (Harrington et al. 2010; Komastka et al. 2003). In the concrete design to be used in the construction of concrete pavements developed as an alternative to asphalt pavements, the relevant standards (ASTM C944 2019) should be considered and with environmental conditions and application (Ebrahimi Besheli et al. 2021). In addition, attention should be paid to the compressive strength, durability, and tensile strength in flexural and non-wearing concrete, which is the main component of concrete pavements (Ebrahimi Besheli et al. 2021). In this context, to provide optimum mechanical properties in concrete, the design of binders, aggregates, plasticizers and set accelerator additives and solutions constituting concrete formation should be made. It is also recommended that the compressive strength of the concrete to be used in the construction of concrete pavements be higher than 35 MPa and the flexural strength higher than 5 MPa (Lee et al. 2005).

Researchers have conducted different studies on concrete pavements and concrete, one of the basic components that make up concrete pavements. Studies have shown that concrete pavements designed with aggregates obtained by recycling from construction and demolition wastes provide low energy consumption, less cost and optimum mechanical properties (Delongui et al. 2018; Lee et al. 2005; Sangiorgi et al. 2015). Reducing permeable surfaces in concrete pavements causes an imbalance in the hydrological cycle, reducing water seepage and significantly increasing runoff, which causes flooding due to excessive loads in the storm-water drainage system. To cope with these adverse situations, a permeable concrete consisting of rationally graded coarse aggregates with a minimum amount of aggregate and sufficient cement content to provide an optimum coating around aggregates without additives has been designed (American Concrete Institute 2010; Chandrappa and Biligiri 2016). Strieder et al. (2022) evaluated the performance of porous concrete pavements with recycled concrete aggregate. The study analyzed concrete permeability, hardened density, hydraulic conductivity, seepage, compressive and tensile strengths, abrasion resistance, modulus of elasticity, and Poisson's ratio. Laboratory study results showed that the replacement of recycled concrete aggregates (RCA) improves hydraulic properties and reduces mechanical behavior (Strieder et al. 2022). Keles et al. (2022) investigated the strength properties of roller compacted concrete pavement (RCCP) under different curing methods. According to the results obtained, it was determined that the best curing method for the compressive and flexural strengths of RCCP is water curing, which provides approximately 29% and 34% increase in strength compared to uncured mixtures (Keleş and Akpinar 2022). Eisa et al. (2022) investigated the use of metakaolin-based geopolymer concrete in concrete pavements. To determine how geopolymerization contributes to the mechanical properties of concrete used in concrete pavements, such as compression, flexural and tensile in bending, the mechanical properties of concrete produced with conventional Portland cement and the mechanical properties of metakaolin-based geopolymer concrete were compared. It was observed that geopolymer concrete pavements reached compressive strengths of 30.3 MPa and 32.3 MPa on the 7th and 28th days, respectively. In contrast, the conventional Portland cement concrete pavements reached a compressive strength of 14.0 and 33.1 MPa on the 7th and 28th days, respectively. The results showed that metakaolin-based geopolymer concretes are more suitable for use in concrete pavements than Portland cement concrete to achieve higher strength values, be less energy consumption, and be more environmentally friendly (Eisa et al. 2022). Acar (2022) investigated the usability of naturally formed Kayseri volcanic slags as filling material in flexible paved roads. The results showed that the geotechnical properties of volcanic slags could be improved by stabilizing them with cement, and it can be used as a construction material in the base fill, sub-base and foundation layers of flexible paved roads and all kinds of fillings (Acar 2022). Yıldız (2012) investigated the usability of self-forming pumice and zeolite added to concrete in road pavements. Wet concrete tests, hardened concrete tests and abrasion tests were carried out on high-strength concretes containing pumice and zeolite with different mixing ratios. The results showed that all mixtures met the minimum concrete strength values and wear limit values specified in ASTM C944 (2019).

In this study, the usability of natural aggregates in the Erzurum region on concrete pavements was investigated. Because concrete pavements that can be produced with local resources will be more economical. Therefore, the physical, mechanical and microstructural properties of concretes that can be used in concrete pavements production were investigated.

2. Experimental Studies

2.1. Material

The type of cement used in the study is CEM I 42.5 R according to the TS EN 197-1 Standard (EN197-1 2004). Micro limestone was used in the mixtures to reduce cement's environmental impact and increase its water absorption capacity (Bekem Kara 2020). The physical and chemical properties of cement and micro limestone are given in Table 1.

The mixture's aggregate is presented in Fig. 1 as 0-5 mm river sand, 0-5 mm stone dust, 5-15 mm fine gravel, 15-25 mm coarse aggregate. Each aggregate conforming to the ASTM C33 (ASTM C33 2016) standard was obtained from the Narman, Oltu, Pasinler and Uzundere regions. The sieve analysis of the blended aggregates used in concrete mixes is presented in Fig. 1. The mixing ratios of the blended aggregates in Fig. 1 are given in Table 2.

