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Research Article

Heavy aggregate and different admixtures effect on pavings: pyrite, corundum and water-retaining polymer

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Abstract: Concrete pavings are widely used in the construction industry as flooring for decorative and structural purposes in the gardens, parks, and roads of America, and Europe. In the present study, the effects of pyrite, corundum, and water-retaining polymer additives on the surface wear resistance of concrete pavings were investigated. Concrete pavings were poured in 2 stages and all of the bottom layers of samples were the same, but upper layers of pavings were produced by adding pyrite in the ratio of 0.10, 0.20, 0.30, 0.40 according to the mass of the aggregate, 5 kg /m^2 corundum-based surface hardener to the paving surface area, and a high amount of water-absorbing polymer at a ratio of 0.05 and 0.10 to the water content of the mixture. Vertical abrasion, splitting tensile strength, water absorption, freeze-thaw resistance, pendulum footed friction, and surface hardness measurements with Schmidt test hammer experiments were made to TS 2824 EN 1338 standard. Also, X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) analyses were carried out to characterize the produced materials. Results of the study indicate that the use of pyrite, corundum, and water-retaining polymers provided improvements in the surface wear resistance of concrete pavings.

Keywords: pyrite, corundum, water-retaining polymer, concrete paving, XRD.

1. Introduction

Concrete paving are building material widely used in the construction industry. They are preferred in places such as parks, gardens, fields, road construction, and ports due to their ability to be manufactured as prefabricated, their curing conditions, their storage especially in adjustable environments, and the absence of time such as setting the production area, reaching the desired strength (Karakurt, et al.. 2020). In the research conducted in 1998, Ghafoori et al. stated that 100 million m^2 of concrete pavings was used annually in Europe. This situation adds an aesthetic appearance to the continent and is thought to cause an increase in property prices (Jamshidi et al.. 2019; Aslantaş, 2004).

Concrete paving is generally designed with a high rate of clamping ratio, they are cast in two layers. The sublayer is a carrier, with its resistance to freezing thawing, and tension, and the upper layer is important in terms of abrasion, dust emission, and aesthetics because it is exposed to mechanical effects and is a visible surface (Jamshidi et al.., 2019; Lin et al.., 2016).

Vibrating special molds are used during the production of concrete paving. Special molds enable the production of high-strength paving with a lower water/cement ratio, abrasion resistance, freeze-thaw resistance, and compressive strength increase (Pheeraphan and Leung, 1997; Gencel et al.., 2012). Abrasion resistance contributes to the durability of concrete pavings, and since the upper layer is exposed to abrasion, it is thought that it will be sufficient to conduct experiments on the upper layer (Popek et al.. 2016; Karpuz and Akpınar, 2009). Concrete wear resistance differs according to strength, porosity, and absorbency values. While the abrasion resistance of high-strength concretes is high, as the porosity and absorbency values increase, their wear resistance decreases (Popek et al.. 2016; Çobanoğlu and Çelik, 2017). Since concrete pavings and roads are exposed to the effects of continuous load and wear, freeze-thaw resistance is also an important feature. The volume and distribution of concrete pores and the water content in these pores cause damage to the internal structure of the concrete with successive freeze-thaw cycles and negatively affect the freeze-thaw resistance (Şahin, 2003; Cai and Lui, 1998; Gua et al.. 2024).

Although the concrete pavings produced in the market have high-pressure resistance, cracks, and breaks occur in the pavings with heavy traffic loads. In order to eliminate or minimize these problems, it is necessary to improve the durability and flexural strength of concrete pavings. It is thought that using materials suitable for its purpose provides the desired improvements in concrete, especially the use of different types of aggregates for wear resistance (Karpuz and Akpınar, 2009; Murugan et al.. 2016). Salguero et al.. (2014) stated that the use of pyrite in sulfuric acid production in concrete will reduce the cost of environmental waste generated and contribute to the quarry sector, adding a separate economic value to the pyrite mine. Corundum, which has a brightening and rounding abrasive, is used in metal polishing, rounding of medium hard metals, filler, or as an abrasive powder. In addition to these, it is widely used as non-slippery floor coverings and concrete hardeners (Çoban, 2011). Polymers are molecules formed by the reaction of simple molecules that are prone to the formation of large molecules by combining with different units under suitable conditions (Bal, 1998). Since polymers are now very diverse, it is possible to select the artificial polymers of that feature and use them as additives, whichever feature is desired to add to the product to be produced (Tonyalı, 2001).

Concrete pavings will serve for a longer period only if the wear resistance is increased due to the improvement to be made in the surface layer. With the increase in concrete production, the supply of river sand, which is used as fine aggregate in concrete, becomes difficult over time, and its cost increases. These reasons have led researchers to find alternative material sources. In addition to being low cost, the researched resources should be resistant to effects such as strength, wear resistance, and freeze-thaw (Chandrappa and Biligiri, 2016). Some studies related to pavements can be found in the literature. Silva et al.., 2022 recycled construction and demolition waste materials by using them as sub-base materials in pavements. As a result, they showed that demolition waste materials can be used as sub-base material with minor corrections (elimination of parts of the aggregates that are not suitable for granulometry, etc.). Kaya (2022) carried out a study to determine the optimum value of the transverse joint spacing of pavements. In the study, the transverse joint recommendations of some specifications are summarized. The results of the study indicated that transverse joint spacing of 15-18 ft was sufficient both economically and structurally. Shakhan et al.. (2022) have focused on improving the performance of flexible pavement in combination with appropriate granulometry analysis. The outcomes of the study revealed that appropriate granulometry values increased wheel track and fatigue resistance.

Apart from the aforementioned studies, studies on improving the physical properties of pavements are quite limited in the literature. As a result of extensive literature research, it can be said that the use of especially heavy aggregates for improving the physical properties of pavements is a relatively new topic. Parquet pavements are elements that form very important social facilities in terms of both architectural, structural, and landscape. For this reason, investigating the production of parquet pavements with different types of aggregates and admixtures will contribute to both sectoral knowledge in the field of construction and cost. In this study, it was aimed to increase the surface abrasion resistance of concrete pavements by using ground pyrite, corundum, and water-retaining polymer in the top layer of concrete pavements. The abrasion, water absorption, splitting tensile strength, compressive strength, and surface hardness of pavements produced with pyrite, corundum, and water-retaining polymer were compared with those without additives.

