DOI: 10.38061/idunas.851831

IDUNAS | NATURAL & APPLIED SCIENCES JOURNAL | 2022 Vol. 5 No. 1 (38-46)

Characterization of Coarse Recycled Aggregates Produced from Concretes with Different Strength Levels

Research Article

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DOI: 10.38061/idunas.851831

Received: 01.01.2021; Accepted: 12.03.2021

Abstract

With the acceleration of Urban Renewal Program, particularly in large cities of Turkey, the problem of finding land-fills and eliminating construction waste with the least environmental pollution necessitates its value-added recycling. However, the presence of adhered weak mortar layer, comprising 20-70% of recycled concrete aggregate (RCA), limits the use of RCA or lowers its inclusion level in concrete mixtures. Within the scope of this study, limestone- and basalt-bearing RCA obtained from 6 different concrete mixtures with three different water/cement ratios (0.45, 0.60, 0.70) were prepared and their water absorption, specific gravity, dense and loose unit weight, flatness indices, Los Angeles degradation values were determined. The results showed that, increasing w/c ratio of the parent concrete increased water absorption of the resultant RCA. However, the specific gravity, unit weight, abrasion resistance and flakiness index of RCA were decreased by increasing w/c ratio of the parent concrete.

Keywords: Recycled Concrete Aggregate, Parent Concrete Strength Level, Water Absorption, Degradation Resistance, Flakiness Index.

1. INTRODUCTION

Among the building materials used today, the most preferred one is undoubtedly concrete. Since, the annual concrete need in the world is approximately 4.5 billion tons, the yearly concrete consumption per person is 0.7 tons on average. The fact that urbanization and the world population has continued to increase with the rapid increase in the last century shows once again the importance of concrete and the materials that make up concrete, one of the most commonly used building materials in many parts of human life. The concrete industry, which uses 12.6 billion tons of raw materials in total each year, is the world's largest consumer of natural resources. In addition to the approximately 3 billion tons of raw materials needed each year for cement production, aggregate mining, processing and transportation consume a significant amount of energy and adversely affect the ecology of the planet (Mehta, 2001 and 2002).

Recycled aggregate, which has been used in construction since the end of the Second World War, is a material that can be used in the stabilization of road constructions. Recycled aggregate provides very good advantages in terms of being environmentally friendly and economical in the construction sector. Waste from demolition and construction works poses a major problem as they accumulate gradually and increase over time, so recycled aggregate offers an excellent alternative solution to this problem. Sustainable concrete should be considered as the main strategy for the construction industry. It is important to decrease energy consumption associated with carbon dioxide emissions that cause greenhouse effect (Mohammed et al., 2018).

According to the "World Commission on Environment and Development", sustainability means "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Naik & Moriconi, 2005). The sensible use of natural resources obtained using waste materials and the reduction of natural aggregate consumption as well as the lower environmental impact achieved by low carbon emissions represent two main activities aiming at meeting the requirements of sustainable reinforced concrete construction (Movassaghi, 2006).

The use of recyclable materials is increasing worldwide, with many impacts on economic, environmental and technological developments. Recyclable materials can break down, erode or be destroyed by nature if not reused. (Asmatulu & Asmatulu, 2011). Environmental impacts from extracting non-renewable raw materials include deforestation, soil loss, air pollution, reduction and pollution of water reserves. The construction industry has a large share of 40% in all materials that cause these effects (Pacheco-Torgal, 2013).

The gradual decrease in aggregate resources, deterioration of the natural environment, increase in environmental pollution and increase in aggregate cost have led to new searches. In this context, crushing waste concrete and evaluating it as recycled concrete aggregate is extremely important in terms of protecting the environment. The use of waste concrete as recycled aggregate is an important gain in terms of both reducing environmental pollution and contribution to the national economy. For this reason, adding economic value to waste concrete comes to the front today (Demirel et al., 2015). With the legal obligation regarding of recycling, new developments are taking place in the recycling field in industrial sector. This is positive for economic development and employment. Raw material production is provided more easily with recycling. In other words, the preparation of the waste material for production requires less processing than the production from nature. This provides energy savings (Öztürk, 2005).