Particle sizes, specific gravity, water absorption capacities and fineness modules of naturally supplied aggregates are given in Table 2. Aggregates used in concrete mixtures are given in Fig. 2. In addition, water-reducing/plasticizer CHRYSO®Delta SL-T chemical additive was used to ensure that the hydration reactions in the mixtures were homogeneously at every point of the concrete and improved the strength and durability.

Table 1. Physical and chemical properties of cement and micro limestone used in the study.

Material		CEM I 42.5 R	Micro Limestone
Physical and Mechanical Properties			
Blaine's Fineness (cm^2/g)		3532	4780
Specific Gravity (gr/cm^3)		3.12	2.70
Setting (min)	Initial	155	-
	Finally	215	-
Compressive Strength (MPa)	7 days	26.7	-
	28 days	55.1	-
Chemical Components (%)			
SiO_2		18.99	1.67
Al_2O_3		4.62	0.40
Fe_2O_3		3.36	0.36
CaO		63.4	53.01
MgO		1.83	-
SO_3		2.80	-
Na_2O		0.27	-
K_2O		0.86	-
Glow Loss		2.17	-
Free CaO		0.7	-

Table 2. Physical properties of aggregates from different regions used in the study.

Region	Aggregate Size (mm)	Capacity of Water Absorption (%)	Modulus of Fineness
Narman	0-5 mm river sand (%55)	2.61	2.56
	5-15 mm fine aggr. (%25)	2.58	5.02
	15-25 mm coarse aggr. (%30)	2.59	6.13
Oltu	0-5 mm river sand (%30)	2.62	2.68
	0-5 mm stone powder (%25)	2.60	2.89
	5-15 mm fine aggr. (%19)	2.61	5.25
	15-25 mm coarse aggr. (%26)	2.60	6.47
Pasinler	0-5 mm river sand (%30)	2.59	2.14
	0-5 mm stone powder (%23)	2.60	2.89
	5-15 mm fine aggr. (%20)	2.61	5.95
	15-25 mm coarse aggr. (%27)	2.59	6.90
Uzundere	0-5 mm river sand (%57)	2.55	2.30
	5-15 mm fine aggr. (%24)	2.56	5.04
	15-25 mm coarse aggr. (%29)	2.54	6.61

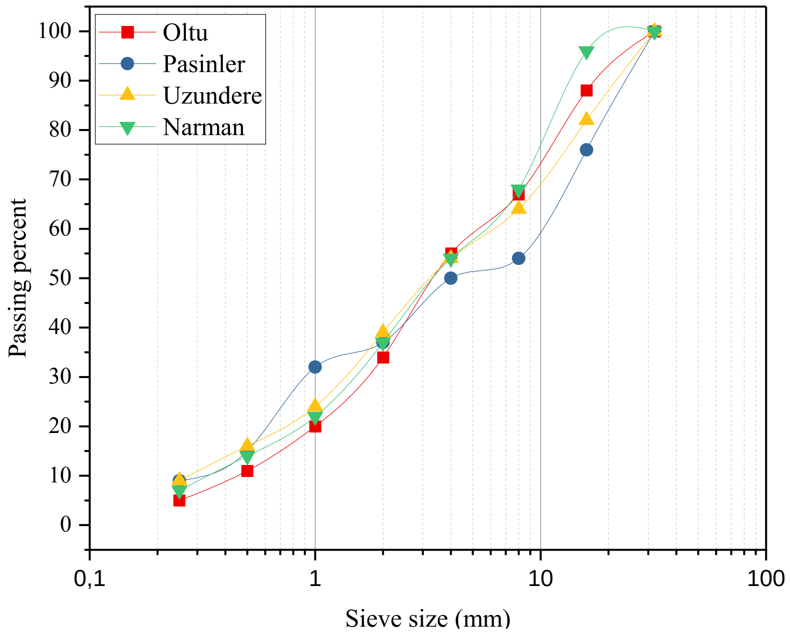


Fig. 1. Sieve analysis of the blended aggregates.

Fig. 2. Aggregates used in the concrete mix.