2. Materials and methods

The pavings were produced to the TS 2824 EN 1338 standard (TS 2824 EN 1338, 2005). Aggregates with different granulometry were used in the lower and upper layers of the pavings. Aggregate, the percentage of which passed the sieve in Figure 1a-1b, was used in the lower layer concrete of the pavings. The aggregate used in the upper layer of the pavings was thinner than the aggregate used in the lower layer. Pyrite pavings were produced by reducing the aggregate mass by 10%, 20%, 30%, and 40% with the aggregate whose percentage passed through the sieve in Figure 1c (Valente et al.., 2014). In a product sold as a corundum-based surface hardener in the market, pavings with corundum were produced by applying it to the upper layer of the pavings according to the amount specified in the user manual and the application description. The polymer pavings were produced by using a powdered polymer with high water absorption on the paving's top layer. Thus, four different groups of pavings whose top layer was produced differently were obtained, namely without additives, with pyrite, corundum, and polymer. The dimensions of the paving are shown in Figure 2 and the other produced paving sizes are 200x100x80 mm. The concretes of the parts written as the lower layer and the upper layer on the paving have different types of aggregates. While the pavings were produced, the lower layer concretes were poured and placed in the mold, then the upper layer concrete was poured before the lower layer concrete sets. Figure 3 shows the production process of concrete pavements schematically. Different aggregates such as pyrite etc. to be used instead of normal aggregates were procured and crushed in a jaw crusher. Then, the mixture was provided according to the concrete mixture calculation and placed in the molds. On test days, the samples were subjected to certain mechanical and durability tests. Scanning Electron Microscopy (SEM) analysis was performed on the specimens. A general schematic representation covering all laboratory, testing, and analysis processes is shown in Figure 3.

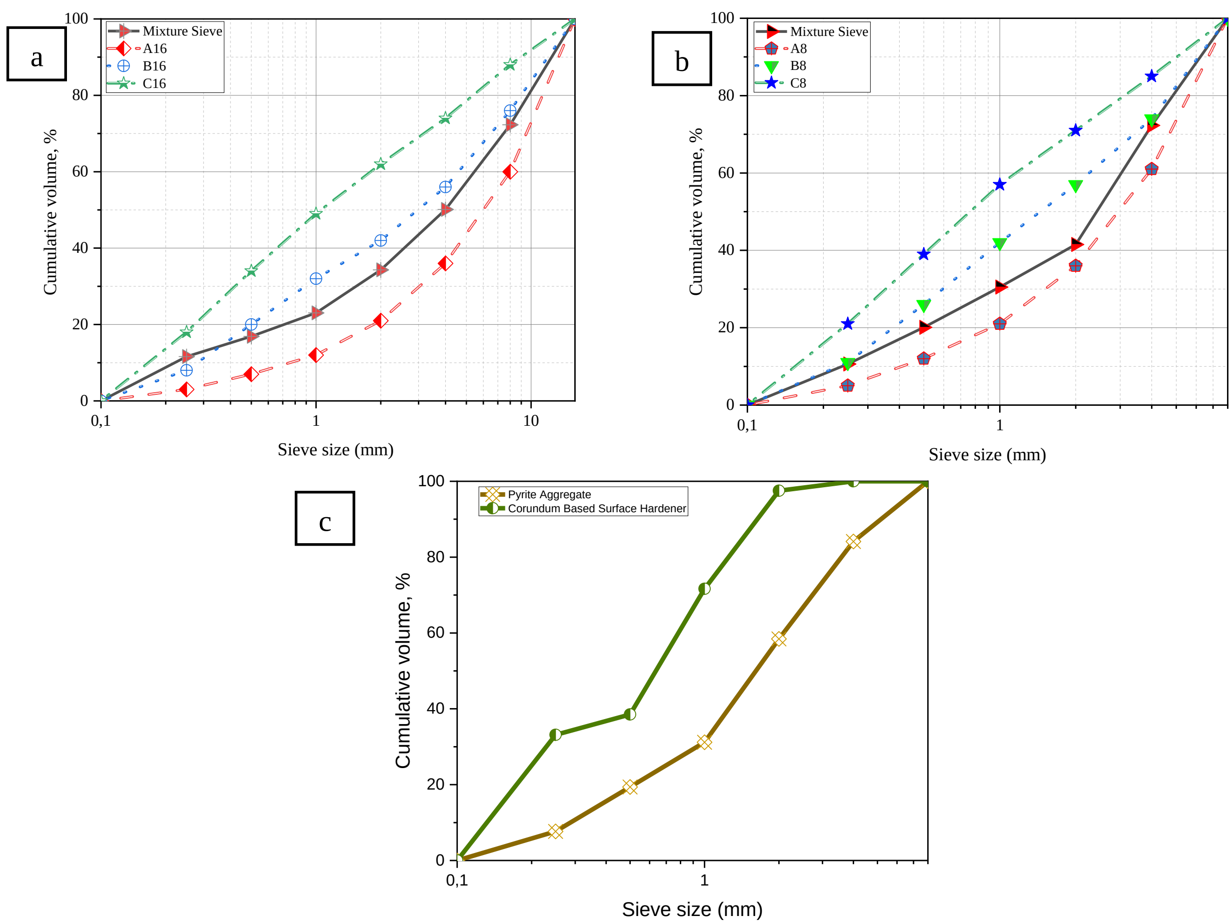

Figure 1. a) The aggregate used in the lower layer granulometer curve, b) the aggregate used in the upper layer granulometer curve, and c) the pyrite and corundum aggregate used in the mixture granulometer curve.

