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**Araştırma Makalesi / Research Article**

# The Characterization of Crushed Natural Stone Aggregates

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## Abstract

Marble and volcanic rocks are a widespread aggregate resource and are increasingly being used in concrete constructions worldwide. This paper presents a study's results to compare the properties of concretes prepared with marble, andesite, and basalt used as aggregates. Three aggregate types were supplied locally from three different areas in Turkey. Chemical, petrographic, and mineralogical analysis was carried out on all these samples. A variety of laboratory tests determined the physical and mechanical properties of all aggregates. Water absorption, material finer than 63 μm, Los Angeles abrasion test, Mg2SO4 soundness, and alkali-silica reaction indicate that andesite aggregate is of lower quality than basalt marble aggregates. Test results show that crushed marble concrete has the highest workability, followed by crushed basalt and crushed andesite aggregates.

***Keywords:*** *Concrete, Aggregate, Natural stone, Marble, Basalt, Andesite.*

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# Kırılmış Doğal Taş Agregaların Karakterizasyonu

**Öz**

Mermer ve volkanik kayaçlar yaygın bir agrega kaynağıdır ve dünya çapında beton yapılarda giderek daha fazla kullanılmaktadır. Bu makalede agrega olarak kullanılan mermer, andezit ve bazaltın karakterizasyonu amacıyla hazırlanmıştır. Türkiye'deki üç farklı bölgeden üç agrega türü tedarik edilmiştir. Tüm bu numuneler üzerinde kimyasal, petrografik ve mineralojik analizler yapılmıştır. Çeşitli laboratuvar testleri ile tüm agregaların fiziksel ve mekanik özellikleri belirlenmiştir. Su emme, 63 µm'den az malzeme, Los Angeles aşınma testi, Mg2SO4 sağlamlığı ve alkali-silika reaksiyonu, andezit agregasının bazalt mermer agregalarından daha düşük kalitede olduğunu göstermektedir. Test sonuçları, kırılmış mermer agregaların en yüksek beton işlenebilirliğine sahip olduğunu, ardından kırılmış bazalt ve andezit agregalarının geldiğini göstermektedir.

***Anahtar kelimeler:*** *Beton, Agrega, Doğal taş, Mermer, Bazalt, Andezit.*

## 1. Introduction

Concrete is made from a mixture of cement, water, and aggregate. Natural materials such as river sand and crushed stone are generally used in concrete as aggregates. The properties of the used aggregate influence the performance of the concrete. Aggregate type, particle size, and shape are essential. The manufacture of concrete products (concrete blocks, block paving, bricks, flooring, etc.) and ready-mixed concrete is essential for sand and gravel. It is an increasingly important use of crushed stone; although sand and gravel in the region are limited, concrete has been an essential use for crushed stone for a long time. Some rocks are suitable for use as aggregate; notably, marble and dolomite have a wide range of industrial applications globally. Due to being a low-cost product and widely spread, they are used in a considerable amount. In addition, reusing aggregates has become increasingly prevalent, and the substitution of natural aggregates with artificial aggregates generated from waste products from other sectors is a minor component of the industry (Limbachiya et al., 2000; Xiao et al., 2006; Etxeberria et al., 2007).

Several investigators have examined the impact of various aggregate kinds on concrete. Wu et al., (2001) examined the influence of crushed quartzite, crushed granite, and marble as coarse aggregate on the mechanical characteristics of high-performance concrete. Kılıç et al., (2008) studied the effect of five different aggregate types (gabbro, basalt, quartzite, marble, and sandstone) on the strength characteristics and abrasion resistance of high strength silica fume concrete. Meddah et al., (2010) examined the effects of coarse aggregate concentration and particle size distribution on the compressive strength of concrete. Their findings revealed that the mixture with a ternary combination of coarse fraction with a maximum size of 25 mm, without admixtures, had the best compressive strength. Yılmaz and Tugrul (2012) studied the impact of various sandstone aggregates on concrete strength. Uysal (2012) investigated the impact of five distinct coarse aggregate types (basalt, marble, dolomite, marble, and sandstone) on abrasion, compressive strength, static and dynamic elastic moduli, and ultrasonic pulse velocity of concrete.

Several investigators have reported the influence of limestone (Özturan and Çeçen, 1997; Poitevin 1999; Donza et al., 2002; Zarif and Tuğrul, 2003; Al-Oraimi et al., 2006), andesite (Black, 2005) and basalt (Özturan and Çeçen, 1997; Alonso et al., 2002; Korkanç and Tugrul, 2004; El-Dash and Ramadan, 2006; Zega et al., 2010) of aggregates to the strength of different individual rocks.

The purpose of this study is to explain how the characteristics of various natural aggregates affect the properties of concrete. This article compares the properties of concretes prepared with the used marble, andesite, and basalt as aggregates. The concrete's physical and mechanical characteristics were studied.

## 2. Material and Methods

### 2.1. Raw materials

#### 2.1.1. Cement

Portland cement CEM I 42.5 R was utilized in all concrete mixes, and it met the TS EN 197-1 (2005) standard.

#### 2.1.2. Aggregates

Marble and limestone, which are widespread in Afyonkarahisar, Turkey, form the primary source of locally crushed rock aggregates. Three types of crushed aggregates, marble, andesite, and basalt, were used as the aggregates in concrete production. Crushed particles with particle sizes ranging from 0 to 22 mm are described as fine, medium, and coarse aggregates, and include crushed basalt (IB) from Ilıca-Kütahya, crushed andesite (IA) from İscehisar-Afyonkarahisar, and marble (BM) from Beyyazı-Afyonkarahisar. Figure 1 shows a map of the location of rock quarries.

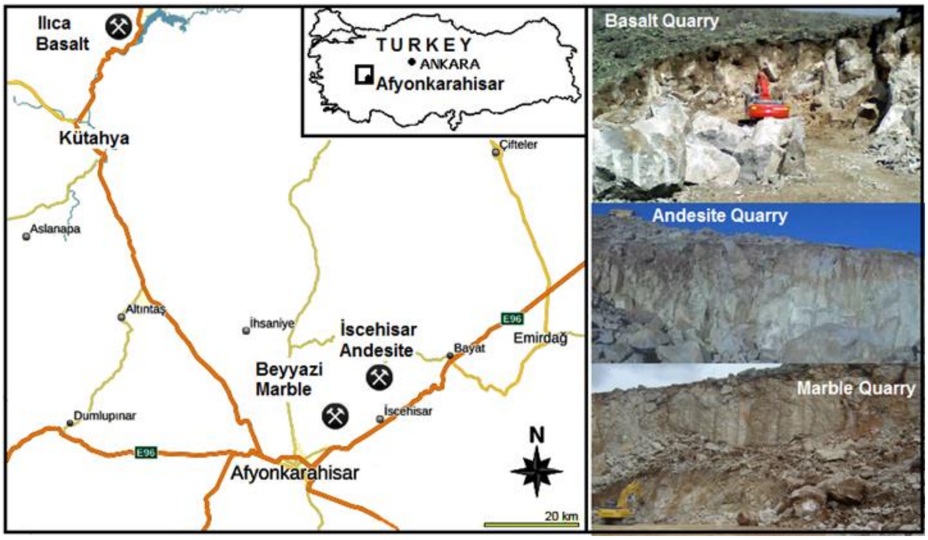



**Figure 1.** Location map of natural stone quarries used as an aggregate in Afyonkarahisar and Kütahya (Turkey).

### 2.2. Mix design

Three natural aggregates were used; all were crushed from marble, andesite, and basalt rocks, which were kept constant in all the mixes. The cement used was CEM I 42.5R with a content of 280 kg/m3. Table 1 shows the mixed proportions utilized in this experiment.