2.2. Mix design and curing

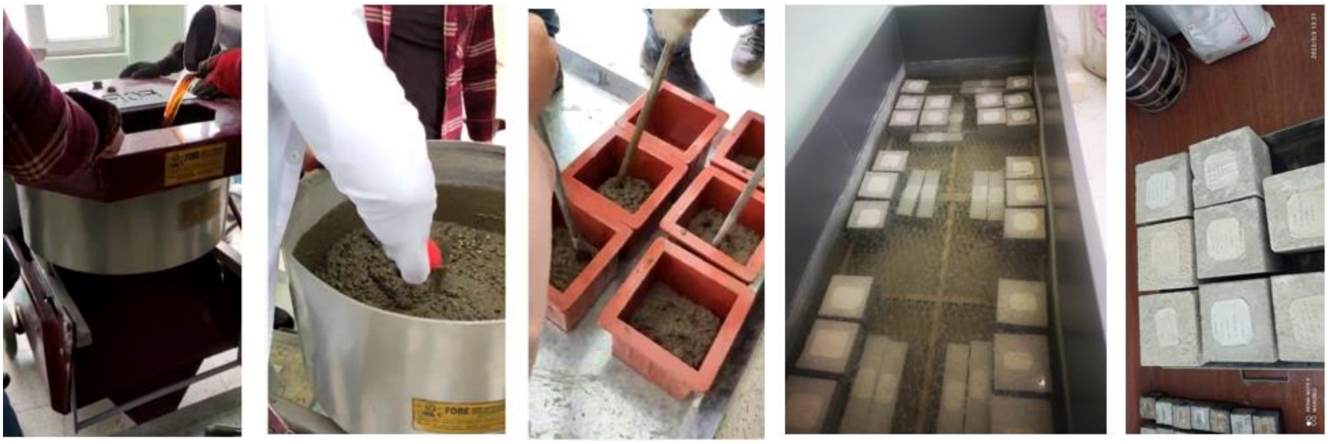
The mixture design of concretes formed with binder cement, micro limestone, chemical additives and related aggregates, the physical and chemical properties given in Tables 1 and Table 2, are made according to TS EN 12350-2 (2009) Standard and shown in Table 3.

Table 3 shows Narman mixture without N_0 micro limestone additive, Narman mixture with N_{10} limestone, Oltu mixture without O_0 limestone additive, Oltu mixture with O10 Pasinler mixture without P_0 limestone additive, Pasinler mixture with P_{10} limestone additive, Uzundere mixture without U_0 limestone additive. And U_{10} represents the Uzundere mix with limestone additives.

The amount of material specified in Table 3 was placed in the manual cement mixer, and the mixture was created. First, cement, river sand, stone powder, aggregate and chemical additives were mixed in a cement mixer in a dry environment for 3 minutes. Then, water was added to the mixture, and the mixture was mixed for 3 minutes. The concrete extracted from the mixer was placed in 15x15x15 cm cube and 7x7x28 cm prism molds (beam mold). Beam and cube samples were kept in a water curing environment until the concrete gained strength on the 7th and 28th days. The samples removed from the water-cured environment were made ready for the hardened concrete tests. The production phase of concrete samples is shown in Fig. 3.

Table 3. Mixing ratios in 1 m^3 of concrete (kg/m^3).

Mixing	Cement	Water	Chemical Additive	Micro Limestone	0-5 River Sand	0-5 Stone Powder	5-15 Fine Aggregates	15-25 Coarse Aggregates
N_0	300	192	3	-	979	-	362	487
N_{10}	270	192	3	30	992	-	367	494
O_0	300	189	3	-	565	456	350	476
O_{10}	270	189	3	30	573	463	354	483
P_0	300	164	3	-	578	435	381	510
P_{10}	270	164	3	30	586	440	386	517
U_0	300	181	3	-	925	-	391	535
U_{10}	270	181	3	30	937	-	396	542



(a) (b) (c) (d) (e)

Fig. 3. Production stages of the concrete samples: a) Preparing the mixture in the mixer; b) Removing the mixture from the mixer; c) Molding the prepared mixture; d) Keeping the concrete samples in the curing environment; e) Concrete samples whose production has been completed.

2.3. Test procedures

According to TS EN 12390-2 (2009) Standard, the consistency determination for fresh concrete mixes was made. The hardened unit volume weights of the concrete samples formed with the aggregate samples taken from different regions were measured according to the ASTM C642 Standard (1997). The mechanical properties of compressive and flexural strength of 15x15x15 cm cube and 7x7x28 cm beam concrete samples were determined according to ASTM C348 (1998) and ASTM C349 (2002) Standards, respectively (Fig. 4). To examine the effects of concrete samples formed with different mixtures on the capillarity water absorption capacity of concrete pavements, the Capillarity water absorption capacities were calculated according to the EN 1015-18 Standard. Capillarity water absorption of fresh concrete mixes was measured in 15x15x15 cm cube samples in the first 24 hours (Fig. 5). Microscopic electron scanning (SEM) was performed to determine the microstructural properties of possible cracks in the concrete samples. Microstructure analyzes were taken at Kastamonu University MERLAB unit. SEM images of the mixtures at different magnifications were determined by Quanta device.

3. Discussion and Results

3.1. Physical properties

Fig. 6 shows that the hardened unit weights of concrete mixes on concrete pavements vary between 2257-2335 kg/m^3. It has been observed that the unit volume weights of the hardened concrete samples are very close to each other. It has been determined that micro limestone in mixtures reduces the hardened unit weight. It was determined that the unit weights of the concrete samples formed with the aggregates taken from the Narman region were 0.38%, 1.02% and 2.87% higher than the calculated unit weights of the concrete samples formed with the aggregates taken from the Oltu, Pasinler and Uzundere regions, respectively. It is understood that the reduction of the hardened unit weights of the concrete samples is negligible. Because the specific gravity of natural aggregates obtained from Erzurum region is close to each other. Therefore, no significant difference was observed between the hardened unit weights of the concrete mixtures.