2.1. *Properties of aggregates*

The aggregate percentage which passed the sieve in Figure 1b, was used in the upper layer concrete of the pavings. The pavings produced with aggregate in Figure 1a and Figure 1b are referred to as additive-free pavings in the study. The largest grain size of the aggregate size distribution graphs to be used in the concrete mix was selected in accordance with the TS 802 standard (TS 802, 2016). A16, B16, and C16 are the limits of the aggregate grain size distribution curve for concrete with an aggregate grain size of 16.0 mm and A8, B8, and C8 are the limits of the aggregate grain size distribution curve for concrete with an aggregate grain size of 8.0 mm. As seen in Figure 1a, the maximum grain diameter of the aggregate used in the lower layer concrete of the pavings is 16 mm.

Figure 1b shows that the maximum particle diameter of the aggregate used in the upper layer of the pavements is 8 mm. The granulometry curve of the aggregate used in the lower layer of the flooring was depicted between the A16 and B16 curves in Figure 1a. The horizontal axis shows mesh size (mm) and the vertical axis shows the percentage of material passing through the screen. The granulometry curve seen between A8 and B8 in Figure 1b belongs to the aggregate used in the top layer concrete of the pavings. Pyrite, corundum, and polymer pavings were produced by mixing the granulometry aggregate in Figure 1c with pyrite aggregate, corundum surface hardener, and polymer with high water absorption.

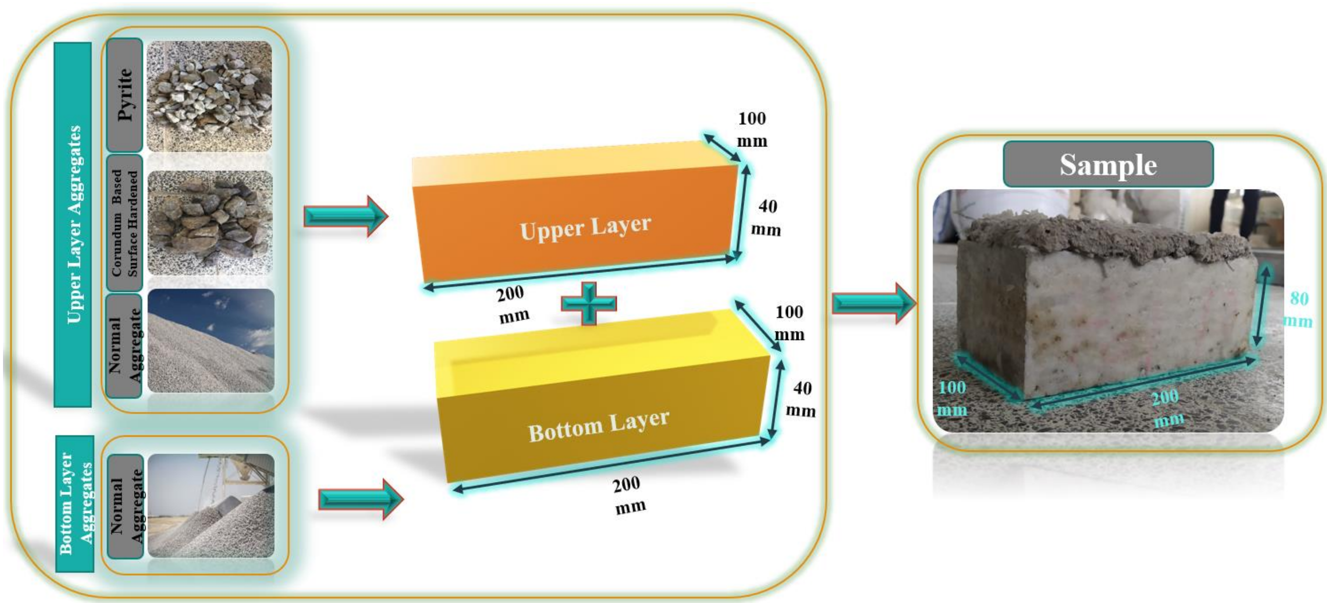

Figure 2. The dimensions of the pavings.

Table 1 shows the specific gravity and water absorption values of the aggregates used in the study. The bottom layer and top layer aggregates in Table 1 were obtained by mixing aggregates with four different finenesses. Pyrite aggregate, on the other hand, consists of a mixture of two aggregates shown as Coarse 1 and Fine 1 in Table 1.

Table 1. Specific gravity and water absorption values of aggregates and pyrite aggregates used in the lower- and upper-layer concrete of the paving.

Bottom layer aggregate	Course 1	Course 2	Fine 1	Fine 2
Specific gravity (g/cm^3)	2.72	2.71	2.47	2.41
Water absorbtion (%)	1.27	0.89	3.74	7.06
Upper layer aggregate	Course 1	Course 2	Fine 1	Fine 2
Specific gravity (g/cm^3)	2.99	2.59	2.55	2.46
Water absorbtion (%)	4.2	2.72	4.63	2.94
Pyrited aggregate	Course 1	-	Fine 1	-
Specific gravity (g/cm^3)	2.79	-	2.51	-
Water absorbtion (%)	2.3	-	3.43	-

2.2. *Paving design*

The material quantities used in all produced pavements are given in Table 2. For each mixture in the table, 3 samples were produced for each of Vertical Wear Length, Mass Loss per Unit Area, Fracture Load, Splitting Tensile Strength, Unit Length Breaking Load, Compressive Strength, and Water absorption tests. In pyrite pavings, the amount of aggregate used in the top layer (surface concrete) concrete of the unadulterated pavings was reduced by 10%, 20%, 30%, and 40%. Four different groups of pyrite pavings were produced by adding pyrite aggregate instead of decreasing mass. Corundum pavings were produced by adding corundum-based surface hardener in an amount of 5 kg/m^2 on the top layer of the pavings. Polymeric pavings were produced by adding 5% and 10% of the water mass to the upper layer of the pavings. The chemical composition and proportions of the pyrite aggregate can be seen in Table 3.

Table 2. Materials used in parquet concretes for 1 m^3 (kg).

