MECHANICAL PROPERTIES AND MICROSTRUCTURES OF REGENERATED CEMENT FROM WASTE CONCRETE

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Abstract: It has been a long time since humans started using waste materials in engineering applications. This approach not only reduces the yield of waste, while minimizing the costs of disposal but also limit the cost of new materials. In the field of construction, the reuse of waste concretes has been a strong research in recent years. However the processing of the wastes normally involves complicated processing and lab equipment. In this report we crush and dehydrate waste concretes with normal lab facilities and re-make the cement composites. The waste concretes were crushed and dehydrated at two temperatures, 1280 and 1400 °C. To balance the concentration of silica and lime, extra lime at 28.5 % and 16 % were added to the waste concretes. The resultant materials were evaluated with respect to the chemical composition, mechanical properties, and microstructures. It is concluded that the material dehydrated at 1400 °C and containing 28.5 % lime presents the best mechanical performance. This report presents a simple and inexpensive method to reuse the waste concretes in applications such as pavements.

Keywords: waste concrete, regenerated cement, mechanical properties, microstructures

1. INTRODUCTION

As a result of modernization, new consumer behaviors generate waste with exponential increase, in a variety of different divisions of the society. Inappropriate treatment of these wastes, lead to strong negative impacts to the environment. As an applicable and effective method to deal with the waste materials, incorporating the wastes into new products can not only reduce the amount of wastes, but also reduce the cost of industrial manufacturing and production [1, 2]. In the section of construction and buildings, the waste concretes cause many environmental and health issues, while more and more concretes are used these years. In the meantime, the production of cements are facing a shortage of the source materials [3-5]. The global market for construction aggregates is consistently increasing [6-9]. Development has inflicted severe damage on the environment and may endanger its sustainability. The exploitation of natural resources, in particular non-renewable resources, for construction purposes leads to millions of tons of construction and demolition waste every year [10, 11]. Since most countries have no specific processing plan for these materials, they are sent to landfill instead of being reused and recycled in new construction. Of the wastes generated by the construction and demolition activities, a significant amount are the mineral waste or soils, such as excavated earth, road construction waste, demolition waste, waste rocks [12, 13]. The share of mineral and solidified wastes in relation to the total amount of waste produced was very large [14-18].

A natural approach to solve these pressing problems is to re-use the waste concretes. Whilst recycling is often cited as the best way to manage waste, there are still challenges to utilize waste concretes in construction, such as the uncertainty as to its environmental benefits, low quality of the final product, owing to lack of knowledge [19-
Waste concrete materials are being increasingly used in constructions. Targeting engineering applicability, waste concretes should be standardized for the key parameters such as gravel size, specific gravity, water absorption ratio, and crushing values should be determined, and these aggregates should be separated from wood, ceramics, iron, and so on [24-28]. Waste concretes are mostly used as protective barrier and ground-filling material against erosion. In such large-scale projects as rebuilding roads and runways, using waste concretes will reduce the cost of removal of the debris [29-32]. The utilization of waste concretes is increasingly gaining popularity in many countries [33-35]. A lot of labs separates the hardened cement pastes from the waste concretes and then dehydrate the cement pastes at high temperature to generate the recycled cements. However, this method only uses a portion of the waste materials at low efficiency. Waste concretes are crushed and ground by means of different methods so that they could be used as concrete aggregates [36, 37]. Waste concrete can be crushed into different sizes of aggregates. In comparison with normal concrete, Waste concretes have a higher water absorption ratio but a lower specific gravity. The mortar percentage used in waste concrete obtained from crushed concrete of destroyed structures was determined via linear traverse method [38-40]. Workability of concrete wastes is normally not good, and hence water amount often needs to be increased [41, 42]. However, it is inevitable that cement ratio will increase in proportion to water added. Therefore, it would be desirable to obtain finer aggregates in order for a proper workability [43]. It is worth noting that the CaCO$_3$ based aggregates produce materials that share similar chemical compositions with the dehydrated cement paste and hence it may be a viable approach to utilize the dehydrated concretes directly and avoiding the separation step. Currently there are not many results on the utilization of the full composition of waste concretes.

