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An experimental investigation on the abrasion strength of aggregate: Elazığ province calcareous aggregate

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ABSTRACT

In order to produce quality concrete in our country which is located in the earthquake zone, it is necessary to ensure that the aggregate to be used is subjected to the necessary abrasion and strength tests and to be used in concrete production after being controlled in accordance with the concrete norms. Due to the geological structure of the country, there are different kinds of aggregates with different properties in and in very large quantities in Turkey. Therefore, it is of great importance to investigate the physical and mechanical properties of aggregates in our country to use them in different fields. The present study aims to determine whether or not this calcareous aggregate, which cannot be stored, is sufficient in terms of abrasion strength. This shows that the strength of the concrete produced by the said aggregate will be high. Thus, both the production of concrete with improved properties is provided and the environmental pollution is prevented. In addition, because it is aimed to use the available resources in the most efficient way, it is thought that evaluating this calcareous aggregate found in nature will contribute to the country's economy found in nature. In the present study, the abrasion strength of the calcareous aggregate extracted from Elazığ province was investigated. The abrasion resistance of the said aggregate was investigated experimentally by changing the Los Angeles parameters under different conditions. In addition, the microstructural morphology of the existing calcareous aggregate was investigated. In this context, Scanning Electron Microscopy test was conducted using an EDX micro-analyzer. As a result of the tests, it was observed that the aggregate abrasion strength decreased with the increasing numbers of balls and revolutions. It was seen that the abrasion strength of the existing calcareous aggregate was higher than most of the related aggregates in the previous studies and it was found to be suitable for use in concrete.

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1. Introduction

Aggregate is a granular material with natural or artificial origin such as sand, gravel, crushed stone, which is pieced together with a binder material comprising of cement and water mixture. Aggregates, which make up about $\frac{3}{4}$ of the concrete volume, must have a high resistance to external influences. In addition, these aggregates to be used in concrete production must be clean, hard, and durable, they should not react harmfully with cement and should have appropriate granulometry, grain shape, and surface void volume (Ekmekyapar and Örüng 1993). Therefore, researchers should pay attention to these properties when selecting aggregates.

The abrasion strength of the aggregate must be high, especially when the concrete surface is subjected to abrasion (Neville, 1981). According to TS 706, if the compressive strength of the aggregate is less than 1000 kgf/m^2 or the abrasion strength of the aggregate is suspected, the abrasion strength of the aggregate must be tested. For example, glazed aggregates, schists, marly aggregates, and coarse mineral stones cannot resist abrasion.

When the studies in the literature are examined, it is seen that the concretes produced with high abrasion strength aggregates have better mechanical properties. Poitevin (1999) examined the usability of calcareous, a hard type of aggregate with high abrasion strength, in concrete and stated that it had a positive

effect on the concrete properties. Erdoğan (1995), Postacıoğlu (1987) and Akman (1984) recommended the use of natural stones, such as black and white calcareous, granite, basalt, and syenite in concrete production. The commonly used method in Turkey is the determination of abrasion on aggregates by the Los Angeles test. In the relevant specification, the TS 706 abrasion limit values were determined as 10% for 100 revolutions and 50% for 500 revolutions. Akbulut et al (2006) carried out Los Angeles wear tests on A and B aggregates from 2 different quarries. The abrasion losses were found to be 15.2% for sample A and 27.3% for sample B at the end of the Los Angeles test. Karpuz and Akpınar (2009) carried out the Los Angeles (LA) wear test to determine the abrasion strength of calcareous and basalt aggregates. The Los Angeles abrasion values were determined as 33.1% for the calcareous aggregate and 21.3% for the basalt aggregate. In addition, Alyamaç and Tuğrul (2014) compared the abrasion strengths of marble and calcareous aggregates. The results showed that the abrasion strength of the calcareous aggregate (LA=22%) was higher than that of the marble aggregate (LA=35%). Similarly, in the study by Tuğrul (2017), the Los Angeles abrasion value of the marble aggregate was determined as 32%. Aksoy (2018) applied the abrasion tests to five different calcareous aggregates from different quarries and determined the Los Angeles abrasion losses of these aggregates. Results showed that the maximum LA value was 45.1% in the tests performed for 500 revolutions. This result seems to be similar to the result of the present study. In Tunç (2018), the abrasion strength of the basalt aggregate was investigated under different experimental conditions. Considering that the compressive strength of the concrete having high abrasion strength will be high, it was concluded that the concrete produced by these basalt aggregates could demonstrate high strength. In addition, it is aimed to determine the usability of waste aggregates in concrete in Tunç (2019)'s study. Thus, however concrete with good strength is produced, it is thought that will be beneficial for environmental health and economy.