Samples	Layer	Cement	Water	Coarse aggregate	Fine aggregate	Pyrite	Corundum	Water retaining polymer
Normal	Bottom	250	159	1497	405	-	-	-
	Upper	470	235	947	591	-	-	-
%10 Pyrite	Bottom	250	159	1497	405	-	-	-
	Upper	470	235	947	531.9	59.1	-	-
%20 Pyrite	Bottom	250	159	1497	405	-	-	-
	Upper	470	235	947	472.8	118.2	-	-
%30 Pyrite	Bottom	250	159	1497	405	-	-	-
	Upper	470	235	947	413.7	177.3	-	-
%40 Pyrite	Bottom	250	159	1497	405	-	-	-
	Upper	470	235	947	354.6	236.4	-	-
Corundum	Bottom	250	159	1497	405	-	-	-
	Upper	470	235	947	591	-	4	-
%5 Polymer	Bottom	250	159	1497	405	-	-	-
	Upper	470	223.25	947	591	-	-	11.75
	Bottom	250	159	1497	405	-	-	-

%10 Polymer	Upper	470	211.5	947	591	-	-	23.5

2.3. *Experiments*

Surface wear resistance, water absorption value, tensile strength in splitting and surface hardness of pyrite, corundum polymer, and additive-free pavings were measured according to the test methods specified in TS 2824 EN 1338 standard (TS 2824 EN 1338, 2005).

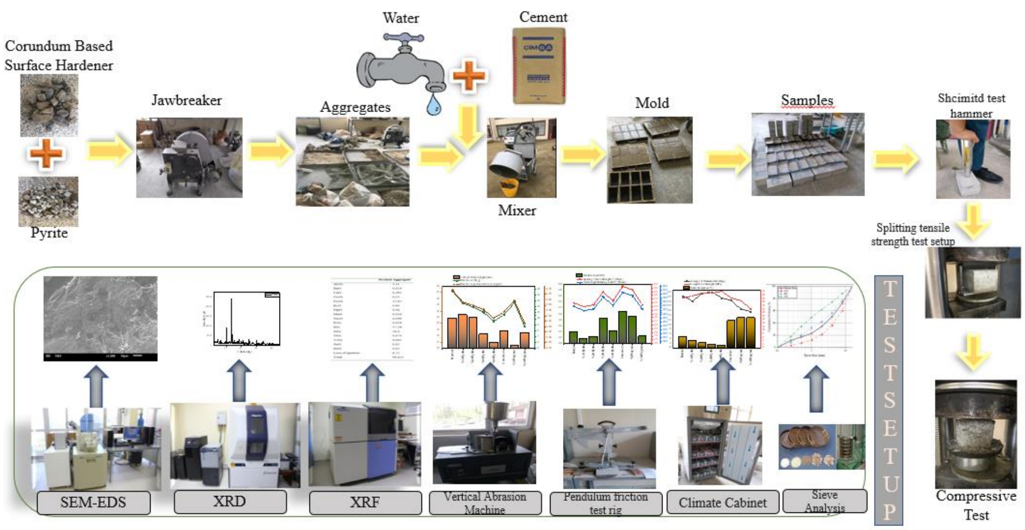

Figure 3. Schematic representation of the paving sample production.

2.3.1. freeze-thaw test

This experiment was carried out to measure the loss of mass of paving samples. After 28 days of curing, samples were isolated with a 3% NaCl solution prepared by using potable water at a height of 5 ± 2 mm from the paving surface in the air conditioning cabinet. Cycle temperatures was from +20 ºC to -20 ºC for 24 hours. It was subjected to freeze-thaw cycles for 28 days, and the mass losses at the end of the experiment were calculated according to the Equation (1).

$$L = \frac{M}{A} \quad (1)$$

L in equation (1) shows the loss of mass per unit area (kg / mm^2), M shows the loss of mass in the paving (kg), and A in equation (1) shows the surface area of the paving (m^2).

Table 3. Chemical composition and proportions (%) of pyrite aggregate (Yavaşi, 2019).

	Pyrited aggregate
Al_2O_3	3.11
BaO	0.024
CaO	0.385
Cr_2O_3	0.23
Fe_2O_3	12.87
K_2O	0.84
MgO	0.46
MnO	0.016
Na_2O	0.049
P_2O_5	0.018
SO_3	17.28
SiO_2	56.9
TiO_2	0.074
$V2O_5$	0.005
ZnO	0.02
ZrO_2	0.02
Loss of ignition	6.72
Total	99.021

2.3.2 Determination of water absorption

After the pavings were kept in an environment at (20 ± 5) ° C, they were immersed in water until they reached a constant mass. The saturated paving mass was taken out of the water and weighed. The pavings were allowed to dry and were weighed again. The total water absorption of the pavings was determined according to Equation (2). This value represents the percentage loss in mass in the paving compared to the dry mass of the sample.

$$\mathrm{Wa} = \frac{M1-M2}{\mathrm{M1}} \quad (2)$$

In the equation (2), Wa shows the water absorption of the paving, M1 shows the water-saturated mass, and M2 shows the oven-dry mass.

2.3.3 Splitting tensile strength

After the surface roughness of the pavings was corrected, they were immersed in water at (20 ± 5) ° C for (24 ± 3) hours and then dried with a cloth to determine splitting tensile strength. The splitting tensile strength value of the experimental concrete block was calculated using different equations such as equation (3, 4, 5, 6,7).

$$S = l * t \quad (3)$$

In Equation (3); S is the fracture area (mm^2), l is the length of the fracture section (mm) as the average of the two measurements made at the top and bottom of the concrete block, and the thickness of the concrete block in the fracture plane (mm) as the average of three measurements, one in the middle and two at the ends. Strength (T) was calculated according to Equation (4).

$$T = \frac{0{,}637 * \mathrm{k} * \mathrm{P}}{\mathrm{S}} \quad (4)$$

In equation (4), T= strength (MPa), P= breaking load (N), k= coefficient by calculating that relation,

$$k = 1.3 - 30 * (0.18 - \frac{\mathrm{T}}{1000})^2 \quad (5)$$

It was calculated according to Equation (6) by dividing the load (P) found in the tensile test in the splitting test, where the breaking load per unit length of the pavings was applied, by the length (L) applied to the force.

$$F = \frac{P}{L} \quad (6)$$

Although it is not necessary to perform a resistance test on the pavings according to the TS 2824 EN 1338 standard (TS 2824 EN 1338, 2005), the samples divided into two in the non-splitting tensile tests were subjected to the concrete strength test and their strengths were calculated in order to obtain information about the strengths of the pavings.

$$D = \frac{F}{100*100} \quad (7)$$

The compressive strength (D) of the paving was calculated according to Equation (7) by dividing the force (F) measured from the concrete press by the area of 100 x100 mm^2.