The acceptability of recycled aggregate is not accepted by consumers because of their lack of trust to recycling activity. As an alternative to natural aggregate, the environmental and economic advantages of using recycled aggregate are greatly affected by economic reasons. By way of example, the choice between recycled and natural material depends on their quality and prices. The quality of recycled aggregate concrete may be the same as the concrete that containing non-recycled aggregate, but recycled aggregate concrete is considered with doubt. Therefore, recycled concrete aggregate may not be desired when the price of such aggregate is much lower than the natural material, even if the recycled aggregate meets the given quality. A major obstacle is the change in the quality of recycled aggregate, which can be easily overcome by construction and demolition waste processing facilities. Another restriction to the reuse of recycled concrete aggregate in construction is the lack of a well-developed gathering, processing plants and transportation. Recycled aggregate must be available in usable quantities. This should be a top priority in supporting the reuse of recycled aggregate in the construction industry, as potentially usable material constraints will have a significant impact on decision-making processes. In most cases there is a concern due to the lack of confidence in the technical feasibility of recycled aggregate. If the product fulfills with high quality standards, it can be considered as a realistic alternative to natural aggregate in structural concrete production (Tam et al., 2018).

The reasons why recycling aggregate is not used in concrete mixtures can be listed as follows (Batman, 2018):

- Problems related to quality control due to insufficient technology in recycling aggregate production processes.
- Lack of towards the recycling aggregate which can be overcome by raising the awareness of the consumer. For example; information about the use of recycled concrete aggregate instead of natural aggregate in low strength concretes can be provided and an awareness effect can be created by explaining its positive effects on the environment.
- It is not economical to open a facility in places where there is not enough demolition waste due to the insufficient facilities.
- Inadequate standards regarding recycling aggregate is another problem.

According to Malešev et al. (2014), recycled aggregate is less advantageous than natural aggregate in terms of physical characteristics. The grains are irregular, mostly angular, rough and with a cracked surface and porous. These grain properties significantly affect the workability of fresh concrete as well as the strength and permeability of the hardened concrete. (Malešev et al., 2014).

According to Padmini et al., (2009), RCA particle is more irregular and has a rougher surface than natural aggregate. Concrete that made from RCA needs more water than normal concrete a given workability. Beside, its density, compressive strength and elastic modulus are lower than that of normal concrete (Padmini et al., 2009). The RCA produced from demolishing waste is generally contaminated with salts, bricks, wood, metal, plastic, cardboard and paper. It has been shown that contaminated aggregate can be used instead of natural coarse aggregates in concrete after separation and screening from the waste. However, as in natural aggregates, features such as water absorption, grain size distribution, grain shape, and abrasion resistance should be tested in recycled aggregates to measure their quality (Rao et al., 2007).

According to a study conducted by the Environmental Council of Concrete Organizations, an estimated 60% savings have been achieved by using RCAs instead of natural aggregates. In a study conducted at Purdue University in the USA, it has been reported that the use of RCA has a cost reduction potential of 2.26-2.93 $ per ton in pavement concrete (Verian et al., 2018).

Coarse recycled concrete aggregate (RCA) is composed of the natural coarse aggregate and the adhered-mortar on its surface. The presence of the residual mortar on RCA is inevitable because complete removal of it would prove costly and detrimental to the integrity of the natural aggregate. Although, as cited by Volz et al. (2014), the quality of RCA is not always dependent on the characteristics of the adhered-mortar (Nagataki et al., 2012), there are many reports indicating that the residual mortar is the cause of high porosity, considerable high water-absorption and low specific gravity of RCA compared to those of virgin aggregate. In general, it is demonstrated that the negative effect of RCA on the properties of resultant concrete becomes considerable when the substitution level of RCA (in place of virgin aggregate) is beyond 25% (Debieb et al., 2010, Fonseca et al., 2011, Etxeberria et al., 2007, Huda et al., 2015). However, it should be emphasized that the substitution level at which the adverse effect of RCA on concrete properties (if any) becomes apparent, also depends on the characteristics of RCA itself. For instance, reducing maximum aggregate size from 20mm to 15mm, through mechanical treatment (additional grinding of RCA) may result in a considerable increase in RCA substitution level without suffering the properties of resultant concrete (Volz et al., 2014). In short, for a better understanding of the RCA and to predict its effects on concrete, the components of these composite material must be discovered separately (Nagataki et al. 2012).

2. EXPERIMENTAL STUDY

Materials

Aggregates

In order to make more accurate comments about the effect of RCA on concrete properties, it is necessary to know properties of the ingredients and properties of the parent concrete. Within the scope of this study, RCAs were obtained from 6 different concrete mixtures, with three different water/cement ratios (0.45, 0.60, 0.70) prepared with limestone and basalt aggregates. The information about the size of the aggregate grains used is as follows: Basalt aggregate has been used with two different particle size fractions, 5-15- and 15-25- mm and limestone aggregate with 0-5-, 5-15- and 15-25-mm size fractions. The physical properties of the aggregates used are shown in Table 1.

