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RESEARCH ARTICLE

Investigation of usability of building rubble as road underfill

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Abstract

For resources to be used efficiently, the structures built on the earth must be long-lasting. The longevity of the roads built with a length of millions of kilometers per year is determined by the nature of the filling material, traffic, equivalent axle load, climatic effects, material fatigue, and layer thicknesses used. The fact that filling material complies with the standards and is easily available will ensure that the road construction works are both economical and long-lasting. Many building rubbles are formed from the buildings that have completed their lives in the urban transformation process. Storage and disposal of this building's rubble are very difficult. To eliminate these difficulties, the usage areas of the rubble should be increased. In this study, some mechanical experiments were carried out on the building rubble obtained from the Black Sea region, and these were interpreted. Grain density, freeze-thaw tests, Micro-Deval, and Determination of Fragmentation Resistance, tests were carried out according to TSE and ASTM standards of aggregates obtained from building rubble. The results obtained from the experiments were compared with the technical specifications of the General Directorate of Highways. It has been revealed that the analyzed aggregate can be used as road fill in highways.

1. Introduction

Today, one of the most studied subjects on the environment is the consumption of natural raw materials and the reduction of the amount of waste material. Replacing areas where natural raw materials are used, using waste products and recycled products will solve this problem [1-4].

Aggregate is among the most consumed and needed raw materials in the rapidly developing world [4]. Many countries use recycled and reclaimed aggregates to reduce the intake of aggregates from natural environments and to protect natural resources [2,6-8].

In addition to the consumption of natural raw materials, one of the most studied subjects today is the reduction of the amount of waste material. Many studies have been carried out to dispose of the wastes resulting from urban transformation and to expand the usage areas [9-11].

Building debris, which has completed its life or formed as a result of natural disasters, is the most ideal place for the production of recycled aggregates. Recycled aggregate is used in many sectors to eliminate the pollution caused by building rubble and to protect natural aggregate resources. In addition, many studies are carried out to expand the usage area of recycled aggregates [12-15].

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The development of countries is increasing in parallel with the quality of highways. The robustness and durability of roads are very important both economically and in terms of safety. Road construction works on highways consist of the following stages; Driving slope piles, Infrastructure, and structures such as Culverts, bridges, Viaduct, Akaduct, Sub-base, Bituminous bases, Wear, and Making road accessories such as lane lines, and guardrails. Of these stages, one of the most important parameters affecting the power and duration of use of the road is the sub-base layer. [16-18].

The lower foundation from the upper construction stages; is a layer that is laid on the leveling surface and is generally constructed of material with a certain granulometry (sand, gravel, stone chips). The task of this layer is in some cases, besides helping the foundation layer above it, it acts as a buffer zone against the effect of water and frost. The bituminous base layer is the part that consists of thinner material (natural sand, natural gravel) between the Sub-base layer and the abrasion layer. The foundation layer consists of a compacted stabilizer. The material brought by trucks, mixed with water at a certain rate, is laid with a paver, crushed with a roller, and compressed, and a tight layer is obtained. The last layer, the Abrasion layer; is the part built on the foundation layer and directly contacted by the traffic. In Turkey, the flooring is usually made of asphalt. Its main task is to create a smooth rolling surface. This layer is built into several layers. Before the final coating is made, a layer called Binder Layer is made with coarser material and less asphalt. Thinner aggregate and more asphalt mixture material also called the wear layer, is laid on this layer. The mechanical properties of the aggregate used in all stages of the superstructure construction are one of the most important factors that will determine the durability and quality of the highway. [18,16,19,20]

The materials used in each layer of the pavement have some characteristics that are specified in the standards. Mostly, these standard properties cover many characteristic features of the material (gradation, grain structure, strength, frost resistance, etc.). These standards sought for materials become more stringent as you go up in the pavement layers and higher quality is desired. Because the upper layers are directly exposed to the loads coming from the traffic, they must be of quality and strength to meet these loads [16-20]. The material properties to be used for the sub-base structure of the roads built in Turkey are specified in the specification created by the General Directorate of Highways (Table 1).