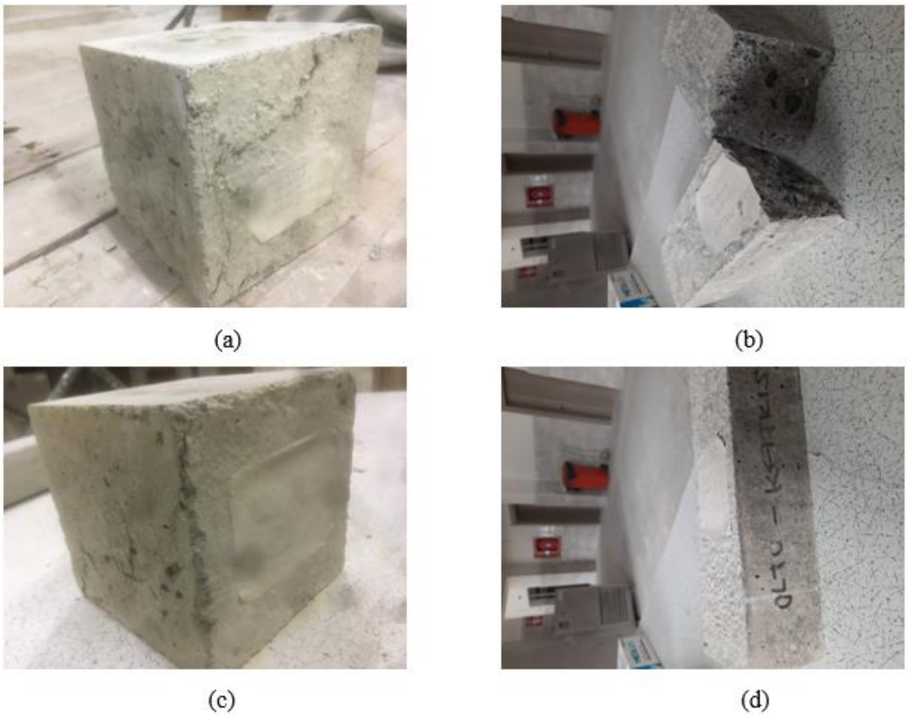


Fig. 4. Hardened concrete tests: a) Micro limestone cube sample; b) Micro limestone beam sample; c) Micro limestone-free cube sample; d) Micro limestone beam sample.

Fig. 5. Capillarity water absorption experiments.

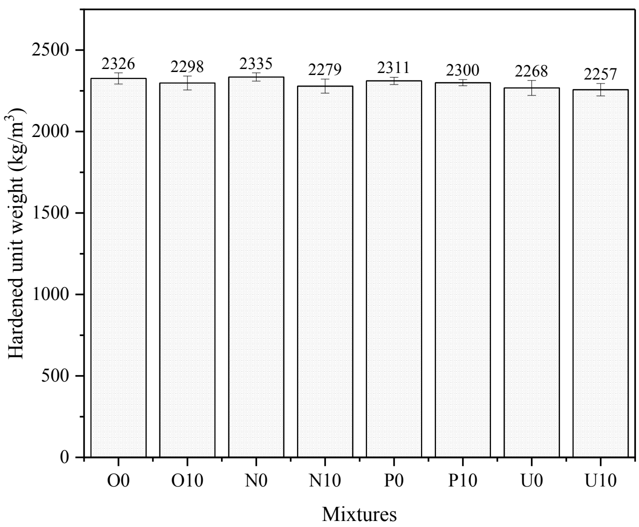


Fig. 6. Hardened unit weights of concrete samples.

3.2. Mechanical properties

According to the hardened concrete tests, Fig. 7 shows that the compressive strength of the concrete mixtures varies between 23.5-44.6 MPa, and the flexural strength varies between 2.93-4.27 MPa.

Generally, it has been determined that micro limestone in concrete mixtures reduces concrete's compressive and flexural strength. It has been observed that the highest compressive strength is in the concrete samples formed with fine and coarse aggregates taken from the Pasinler region without using micro limestone. It was observed that the 28-day concrete compressive strength of the concrete formed with the aggregates taken from Pasinler region was 44.6 MPa and the 7-day concrete compressive strength was 35.5 MPa. It was determined that the compressive strength of the concrete formed with the aggregates taken from Pasinler region was 0.22%, 9.64% and 26.45% higher than the compressive strength of the concrete formed with the aggregates taken from the Oltu, Narman and Uzundere regions, respectively. In terms of compressive strengths, it was observed that the most suitable mixture for concrete pavements, among the concrete mixtures designed in this study, was the concrete mixture formed with aggregates taken from Pasinler region, and concrete mixtures formed with aggregates taken from Uzundere region were not suitable. In addition, it was determined that the strength of the concrete formed with aggregates from the Oltu region, with a flexural strength of 4.27 MPa, is higher than the strength of the concrete formed with aggregates from Pasinler, Narman and Uzundere. It has been determined that the flexural strength of the concrete formed with the aggregates taken from Oltu region is 5.62%, 9.13% and 6.86% higher than the compressive strength of the concrete formed with the aggregates taken from Pasinler, Narman and Uzundere regions, respectively. In addition, as the unit weights of the mixtures decrease, their compressive and flexural strengths decrease. The reduction in unit weight indicates that the porosity is relatively increased. Therefore, the mechanical properties of concretes are adversely affected. In Fig. 8, the flexural strength of concrete samples increases linearly with increased compressive strength. Generally, there is a direct proportionality between the compressive strength of concrete and other mechanical properties. Therefore, as the compressive strength increases, the flexural strength of concrete increases.