The present study investigates the abrasion resistance of calcareous aggregates extracted from the Elazığ province. The abrasion strengths of the said aggregate were investigated experimentally under different conditions by changing the Los Angeles (L.A.) parameters. The increasing numbers of balls and the revolutions are the parameters of this experimental study. The study aims to contribute to the economy by using aggregates with high abrasion resistance (i.e. low L.A. value), which can be easily found in nature, to obtain an environmental benefit, and to search for the optimum ways to improve the abrasion strength. Considering the importance of achieving more economical concrete with high quality and performance, it will be tried to fill the gap in the literature with the research subject of the present study.

2. Calcareous Aggregate

The other name of the calcareous stone, known as sedimentary rocks that have a chemical composition with at least 90%

calcium carbonate (CaCO_3), is calcareous. Calcareous, which is abundant in nature, is a general term used for carbonate sedimentary rocks and fossils. In principle, it contains calcium carbonate or calcium carbonate/magnesium carbonate compounds ($\text{CaCO}_3/\text{MgCO}_3$) in its structure. In addition, different elements such as iron, aluminum, silicon, and sulfur can also be found in its content. In its pure form, calcareous is composed of calcite and very little amount of aragonite crystals. Calcite and aragonite are two distinct crystalline forms of calcium carbonate and theoretically contain 56% CaO and 44% CO_2 . But these are never found in pure form in nature. The hardness of the calcareous is 3 and its specific gravity is between 2.5-2.7 g/cm^3 (Dinç, 2004). Calcareous aggregates can be generally seen in yellow tones in nature (Fig. 1).



Figure 1. Istanbul – calcareous aggregates in Damandır

Calcareous deposits are formed as travertines in underground waters, and as chemical, organic and mechanical sedimentations in seas or fresh waters. The calcareous aggregate has been extensively used in the construction sector in buildings, roads and bridges. In addition, calcareous can be used in the fields such as lime production, cement making, metallurgy and agriculture. The most important characteristics of calcareous aggregate are as follows:

- The calcareous aggregate has a very strong structure and is resistant to abrasion.
- The calcareous aggregate is approximately 6% lighter than aggregates such as granite and pebble.
- Besides providing natural water flow and drainage, the calcareous aggregate is an ideal product that can be used for pollution control and sustainability of forestry.
- Due to its various grain sizes, the calcareous aggregates can be used in a wide range of application areas such as fillers, base courses, landscaping and agriculture.
- The calcareous aggregate is abundant in Turkey.

➤ Calcareous aggregate is one of the lowest-cost construction aggregates.

3. Experimental Program

3.1. Material and Method

The calcareous aggregates extracted from Elazığ province were used in this experimental study (Fig. 2).



Fig. 2. Elazığ province calcareous aggregates in the quarry; (a) coarse aggregate, (b) fine aggregate (Tuğrul, 2015)

Figure 3 shows the granulometry curve of the mixture of calcareous aggregate having the largest grain diameter (31.5 mm). According to TS 802, the aggregate granulometry curve must be between the A32-B32 standard curves in order to provide the maximum compactness. It is seen that the calcareous aggregates used in the present study are suitable for use in concrete (Fig. 3).

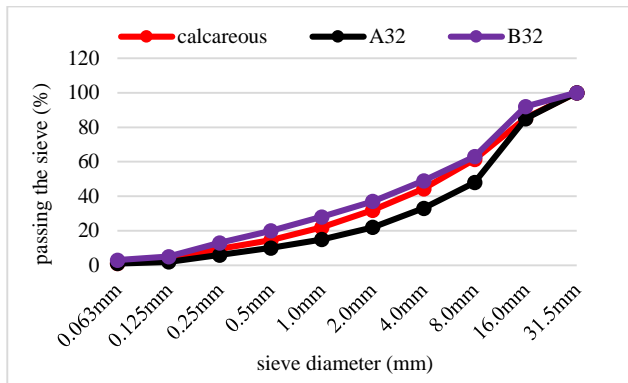


Figure 3. The granulometry curve of calcareous aggregates

In addition, physical properties such as unit weights, saturated surface dry specific gravities and water absorption rates of calcareous aggregates used in the study are presented in Table 1.