Table 1. Physical properties of coarse and fine aggregates in parent concrete

Properties	Limestone Aggregate			Basalt Aggregate	
	0-5 mm	5-15 mm	15-25 mm	5-15 mm	15-25 mm
Dry Rodded Unit Weight (kg/m³)	1889	1573	1548	1646	1590
SSD Specific Gravity	2.65	2.68	2.71	2.81	2.83
Water Absorption Capacity (%)	0.92	0.30	0.23	0.45	0.40

Superplasticizer

Properties of the polycarboxylate ether-based superplasticizer admixture obtained from its manufacturer are given in Table 2.

Table 2. Properties of superplasticizer admixture

Alkali Content (%) (Na_2O)	Density (g/cm³)	Solids Content (%)	Chloride Content (%)	pH at 25 °C	Operating Range (%)*
<5	1.096	34.63	0.011	5.87	0.6-2.0

*By weight of cement

Cement

In the experimental study, a CEM I 42.5R cement was used. The chemical, mechanical and physical properties of the cement are given in Table 3.

Table 3. Chemical composition, physical and mechanical properties of cement

Chemical Composition (%)		Physical Properties	
SiO_2	19.32	Specific Gravity	3.12
Al_2O_3	5.21	Blaine Specific Surface (cm²/g)	3674
Fe_2O_3	1.95	Initial Setting Time (min)	150
CaO	63.02	Final Setting Time (min)	200
MgO	2.02	**Compressive Strength (MPa)**	
Na_2O	0.36	2-day	24.0
K_2O	0.83	7-day	39.3
SO_3	3.12	28-day	49.5
Loss on Ignition	3.67		
Cl	0.0074		
Insoluble Residue	0.63		
Free CaO	1.06		

Mix proportions of parent concrete

A total of 6 different concrete mixtures were prepared to obtained RCA. These mixtures had three different w/c ratios (0.45, 0.60, 0.70) and they were prepared with limestone or basalt coarse aggregates. The actual mix proportions of concrete mixtures are given in Table 4. In the abbreviations of the mixtures, the terms “LS” and “B” refer to limestone and basalt coarse aggregates, respectively, while the numbers indicate the w/c ratio of parent concrete.

Table 4. The actual mix proportions of parent concretes (kg/m^3)

Mixture	W/C Ratio	Cement	Water	Aggregate, SSD Limestone 0-5 (mm)	SSD Limestone 5-15 (mm)	SSD Limestone 15-25 (mm)	SSD Basalt 5-15 (mm)	SSD Basalt 15-25 (mm)	Unit Weight
RCA-LS 45	0.45	385	172	1018	420	425	0	0	2420
RCA-LS 60	0.60	286	171	1046	432	440	0	0	2375
RCA-LS 70	0.70	287	201	1009	418	423	0	0	2338
RCA-B 45	0.45	373	167	986	0	0	426	429	2381
RCA-B 60	0.60	280	168	1024	0	0	449	452	2373
RCA-B 70	0.70	282	197	991	0	0	428	431	2329

3. RESULT AND DISCUSSION

After determining the 28-day compressive strength of the 150 mm cube samples kept in the curing pool for 28 days, they were crushed using a jaw crusher to obtain RCA. The 15-25 mm size fraction of RCA was separated to be used in further investigations. The compressive strength of parent mixtures was determined in accordance with TS EN 12390-3 standard. The water absorption capacity and specific gravity (TS EN 1097-6), particle size distribution (TS EN 933-1:2012(EN)), bulk density (TS EN 1097-3), resistance to fragmentation (TS EN 1097-2), flakiness index (TS EN 933-3) of the RCA were also determined.

Compressive strength of parent concrete mixtures

The compressive strength of parent mixture is given in Table 5. As it was expected the strength of concrete reduced by increasing w/c ratio. Thus, strength values in the range of 25.4 MPa to 55.8 MPa were obtained. Moreover, for the same w/c ratio, basalt coarse aggregate-bearing mixtures showed somewhat greater compressive strength than their limestone coarse aggregate-bearing counterparts.

Table 5. Compressive strength of parent concrete mixtures

Mixture	W/C Ratio	28-day Compressive Strength (MPa) Sample 1	Sample 2	Sample 3	Average	Standard deviation
RCA-LS 45	0.45	51.48	48.86	49.38	**49.91**	**1.13**
RCA-LS 60	0.60	33.25	32.63	32.32	**32.73**	**0.39**
RCA-LS 70	0.70	25.23	25.79	25.22	**25.41**	**0.27**
RCA-B 45	0.45	54.99	56.47	55.96	**55.81**	**0.61**
RCA-B 60	0.60	33.12	34.98	34.76	**34.29**	**0.83**
RCA-B 70	0.70	26.60	28.40	27.90	**27.51**	**0.76**

Particle size distribution

Sieve analysis test results of the coarse aggregates used in the parent mixtures and RCAs are given in Table 6.