This study aims to solve the problems encountered by reducing aggregate production and reducing the environmental effects of construction waste. To achieve this aim, some mechanical experiments were carried out on the construction rubble demolished for urban transformation from 5 different points in Turkey/Trabzon. The results obtained were compared with the standards in the literature, and the usability of the recycled aggregates (GKA) obtained from the construction rubble obtained from this region as road infrastructure filling was examined according to the standards.

Table 1. Physical properties of the road subbase material [19]

Experiment name	Specification limits	Test Standard
Weather resistance (Freeze-Thaw Test), %	≤20	TS EN 1367-2
Fragmentation resistance (Los Angeles Experiment), %	≤35	TS EN 1097-2
Water absorption, %	≤3	TS EN 1097-6
Determination of resistance to wear (Micro-Deval Test), %	≤14	TS EN 1097-9

2. Methodology

In this study, construction debris taken from certain regions of Trabzon, located in the north of Turkey, which is in the process of urban transformation, was used. The study started in 2015 and continued until

2020. The process was prolonged because the areas where the study was carried out were not demolished simultaneously.

For the samples taken to represent the rubble characterization in the region, construction wastes were taken from 5 different points of the province. The samples were taken from unreinforced raw concrete, placed in sacks, and brought to the laboratory by vehicles (Fig. 1).

Fig. 1. Location map where the building rubble was taken and pictures showing the location (a. Çağlayan, b. Çömlekçi, c. Erdoğdu, d. Pelitli, e. Tabakhane)

2.1. Determination of particle density and water absorption rate of recycled aggregates

Specific gravity value is frequently used in road construction. For the aggregates obtained from the building rubble, the specific gravity and water absorption rates of the materials were determined by using the wire basket method according to TS EN 1097-6 [21].

For aggregates between 31.5 mm and 63 mm, the wire basket method is used. The aggregate sample is placed in the wire basket and the wire basket is immersed in the tank containing water at (22 ± 3)°C so that the water level is at least 50 mm above the top of the basket.

Immediately after immersion, the basket is removed from the test sample section by lifting the basket approximately 25 mm above the bottom of the tank and dropping it from this height 25 times once per second. The basket and aggregate are kept completely immersed in water at (22 ± 3)°C for (24 ± 0.5) hours. The basket and the test sample portion are shaken and weighed in water at (22 ± 3)°C. The basket and aggregate are removed from the water and left for a few minutes for the water to evaporate. The aggregate is carefully emptied from the basket onto one of the dry cloths. The empty basket is submerged again, shaken 25 times, and weighed in the water. The surface of the aggregate grains is carefully dried and when the cloth is no longer able to absorb moisture, the grains are transferred onto a second dry, soft absorbent cloth. Aggregate grains are spread on this second cloth with a thickness of no more than one aggregate grain and exposed to the atmosphere, protected from direct sunlight or any heat source until all visible water films are removed. However, in this case, the aggregate particles still have a damp appearance. Aggregate particles are weighed. The aggregate grains are transferred to a tray and dried in an oven at (110 ± 5)°C to constant mass and weighed. After the weighing process is completed, it is calculated with the relation specified in the standards.

2.2. Freeze-thaw test

A freeze-thaw experiment was conducted to see how the road fill is affected by climate change. This test provides information on the behavior of the aggregate when subjected to successive freezing and thawing effects. The freeze-thaw test is applied to aggregates with grain sizes between 4 mm and 63 mm. Aggregate amounts specified in TS EN 1367-2 standards were used in this experiment [22].

Samples of +8-16 mm size taken from the study area were subjected to 10 freeze-thaw cycles. Here, cooling underwater to -17.5 °C and then dissolving in a water bath at about 20 °C was carried out.

After the freeze-thaw cycles were completed, the aggregates were passed through an 8 mm sieve and the % mass loss was calculated.

2.3. Determination of resistance to wear (Micro-Deval) test

To measure the resistance of the aggregates to abrasion, the micro-deval test was performed on the samples taken from the study area. The experiment was carried out in the laboratory according to the ASTM, (D 6928) standard [23]. A total of 1500 g samples were prepared, including +4.75 mm, 750 g between –6.3 mm, and 750 g between 6.3 mm, – 9.5 mm. These samples were dried in an oven before the experiment, and the moisture was removed from 1500 g of sample, 5000 g of 1 cm diameter steel ball, and 2 liters of water were put into the drum and the experiment was carried out (Fig. 2).