Table 1. Physical properties of calcareous aggregates (Tuğrul, 2015)

B_g^{coarse} (g/cm ³)	B_s^{coarse} (g/cm ³)	B_g^{medium} (g/cm ³)	B_s^{medium} (g/cm ³)
1.55	1.72	1.60	1.74
S_{dyk}^{coarse} (g/cm ³)	S_{dyk}^{medium} (g/cm ³)	S_a^{coarse} (%)	S_a^{medium} (%)
2.66	2.69	0.9	1.0

where B_g^{coarse} = loose unit weight for coarse aggregate, B_s^{coarse} = compact unit weight for coarse aggregate, B_g^{medium} = loose unit weight for medium aggregate, B_s^{medium} = compact unit weight for medium aggregate, S_{dyk}^{coarse} = saturated surface dry specific weight for coarse aggregate, S_{dyk}^{medium} = saturated surface dry specific weight for medium aggregate, S_a^{coarse} = water absorption rate for coarse aggregate and S_a^{medium} = water absorption rate for medium aggregate.

3.2. Los Angeles Abrasion Test

The Los Angeles abrasion test was carried out according to TS EN 1097-2 or ASTM C 131 standard to determine the abrasion strength of calcareous aggregates. The tests were carried out with the existing Los Angeles abrasion test device and the balls in the Building Materials Laboratory of Firat University given in Figure 4 (Fig. 4). A total of 5000 g samples, 2500 g from coarse calcareous aggregates and 2500 g medium calcareous aggregates in conformity to the standard (TS 706 EN 12620+A1), were washed, dried at 110±5 °C in the drying oven and weighed for the test. This procedure was continued until the sample has reached a constant weight. The balls and oven dry samples were put into the drum, which rotated at a constant speed of 31-33 revolutions per minute, the cover was closed, and the drum was rotated at 500 rpm. The test samples were sieved on a 1.4 mm mesh sieve and the samples remaining on the screen were weighed. After these procedures, the LA (%) value was determined according to the TS EN 1097-2 standard. According to the TS 706 abrasion limit value, the calculated LA value should not exceed 10% for 100 revolutions and 50% for 500 revolutions.



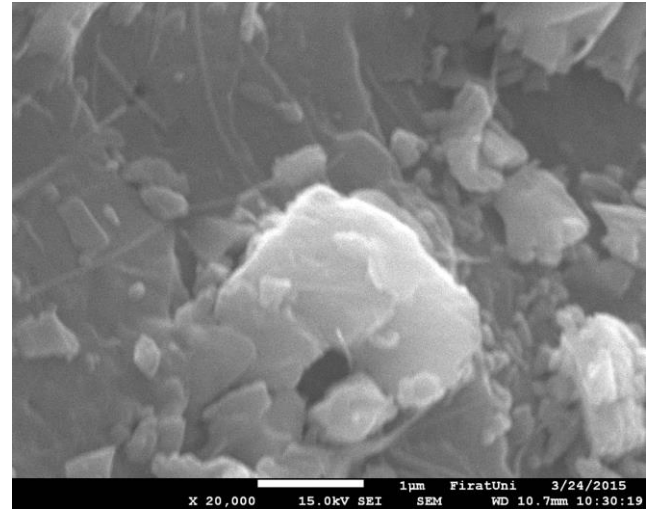
Figure 4. Los Angeles abrasion device and 12 balls

A number of tests were performed under different conditions by changing the Los Angeles (LA) parameters to examine the abrasion strength of the existing calcareous aggregates. The effects of different ball number and different rev number parameters on abrasion strength were investigated. The abrasion tests were carried out separately with the calcareous aggregates used in the tests to evaluate the effect of each parameter on the abrasion strength. The tests were performed for 12 balls (5000 g), 18 balls (7500 g), and 24 balls (10000 g). The numbers of revolutions were set at 500, 1000, 1500 and 2000 revolutions.