Table 6. Particle size distribution of aggregates

Aggregate Type	**Percent Passing**			
	31.5 mm	**25 mm**	**20 mm**	**16 mm**
Limestone	100	99	57	0
Basalt	100	99	46	0
RCA-LS 45	100	77	52	0
RCA-LS 60	100	81	65	0
RCA-LS 70	100	78	59	0
RCA-B 45	100	76	53	0
RCA-B 60	100	80	64	0
RCA-B 70	100	79	65	0

Mechanical and physical properties of aggregates

The water absorption capacity, flakiness index, resistance to fragmentation, unit weight and specific gravity of aggregates are given in Table 7.

Table 7. Water absorption capacity, flakiness index, resistance to fragmentation, unit weight and specific gravity of aggregates

Aggregate Type	**Water Absorption (%)**	**Flakiness Index (%)**	**Fragmentations Resistance**	**Unit Weight (kg/m^3)**		**Specific Gravity**	
			Weight Loss (%)	**Compacted**	**Loose**	**Dry**	**SSD**
Limestone	0.23	20.15	26,50	1548	1466	2.69	2.71
Basalt	0.4	12.28	12,83	1590	1521	2.82	2.83
RCA-LS 45	5.76	33.71	26,94	1291	1200	2.36	2.46
RCA-LS 60	6.58	19.6	30,52	1238	1092	2.23	2.39
RCA-LS 70	7.26	18.03	31,98	1210	1061	2.19	2.37
RCA-B 45	5.32	29.18	18,25	1349	1235	2.42	2.53
RCA-B 60	5.97	13.82	24,80	1242	1171	2.29	2.42
RCA-B 70	6.93	14.94	29,10	1219	1097	2.22	2.39

As it can be seen from Table 7. with increasing w/c ratio of the parent concrete results in an increase in water absorption capacity of RCA. While the water absorption capacity limestone and basalt aggregates are below 0.5%, the water absorption capacity of the coarse RCAs containing these aggregates is in between 5.32% and 7.26%. Higher water absorption capacity in RCAs is arisen from the presence of adhered mortar on RCA.

The flakiness index of RCAs prepared from the parent concrete mixtures with 0.45 w/c ratio was higher than other RCA. In general, the flakiness index of the RCA reduced by increasing the w/c ratio of the parent concrete. The fact is more pronounced in basalt RCA.

It is seen that RCAs prepared from the parent concrete mixtures with higher w/c ratio also have higher Los Angeles coefficients. It was observed that the Fragmentations resistance of RCA obtained from 0.45 w/c ratio mixtures was closer to the parent aggregate. However, increasing the w/c ratio of the parent concrete increased the Los Angeles loss on weight of the aggregate. The fact arises from the increased adhered mortar on RCA upon increasing w/c ratio of the parent concrete. Compared to the Los Angeles loss on weight of limestone aggregate, limestone RCA showed at most 21% higher weight loss. The corresponding value for basalt RCA was around 126%.

The specific gravity and unit weight of RCAs reduced with increasing w/c ratio of the parent concrete. Compared to the dry bulk specific gravity of corresponding parent aggregates, the specific gravity of limestone RCA was 19% lower. The corresponding value was 21% for basalt RCA.

5. CONCLUSIONS

For the material used and tests applied the following conclusions were drawn:

- The water absorption capacity of RCA was found to be higher than that of corresponding parent aggregate arisen from the presence of adhered mortar on RCA. Increasing the w/c ratio of the parent concrete from 0.45 to 0.7 caused an increase in the water absorption capacity of limestone RCA from 5.76% to 7.26%. The corresponding values were 5.32% and 6.93% for basalt RCA.
- Parent concrete mixtures with the highest w/c ratio (0.7) resulted in RCA with the lowest unit weight. Besides, using basalt in parent concrete led to higher RCA unit weight compared to limestone-incorporating RCA
- The RCAs prepared from 0.45 w/c ratio mixtures showed the highest amount of flaky particles. The fact was more pronounced in limestone RCA than basalt RCA.
- The Los Angeles weight loss of limestone RCA prepared from 0.45 w/c ratio parent mixtures was very close to that of the natural limestone aggregate. This was not the case in the RCAs prepared from parent concrete mixtures having higher w/c ratio, irrespective of the aggregate type of parent mixture. The difference between the Los Angeles weight losses of limestone aggregate and limestone RCA was around 21%. The corresponding value for basalt aggregate and basalt RCA was considerably high (126%).

6. ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support provided by TÜBİTAK under grant No: 119R037.

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