The dry ingredients were combined in the rotating pan's 55 dm3 capacity. The standardized mixing process was as follows: cement and all aggregates were mixed first, followed by water. The whole mixing time was around 4 minutes. All mixtures had a water-to-cement ratio of 0.54. From each mix, 15×15×15 cm cubes were cast. All samples were compressed into three layers, with each layer compacted 25 times (Fig 2). After 24 hours, the specimens were taken from the mold. After that, the specimens were cured in a water tank for 7 to 28 days. At the end of the curing period, all specimens were tested.

**Table 1.** Concrete mix proportions

| Material | Quantity (kg/m$^3$) |
|---|---|
| Cement (42,5 CEM-I R) | 280 |
| 0-4 mm aggregate | 1150 |
| 4-12 mm aggregate | 310 |
| 12-22 mm aggregate | 480 |
| Water | 175 |
| w/c | 0.54 |

**Figure 2.** Filling the molds with concrete

**2.3. Chemical, mineralogical and petrographic analysis**

X-ray fluorescence (XRF) spectrometry was used at the Çanakkale Seramik Laboratory (Turkey) to identify major element oxides. A polarizing optical microscope (Nikon LV100POL) was used to study the mineralogical and petrographic characteristics of marble, andesite, and basalt rocks at Afyon Kocatepe University (Turkey), and XRD analyses are undertaken by the Çanakkale Seramik Laboratory (Turkey).

**2.4. Properties of aggregates and concrete**

Crushed aggregates were separated based on size. It was sieved using standard sieves and divided into three groups: 0-4, 4-12, and 12-22 mm. The separated aggregate combinations were achieved with a grade that requirements the standards of TS 3530 EN 933-1. Different physical and mechanical properties were determined for each aggregate sample (basalt, andesite, and marble aggregates) such as grain size distribution, loose unit weight, condensed unit weight, bulk specific gravity (saturated surface dry), dry specific gravity, apparent specific gravity, material finer than 63 μm, water absorption, percentage of fines, flakiness index, Los Angeles abrasion test, freeze-thaw loss,% (with Magnesium sulfate), the methylene blue test, organic impurities, chloride content, sulfide soluble in acid, total sulfur content, alkali-silica reaction (ASR). According to TS EN (Technical Specification European Standard) standards, the laboratory tests are performed at the Saglamlar Insaat A.S Laboratory in Afyonkarahisar, Turkey. Aggregates and concrete samples for physicomechanical tests and Table 2 includes the standards utilized for each test performed.

**Table 2.** Related standards for aggregates tests

| Tests | Related standards |
|---|---|
| Grain size distribution | TS 3530 EN 933-1 (1999) |
| Loose unit weight (bulk density) (kg/m3) | TS 3529 (1980) |
| Condensed unit weight (bulk density) (kg/m3) | TS 3529 (1980) |
| Dry specific gravity (g/cm3)<br>Bulk specific gravity (saturated surface dry)<br>Apparent specific gravity | TS EN 1097-6 (2002) |
| Water absorption (%) | TS EN 1097-6 (2002) |
| Material finer than 63 μm | TS 3530 EN 933-1 (1999) |
| Percentage of fines (%) | TS 3527 (1980) |
| Flakiness Index (%) | TS 9582 EN 933–3 (1999) |
| Los Angeles abrasion test (%) | TS EN 1097-2 (2000) |
| Freeze-thaw loss, % (with Magnesium sulfate) | TS EN 1367-2 (1999) |
| The methylene blue test | TS EN 933–9 (2010) |
| Organic impurities | TS EN 1744-1 (2010) |
| Chloride content | TS EN 1744-1 (2010) |
| Sulfide Soluble in Acid | TS EN 1744-1 (2010) |
| Total Sulfur Content | TS EN 1744-1 (2010) |
| Alkali–silica reaction (ASR) | ASTM C 1260 (1997) |

## 3. Experimental Investigation and Results

### 3.1. Chemical analysis

Chemical analyzes were performed to determine the chemical properties of the stones being tested. The origin of the volcanic rocks was determined according to the results of chemical analysis. Table 3 shows the findings of the chemical analysis. Because they looked to be the best and were already extensively used, the chemical criteria silica ($SiO_2$) weight percent and total alkalis ($Na_2O$+ $K_2O$) wt percent were chosen (Le Bas and Streckeisen 1991). As shown in Fig. 3, andesite and basalt samples are categorized using $Na_2O$+$K_2O$ – $SiO_2$ diagrams (Le Bas et al., 1992). It is seen that andesite samples are located in the trachy-andesite area; however, basalt is located in the basaltic andesite area.

**Table 3.** Chemical composition of rocks used as aggregates

| | | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 52.80 | 15.60 | 0.90 | 8.03 | 9.00 | 4.20 | 2.78 | 2.46 | 0.142 | 3.40 |
| Basalt | 2 | 53.30 | 15.90 | 0.95 | 8.21 | 9.05 | 4.11 | 2.83 | 2.49 | 1.155 | 2.70 |
| | 3 | 52.20 | 16.20 | 0.89 | 8.11 | 9.10 | 4.16 | 2.90 | 2.37 | 0.880 | 3.20 |
| | 1 | 60.30 | 15.08 | 0.83 | 6.12 | 4.31 | 1.36 | 3.14 | 4.12 | - | 3.00 |
| Andesite | 2 | 61.00 | 17.00 | 0.56 | 5.46 | 4.32 | 1.40 | 3.27 | 4.78 | - | 2.20 |
| | 3 | 60.70 | 16.23 | 0.78 | 6.11 | 4.40 | 1.68 | 3.41 | 4.01 | - | 2.70 |
| | 1 | 0.21 | 0.17 | 0.01 | 0.07 | 35.20 | 17.72 | 0.02 | 0.01 | - | 47.00 |
| Marble | 2 | 0.31 | 0.14 | 0.01 | 0.05 | 37.00 | 16.91 | 0.01 | 0.01 | - | 46.00 |
| | 3 | 0.22 | 0.18 | 0.01 | 0.05 | 36.00 | 16.35 | 0.01 | 0 | - | 47.00 |

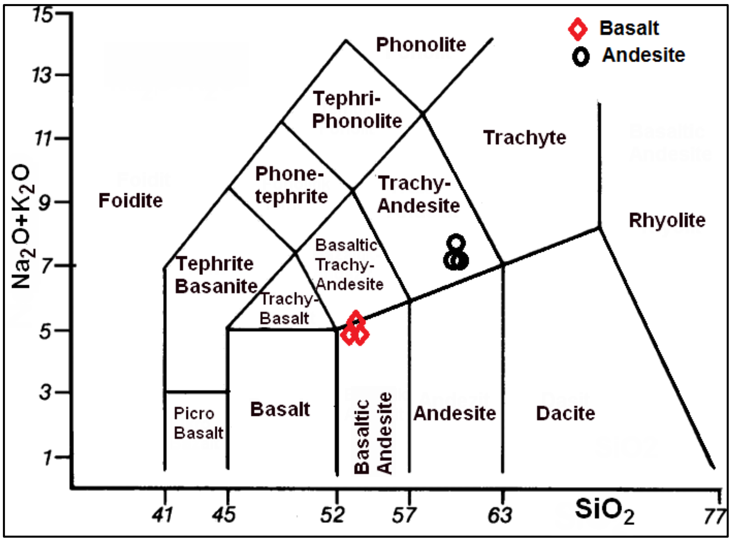



**Figure 3.** The classification of the volcanic rocks based on total alkali versus silica (TAS diagram proposed by Le Bas et al., (1992)).