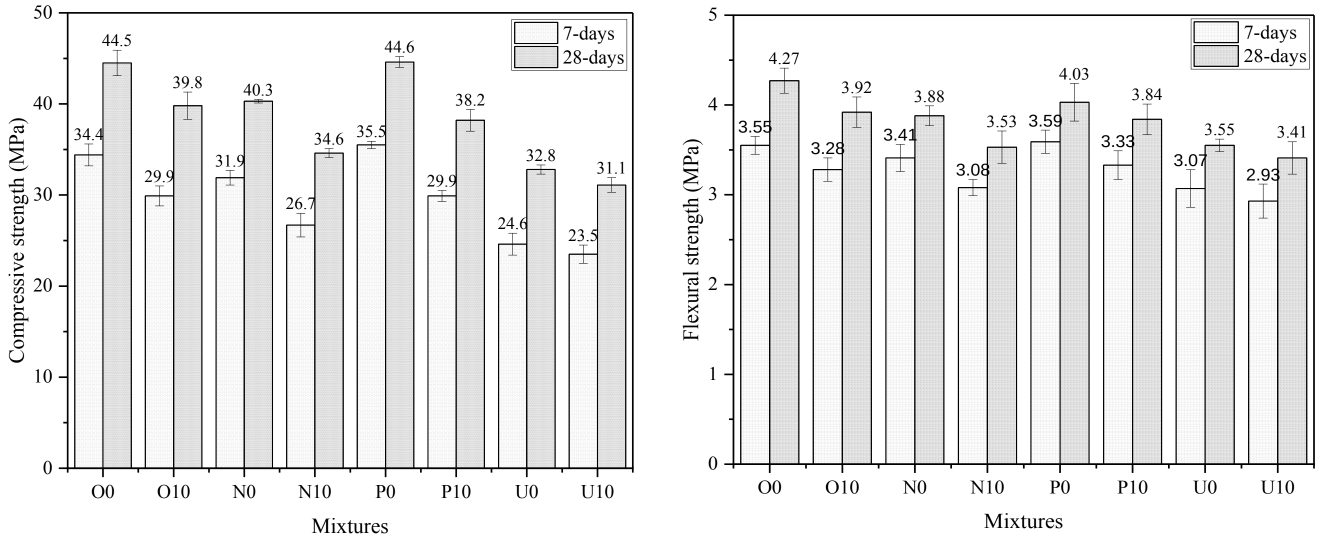


Fig. 7. Compression and flexural strength test results.

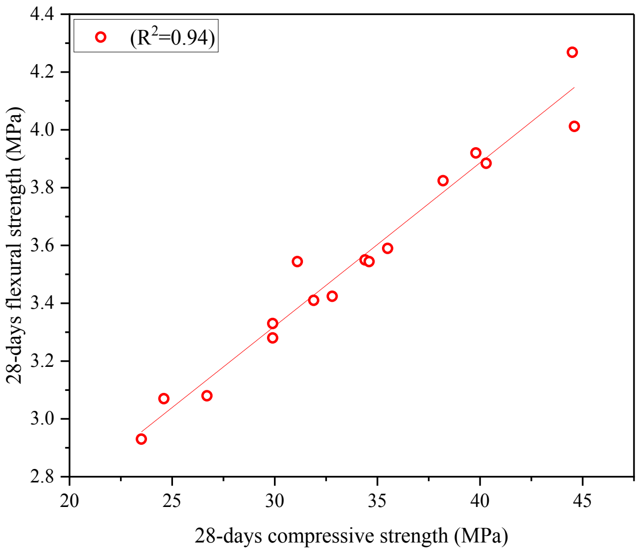


Fig. 8. Relationship between compressive and flexural strengths.

3.3. Capillarity water absorption capacities

Fig. 9 shows the capillarity water absorption capacities of concrete mixtures. It was observed that the capillarity water absorption capacities of the mixtures were below 1.26 kg/m². It was determined that the concrete mixture with the highest capillarity water absorption was U_{10} with a value of 1.26 kg/m² and the mixture with the lowest capillarity water absorption was O_0 with a value of 0.13 kg/m². It has been determined that the capillarity water absorption of the concrete formed with the aggregates taken from the Oltu region is 62.85%, 23.52% and 86.45% less than the capillarity water permeability of the concretes formed with the aggregates taken from the Narman, Pasinler and Uzundere regions, respectively. It has also been determined that micro limestone in mixtures increases the capillarity of water absorption.

