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Evaluation of Resistance to Los Angeles Abrasion and Physical Factors with Grindability Properties of Some Aggregate Materials

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Abstract: In recent years, the usage of aggregate materials has increased both in Turkey and the entire world. It can be said that the main reason of this rise is the population growth together with the demand towards the more qualitative life. Therefore, the usability of some aggregate materials was investigated in the present paper. The properties of Los Angeles abrasion resistance, freezing-thaw resistance, slake durability strength and frost resistance of basalt and andesite samples obtained from Karaman and Ankara regions were studied at the first stage. In the second order, the grindability performance of these materials was also determined from the discontinuous grinding tests and the obtained results were correlated. Whereas the Los Angeles resistance of the basalt sample was higher than the andesite sample, the mass losses after the freezing-thaw and the frost tests for the andesite sample were superior. Both of the basalt and andesite samples were classified as 'very high' for their slake durability strength (I_{d-2}) values. The material percentage of the andesite sample, which is passing through the sub-size (≥ %90) was greater than the value obtained for the basalt sample during the same grinding time. The resistance to the crushing process was obtained to be maximum at -850+600 µm of feed size for the basalt and the andesite samples.

Introduction

The aggregates considered to be used as natural materials have a large share in many areas such as construction, concrete production, road and railway sectors. The aggregate materials should have been qualified in terms of their reserves and specifications. Additionally, it should not cause any environmental problems. Therefore, the planning and the engineering processes should be designed in a highly effective manner. Otherwise, quite serious social and environmental problems are likely to occur.

Aggregates are commonly regarded as cheap filling materials used in concrete production due to their lower cost comparatively to cement (Caglayan et al., 1999). Therefore, it is important to determine physical and mechanical properties of aggregates prior to usage. Besides, size reduction operations considered as basic mineral processing operations are quite expensive due to more energy requirement. Various approaches are available to calculate the consumed energy for size reduction operations. Rittinger (1867), Kick (1885) and Bond (1952) laws are the most known approaches and related to work index of materials.

The relationship between the mechanical strength and the resistance to the grindability of rocks is probable. Through the determination of this relationship, the estimation of their work index and the breaking characteristics of materials are possible from their mechanical strengths. There are some research works in the literature which revealed the relationship between the grinding parameters and the mechanical strength of the materials (Bearman, 1999; Ozkahraman, 2005; Ozer and Cabuk, 2007; Aras, 2009, Kahraman et al., 2015).

In this study, some mechanical and physical specifications such as density slake durability resistance, abrasion, freezing-thaw resistance, frost losses with grindability properties of the basalt and the andesite samples were determined.

Determination of Mechanical Properties of Aggregates

Los Angeles (Abrasion) Test

Los Angeles (abrasion) test is a method which is applied to determine the fracture strength of coarse aggregates (TS EN 1097-2).

A hollow steel cylinder device closed at the both ends and capable of rotating around its horizontal axis, filled with a number of steel balls having a certain weight is used. In this experiment, totally 5000 grams of sample consisting 3500 grams of sample with the 10-12.5 mm of sieve width and 1500 grams of sample with the 12.5-14 mm of sieve width is used. The samples prepared according to the experimental requirements is first washed and then dried in an oven at 110+5 °C until the weight does not change and the weight of sample (M_1) is recorded.

After 11 of stainless steel balls and aggregate sample are put into the device, the cap is closed tightly and the drum is rotated for 500 revolutions at a constant speed of 30 to 33 rpm during 15 minutes. Then the device is stopped and the aggregates are poured onto the tray carefully. The material is then screened with 1.6 mm sieve and the weight of material retained on the 1.6 mm sieve (M_2) is noted. The percentage of Los Angeles abrasion mass loss (LA) is determined by calculating the difference between the retained material (larger particles) compared to the original sample weight (Eq. 1). The LA abrasion value of materials is declared with regard to the Table 1.

$$LA=(M_1-M_2)/(M_1)*100 \qquad (1)$$

Aggregate Strength against the Physical Factors

Not only some physical changes arise from seasonal variances like freeze-thaw, wet-dry, warm up, cool down affect the strength of the aggregates but also decrease of aggregate strength in the event of frequent repetition of this situation. Specification of aggregate strength against the physical factors is important and the determination of the frost resistance of aggregates especially under the influence of long term air is definitely required.

The frost resistance of aggregates can be performed by two different ways (normal and accelerated) according to the standards of TS EN 1367-1 and TS EN 1367-2. Chemical solutions such as Mg_2SO_4 or Na_2SO_4 are mainly used in the accelerated process.

Table 1. The categories according to the largest Los Angeles abrasion value.