### 3.2. Mineralogical and Petrographic Analysis

**Polarizing optical microscope studies**

The mineralogical and petrographic characteristics of the examined rocks were investigated using a polarizing optical microscope and X-ray diffractometry (XRD). Thin section studies determined the petrographic characteristics of the collected rocks from the Afyonkarahisar and Kütahya regions. These investigations determined the mineralogical composition, matrix, and particle size of the examined rocks.

Basalt is an extrusive igneous rock composed primarily of plagioclase and pyroxene minerals. It had a holocrystalline to hypocrystaline texture, with fine grain size and rare plagioclase and pyroxene. In a thin section, the Ilıca-Kütahya basalts contain plagioclase (feldspar), clinopyroxene, and olivine minerals. Partially altered olivine micro phenocrysts, plagioclase microlites show flow texture. Olivine appears mainly as subhedral to anhedral phenocrysts and micro phenocrysts in the matrix. Plagioclase is the gray mineral, olivine is the bluish-green to blue grain at the top, and the rest is mainly pyroxene (Fig. 4).

Andesite is a kind of rock that is intermediate in composition between primary (basalt) and acid (rhyolite). Andesite is a grey-black, fine-grained volcanic rock rich in silica (53–63%). It has a porphyritic texture and is made up of microliths of plagioclase (feldspar) and pyroxene, feldspar, pyroxene, and biotite phenocrysts in a glass matrix. In a thin section, the İscehisar-Afyonkarahisar andesite contains crystals of plagioclase, sanidine, clinopyroxene, hornblende, biotite, and olivine minerals (Fig. 5). Plagioclase crystallizes as microlites and sometimes as small phenocrysts with a flowing texture.

Marble, or recrystallized limestone, is a common aggregate resource in the Afyonkarahisar region and is increasingly being utilized in concrete construction. In a thin section, the Beyyazi-Afyonkarahisar marble contains crystals of calcite and dolomite minerals. Calcite crystals with mostly curved borders are uncommonly embayed and sutured. Calcite is abundant; the more significant pieces show regular polysynthetic twinning. Beyyazi-Afyonkarahisar marbles have a granoblastic texture and concentrated veins formed by dolomite minerals (Fig. 6).

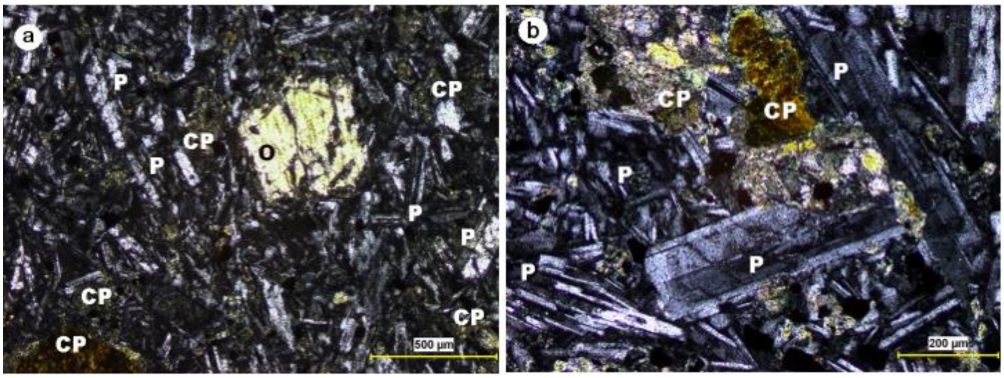



**Figure 4.** A photograph of a thin section of Ilıca basalt (IB) with a fine-grained groundmass with plagioclase (P), clinopyroxene (CP), and olivine (O) crystals. Photomicrographs (a-b) taken with crossed Nicols.

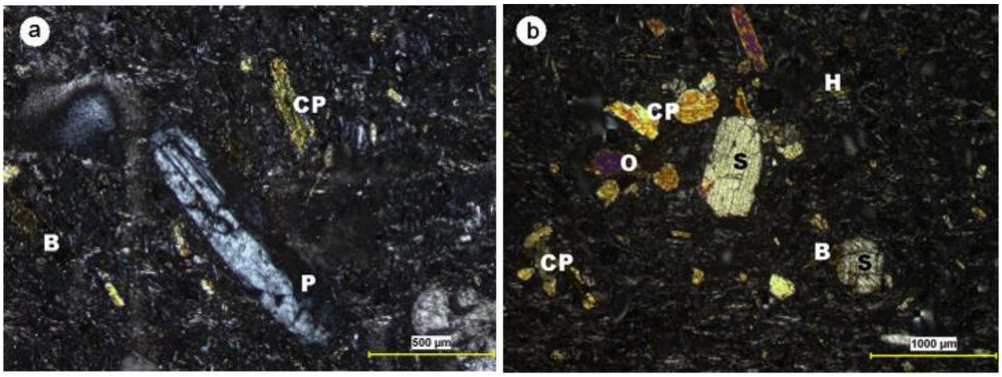



**Figure 5.** A photograph of a thin section of an İscehisar-Afyonkarahisar andesite with a fine-grained groundmass with plagioclase (P), sanidine (S), clinopyroxene (CP), hornblende (H), biotite (B), and olivine (O) crystals. Photomicrographs (a-b) taken with crossed Nicols.

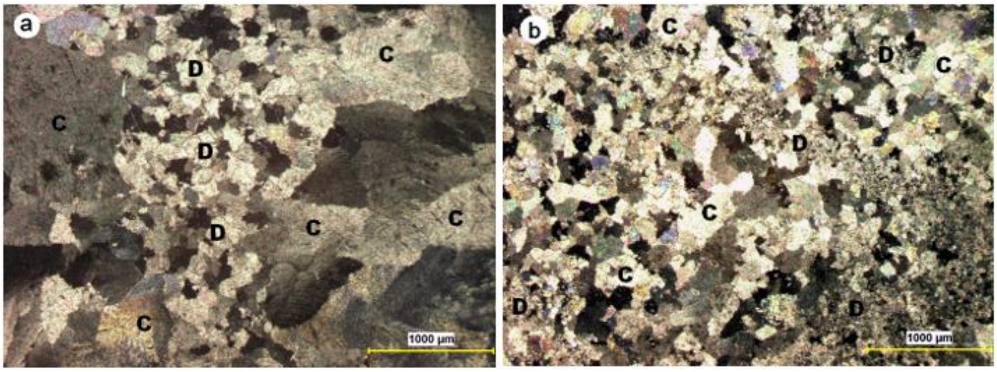



**Figure 6.** A photograph of a thin section of a Beyyazi-Afyonkarahisar marble with calcite (C) and dolomite (D) crystals. Dolomite minerals were formed along in the fractures. The photomicrographs (a-b) were taken with crossed Nicols.

**X-ray diffractometry (XRD) analyses**

The mineralogical nature of basalt, andesite, and marble crystalline phases was determined by X-ray diffraction research. XRD analyses of the Ilıca basalt reveal that labradorite, sanidine, muscovite, and montmorillonite are present within the rock. The XRD pattern for an Ilıca basalt sample is depicted in Fig. 7. The İscehisar andesite samples are composed of sanidine, montmorillonite, muscovite, andesine and tridymite (Fig. 7). Tridymite, the main silica phase, is found solely in andesite samples. In addition to this mineral, volcanic rocks include a substantial component of amorphous materials (volcanic glass). In XRD patterns of Beyyazi marble, two peaks of calcite and dolomite minerals were observed (Fig. 7). Rock is called dolomitic marble.