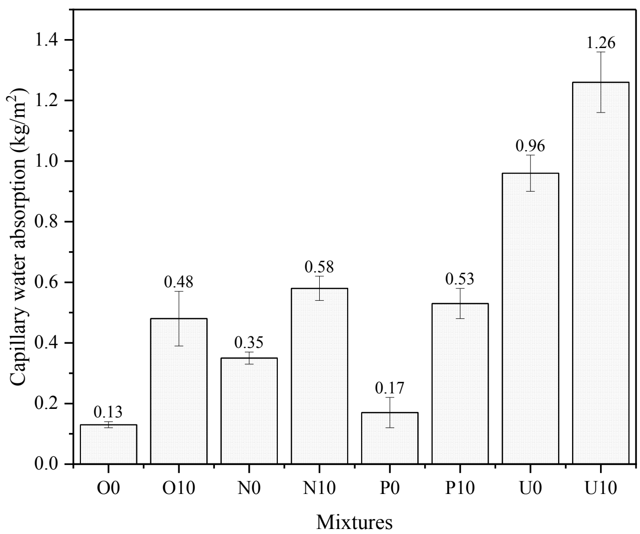


Fig. 9. Capillarity water absorption of concrete samples.

Fig. 10 shows the relationship of 28-day compressive strengths with capillary water absorption and hardened unit weights. The increase in the compressive strength of the concrete samples decreases the capillary water absorption values parabolic and increases the hardened unit weights parabolic. As the compressive strength of concrete mixes increases, the capillary void volume decreases. Therefore, the capillary water absorption of mixtures with high compressive strength decreases. As the unit weight of the mixtures increases, the compressive strength also increases. This is another indicator showing that the capillary void volume in the mixture has decreased.

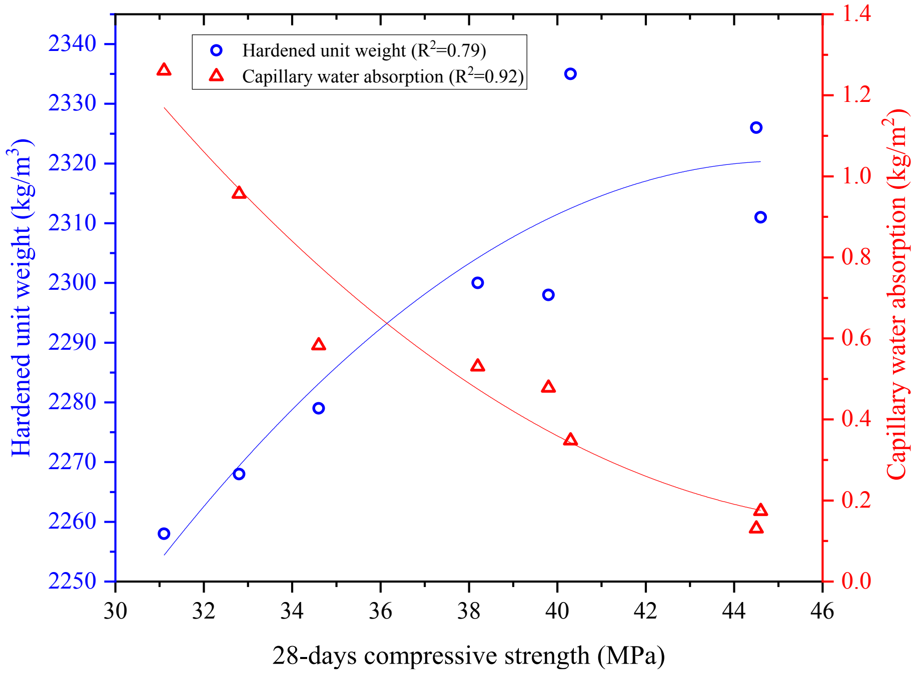


Fig. 10. The relationship of 28-day compressive strength of concrete samples with capillary water absorption and hardened unit weights.

3.4. Analysis of microstructural results

SEM images in Fig. 11 were obtained from the mortar phase of the mixtures. It was observed that SEM images obtained from different mixtures were similar to each other. As seen in the SEM images, it is seen that the matrix is dense. Due to the dense microstructure formed, the target compressive strength was achieved in the mixtures. A dense CSH gel was observed in the P10 mixture, with a compressive strength of about 40 MPa. In addition, it was observed that the interfacial transition (ITZ) region between the aggregate and the matrix was intense. Microcracks were observed in some regions of the matrix. These cracks were mostly formed after the compressive strength test. In addition, micro limestone particles smaller than 50 µm were also seen in the matrix. The microstructure condensation property of micro limestone particles was determined. As a result of the hydration reaction, needle-like CSH gels were formed. In addition, spherical air voids were determined in the matrix. These air voids were formed due to insufficient vibration. The air voids formed are usually less than 50 µm in diameter. In particular, SEM images show that micro limestone is more concentrated in some regions. This indicates that the micro limestone tends to agglomerate. As a result, a dense microstructure was observed in SEM images. It has also been determined that hydration products such as CSH are formed.