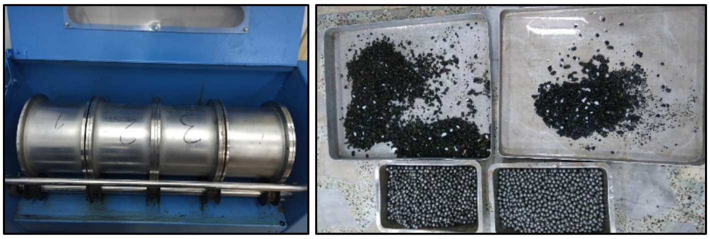

Fig. 2. Micro-Deval wear test

The samples removed from the drum were sieved through a 1.18 mm sieve and after the material on the sieve was dried in the oven, they were weighed, and the Micro-Deval wear value was calculated by dividing the weight loss by the initial weight.

2.4. Determination of fragmentation resistance: Los Angeles experiment

To determine the abrasion resistance of the aggregates studied, the Los Angeles fragmentation resistance test was carried out according to TS 3694 standards [24].

Los Angeles test instrument was used in the experiment according to TS 3694 standards. 5000 gr samples were prepared for the abrasion test. The test sample was washed and dried in an oven at 110°C until it reached a constant weight. 11 steel spheres, which are required according to the sample and abrasion class, were placed in the test device and the tool was made 500 cycles at 30-33 cycles/minute. After the required number of cycles was completed, the sample was sieved through a 1.70 mm sieve, and the material remaining on the sieve was washed and dried in a 110°C oven until it reached a constant weight and weighed.

2.5. Determination of Schmidt hardness

Schmidt hammer measurements have different standards; In this study, ASTM C805, (2004) method was used. In this method, a single hit is made on ten different points on the sample with a Schmidt hammer, the average of these hits is taken, the values 7 units below and above the average are canceled and the average of the remaining ones are taken as the Schmidt hardness value.

Within the scope of this study, Schmidt hammer measurements were made on the samples brought to the laboratory and in the field to characterize the material of construction waste and determine the hardness class.

3. Findings and discussion

Density, freeze-thaw, and Los Angeles experiments were carried out by converting the concrete masses taken from the building rubble to the aggregate size. The results obtained are examined under the headings below and compared with the values specified in international standards.

3.1. Particle density and water absorption rate

After the density and water absorption tests performed on the aggregates recovered by the wire basket method, it was found that the water absorption ratio of the aggregates was 2,7% and their average density was 1,99 g/cm3 (Fig. 3).

In the density measurements made on the recycled aggregate, it was seen that the highest density was in the samples taken from the "Erdoğdu" region. Similar results were found in density tests performed on reclaimed aggregates before this study. Poon et al. [8] found the recovered aggregate densities to be 2,1 g/cm^3 in their studies. Külekçi, on the other hand, measured the density as 1,9 g/cm^3 in the samples he took from a similar region [2].

3.2. Values of Freeze-Thaw test

Construction debris taken from 5 different regions was brought to the appropriate size and subjected to a rotational dissolution cycle. At the end of the 10 cycles, it was understood that the mass loss was 7.74% in the aggregates taken from the "Tabakhane" region. At the end of 15 days, the result did not change, and the highest loss was again in the "Tabakhane" region. The average mass loss at the end of 15 cycles is 24,64% (Fig. 4).

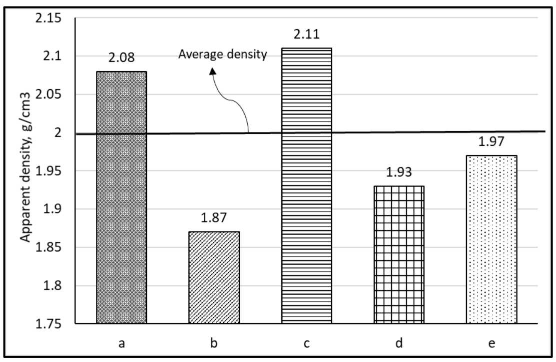

Fig. 3. Density of recycled aggregates (a-Çağlayan, b-Çömlekçi, c-Erdoğdu, d- Pelitli, e-Tabakhane)