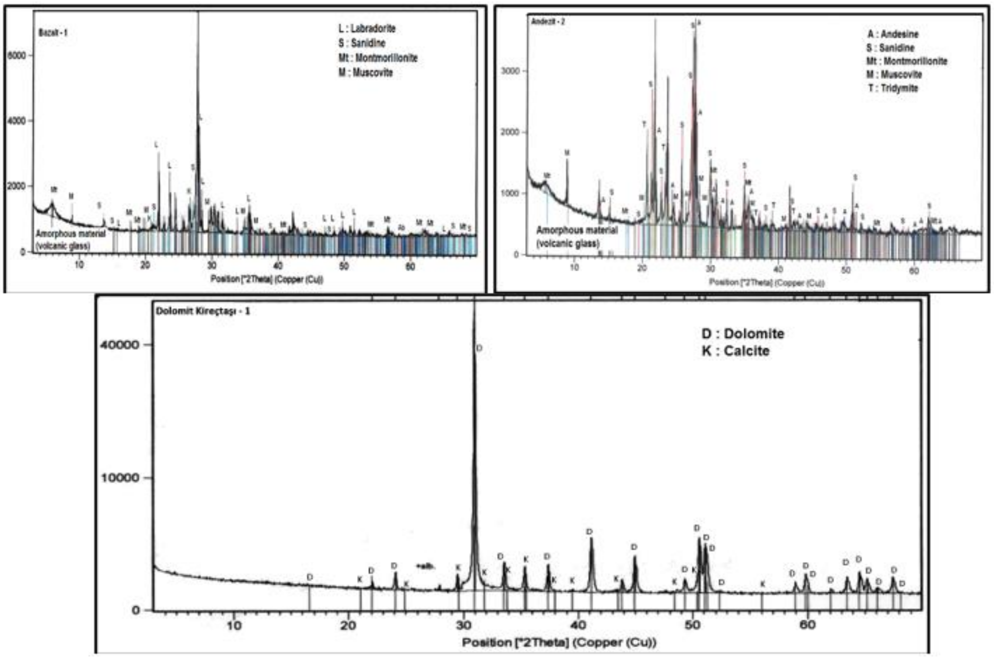



**Figure 7.** X-ray diffraction (XRD) diffractogram of basalt, andesite, and marble samples.

### 3.3. Aggregate tests

Aggregate, the primary ingredient of concrete, accounts for 60 to 80 percent of the overall volume of the material. The workability and hardened characteristics of concrete are affected by the kind and particle size distribution of the aggregates. There are two primary reasons for increasing the aggregate content of concrete. The first is that cement costs more than aggregate; therefore, utilizing more aggregate lowers the cost of creating concrete. The second is that most hardened concrete durability issues, such as shrinkage and freezing, and thawing, are caused by cement (Rached et al., 2009). A variety of laboratory tests determined the physical and mechanical properties of all aggregates. TS and TS EN Standards performed tests. Every test was carried out at least three times.

#### 3.3.1. Grain size distribution

The frequency of a distribution of a given aggregate's particle sizes is characterized as an aggregate's graduation (Lamond and Pielert, 2006). Aggregate particle size distribution is one of the most important characteristics regarding the utilization of aggregates in concrete. Sample rocks were crushed into aggregates using a priming crusher, then sieved and divided into three sizes: 0–4 mm as fine aggregate, 4–12 mm as medium aggregate, and 12–22 mm as coarse aggregate. The separated aggregate combinations were achieved with a grade that meets the standards of TS 3530 EN 933-1 (1999). Three crushed aggregates were tested and used in this study: basalt, andesite, and marble.

Table 4 depicts the particle size distribution of the aggregates examined. Figure 8 depicts the sieve analysis test findings, divided into three sizes: 0–4 mm as fine aggregates, 4–12 mm as medium aggregates, and 12–22 mm as coarse aggregates. As demonstrated in Fig 9, the sieve analysis value of the ratio obtained for all mix aggregate is within the required limit. The grading curve for natural aggregates is positioned between the lower and higher limits of the aggregate grading requirement from TS 706 EN 12620. (2009). As a result of this finding, all aggregates are appropriate for concrete building operations.

**3.3.2. Unit weight (bulk density) and specific gravity**

The bulk density of an aggregate, or its unit mass, represents a portion of its void content at a particular degree of compaction and is, therefore, an indirect indicator of its grading and form properties. For typical aggregates, the bulk density ranges from 1200 to 1800 kg/m3 (Smith and Collis 1993). The aggregates' loose unit weight (bulk density) and condensed unit weight are calculated using the TS 3529 test technique.

**Table 4.** Grading of crushed aggregates for all aggregate type (% Passed)

| | Basalt | | | Andesite | | | Marble | | |
|---|---|---|---|---|---|---|---|---|---|
| Sieve (mm) | 0-4 mm | 4-12 mm | 12-22 mm | 0-4 mm | 4-12 mm | 12-22 mm | 0-4 mm | 4-12 mm | 12-22 mm |
| 22.4 | | | 100 | | | 100 | | | 100 |
| 16 | | | 51.65 | | | 25.42 | | | 22.21 |
| 11.2 | | 95.55 | 10.9 | | 96.87 | 3.37 | | 97.08 | 1.13 |
| 8 | | 52.04 | 0 | | 40.83 | 0 | | 46.94 | 0 |
| 5.6 | | 19.05 | | | 6.86 | | | 8.1 | |
| 4 | 89.32 | 0 | | 97 | 0 | | 98.44 | 0 | |
| 2 | 66.63 | | | 63.86 | | | 69.87 | | |
| 1 | 49.94 | | | 45.24 | | | 51.45 | | |
| 0.5 | 37.82 | | | 31.79 | | | 38.28 | | |
| 0.250 | 26.41 | | | 21.33 | | | 28.91 | | |
| 0.125 | 16.33 | | | 11.96 | | | 17.86 | | |
| 0.063 | 7.3 | | | 3.9 | | | 6.1 | | |
| | 0 | | | 0 | | | 0 | | |