2.3.4 Abrasion resistance

After the parquet was painted with chalk, it was placed in a vertical abrasive device and approached to contact the abrasive disc. The abrasion dust control valve was opened and at the same time the device was operated to make the abrasion disc (60 ± 3) 75 rotations per second. After 75 turns of the disc, the flow of abrasive powder and the disc were automatically stopped by the device. In order to obtain more reliable data, three samples from each series were tested and the data were obtained by taking the average of the measurements made for each.

2.3.5 The unpolished slip resistance value (USRV)

The unpolished slip resistance value (USRV) of the pavings was determined by using the pendulum friction test equipment in Figure 4 by evaluating the slip properties on the upper surface of the sample. The pendulum was released after the test sample was placed on the pendulum friction equipment. When the rubber tip of the pendulum hit the parquet, the number appearing on the device scale was determined. The same process was repeated six times and from the calculated average value, the unpolished slip resistance value of the parquet was calculated.

Figure 4. Pendulum friction test equipment.

2.3.6. Experimental of surface hardness

Surface hardness of the pavings was measured with a Schmidt test hammer by stroking the parquet placed on the concrete surface in vertical direction. The equipment for the measurement is shown in Figure 5.

Figure 5. Surface hardness measurement on pavings with the Schmidt test hammer.

2.4. *Micro-structural analysis*

2.4.1 X-ray diffraction (XRD) analysis

X-ray diffractometric powder method (XRD) was conducted with monochromatic wavelength λCu-K-beta, sample was scanned in the angle range of 4°–90° 2ϴ°. The XRD textures of the produced sample are given in Figure 6. The main reaction phases were determined with the Qualx program (Altomare et al.., 2008; Altomare et al.., 2015). The reaction phases of the paving sample are Quartz (21.72, 26.66, 36.56, 42.32, 50.16 and 59.98 2ϴ). Considering the general material properties of the produced concrete, the expected phase has occurred (Bulatović et al.., 2017). As a result of the chemical analysis of pyrite in Table 3, the amount of SiO_2 is approximately 56%. The presence of main-phase Quartz in the XRD results supports the XRF results.

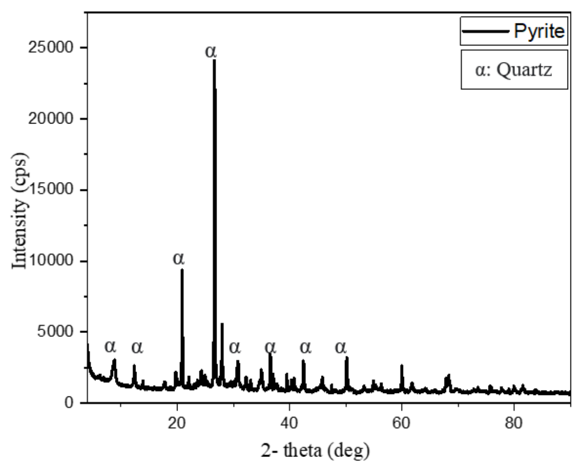

Figure 6. XRD pattern of pyrite sample.

2.4.2 *Scanning Electron Microscopy (SEM) analysis*

SEM images at x10000, x5000, and x1000 magnification were taken in order to have information about the internal structure of the pyrite sample, which gave the best strength values. SEM image of the sample with maximum strength (40% pyrite) is given in Figure 7. Since heavy aggregate is used and the compressive strength is high, it is seen that a compact matrix is formed in the structure (Liu et al.., 2022). When Figure 7 is examined in general, it is noteworthy that there are entities belonging to different structures. In SEM images, the presence of C-S-H gel, micro hole, and microcrack structures draws attention. There are also unremnant materials.

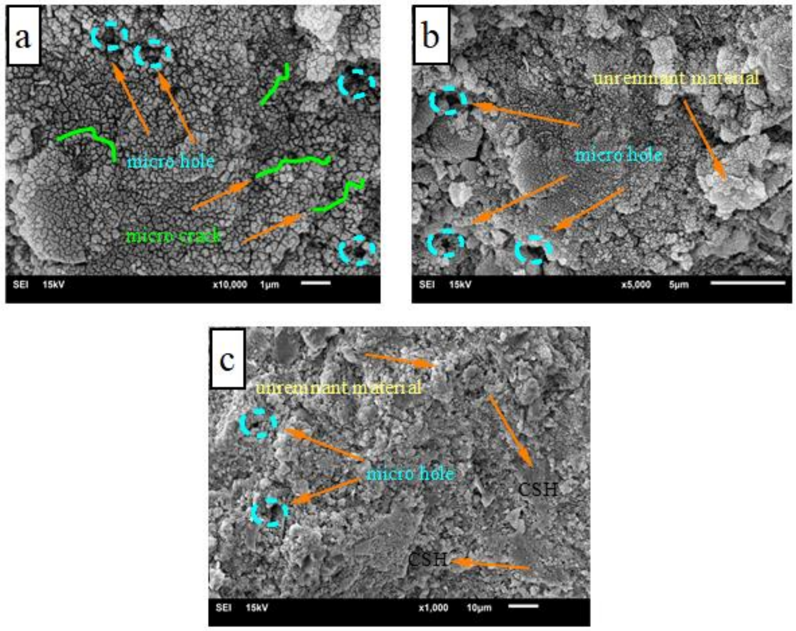

Figure 7. SEM images of pyrite sample (**a**: x1000, **b**:x5000 and **c**:x1000).