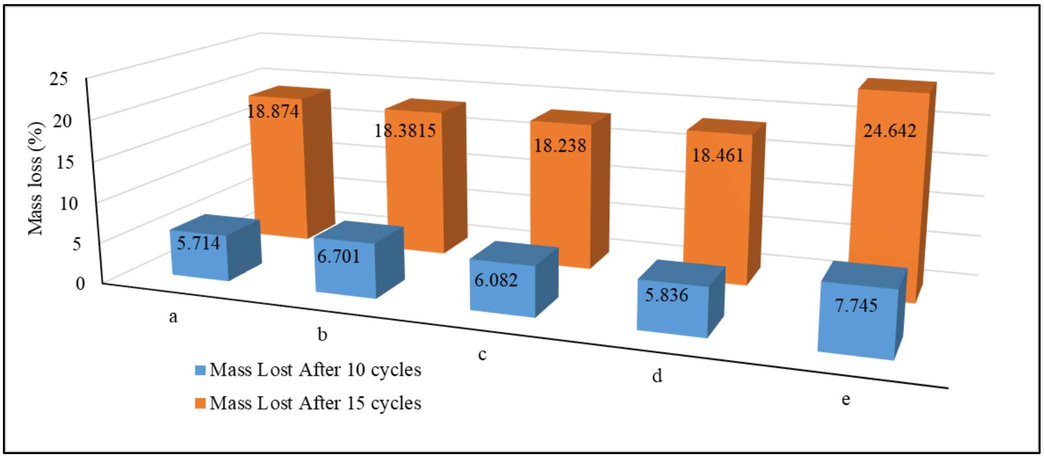

Fig. 4. Mass losses as a result of the freeze-thaw test (a-Çağlayan, b-Çömlekçi, c-Erdoğdu, d- Pelitli, e-Tabakhane)

3.3. Determination of resistance to wear

The Micro-Deval test shows the wear resistance of aggregates. A high micro-Deval coefficient indicates a low wear resistance of the aggregates. The Mikro-Deval test was applied according to TS EN 1097-9. The average of the results obtained from the four drums was found to be 8%. In the KGM technical specifications, the Micro-Deval value of the aggregate to be used as the base material for the road is required to be ≤14. It has been observed that the Micro-Deval wear values of the recycled aggregates studied in this region comply with the limit value of the technical specification (Fig. 5).

3.4. Determination of fragmentation resistance

According to KGM specifications, the Los Angeles wear loss of the material to be used in the base layer should be 35% maximum. For the wear layer, the maximum loss should be 30% [20]. In the study, it was observed that the highest fragmentation was in Tabakhane samples, and the region most resistant to fragmentation was Pelitli. The mean fragmentation resistance of all regions was found to be 37 % (Fig. 6).

3.5. Schmidt Hardness values

In this study, the Schmidt hardness test was performed on construction wastes taken from 5 different points according to ASTM C805, (2004) standards. The rebound numbers found were converted to uniaxial compressive strength with the help of the chart prepared by Deere and Miller (1966).

As a result of the measurements made, it was understood that the samples with the highest strength were in the "Tabakhane" region, and the least strength was in the "Erdoğdu" region (Table 2).

4. Results

In this study, building debris taken from 5 different regions of Trabzon province was converted into aggregate. Density, water absorption, freeze-thaw, abrasion, and disintegration resistance tests were carried out to examine the usability of the recovered aggregates in road fill. The results found are discussed in the following items.

- As a result of the density and water absorption experiments, the average water absorption rate was found to be 2.7%. The acceptable rate in the technical specifications of highways is 3%.
- As a result of the freeze-thaw test performed on the samples in the study, after 15 cycles, the maximum mass loss was in the E region with 24 to the face. The maximum acceptable rate in the technical specification is 20%. In other sample regions, this rate is at an acceptable level of 18%. It is suitable for usability in the road infrastructure in case of combining the samples or removing the E region.