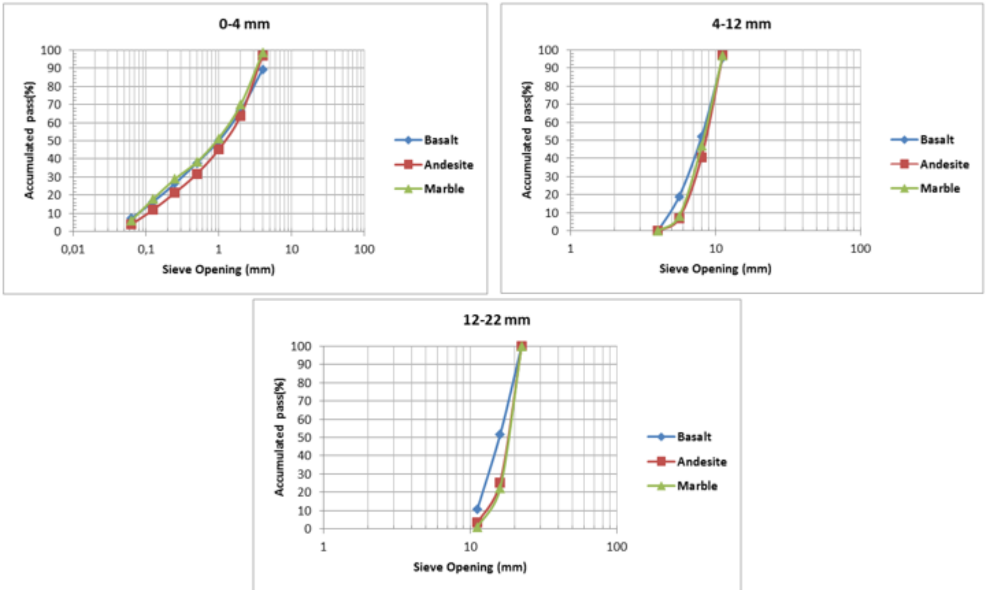



**Figure 8.** Grain-size distributions curve of the separated into three different sizes of natural aggregates.

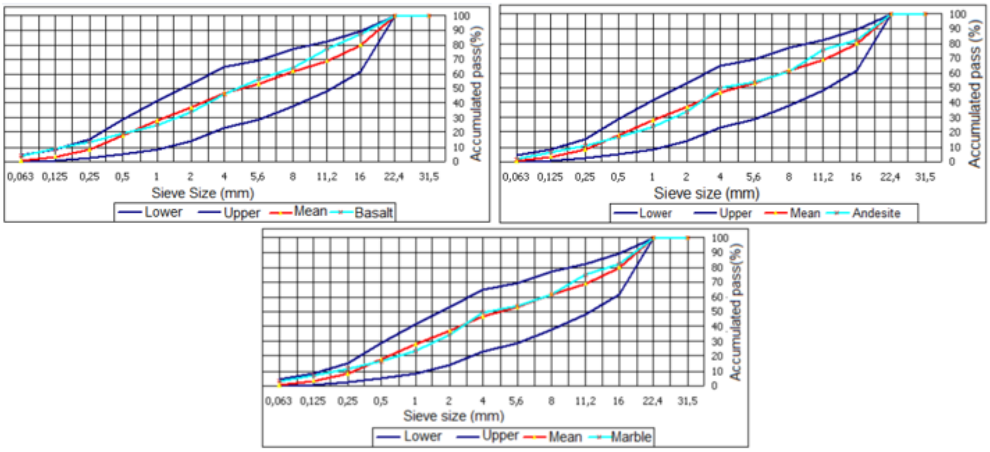



**Figure 9.** Sieve analysis within the lower and upper limit of the grading requirement for crushed natural aggregates from TS 706 EN 12620 (2009).

Loose unit weight and condensed unit weight of separated aggregates values were presented in Table 5. The loose unit weight of the specimens for basalt, andesite, and marble aggregates ranges from 1381 to 1571 kg/m³, 1291 to 1599 kg/m³, and 1361 to 1751 kg/m³ (Fig 10). Table 6 shows the ratio of natural aggregates' loose bulk density to compacted bulk density. The loose bulk density to compacted bulk density ratio ranges between 0.88 and 0.99. According to Neville and Brooks (2002), this number is between 0.87 and 0.96, as indicated by the code. The specific gravity is a characteristic of the concrete, which needs to be determined in making calculations of the mix design of concrete. There are several specific gravities; dry specific gravity, bulk specific gravity, and apparent specific gravity. The specific gravity was determined according to the procedure described in TS EN 1097-6 (2002). Test results obtained from dry, bulk and apparent specific gravity of the aggregates are summarized in Table 7. This is lower than the natural aggregate values reported by Neville and Brooks (2002), which range from 2.6 to 2.7. Apparent specific gravity ranges between 2.37 and 2.88 g/cm$^3$ (Fig 11). Andesite has lower specific gravity values than the other rocks. The marble specimens received the greatest value.

**Table 5.** Properties of the loose unit weight and condensed unit weight of the aggregates

| Type | Grain size (mm) | Loose unit weight (kg/m$^3$) Min | Max | Mean | Standard required | Condensed unit weight (kg/m$^3$) Min | Max | Mean | Standard required | CU W/L UW % |
|---|---|---|---|---|---|---|---|---|---|---|
| Basalt | 12-22 | 1381 | 1403 | 1392 | (TS 3529, 1980) ≥1250 (kg/m$^3$) | 1491 | 1514 | 1504 | (TS 3529, 1980) 1500-1900 (kg/m$^3$) | 0,93 |
| | 4-12 | 1413 | 1474 | 1447 | | 1531 | 1556 | 1543 | | 0,94 |
| | 0-4 | 1527 | 1571 | 1547 | | 1611 | 1651 | 1631 | | 0,95 |
| Andesite | 12-22 | 1291 | 1297 | 1294 | | 1445 | 1450 | 1447 | | 0,89 |
| | 4-12 | 1306 | 1310 | 1308 | | 1469 | 1471 | 1470 | | 0,89 |
| | 0-4 | 1593 | 1599 | 1596 | | 1598 | 1627 | 1612 | | 0,99 |
| Marble | 12-22 | 1361 | 1381 | 1371 | | 1559 | 1567 | 1563 | | 0,88 |
| | 4-12 | 1441 | 1476 | 1457 | | 1598 | 1605 | 1601 | | 0,91 |
| | 0-4 | 1729 | 1751 | 1742 | | 1873 | 1884 | 1878 | | 0,93 |

**Table 6**. Properties of the dry, bulk, and apparent specific gravity of the aggregates

| Type | Grain size (mm) | Dry specific gravity (g/cm$^3$) Min | Max | Mean | Bulk specific gravity (saturated surface dry) (g/cm$^3$) Min | Max | Mean | Apparent specific gravity (g/cm$^3$) Min | Max | Mean | Standard required |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Basalt | 12-22 | 2,61 | 2,63 | 2,62 | 2,64 | 2,66 | 2,65 | 2,70 | 2,72 | 2,71 | (TS EN 206-1) 2 - 3 (g/cm$^3$) |
| | 4-12 | 2,60 | 2,63 | 2,61 | 2,64 | 2,66 | 2,65 | 2,71 | 2,74 | 2,72 | |
| | 0-4 | 2,54 | 2,61 | 2,58 | 2,61 | 2,67 | 2,65 | 2,73 | 2,76 | 2,75 | |
| Andesite | 12-22 | 2,25 | 2,27 | 2,26 | 2,31 | 2,32 | 2,32 | 2,37 | 2,39 | 2,38 | |
| | 4-12 | 2,19 | 2,23 | 2,21 | 2,26 | 2,30 | 2,28 | 2,37 | 2,39 | 2,38 | |
| | 0-4 | 2,03 | 2,14 | 2,10 | 2,18 | 2,26 | 2,22 | 2,39 | 2,42 | 2,40 | |
| Marble | 12-22 | 2,78 | 2,81 | 2,79 | 2,81 | 2,83 | 2,82 | 2,85 | 2,87 | 2,86 | |
| | 4-12 | 2,71 | 2,73 | 2,72 | 2,75 | 2,77 | 2,76 | 2,83 | 2,85 | 2,84 | |
| | 0-4 | 2,68 | 2,71 | 2,69 | 2,74 | 2,76 | 2,75 | 2,84 | 2,88 | 2,86 | |

