Improve Recycled Concrete Aggregate properties in Order to Use It in Paving Application as Aggregate

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Abstract: The amount of crushed cement concrete continues to increase daily as a result of the demolition of old structures, thereby increasing pollution. To cope with the pressure imposed by the rise in environmental awareness and the stringent disposal regulations set by environmental protection agencies, effective measures for handling and disposing of crushed concrete must be implemented. Instead of simply disposing of crushed concrete, alternative efforts should be considered to utilize it as a recyclable material. The objective of this study was to improve recycled concrete aggregate (RCA) to be able to use it in paving application. Three types of treatments applied to improve RCA properties. In this study three types of treatment were used to improve RCA properties. Theses treatment are soak RCA in HCL acid for 24 hours, grind RCA in Los Angeles Abrasion machine, re-grind RCA particle in jaw crush machine. In order to evaluate each treatment the aggregate properties are determined. All properties were determined for RCA passing and retained sieve size of 5 mm and 1.18 mm respectively. The calculated properties are bulk specific gravity of aggregate, absorption value, abrasion value of aggregate and angularity number of RCA.. The most important conclusions are Soaking RCA in HCL acid has side effect on the specific gravity of aggregate, Putting RCA in Los Angeles Abrasion machine make RCA particles more rounded. Finally, crush RCA in jaw crusher machine for second is best way to improve RCA properties.

1. Introduction

According to the ASTM definition, aggregate is a granular material such as crushed stone, sand, gravel or iron blast furnace slag. Aggregate which is retained on a sieve size of 4.75 mm (No. 4) is called coarse aggregate, whereas aggregate which passes a sieve size of 4.75 mm (No. 4) and is retained by a sieve size of 75 μm (No. 200) is called fine aggregate [1]. Aggregate is usually used in Portland cement concrete, asphalt pavement, and as a filler to develop and maintain structures [2]. The basic skeleton of asphalt mixtures comes from the aggregate while the asphalt acts to hold them together in the matrix. The final performance of asphalt mixtures is greatly influenced by the mechanical and physical properties of the aggregate. The following figure 1 is based on the literature which addresses the relation of aggregate properties and the performance of asphalt mixtures [3].
The aggregate which is used in pavement construction is usually produced from crushing natural stone resources like basalt, granite and limestone. Meanwhile, natural resources are in great demand with the rapid development of human activities and especially the development of the highway industry. According to recent statistics, aggregate is the second most consumed material per capita on the Earth [4]. Hot mix asphalt contains 75–85% by volume and 90–95% by weight of aggregate [2–5]. For each kilometre of flexible pavement, 12500 tonnes of aggregate are used [5,6]. In the United Kingdom, 15 million tonnes per year of aggregate are used in road construction [7]. In Turkey, 290 million tonnes per year are created, around 35% of which is used in road construction [4]. In China, 5.6 ×108 tons of aggregate were used in asphalt mixes in 2010 [8]. Moreover, a shortage of natural aggregate and landfill sites is a common problem in Europe and other countries like Australia and Japan [9]. It is estimated that the concrete industry uses approximately 10 billion tons of aggregate worldwide [10,11]. This means that in the future the rate of production of natural aggregate will be too slow and unable to meet the demand for aggregate from the construction industry. The aggregate shortage problem can be solved by recycling concrete. In addition, Recycling waste concrete from the demolition of old structures as aggregate in hot mix asphalt is a good solution to decrease the amount of environment pollution.

The difference between the virgin aggregate and recycled concrete aggregate is the attached cement mortar. This attached cement mortar usually has higher porosity, lower strength and higher water absorption than natural aggregate. Therefore, it has a negative effect on the mechanical properties and performance of the mixture. Some studies suggest removing or decreasing the amount of attached mortar to improve the properties of RCA, whereas other studies suggest improving the properties of the attached mortar. It was concluded from reviewing the literature on improving RCA properties that there are two groups: the first group of treatments applies to the RCA in general without using it in the mixtures, while the second group of treatments applies to the RCA and the properties of the asphalt mixtures studied.

Treatments applied to RCA without evaluating asphalt mixes properties. These treatments are applied to the RCA before using it as aggregate in the asphalt or Portland cement mixtures. There are two common methods: First method is removing or decreasing the amount of attached mortar, and the other method is improving the properties of the attached mortar. The summary of these treatment is shown in figure 2.
Two common procedures are used to remove or decrease the amount of attached mortar before using the RCA as aggregate in the mixtures. These procedures are follows:

Mechanical Grinding: The principle of this method uses traditional grinding. Rolling vibration with a high-speed rotating eccentric gear in a grinding mill affects the attached mortar, which is ground by this action. It can be further modified by improving the eccentric gear to gain a higher speed, and thus to improve the attached mortars and the quality of the RCA [12]. Heating the RCA before grinding it makes removing the mortar easier. According to the study, recycled concrete aggregate was heated at around 300 °C to dehydrate the attached mortar and make it more brittle, before grinding in a grinder. Generally, the amount of removed mortar increases with increase of the temperature, whereas, when the temperature is higher than 500 °C, the properties of the RCA will be degraded [13].