LA abrasion value	Category, LA
≤15	LA_{15}
≤20	LA_{20}
≤25	LA_{25}
≤30	LA_{30}
≤35	LA_{35}
≤40	LA_{40}
≤50	LA_{50}
>50	$LA_{declaration}$

Determination of Freezing-Thaw Resistance

The resistance of the aggregate exposed to successive freeze and thaw process should be determined in order to evaluate their strength. The 3000 grams of test sample obtained from 8-16 mm of particle sized aggregate pile is washed and dried in the oven at 110 + 5 °C. After cooling to ambient temperature, the weight of sample (M_1) is recorded.

Test samples are placed into the metal boxes and distilled water is poured till the water level is covered at least 10 mm over the level of the samples. After the boxes are closed tightly, they are kept at 20 °C for a period of 24 hours. The metal boxes are then placed into a cooler paying attention of the 5 cm of distance between them. Samples in the cooler are subjected to the freeze-thaw cycles for 10 times in the following manner.

a) Temperature is reduced from 20°C to 0°C through 150 min and kept for 210 min at 0 °C.

b) Temperature is reduced from 0°C to -20°C through 180 min and kept for 240 min at -20 °C.

The sample is discharged through a sieve having a half opening of preliminary sieve width after completion of 10 cycles. Test sample is then washed and screened on the sieve by hand. The aggregates remained on the sieve dried in the oven at 110 + 5 °C until constant mass is reached. As soon as the sample is cooled, the weight is recorded (M_2).

TS EN 1367-1 standard is followed for the construction of this experiment. The mass loss is calculated after the freeze-thaw test by using following Equation (2).

$$F=(M_1-M_2)/M_1*100 \qquad (2)$$

Frost Resistance Test with Sodium Sulphate (Na_2SO_4) Solution

TS EN 1367-2 standard can be utilized step by step and repeatedly in order to define the freezing and the thawing effect on the aggregates. In this test, the aggregates are periodically submerged in the chemical solution and the frost resistance is determined after drying in an oven.

The 500 grams of test sample obtained from 10-14 mm of particles is washed with distilled water and dried in the oven at 110+5 °C during 24 hours' time period. After cooling of the sample to room temperature, the aggregates are screened by the sieve (10-14 mm) and weighed (M_1).

Then, the aggregates are put into the wire basket container and the container is also submerged into the bucket, which contains chemical solution covering at least 10 mm over the sample level. After 16-18 hours, the sample is removed from the bucket, percolated and weighed after dried at 105 °C. This process is repeated for five times periodically. The aggregates are washed with $BaCl_2$ solution to remove the sodium sulphate and then dried again during 24 hours time period. The aggregates are then weighed and it is recorded as M_2 after screened with sieve (10 mm). The weight loss is calculated by using Equation 2.

Determination of Slake Durability Strength

This index is used for the classification of rocks (ASTM D4644 and TS 8543) and for also comparison with each other, providing the prediction of the deterioration of rocks under atmospheric conditions by determining the stability against water.

This experiment is purely based on ten representative samples that are intact (weighing 40 to 60 g each and totally 450 to 550 g) placed into the specially designed drum rotating at 20 rpm for a period of 10 minutes.

a) Test samples placed into the clean drum are dried at 105 °C for 16 hours.

b) The weight of the drum and the samples is recorded as A.

c) The drum and the sample dried in the oven for 16 hours at 105 ºC or to constant mass after the rotation period completed. The weight of the drum and the samples is recorded as B.

d) After the second cycle, same operations are repeated and the weight of the drum and the sample is recorded as C.

e) The weight of the empty drum is recorded as D.

The slake durability index is calculated for first (I_{d-1}) and second (I_{d-2}) cycle from the Equations 3 and 4, respectively. If the value of I_{d-2} is between 0-10%, the I_{d-1} value is used for classification.

$$I_{d-1}=(B-D)/(A-D)*100 \quad (3)$$

$$I_{d-2}=(C-D)/(A-D)*100 \quad (4)$$

The classification of the slake durability strength of materials is performed according to the Table 2.

Table 2. Classification of the slake durability strength (Gamble, 1971).

Index value (%)		Classification
I_{d-1}	I_{d-2}	
<60	0-30	very low
60-85	30-60	low
85-95	60-85	medium
95-98	85-95	medium-high
98-99	95-98	high
>99	98-100	very high

Materials and Methods

The basalt and the andesite samples used for experiments were obtained from the deposits located in the vicinity of Ankara and Karaman cities. Geological maps of these deposits are illustrated in Figures 1 and 2, respectively.

The samples were put into the sample vessel to use for appropriate tests after classification by screening for different sizes. A steel ball mill (20 cm of inner diameter, 19.1 cm of length, volume of 6000 cm^3) was employed for the determination of grindability performance.