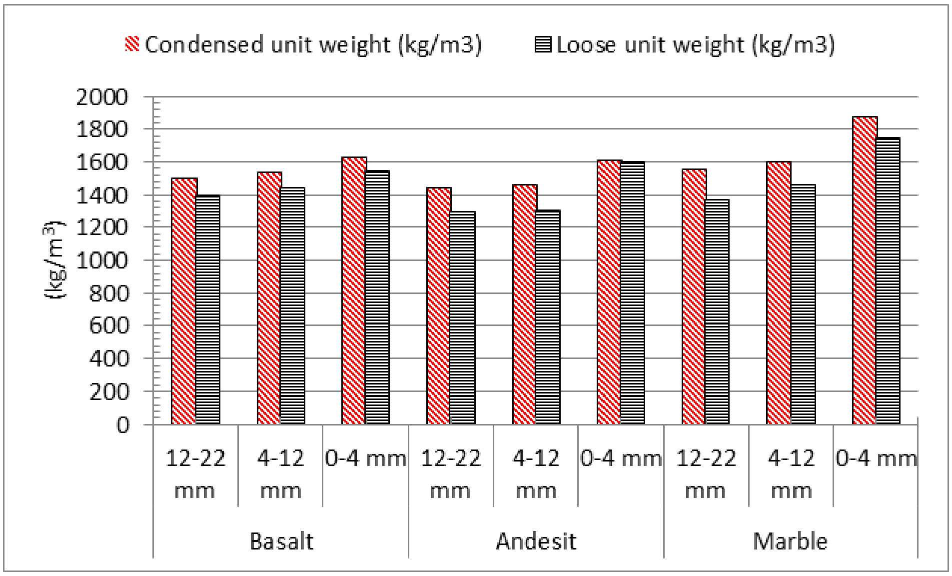



**Figure 10.** Loose unit weight and condensed unit weight of the aggregates.

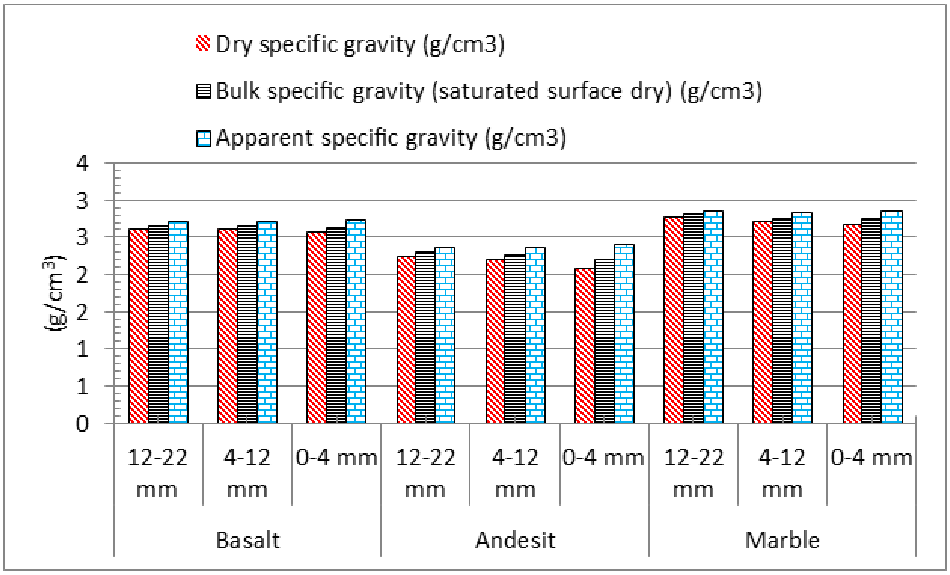


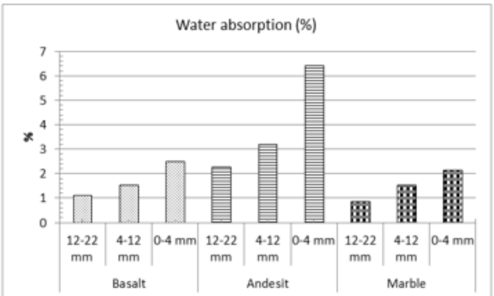

**Figure 11.** Dry, bulk, and apparent specific gravity of the aggregates.

**Table 7**. Properties of the water absorption and material finer than 63 μm of the aggregates

| Type | Grain size (mm) | Water absorption (%) | | | Standard required | Material finer than 63 μm (%) | | | Standard required |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | | Min | Max | Mean | |
| Basalt | 12-22 | 1.01 | 1.21 | 1.12 | | 0.4 | 0.6 | 0.5 | |
| | 4-12 | 1.28 | 1.80 | 1.55 | | 0.6 | 0.7 | 0.65 | |
| | 0-4 | 2.25 | 2.72 | 2.51 | (TS 706 | 2.8 | 3.1 | 3.0 | (TS 706 |
| Andesite | 12-22 | 2.22 | 2.30 | 2.27 | EN | 0.9 | 1.2 | 1.0 | EN |
| | 4-12 | 3.10 | 3.37 | 3.21 | 12620) | 1.05 | 1.24 | 1.13 | 12620) |
| | 0-4 | 5.38 | 7.26 | 6.42 | | 14.1 | 15.8 | 14.0 | |
| Marble | 12-22 | 0.76 | 0.97 | 0.86 | <%10 | 0.71 | 0.80 | 0.75 | <3 |
| | 4-12 | 1.41 | 1.75 | 1.56 | | 0.70 | 0.73 | 0.71 | |
| | 0-4 | 1.99 | 2.48 | 2.17 | | 11.6 | 12.8 | 12.1 | |

**3.3.3. Water absorption and material finer than 63 μm**

The water absorption of the aggregates examined was measured using the techniques suggested by TS EN 1097-6. (2002). Table 8 shows the findings of water absorption levels ranging from 0.76% to 7.26%. The highest mean value of water absorption in andesite specimens was determined. The water absorption values of basalt and marble are lower than those of andesite rocks. The water absorption of andesites ranges from 2.22 to 7.26% (Fig 12).



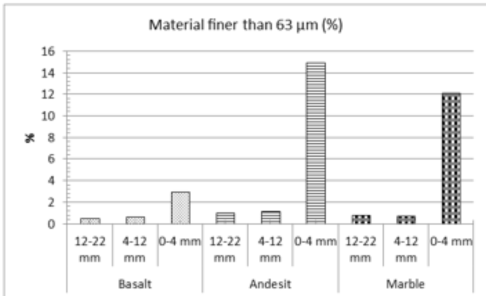




**Figure 12.** Water absorption and material finer than 63 μm of the aggregates

The proportion of fines in aggregates, such as clay, silt, and dust, is defined as the material passing a 63 m screen. These fine aggregate ingredients cause cementing material to expand or disrupt the connection between aggregate and cement. Test results obtained from material finer than 63 μm test are summarized in Table 8. According to the findings, the average percentage of fines ranged between 0.50 and 14.00%. Fines percentages are greater in andesite (0-4 mm) and lower in basalts (12-22 mm).

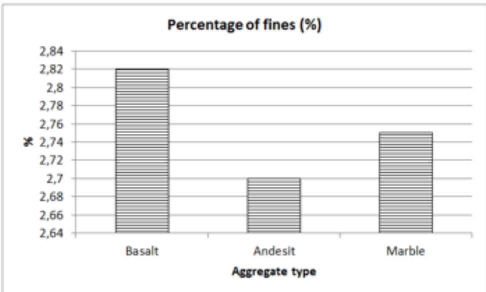
#### 3.3.4. Percentage of fines and flakiness index

According to TS 3530 EN 933-1, (1999), the fineness modulus (FM) of either fine aggregate is determined by adding the cumulative percentages by mass retained on each defined series of sieves and dividing the amount by 100. Table 8 summarizes the findings. The aggregates' fineness modulus (FM) varies between 2.82%, 2.7%, and 2.75% (Fig 13).