4. Conclusions

The usability of the concretes, which are obtained by natural means and formed with aggregates found in Erzurum region, on concrete pavements was investigated for the mechanical properties, physical properties, capillary water absorption, and microstructural structure of the micro limestone or non-limestone concrete mixes formed with these aggregates, in this work. The results of the study are summarized below.

- The use of micro limestone reduced the unit weights of the mixtures. However, since the specific weights of natural aggregates are close to each other, the unit weights are very close to each other.
- 7 and 28 days, the mixtures' mechanical properties (compressive and flexural strength) using micro limestone decreased. However, if micro limestone is used, C30/37 class concretes can also be produced. Similarly, micro-limestone reduced the 7- and 28-day flexural strengths of concretes. As the compressive strength of concrete mixtures increased, the flexural strength also increased. Maximum compressive and flexural strengths were obtained in the concretes formed with the aggregates taken from the Oltu and Pasinler regions.
- Since micro limestone increases the capillary void volume, the capillary water absorption of the mixtures increases. Especially the aggregates belonging to the Uz-

undere region increased the capillary water absorption considerably. On the other hand, aggregates in the Oltu region reduced capillary water absorption.

- Micro limestone particles with cement fineness were observed in SEM images. Micro limestone grains have concentrated the microstructure. In addition, needle-like CSH gels were formed due to hydration.
- As a result, it has been determined that concrete pavements can be produced with natural aggregates from the Erzurum region. Even when 10% micro limestone is used instead of cement, C30/37 class concretes can be produced. In this way, more environmentally friendly concrete pavements will be made.

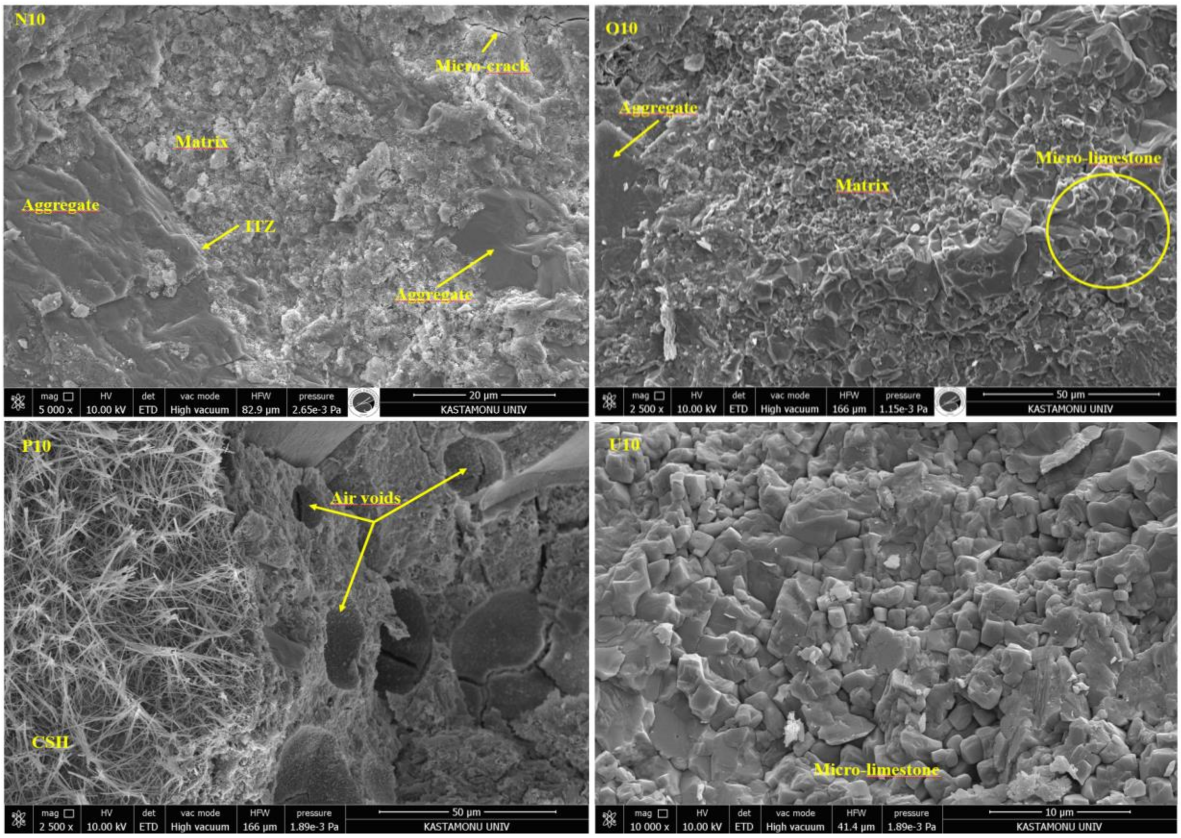


Fig. 11. SEM images of mixtures.