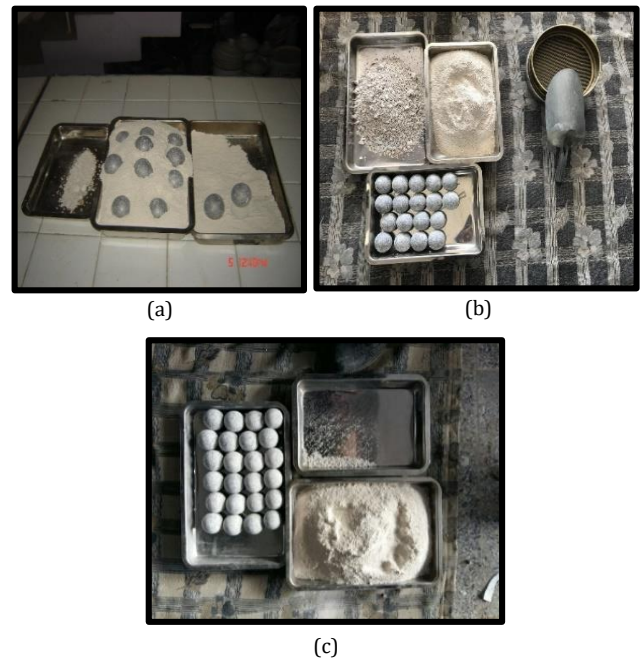
4. Experimental Findings

The human eye is limited in its ability to see very fine details to examine the elementary structure of a material. For this reason, the devices in which the electronic and optical systems can be used to perform operations and analyzes on high magnifications have been developed. Scanning Electron Microscope (SEM) works on the principle of scanning the surface with high energy electrons, which focus on a very small area. Micro and nanoscale structures of all solid materials can be determined by SEM and elemental analysis of these structures can be made. Precise measurements can also be taken on surfaces that are not smooth on SEM. Moreover, it is a highly preferred device because of its three-dimensional visualization and element analysis. Therefore, it is obvious that the measurements taken with SEM will be higher than the classical methods.

The Scanning Electron Microscopy (SEM) test was performed by using an EDX micro-analyzer to investigate the microstructure of calcareous aggregate. The magnification of the SEM image was chosen as $\times 20000$ magnification (Fig. 5). A low porous microstructure was observed when the elementary structure of the said aggregate was examined. Furthermore, it was seen that these micro cracks had a low thickness. According to SEM analysis performed, it was concluded that the existing calcareous aggregate was more stable than many other aggregates.

**Figure 5.** SEM image for $\times 20000$ magnification

The images of the materials passing through and remaining on the 1.4 mm sieve at the end of the Los Angeles abrasion tests can be seen in Fig. 6.

**Figure 6.** The remaining amounts of oversize and undersize abraded aggregates, (a) 12 balls, (b) 18 balls, (c) 24 balls.

In the present experimental study, it is seen that the LA value of the said calcareous aggregate is below the boundary conditions. The tests conducted to determine the abrasion strength of the aggregates with increasing number of abrasive balls and increasing number of revolutions and to determine

the maximum abrasion strength limit of the calcareous aggregates were investigated in two groups. In the first group of tests, the relationship between the number of revolutions and the LA (%) value was investigated for the increasing numbers of balls. For this purpose, balls with a constant weight and diameter were increased 6 pieces at a time and tests were carried out with 12-18-24 balls. As the number of revolutions increased (500–1000–1500–2000), it was seen that the LA value increased and therefore the abrasion strength of the calcareous aggregates decreased. The highest LA value was obtained with 12 balls of 500 revolutions, while the lowest LA value was obtained with 24 balls of 2000 revolutions. The LA values calculated for both 12 ball/1500 rpm and 12 balls/2000 rpm were seen to be above 90%. Similarly, the LA values of the calcareous aggregates were found to be quite high as a result of the abrasion tests carried out for 1000-1500-2000 revolutions using both 18 balls and 24 balls. While a linear change was observed from 500 to 1500 revolutions, it was observed that LA value was approaching the asymptote when passing from 1500 to 2000 revolutions. As a result of the abrasion tests, it was found that the calcareous aggregates did not show much resistance against 2000 rpm abrasion for all numbers of balls (Fig. 7).

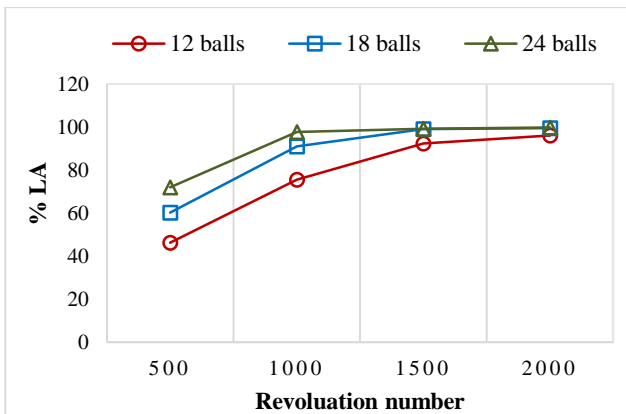


Figure 7. The change in the LA (%) value with the numbers of revolutions for the increasing numbers of balls