In general, solid and hard or brittle rocks yield more flakes than weak rocks, while the latter produces more particles when crushing (Smith and Collis 1993). The flakiness index was calculated using the techniques outlined in TS 9582 EN 933–3. (1999). Table 8 summarizes the findings. As seen in this table, the basalt's flakiness index, andesite, and marble aggregates range 12.26%, 24.3%, and 14.6%, respectively (Fig 13). The maximum flakiness index values are obtained from the andesite. All the samples tested for flakiness index satisfied the requirements for use in standard concrete applications.

**Table 8.** Fines percentage properties and flakiness index of aggregates.

| Type | Percentage of fines (%) | | | Standard required | Flakiness Index (%) | | | FI category | Standard required |
|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean | | Min | Max | Mean | | |
| Basalt | 2,79 | 2,86 | 2,82 | TS EN 706 | 11,5 | 13,3 | 12,26 | FI15 | TS 706 EN 12620 |
| Andesite | 2,68 | 2,73 | 2,7 | | 23 | 25,3 | 24,3 | FI35 | |
| Marble | 2,74 | 2,75 | 2,75 | | 14,3 | 15,3 | 14,6 | FI15 | |



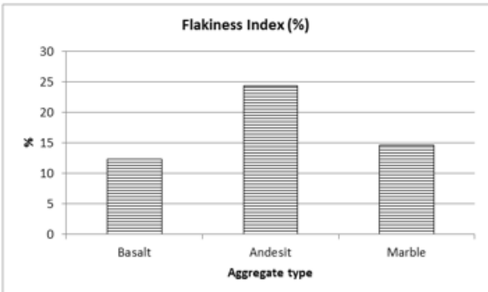




**Figure 13.** The aggregates' fines percentage and flakiness index

#### 3.3.5. Los Angeles abrasion test and $Mg_2SO_4$ soundness

Many aggregates must be durable or resistant to wear or deterioration (Smith and Collis, 1993). To assess the durability of all aggregates, the Los Angeles abrasion test was performed by TS EN 1097-2, (2000). Table 9 summarizes the Los Angeles abrasion values (after 500 cycles). According to the data, basalt aggregates had the lowest abrasion (12.8%, 14.8%), whereas andesite aggregates had the highest abrasion (14.8 percent) (25.7%, 26.9%) (Fig. 14). According to the findings of the Los

Angeles abrasion tests, basalt exhibits lower abrasion loss than andesite and limestone. According to TS EN 12620 (2009), the Los Angeles abrasion value of the aggregate used to create concrete should be less than 50%. All aggregates tested for Los Angeles abrasion values satisfied the requirements for use in standard concrete applications.

**Table 9.** Properties of the Los Angeles abrasion test and $Mg_2SO_4$ soundness of the coarse and medium aggregates

| Type | Grain size (mm) | Los Angeles abrasion test (%) | | | Standard required | $Mg_2SO_4$ soundness (% loss) | | | Standard required |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | | Min | Max | Mean | |
| Basalt | 12-22 | 12,2 | 13,5 | 12,8 | | 3,00 | 3,47 | 3,23 | |
| | 4-12 | 14,1 | 15,8 | 14,8 | | 6,90 | 12,80 | 9,23 | |
| | 0-4 | * | * | * | | * | * | * | |
| Andesite | 12-22 | 24,3 | 26,9 | 25,7 | TS EN 12620 <%50 | 12,00 | 14,28 | 13,00 | TS EN 12620 <%35 |
| | 4-12 | 25,8 | 27,5 | 26,9 | | 19,2 | 22,35 | 20,92 | |
| | 0-4 | * | * | * | | * | * | * | |
| Marble | 12-22 | 22,3 | 23,7 | 22,9 | | 5,81 | 7,95 | 6,78 | |
| | 4-12 | 23,2 | 24,1 | 23,8 | | 12,5 | 14,87 | 13,69 | |
| | 0-4 | * | * | * | | * | * | * | |

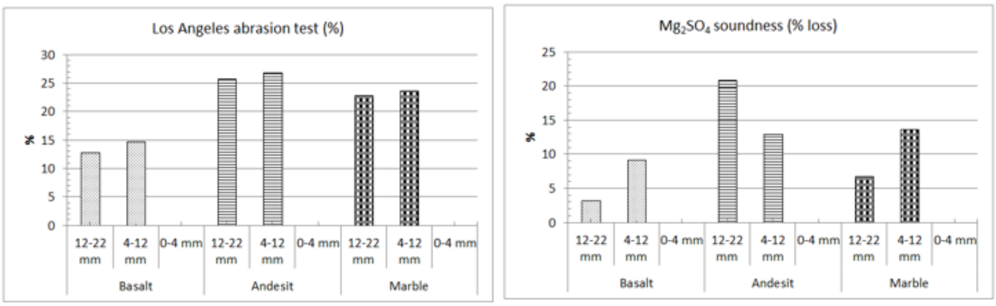



**Figure 14.** The Los Angeles abrasion test and $Mg_2SO_4$ soundness of the coarse and medium aggregates

When volume variations in the aggregate caused by weather, such as alternating cycles of wetting and drying or freezing and thawing, cause concrete degradation, it is called unsound. The word "soundness" refers to an aggregate's capacity to withstand severe volume fluctuations caused by changes in the physical environment, such as freeze-thaw cycles, thermal changes at temperatures above freezing, and so on (Smith and Collis, 1993). This test is a sped-up version of the freeze-thaw test that uses magnesium sulfate solutions. Crystallized magnesium sulfate ($Mg_2SO_4$) was used in this study. One of the major issues in the cold region where aggregates are utilized is freeze-thaw. The aggregates were subjected to a $Mg_2SO_4$ soundness test by TS EN 1367-2. (1999). Table 10 summarizes the findings. According to the findings, maximum $Mg_2SO_4$ soundness value (% loss) was observed for the andesite aggregates (13.0%, 20.92%), and the minimum loss was observed for the basalt aggregates (3.23%, 9.23%) (Fig. 14). According to TS EN 12620, (2009), the $Mg_2SO_4$ soundness value (% loss) should be less than 35% for the aggregate that will be used to produce concrete. All aggregates tested for $Mg_2SO_4$ soundness values satisfied the requirements for use in standard concrete applications.

**3.3.6. Other aggregate tests**

The active clay materials expand, depending on the moisture content. Swelling depends on the type of clay minerals. Swelling minerals are considered the minerals of the smectite group, with a significant representative of the montmorillonite. Smectite is a relatively common secondary product in volcanic rocks andesite, basalt, etc., resulting from low-grade alteration and weathering. Tests with methylene blue have become popular to test aggregates, i.e., the existence of smectite minerals. The Methylene blue test is carried out on the 0/4 mm fraction in fine aggregates according to the TS EN 933–9, (2010) specifications. The methylene blue values (MB) of the aggregates varied from 0.49 to 0.75. The results are given in Table 10. In addition to XRD analysis shows the presence of the clay minerals in basalt and andesite specimens. According to the results obtained, minimum methylene blue values were observed for the marble aggregates (0.49%), and the maximum values were observed for the andesite aggregates (0.75%). According to TS EN 933–9, (2010), the methylene blue values should be less than 1 for the aggregate used to produce concrete. According to this standard, all aggregates are suitable for use in concrete applications (Fig 15).