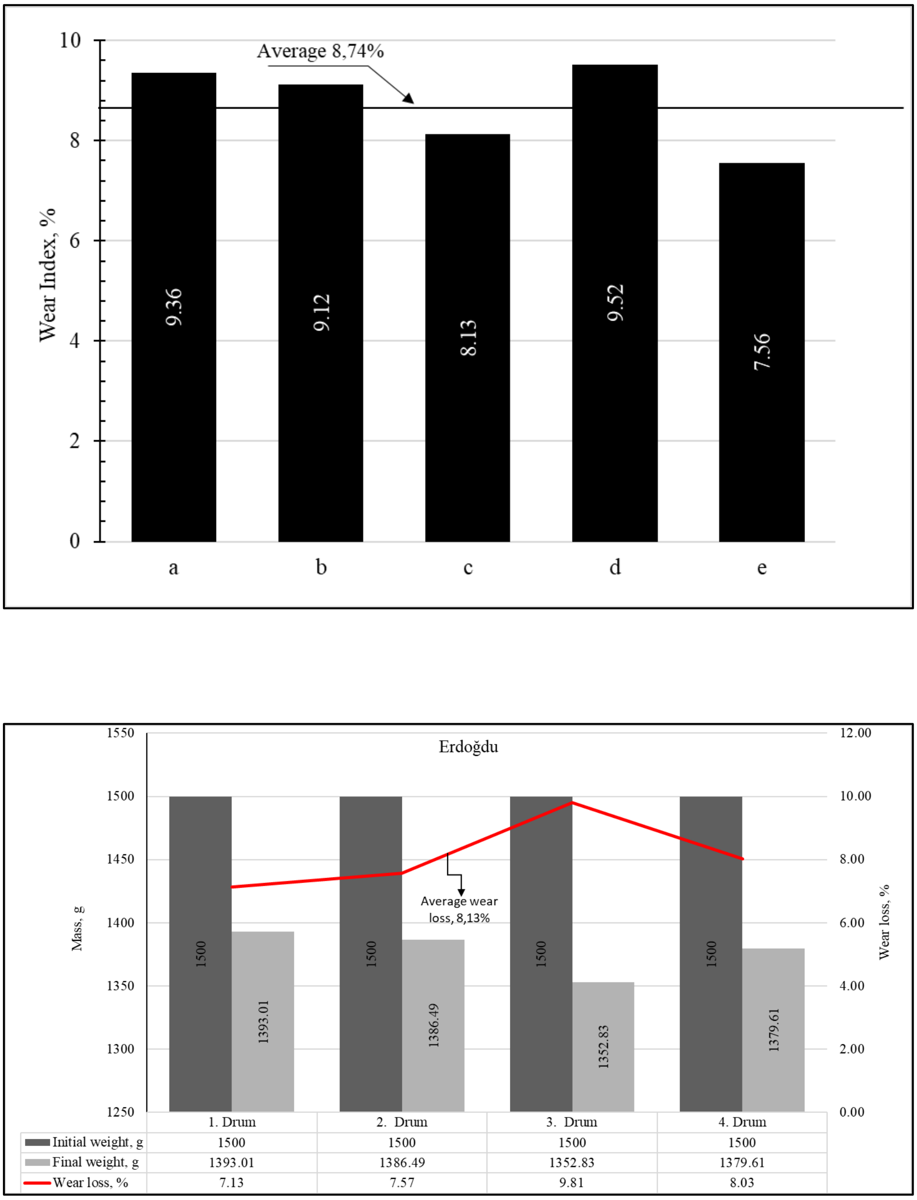

Fig. 5. The amount of wear of the samples taken from the region (a-Çağlayan, b-Çömlekçi, c-Erdoğdu, d- Pelitli, e-Tabakhane) and Mass losses of aggregates taken from Erdoğdu region compared to drums