Pre-soaking the RCA in water can remove some poor mortar from the RCA surface and separate out impurities [14]. In this method, stronger mortar cannot be removed.

Pre-soaking the RCA in acid can help to dissolve the cement. Therefore, acid solution can be used to remove the attached mortar and improve the properties of RCA [15]. The most effective acid is hydrochloric acid HCl, whereas sulphuric acid H2SO4 tends to crystallise and phosphoric acid H3PO4 is unstable. Soaking RCA in HCl (0.1 mol) for 24 hours improves the water absorption value [15]. However, this method increases the construction cost.

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Pre-soaking the Attached Mortar there are many chemical materials that can improve the properties of attached mortar by filling the weak areas, but these increase the construction cost. These materials are as follows:

Polymer emulsion, which has adhesive properties and can solidify in a short period of time, can be used. Polyvinyl alcohol (PVA) emulsion and silane-based polymers can be used to decrease the sensitivity of RCA to water. When the RCA is soaked in polymer emulsion, the polymer molecules fill the pores of the attached mortar and seal the surface of the RCA [16]. The water absorption of the RCA decreases with increased PVA concentration and 10% of PVA is an adequate concentration. Polymer treatment can improve the water sensitivity for RCA, but it cannot improve its compressive strength [17].
Pozzolan slurry can be used to improve the porosity of the mortar attached on the surface of the RCA. When the RCA is immersed in or sprayed with pozzolanic slurry that contains silica fumes, the fumes fill the pores and voids in the attached mortar [18]. Moreover, the porosity of attached mortar can be reduced by carbonation. CO$_2$ can pass through the pores in the attached mortar and react with calcium hydroxide and hydrated calcium silicate which are the main hydration elements in the mortar [19].

\[
\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} \tag{1}
\]

\[
\text{C-S-H} + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{SiO}_2 + n\text{H}_2\text{O} \tag{2}
\]

The carbonation increases the solid volume of calcium hydroxide by 11.5% and C-S-H by 23.1% [20].

**Treatment Applied to the RCA and Evaluation of Asphalt Mixtures Properties**

Several researchers have studied the use of treatments to improve the performance of asphalt mixtures containing RCA:

i. **Pre-Coat Recycled Concrete Aggregate with Slag Cement**

Slag cement is used for coating the recycled concrete aggregate with a coating thickness of 0.25, 0.45 and 0.65 mm to reinforce the ability of the RCA. The optimum thickness was 0.25 mm, which improves the Los Angeles abrasion value, increases the stiffness of the mix and improves the permanent deformation resistance of the mix. However, the treatment has a negative effect on the moisture sensitivity of the mixture [21].

ii. **Coating Recycled Concrete Aggregate with a Liquid Silicone Resin**

In order to improve the Recycled Concrete Aggregate, the coarse aggregate was soaked in liquid silicone resin for 1 hour and kept in an oven at 60 °C for 24 hours. This treatment improved the strength and absorption of the aggregate and increased the moisture damage resistance. However, the treatment has a negative effect on the permanent deformation resistance of the mixture [8].

iii. **Keeping the Mixture in the Oven for Several Hours at Mixing Temperature Prior to Compaction**

The mixture was kept in the oven for 0, 2 and 4 hours at mixing temperature prior to compaction. This treatment increases the resilient modulus value and makes the mixtures stiffer [22].

iv. **Coating Recycled Concrete Aggregate with Bitumen Emulsion**

In order to improve the properties of the RCA, it was coated with 5% bitumen emulsion prior to the mixing process. This treatment improved the moisture damage resistance and made the mixture more homogeneous [22].