**Table 10.** Properties of the Methylene blue test, organic impurities, chloride content, sulfide soluble in acid, total sulfur content, alkali-silica reaction (ASR) of the aggregates

| Tests | Standard required | Basalt | | | Andesite | | | Marble | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Av. | Min | Max | Av. | Min | Max | Av. |
| Methylene blue test (MB) | <1 | 0.72 | 0.75 | 0.74 | 0.75 | 0.75 | 0.75 | 0.47 | 0.50 | 0.49 |
| Organic impurities (%) | suitable | 1 - 2 | | | 0 - 1 | | | 1 - 2 | | |
| Chloride content (%) | <0.01 | 0.0024 | | | 0.0016 | | | 0.0047 | | |
| Sulfide soluble in acid (%) | <0.8 | 0.02 | | | 0.024 | | | 0.04 | | |
| Total sulfur content (%) | <%1 | 0.022 | | | 0.027 | | | 0.035 | | |
| Alkali–silica reaction (%) | <0.1 | 0.093 | | | 0.158 | | | 0.078 | | |

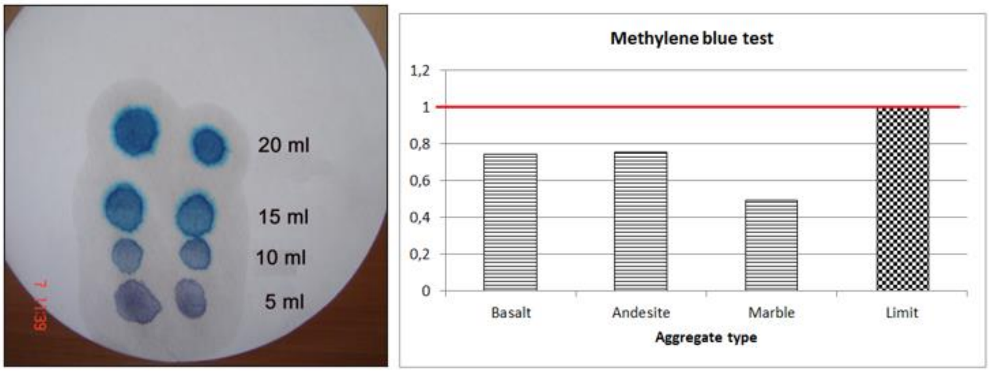



**Figure 15.** Methylene blue test of the fine aggregates.

Organic and chemical contaminants may slow the setting of concrete and reduce the hardened material's strength. A simple test based on TS EN 1744-1, (2010) defines the test for detecting the most dangerous organic and chemical substances. Organic impurities, chloride content, sulfide soluble in acid, total sulfur content, alkali-silica reaction (ASR) of the aggregate test results are given in Table 10. The results of these studies are summarized in Table 10 and shown in Figure 16.

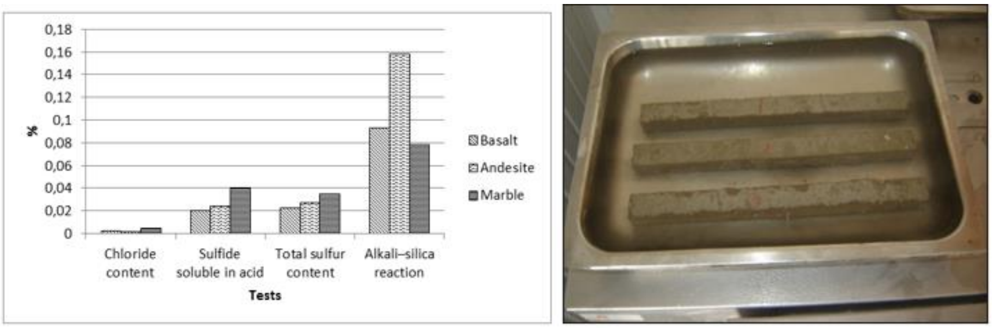



**Figure 16.** Chloride content, sulfide soluble in acid, total sulfur content, alkali-silica reaction (ASR) of the aggregates. Mortar bars of alkali-silica reaction test.

ASR is more common and more damaging to the mechanical characteristics of concrete. ASR is a chemical reaction between the cement between the alkaline components and the active silica-based mineral elements of specific aggregates. The reaction produces a gel that absorbs water, expands, and imposes internal pressure that can sometimes be considerably more than what concrete can withstand, resulting in micro-cracks.

To enable ASR, three key components are required: sufficient alkalis in the pore solution, a sufficient number of reactive mineral phases in the aggregate particles, and sufficient moisture. There are now numerous ways for assessing the potential reactivity of a particular aggregate (Marzouk and Langdon 2003). Alkali–silica reaction of aggregates determined according to ASTM C 1260-94, (1997) procedure. The results are given in Table 10. Alkali-silica reactivity potential of aggregates was investigated in concrete samples. Expansions exceeding 0.1% to 0.2% cause the aggregate to be classified as potentially reactive. Secondary minerals such as montmorillonite clays may contaminate the andesitic aggregates. In this case, andesite aggregates (0.158) expansions exceeding the limit of the alkali-silica reaction value. Basalt (0.093) and marble (0,078) aggregates showed no expansion.

**4. Conclusions**

Natural sand, gravel, and crushed rock aggregates represent a large proportion of the construction industry's materials. The primary ingredient of concrete is aggregate, and the characteristics of aggregate impact the properties of concrete. Three types of aggregates were employed for this project: marble, andesite, and basalt. The mineralogical and petrographic characteristics of the examined rocks were investigated using a polarizing optical microscope and X-ray diffractometry (XRD).

Mineralogical and petrographic determination is insufficient to predict aggregate performance. A variety of laboratory tests determined the physical and mechanical properties of all aggregates. TS and TS EN Standards performed tests. Aggregates were crushed and sorted based on size. It was sieved using standard sieves and divided into three groups of 0-4, 4-12, and 12-22 mm. Studies on three types of aggregates (marble, andesite, and basalt) concrete are carried out in this paper. The following results were obtained:

XRD analyses of the Ilıca basalt reveal that labradorite, sanidine, montmorillonite, and muscovite are present within the rock. Andesite samples are composed of sanidine, montmorillonite, muscovite, andesine and tridymite. XRD analyses for the basalt and andesite indicated montmorillonite type clay minerals. Water absorption, material finer than 63 μm, Los Angeles abrasion test, $Mg_2SO_4$ soundness, and alkali-silica reaction indicate that andesite aggregate is of lower quality than basalt marble aggregates because of the clay it contains. The natural andesitic aggregate is a particular case because, in the Los Angeles abrasion test, basalt and marble aggregates lose less weight than andesite, directly related to its poor quality.

The highest mean value of water absorption in andesite specimens was determined. Basalt and marble have lower water absorption values than andesite rocks. The water absorption rate of andesites ranges from 2.22% to 7.26%.

The bulk density of concrete is determined by the kind and quantity of aggregate used. Fresh concrete with marble aggregate has the highest bulk density (2490 kg/m$^3$), whereas concrete with maximum andesite aggregate has the lowest (2174 kg/m$^3$). The largest slump was seen in concrete created with marble aggregates (17 cm), while the lowest slump was reported in concrete made with andesite aggregates (14.5 cm).

Basalt and marble have many properties compared to the andesite and are therefore very suitable for concrete aggregate. The results indicate that basalt from the Kütahya-Ilıcak, marble from Beyyazi-Afyonkarahisar and andesite from İscehisar-Afyonkarahisar region can be used as concrete aggregates.

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