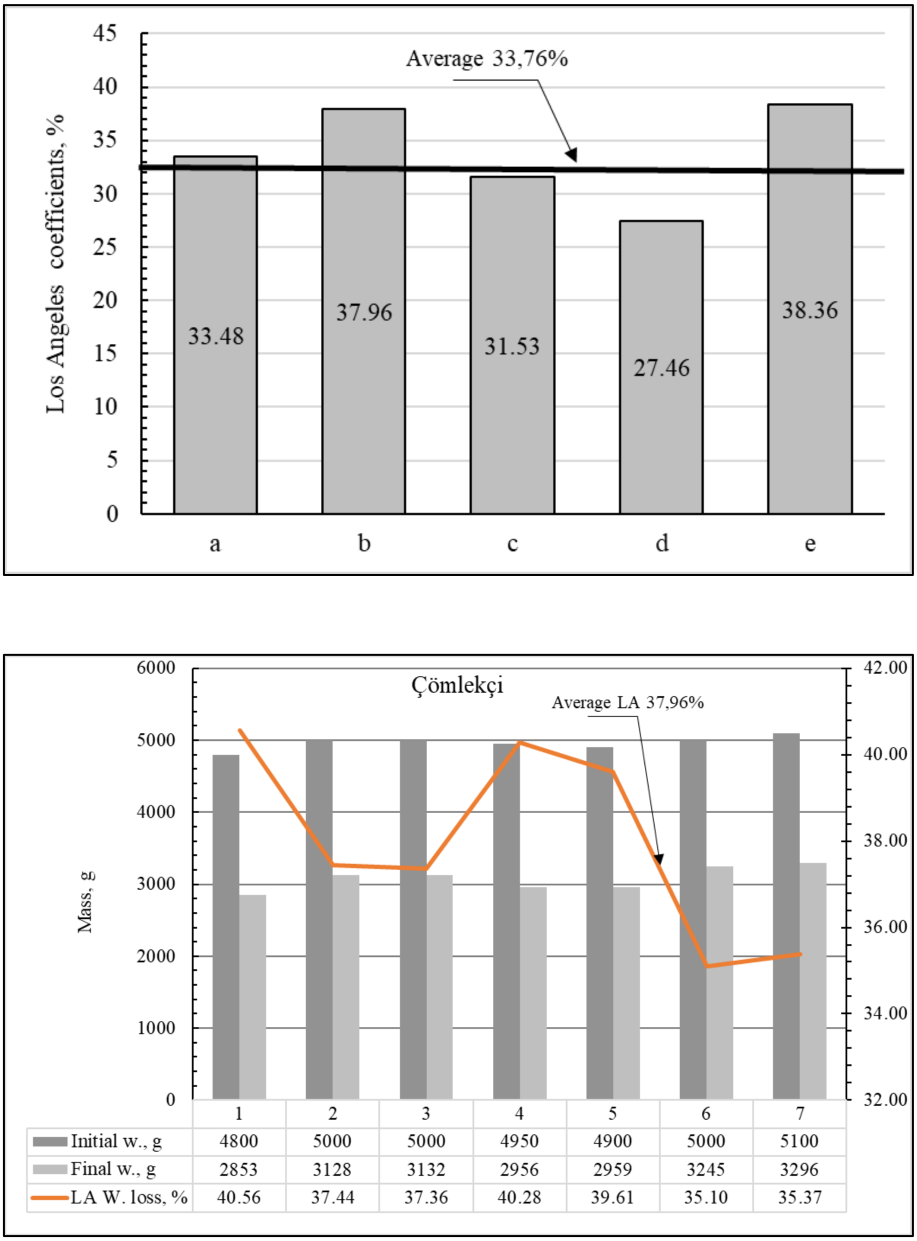

Fig. 6. Los Angeles wear test results (a-Çağlayan, b-Çömlekçi, c-Erdoğdu, d- Pelitli, e-Tabakhane) and Mass losses in the pottery area during the experiment

Table. 2. Average Schmidt recoil numbers (a-Çağlayan, b-Çömlekçi, c-Erdoğdu, d- Pelitli, e-Tabakhane)

Sample location	a	b	c	d	e
Average hammer rebound, R	27.3	29.4	26.7	28.3	31.4
Translated strength results, MPa	24	27	23	26	29

- As a result of the micro-deval test, it has been revealed that the wear values are in accordance with the technical specifications and can be used as road fill.
- In the Highways' technical specifications, the material to be used in the road infrastructure for Turkey is required to show a maximum of 35% breaking resistance. Although this value was exceeded in the E and B regions in the study, the average fragility was found to be 33%.

As a result of all the studies, it has been revealed that the building rubble formed in the Trabzon region can be recycled and used as aggregate in the road underfill.

Declaration of conflicting interests

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

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