**methodology**

Two types of aggregate, granite and recycled concrete aggregate were used in this study. The most important properties were determined for both aggregate types. The mechanical and chemical properties of recycled concrete aggregate were calculated for each fraction size separately. The mechanical properties of the aggregate are shown in table 1. The Flakiness Index, Elongation Index and Soundness Test met the specification requirements. The Soundness Test value for RCA was higher than for granite. The soundness value of RCA is higher than granite by 70 percent. The results for the Angularity Number Test and Particle Shape Index showed that RCA was more angular than granite, and angularity for RCA grew with decreasing aggregate particle size.
| Aggregate size (mm) passing-retained | Test                                           | Specification                  |
|-------------------------------------|-----------------------------------------------|--------------------------------|
| 19-9.5                              | Los Angeles Abrasion value (%)                | ASTM C131                      |
| 9.5-4.75                            |                                               |                                |
| 4.75-2.36                           |                                               |                                |
| Test                                |                                               |                                |
| 20-14                               | Bulk specific gravity                         | ASTM C127                      |
| 14-10                               |                                               |                                |
| 10-5                                |                                               |                                |
| 5-3.35                              |                                               |                                |
| 3.35-1.18                           |                                               |                                |
| 1.18-0.075                          |                                               |                                |
| Test                                |                                               |                                |
| 20-14                               | Absorption (%)                                | ASTM C127                      |
| 14-10                               |                                               |                                |
| 10-5                                |                                               |                                |
| 5-3.35                              |                                               |                                |
| 3.35-1.18                           |                                               |                                |
| 1.18-0.075                          |                                               |                                |
| Test                                |                                               |                                |
| 19-9.5                              | Flakiness Index and Elongation Index          | BS 812: Part 3                 |
| 9.5-4.75                            |                                               |                                |
| 4.75-2.36                           |                                               |                                |
| 2.36-1.18                           |                                               |                                |
| 9.42                                |                                               |                                |
| Test                                |                                               |                                |
| 19-12.5                             | Soundness Test (%)                            | ASTM C88                       |
| 12.5-9.5                            |                                               |                                |
| 9.5-4.75                            |                                               |                                |
| Test                                |                                               |                                |
| 19-12.5                             | Impact Test (%)                               | BS 812: Part III               |
| 12.5-9.5                            |                                               |                                |
| 9.5-4.75                            |                                               |                                |
| Test                                |                                               |                                |
| 19-12.5                             | Angularity number                             | MS 7.5                         |
| 12.5-9.5                            |                                               |                                |
| 9.5-4.75                            |                                               |                                |
| Test                                |                                               |                                |
| 19-12.5                             | Particle Shape Index                          | ASTM D3398                     |
| 12.5-9.5                            |                                               |                                |
| 9.5-4.75                            |                                               |                                |
2. Methodology
In this study three types of treatment were used to improve RCA properties. Theses treatment are soak RCA in HCL acid for 24 hours, grind RCA in Los Angeles Abrasion machine, re-grind RCA particle in jaw crush machine. In order to evaluate each treatment the aggregate properties are determined. all properties were determined for RCA passing and retained sieve size of 5 mm and 1.18 mm respectively.

RCA was soaked in HCL acid at 0.1 M concentration for 24 hours. RCA acid was used for two reasons. The first reason was to remove or decrease the attached mortar amount to improve RCA particles properties. The second reason was this acid is one of the least harmful sturdy acids to handle regardless of its acidity and it has the non-volatile and harmless chloride ion.

One of the methods which used to decrease amount of attached mortar is putting RCA in Los Angeles Abrasion machine. In this study 5000 g of RCA was poured in the machine with 11 standard steel balls and operated 150 revolution. 150 revolutions were used to not effect on the aggregate particles and just decrease the attached mortar.

The last treatment which used in this study was using jaw crusher machine. After primary crushing of RCA in jaw crusher, the RCA which retained sieve size of 5 mm is crushed again in jaw crusher. In this method the attracted mortar where removed

Result and Discussion
In order to evaluate each treatment, the most critical properties after treatment are determined. The first property which determined was aggregate specific gravity the result is shown in figure 3. It can be noted the specific gravity improved for treatment 2 and 3 that is because of attached mortar was removed whereas the specific gravity decreased after soaking RCA in HCL acid for 24 hours. That is because of interaction between aggregate and HCl acid.

The second property which determined was aggregate absorption value. Figure 4 shows absorption value of each treatment. The absorption was decreased by applying each treatment. The best treatment is re-crushing the RCA in jaw crusher. The absorption value decreased by 31%, 74% and 75% by applying treatment 1, 2 and 3 respectively.

The third property which determined was aggregate abrasion value. Figure 5 shows abrasion value of each treatment. The abrasion was decreased by applying each treatment. The best treatment is soaking RCA HCL acid. The abrasion value decreased by 11%, 7% and 3% by applying treatment 1, 2 and 3 respectively.

The last property which determined was aggregate Angularity number. Figure 6 shows Angularity number of each treatment. The Angularity number was increased by applying treatment 1 and 3 whereas the Angularity number was decreased by applying treatment 2. that RCA particles becomes more rounded. The best treatment is soaking RCA HCL acid. The abrasion value decreased by 11%, 7% and 3% by applying treatment 1, 2 and 3 respectively.
Figure 3. Bulk Specific Gravity after Each Treatment

Figure 4. Absorption value after Each Treatment
Figure 5. Abrasion value after Each Treatment

Figure 6. Angularity Number after Each Treatment

3 Conclusion
i. All treatments have significant effect to decrease Absorption value of RCA by decreasing attached mortar amount.
ii. All treatments have significant effect to decrease Abrasion value of RCA by decreasing attached mortar amount.
iii. Soaking RCA in HCL acid has side effect on the specific gravity of aggregate
iv. Putting RCA in Los Angeles Abrasion machine make RCA particles more rounded
v. Crush RCA in jaw crusher machine for second is best way to improve RCA properties.
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