3. Results and discussion

3.1 Results

The vertical wear lengths measured in the pavings are shown in Figure 8 and the measurements were obtained from the average values of 12 measurements made on six paving from each parquet group. The values of fracture load, splitting tensile strength, and breaking load per unit length determined in the strength measurements are shown in Figure 9. The tensile strengths in the splitting in Figure 9 were calculated by Equation (4), and the unit length breaking load was calculated by Equation (6). According to TS 2824 EN 1338 standard (TS 2824 EN 1338, 2005), paving average strength (T) should not be less than 3.6 MPa. None of the single strength test results should be less than 2.9 MPa, and none of the sample breaking loads should be less than 250 N / mm, and it was seen that the values in the table meet the requirements specified by the standard.

The mass loss values per unit area of the pavings where the freeze-thaw test is applied are shown in Figure 8. The paving, which has a low mass loss per unit area, has a high resistance to the freeze-thaw effect. The mass loss (L) per unit area in Figure 8 was calculated by Equation (1). The TS 2824 EN 1338 standard (TS 2824 EN 1338, 2005) also requires the surface area of the pavings to be tested to be smaller than 25000 mm^2 ($A < 25000\ mm^2$). Since the surface area of the sample subjected to the test is 200x100 = 20000 mm^2, the standard has met the smallness requirement. TS 2824 EN 1338 standard (TS 2824 EN 1338, 2005) expresses the blocks resistant to freezing and thawing together with the salt effect with Class 3, class designation D. In Class 3, D type pavings, the mass loss in the average unit area should be less than 1.0 kg /m^2 and each single value should be less than 1.5 kg / m^2. The mass loss values per unit area are calculated by taking the average measured over three paving samples.

The friction values measured on the pendulum standing on the upper surface of the pavings are shown in Table 4, and the friction values are the average values of six measurements on three pavings for each group. Surface hardness values measured with Schimitd test hammer, compressive strength, and water absorption values are the average of thirty test hammer readings on three samples and were demonstrated in Figure 10. The compressive strength test was carried out by applying force to the 100x100 mm surface of the 100x100x80 mm block. Water absorption values are the average values calculated from three samples.

3.2. Discussion

In this study, it was investigated how the pyrite aggregate, corundum-based surface hardener, and polymer with high water absorption capacity affect the mechanical and physical properties of the pavings, especially the surface wear properties of the pavings. Corundum-based surface hardeners are a product known in the concrete industry and used to increase the surface wear resistance of concretes. Pyrite is often encountered as a by-product in copper mining and is one of the solid wastes not widely used. Highly water-retaining polymer is a product that is rarely used directly in concrete or paving in the concrete industry. If the abrasion resistance of the pavings is improved thanks to the process applied only on the surface layer of the pavings, it will be possible to use the pavings for a longer time in the service environment.

As can be seen in the values in Figure 8, the maximum vertical erosion length in paving types was found in pavings with 10% pyrite. It is seen that the vertical wear length of 10% pyrite and 20% pyrite parquet and the vertical wear length of the reference pavings are very close to each other, and it states that the addition of more than 20% pyrite aggregate increases the paving surface wear resistance. As a result, it is seen that the pyritic aggregates increase the surface wear resistance of the paving, and it is seen that the vertical wear length decreases as the proportion of pyrite aggregate added to the upper layer of the paving increases. The minimum vertical abrasion length has been observed in flooring with 5% water-retaining polymer and 40% pyrite aggregate. Although corundum-based surface hardener is a material that is used in market concretes and whose surface hardening properties are known, the use of fine aggregate containing 40% pyrite in this study in the upper layer of the paving increased the wear resistance of the paving more than the corundum based surface hardener, but this low wear detected in 5% polymer parquet length needs to be considered.

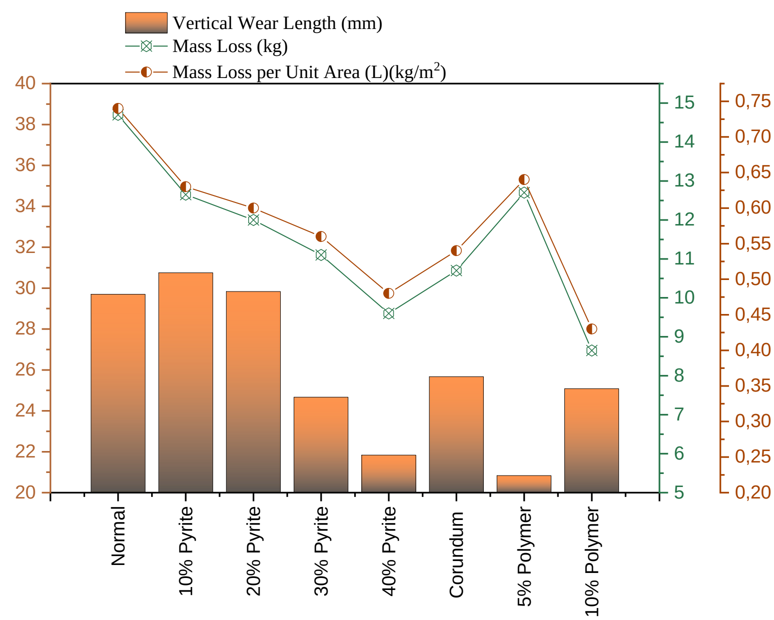

Figure 8. Vertical wear length, mass loss, and mass loss per unit area of normal, pyrite, corundum and polymer samples.

The values read in Figure 8 and the vertical wear lengths are discussed by making comparisons with the studies in the literature. Uygunoglu et al.. (2012) measured the vertical wear lengths of 23 to 30 mm in the pavings produced with crushed aggregate, recycled concrete aggregate, and marble waste aggregate concrete. The study indicated that the tensile strength during splitting with crushed stone aggregate was 5 MPa and the vertical abrasion length was around 23 mm in pavements with a compressive strength of 29 MPa. The vertical wear lengths and strengths were measured in the normal aggregate reference pavings in this study with the values in the work of Uygunoglu et al. (2012) and Ozalp et al. (2016). It is seen that the values obtained are consistent with the studies in the literature.