In Fig. 8, the correlation between the increasing number of revolutions and the number of balls and LA (%) value was investigated. For this purpose, the abrasion tests were repeated for each number of revolutions (500–1000–1500–2000 rpm) using 12-18-24 balls. It was seen that as the number of balls increased, the LA values increased, and the abrasion strengths calcareous aggregates decreased. For 500 and 1000 revolutions, a linear change was seen from 12 balls to 18 balls, while the rate of change decreased from 18 to 24 balls. It is seen that the results are very close to each other in all tests conducted for 1500 and 2000 revolutions. According to Figs. 7 and 8, the LA values (%) increase and therefore the abrasion strengths of these calcareous aggregates decrease with the increasing number of balls and revolutions. The best results

were obtained from the tests conducted for 12 balls and 500 revolutions according to the standard. According to the results of this experimental study, the calcareous aggregate can be used in the concrete production because its LA abrasion value is below the limit value specified in the standards. Moreover, the increase in the number of balls and revolutions has been found to have an adverse effect on the abrasion strength.

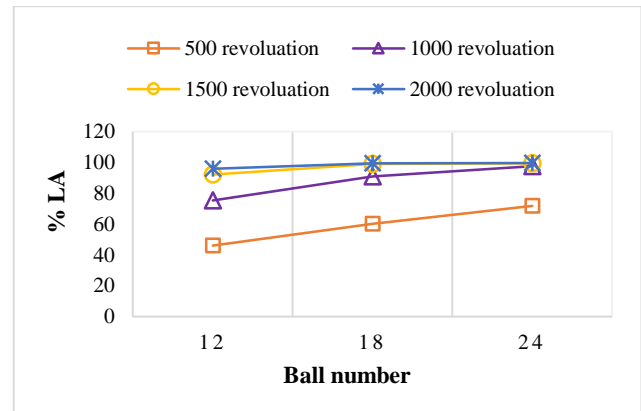


Figure 8. The change in the LA (%) value with the numbers of balls for the increasing numbers of revolutions

Standard LA abrasion values of the calcareous aggregate tested in the present study and standard LA abrasion values of the aggregates tested in the previous studies are compared in Figure 9. The experiments were carried out for 12 balls and 500 revolutions. When LA abrasion values are examined, the travertine aggregate extracted from Konya province in Turkey that has the lowest abrasion strength is observed. This travertine aggregate was tested in Uğur et al (2010)'s study. The LA value of the limestone aggregate obtained from Elaziğ province in Turkey seems to be quite close to the LA value of the calcareous aggregate tested in the current study. This limestone aggregate was tested in Aksoy (2018)'s study. The aggregate having the lowest LA value is Kılıç et al. (2008), sandstone aggregate tested. Thus, it was concluded that the calcareous aggregate used in the present study is resistant to abrasion when compared to the tested some aggregates.

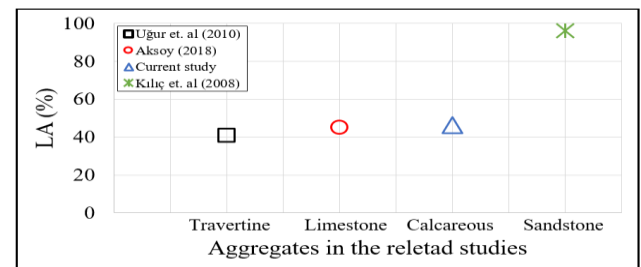


Figure 9. Comparison of the LA abrasion values of the aggregates used in the current study and in the previous studies

5. Conclusions

In this study, the abrasion strength of the calcareous aggregates extracted from Elazığ province was experimentally analyzed with the parameters of increasing numbers of balls and revolutions. In addition, it was wanted to determine the maximum abrasion strength limit of the calcareous aggregates. High abrasion resistance aggregates must be used to obtain high-performance concrete. The results of the present study, where the abrasion strength of the calcareous aggregate type was investigated, are as follows:

- ◆ The abrasion strength of the aggregates decreased with increasing number of revolutions (500-1000-1500-2000 rpm).
- ◆ As the number of balls increased (12-18-24 balls), the abrasion strength of the aggregates decreased, and the LA values increased.
- ◆ The lowest LA (%) value was obtained from the abrasion tests for 12 balls/500 rpm, while the highest LA (%) value was obtained from the abrasion tests for 24 balls/2000 rpm.
- ◆ According to the abrasion tests carried out for 1500 and 2000 revolutions, the LA (%) values were between 90 and 100, and it was concluded that the existing calcareous aggregates could not resist against abrasion.
- ◆ According to the SEM analysis, it was seen that the calcareous aggregate had regular microspores and the micro crack thickness was low.
- ◆ Since the standard LA value of the existing calcareous aggregate was determined to be below the limit value according to TS 706, it was concluded that it could be safely used as the aggregate in concrete.

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