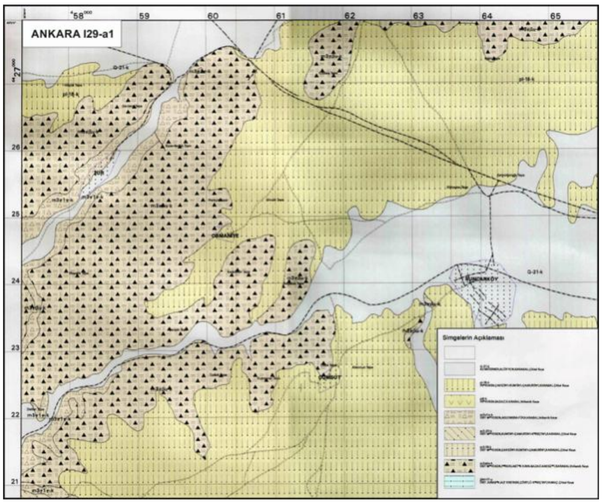

Fig.1 Geological map of Ankara vicinity.

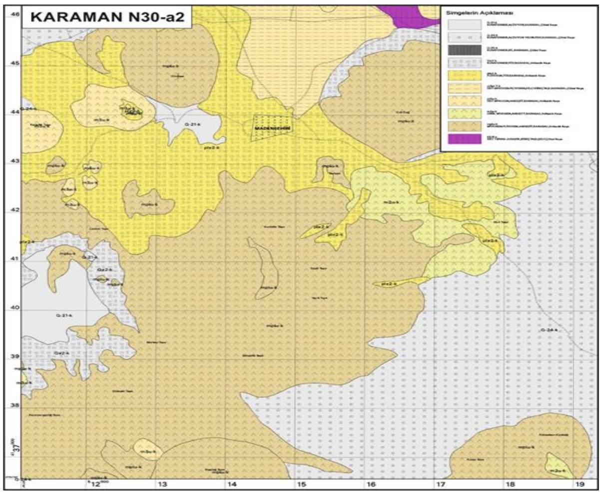

Fig. 2 Geological map of Karaman vicinity.

Ninety two of stainless steel balls (specific gravity of 7.8 g/cm^3) were used, whereas the fractional ball filling (J, Eq. 5) was 0.2, the fractional powder filling (f_c) was 0.04. The mill speed was selected as 75% of critical velocity. Powder-ball loading ratio (U, Eq. 6) was also 0.5 and the amount of the powder were determined as 386 grams for the basalt sample and 351 grams for the andesite sample by using Equation 7. The experiments were performed in dry medium.

$$J = [(Ball\ weight/ball\ density)]\ /volume\ of\ mill\ *(1/0.6) \quad (5)$$

$$U=fc/(0.4*J) \quad (6)$$

$$fc= [(Sample\ weight/sample\ density)]\ /volume\ of\ mill\ *(1/0.6) \quad (7)$$

Results and Discussion

Determination of Physical Properties

The densities of samples were ascertained as to be 2.68 g/cm^3 for the basalt and 2.44 g/cm^3 for the andesite sample by using a pycnometer.

Determination of Mechanical Properties

Los Angeles (Abrasion) Test Results

Abrasion tests given in the previous section were performed according to the standards as described in detail and the obtained results are given in Table 3.

Table 3. Los Angeles abrasion values.

Sample	LA (%)
Basalt	16.18
Andesite	42.28

The LA value (mass loss) of the basalt sample was ascertained as 16.18% and this value was lower than that of the andesite sample (42.28%). According to the categories given in Table 1, the basalt and the andesite samples were involved in LA_{20} andLA_{50}, respectively.

Freezing-Thaw Test Results

The obtained results were given in Table 4 in consequence of the freezing-thaw tests carried out on the basalt and the andesite samples.

Table 4. The mass loss of the freezing-thaw tests.

Sample	Mass loss (%)
Basalt	0.62
Andesite	0.86

According to the TS 10449 standard, the mass loss of samples due to freezing and thaw cycles are categorized as given in Table 5. In addition, the mass loss of specimens used for the facing stone should be under 1%. Both for the basalt and the andesite samples, the obtained mass loss values were lower than the value of 1% and they took place in the F_1 category.

Table 5. The categories versus the highest freezing-thaw resistance.

Mass loss of Freezing-thaw (%)	Category F
≤1	F_1
≤2	F_2
≤4	F_4
>4	$F_{declaration}$

Frost Resistance Test Results

The mass loss values obtained from frost resistance tests were given in Table 6. The mass loss value of the basalt sample was lower and this sample took place in the MS_{18} category according to the Table 7. The mass loss of the andesite sample was found to be 69.84%.

Table 6. The mass loss of the frost resistance tests with chemical solution.

Sample	Mass loss (%)
Basalt	12.22
Andesite	69.84

Table 7 The categories versus the highest mass loss values with chemical solution (TS 706 EN 12620).