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Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

REFERENCES

Acar MC (2022). Usability of Kayseri volcanic slags as filling material on flexible paved roads. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 37(1), 47-56.

ACI 522R-10 (2010). Report on Pervious Concrete. ACI Comitee 522, American Concrete Institute, USA.

Airey GD (2002). Rheological evaluation of ethylene vinyl acetate polymer modified bitumens. *Construction and Building Materials*, 16(8), 473-487.

ASTM C33-16 (2016). Standard Specification for Concrete Aggregates. ASTM International, United States.

ASTM C348 (1998). Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. ASTM International, United States.

ASTM C349 (2002). Standard test method for compressive strength of hydraulic-cement mortars (Using portions of prisms broken in flexure). ASTM International, United States.

ASTM C642 (1997). Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. ASTM International, United States.

ASTM C944 (2019). Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method. ASTM International, United States.

Bekem Kara İ (2020). Effect of the use of calcite as a substitute for cement on compressive strength. *Journal of Investigations on Engineering & Technology*, 3(1), 10-16.

Budak G, Ünlu M, Minta S (2009). Introduction of a laboratory mix design method for roller compacted concrete pavements in Turkey. *6th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control, MAIREPAV 2009*.

Chandrappa AK, Biligiri KP (2016). Pervious concrete as a sustainable pavement material-Research findings and future prospects: A state-of-the-art review. *Construction and Building Materials*, 111, 262-274.

Delongui L, Matuella M, Núñez WP, Fedrigo W, Silva Filho LCP da, Ceratti JAP (2018). Construction and demolition waste parameters for rational pavement design. *Construction and Building Materials*, 168, 105–112.

Ebrahimi Besheli A, Samimi K, Moghadas Nejad F, Darvishan E (2021). Improving concrete pavement performance in relation to combined effects of freeze–thaw cycles and de-icing salt. *Construction and Building Materials*, 277, 122273.

Eisa MS, Fahmy EA, Basiouny ME (2022). Using metakaolin-based geopolymer concrete in concrete pavement slabs. *Innovative Infrastructure Solutions*, 7(1), 1-11.

EN 197-1 (2004). Composition, Specifications, and Conformity Criteria for Common Cements. European Standard.

EN 12350-2 (2009). Testing Fresh Concrete - Part 2: Slump test. European Standard.

EN 12390-2 (2009). Testing Hardened Concrete - Part 2: Making and Curing Specimens for Strength Tests. European Standard.

Harrington D, Abdo F, Adaska W, Hazaree C (2010). Guide for roller-compacted concrete pavements. *Institute for Transportation, Iowa State Univerisity*, August, 104.

Isacsson U, Lu X (1995). Testing and appraisal of polymer modified road bitumens-state of the art. *Materials and Structures*, 28(3), 139-159.

Keleş ÖF, Akpinar MV (2022). Strength properties of roller compacted concrete pavement (RCCP) under different curing methods. *Construction and Building Materials*, *324*, 126530.

Komastka SH, Kerkhoff B, Panarese WC (2003). Design and Control of Concrete Mixtures. Preface and Acknowledgments. Portland Cement Association, USA.

Kozak M (2011). Investigation of concrete roads and concrete road construction. *Electronic Journal of Construction Technologies*, 7(7), 89-99.

Lam MNT, Le DH, Jaritngam S (2018). Compressive strength and durability properties of roller-compacted concrete pavement containing electric arc furnace slag aggregate and fly ash. *Construction and Building Materials*, 191, 912–922.

Lee EB, Lee H, Akbarian M (2005). Accelerated pavement rehabilitation and reconstruction with Long-Life asphalt concrete on high-traffic Urban highways. *Transportation Research Record*, 56–64.

Nanni A, Ludwig D, Shoenberger J (1996). Roller compacted concrete for highway pavements. *Concrete International*, 18(5), 33-38.

Sangiorgi C, Lantieri C, Dondi G (2015). Construction and demolition waste recycling: An application for road construction. *International Journal of Pavement Engineering*, 16(6), 530-537.

Şengün E, Öztürk Hİ, Yaman İÖ (2020). Mekanistik-ampirik ve geleneksel beton yol tasarım yöntemlerinin karşılaştırılması: Afyon-Emirdağ deneme kesimi. *Teknik Dergi*, 31(5), 10251–10274. (in Turkish)

Strieder HL, Dutra VFP, Graeff ÂG, Núñez WP, Merten FRM (2022). Performance evaluation of pervious concrete pavements with recycled concrete aggregate. *Construction and Building Materials*, 315, 125384.

Suo Z, Wong WG (2009). Nonlinear properties analysis on rutting behaviour of bituminous materials with different air void contents. *Construction and Building Materials*, 23(12), 3492–3498.