Also, it was observed that pyrite, water-retaining polymer, and corundum pavings increased the wear resistance. The splitting tensile strength values in the split measured in the pavings are shown in Figure 9. Splitting tensile strengths had values between 4 and 5.1 MPa. The tensile strength measured in the pavings with 30% pyrite, 40% pyrite, corundum, and 5% polymer was significantly higher than the reference pavings, and it was seen that only the improvement in the surface layer provided an increase in the tensile strength of the paving. Gencel et al. (2012) used marble waste at the rates of 0%, 10%, 20%, 30%, and 40% in concrete pavings.

The pavings in his study were produced with CEM-II 42.5 N class cement, and the cement amount was 400 kg / m^3. Gencel et al. (2012) reached a tensile strength of 5.2 MPa in the mixture with a maximum of 10% waste marble. In this study, the highest value was 4.8 MPa in samples with 30% pyrite content and 5.1 MPa in samples with corundum. In this study, because the lower and upper layers are tested together and the dosage is different in both layers, the value is likely to be low in the pyrite-added samples, but the proximity of the values shows that the study is compatible with the literature. Uygunoğlu et al. (2012) substituted 0%, 10%, 20%, 30%, 40% fly ash into the mixture in their experiments on concrete parquets. The samples were produced using a 0.45 water/cement ratio, 300 kg / m^3 CEM-I 42.5 R cement dosage, 40% coarse and 60% fine aggregate by volume. In his study, it was stated that the splitting tensile strength decreased for all series as the amount of substituted fly ash increased. The best result was in the range of 4.7- 4.6 MPa for crushed stone and marble waste fine aggregate samples with 10% fly ash. It was observed that the materials used in this study provided more improvement in paving properties compared to the materials used by Gencel et al. (2012) and Uygunoğlu et al. (2012).

The compressive strength values measured in the pavings are depicted in Figure 10. It was observed that when the ratio of pyritic aggregate changes, a difference in compressive strength is observed, and when this ratio increases from 10% to 40%, a 13% increase has been observed in the compressive strength of the paving compared to the reference paving. It was found that the compressive strength of the samples using 5% and 10% polymers was significantly lower than the strength of the reference samples. Karpuz and Akpınar (2009) carried out a series of studies using fine aggregates of limestone and basalt. The dosage of cement used throughout the studies is 400 kg/m^3.

Karpuz and Akpınar (2009) determined the 28-day average compressive strength of the samples as 63 MPa. Gencel et al. (2012) found the compressive strength values a minimum of 42 MPa and a maximum of 52 MPa in their studies using 400 kg/m^3 cement. Sadek et al. (2017) used 600 kg/m^3 cement and substituted 10% to 60% clay slag into the mixture in their paving study. The outputs of the study show that the 28-day compressive strength of the samples is between 46 and 62 MPa. Considering similar studies in the literature, the compressive strengths of concrete were measured higher than in this study, as the experiments were made in the material layer rather than the bottom and top layers. In this study, the production of concrete paving blocks was designed separately and the mixture content of the lower and upper layer was separately designed and pavings were produced similar to the production in paving factories.

Mass loss values per unit area of pavings subjected to freezing and thawing are shown in Figure 8. When the samples exposed to freezing and thawing cycles were examined, the least mass loss was seen in the pavings with a 10% polymer substitute. Then, the least mass loss was observed in the samples with 40% pyrite substituted and corundum substituted. Sun et al. (1999) in their studies on the effects of load and freeze-thaw in high-strength concrete, found that as the quality of the concrete increases, the resistance to freeze-thaw increases. In the experiments conducted within the scope of this study, the highest compressive strength and freeze-thaw resistance were determined in samples with 40% pyrite. Relationships between compressive strength and freeze-thaw resistance have also been found in the literature; however, while the compressive strength values below the standard were obtained in the 10% polymer samples used, the freeze-thaw strength was relatively higher than the compressive strength. This shows that water-retaining polymers could be used as an economical solution for pavings that are subjected to freeze-thaw and do not require high strength.

Table 4. Friction values measured with pendulum feet in pavings.

Sample name	USRV

Normal	0.451
%10 Pyrited	0.601
%20 Pyrited	0.561
%30 Pyrited	0.561
%40 Pyrited	0.536
Corundum	0.665
%5 Polymeric	0.646
%10 Polymeric	0.606

The unpolished slip resistance values (USRV) of the pavings are shown in Table 4. When we look at the relationship between the values determined using the pendulum friction test setup and the surfaces of the samples, it is seen that the shear resistance values increased in the samples with high surface roughness. When the abrasion resistance of the polymer-added samples decreased, there was a decrease in the slip values of the pendulum tester. However, among the pyrite aggregate samples, it was observed that the shear resistance value decreased as the wear resistance increased. Yoshitake et al. (2016) in their research on the abrasion and slip resistance of pavement blocks with fly ash, found that as the abrasion resistance decreased, the pendulum test device slip values also decreased. Compared to this study and the studies in the literature, a partial harmony was observed between the wear resistance and the slip resistance. It is thought that the reason for this is the smoothing of the surfaces of the samples with a hand trowel.