Solution mass loss (%)	Category MS
≤18	MS_{18}
≤25	MS_{25}
≤35	MS_{35}
>35	$MS_{declaration}$

Slake Durability Strength Test Results

The I_{d-1} and I_{d-2} values of the basalt and the andesite samples were given in Table 8, respectively. The I_{d-2} values of the samples were greater than 99% and pertained to 'very high' category given in Table 2. Therefore, the resistivity of the samples against the abrasion and fragment were quite high.

Table 8. Slake durability test results.

Sample	I_{d-1} (%)	I_{d-2} (%)
Basalt	99.5	99.1
Andesite	99.43	99.05

Determination of Grindability Performance

The time dependent grindability performances of the basalt and the andesite samples were also determined. For this purpose, three different size ranges from each sample such as 0.850+0.600 mm, -0.600+0.425 mm and -0.425+0.300 mm were prepared. Each sample was fed into the mill separately and after the mill was stopped at certain intervals, whole sample was discharged from the mill. Approximately 50 grams of representative sample was taken from the discharged sample by cone and quarter method. This representative sample was washed using the one-down size of sieve for 5 minutes time period and then dried at least for 10 minutes. After the screening for 10 minutes, the sample retained on the sieve was weighed. The grindability performance was adjusted by the determination of the percentage of sample passing the sieve. This operation was performed for each sample and the obtained results were given in Figures 3 and 4 for the basalt and the andesite samples respectively.

The amount of material passing from the sieve was increased with a rise in grinding time. While, the basalt sample had the greatest percentage of sample passing to the sub-dimension at -425+300 µm size range (Fig. 3). This value was obtained for the andesite sample at -600+425 µm size range (Fig. 4). In addition, the resistance to the breaking for both samples was the greatest at -850+600 µm size range of feed. The percentage of material passing through the sub-dimension was the less at this size range. Similar findings were also reported in the study by Aras (2009) who investigated the relationship between mechanical properties and grinding performance of some rocks.

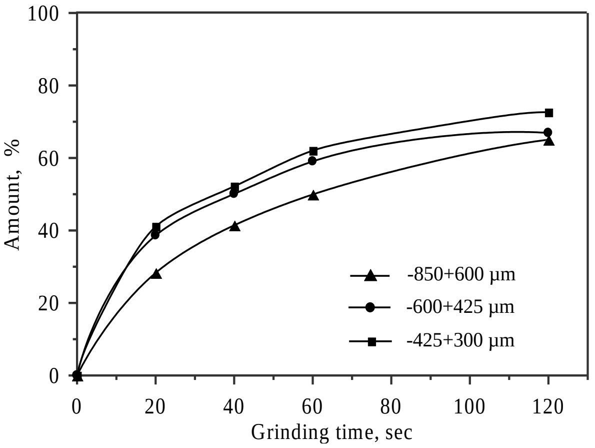

Fig. 3 Time dependent grindability performance of basalt sample.

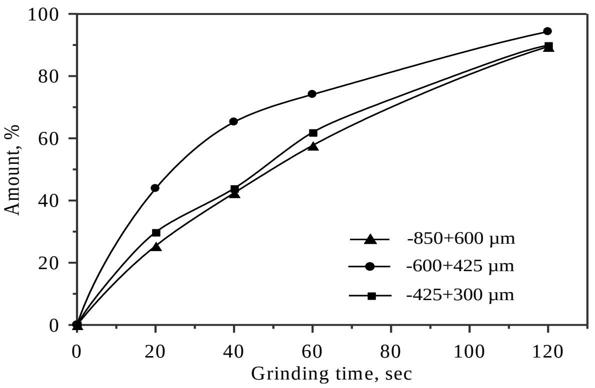

Fig. 4 Time dependent grindability performance of andesite sample.

Conclusion

The abrasion, the freezing-thaw, slake durability and frost resistance properties of the basalt and the andesite samples used as aggregate were investigated in the first stage of this paper. In the second phase, the grinding performances of samples were revealed for different feed size range using a steel ball mill. The obtained results were given below. The mass loss of abrasion of basalt was lower (16.18%) than that of andesite (42.28%). The basalt and the andesite samples fall into the categories of LA_{20} and LA_{50}, respectively. It was concluded that the loss of freezing-thaw of the basalt (0.62%) was lower than the andesite (0.86%). Both samples were conformant for their values (F_1) under 1%. It was also concluded that the slake durability index (I_{d-2}) of both the andesite and the basalt samples were very close. Due to the I_{d-2} values of the samples above the 99%, they belonged to very high category. The freezing loss with sodium sulphate was seen into superior for the andesite sample. The basalt sample belonged to the MS_{18} category with 12.22% of freezing loss. When compared for the grindability performance of two samples, the percentage of andesite sample passing through the sub-dimension was greater and this value was above the 90% for all size ranges.

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