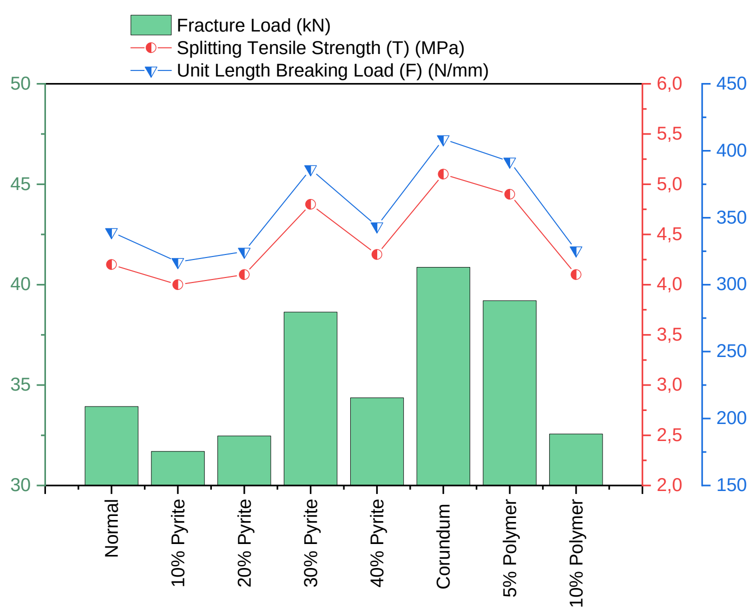

Figure 9. Fracture load, splitting tensile strength and unit length breaking load of normal, pyrite, corundum and polymer samples.

Schmidt test hammer values measured in the pavings are shown in Figure 10. While the highest value belongs to the sample with 24.1 and 30% pyrite fine aggregate, the lowest value was found to belong to the sample with 15.7 and 10% polymer. It is estimated that the Schmidt test hammer values will be higher when the pyrite content is between 20% and 30%. Çobanoğlu and Çelik (2017) found that the use of the vertical wear test as a reference was investigated in determining the wear resistance of stones used in buildings, and found that as the Schmidt test hammer values increased, the wear resistance increased. This determination was encountered in the pyrite pavings in this study, but it was observed that the use of water-retaining polymer on the parquet surface reduced the surface hardness of the paving.

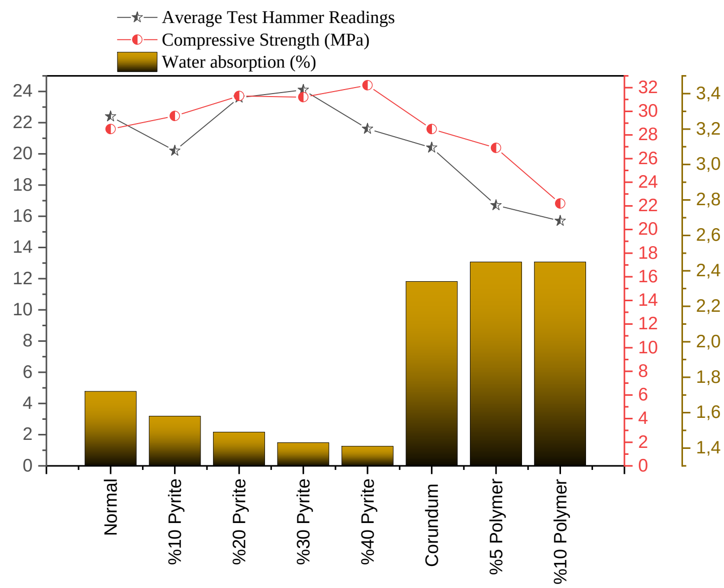

Figure 10. Average Schmidt hammer readings, compressive strength water absorption of normal, pyrite, corundum, and polymer samples.

The water absorption values measured in the pavings are shown in Figure 10. It has been observed that the water absorption values of the reference pavings and the pyrite pavings are close to each other, but there are small differences. Water absorption values of corundum and polymeric samples were found to be 60-65% higher than normal and pyrite fine aggregate added samples. In the experiments conducted by Gencel et al. (2012) with concrete pavings with added marble, the water absorption values decreased as the waste-marble ratio of the mixture increased. The highest water absorption is 5%, which is encountered in samples with 10% waste marble. The acceptable water absorption amount in the TS 2824 EN 1338 standard (2005) is at most 6%. In this study, the highest water absorption value was seen with the value of 2.45% in the 10% polymer-added concrete paving samples, while the lowest value was observed in the 40% pyrite-added concrete parquet sample. Also, it was observed that the water absorption rate decreased as the substitution rate increased in the pyrite aggregate samples.

4. Conclusions

In this study, the effects of pyrite, corundum, and water-retaining polymer on the surface wear resistance of concrete pavings were investigated. In this context, values such as freeze-thaw, water absorption, splitting tensile strength, abrasion resistance, polished abrasion resistance, and surface hardness were tested. In the light of the data obtained within the scope of the experiments, the following conclusions were reached:

1. It has been observed that concrete pavings give better results than reference pavings in terms of surface wear resistance with additives such as pyrite aggregate, corundum-based surface hardener, and high water retaining polymer.
2. It has been determined that the pavings with high surface abrasion resistance have high tensile strength in splitting.
3. The highest tensile strength in splitting was observed in corundum-based concrete pavings with surface hardener additives, and then in concrete pavings with 30% pyrite fine aggregate and 5% water retaining polymer additives.
4. It has been found that the mass loss per unit area after the freeze-thaw test of the corundum and water-retaining polymer pavings with high water absorption rate is less than the reference pavings.
5. It could said that the non-polished slip resistance value (USRV) of concrete pavings with corundum based surface hardener additives and 5% polymer additives is higher than the non-polished and pyrite fine aggregate added concrete pavings.
6. The highest Schmidt test hammer value was observed in pyrite fine aggregate added concrete parquet samples. In concretes with water retaining polymer additives, Schmidt test hammer values were found to be lower than other concrete paving samples.

7. The fact that the void structure of the water-retaining polymer floorings with high water absorption amount is one of the reasons why the loss of mass per unit area after the freeze-thaw test is in the pavings with the least water-retaining polymer content.

Concrete paving has a great structural and architectural use in the world. Since it has a large sector, it needs to be worked on so that they can be produced more efficiently. It is understood that heavy aggregates and chemicals such as pyrite make positive contributions to the strength of concrete paving. In this study, some heavy aggregates and chemical additives were used. However, the effect of the materials used on concrete pavements should be repeated and analysed with other aggregate and chemical types that can be used outside of this study.

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