In this paper, we use the waste concretes with CaCO$_3$ based aggregates as the source materials to regenerate cementitious materials. This method is much easier and less cost-consuming in construction activities. We used high temperature kiln to dehydrate the crushed waste concretes and then we studied the chemical composition, mechanical properties and the microstructures of the regenerated concretes. These results will provide guidance on the engineering utility of the waste concretes in construction.

2. EXPERIMENTAL

The waste concretes were kindly provided by QUATTRO UK LTD from a source of demolished building. The materials were broken and ground into powders and sieved at 800 µm. Because the full compositions were dehydrated, the materials contain a large amount of SiO$_2$ from the fine aggregates. For this reason we added an extra amount of lime of 28.5 % or 16 % in weight to balance the compositions of Ca and Si. In addition, extra Fe and Al oxides were also added at about 1 %. The mixed raw materials are dehydrated at two different temperatures 1280 and 1400 °C for about 1 hour. The dehydrated materials are quickly cooled down to room temperature. The processing is presented in Figure 1. No difference was observed on morphology on the materials processed based the two methods.

![Figure 1. Temperature processing of the waste concrete.](image)

The chemical compositions were first analysed with x-ray diffraction (XRD) with a Bruker D8 instrument. In total four different materials are prepared to compare these two parameters, as shown in Table 1. Another control sample with no waste concrete was also prepared and studies for comparison purpose.
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Table 1. The four materials with different addition of CaCO$_3$ and dehydration temperatures

<table>
<thead>
<tr>
<th>Material ID</th>
<th>CaCO$_3$</th>
<th>Dehydration temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.5 %</td>
<td>1280</td>
</tr>
<tr>
<td>2</td>
<td>16 %</td>
<td>1280</td>
</tr>
<tr>
<td>3</td>
<td>28.5 %</td>
<td>1400</td>
</tr>
<tr>
<td>4</td>
<td>16 %</td>
<td>1400</td>
</tr>
</tbody>
</table>

The mixing procedures follow the ASTM standard C305 – 14. The resulting fresh materials are cast into plastic cylinder molds with the aid of vibration. All samples were sealed and kept at room temperature and demolded on the day of testing’s. The samples were subject to compressive and tensile tests at three different ages, 1, 7 and 28 days, with a MTS universal test machine. To understand the mechanism behind the mechanical properties, scanning electron microscopic (SEM) images were taken on the concretes at the age of 28 days.

3. RESULTS AND DISCUSSION

3.1. Chemical composition

The dehydrated pastes were analysed with XRD and the results are presented in Figure 2. It is clearly seen that the both dehydrated samples, the characteristic peaks of C$_3$S, C$_2$S, C$_3$A, and C$_4$AF are present, which are consistent with the ordinary clinkers. It is noteworthy that the phases of CSH and CH are not seen in the dehydrated materials, which means that the dehydration is completed. While it is challenging to quantitatively calculate the respective compositions of each material based on the relative intensities of the XRD peaks, it is concluded the compositions are similar among the dehydrated paste and the raw clinker. Especially there is no obvious difference between the materials dehydrated at 1280 °C and 1400 °C.

Fig. 2. XRD patterns of the dehydrated cement pastes and the raw clinker.

3.2. Mechanical properties

The mechanical properties of the waste replaced samples were compared with studies of compressive tests and tensile tests. The results are also compared with the a control mix without waste replacement. Figure 3 shows the results of compressive strength at the three different ages. As expected, the overall strengths are decreased when the waste materials are used. And with more replacement, the strength are even lower. It is noticeable that the at higher processing temperature 1400 °C, the overall strengths are higher than 1280 °C, which is because at the higher temperature, the waste materials are more fully converted to the clinkers, allowing complete reaction
between cement and water. An incomplete conversion from hydration products to clinkers may leave the unavailability of reaction spots in the matrix phase, resulting in a non-uniform microstructures. This is the reason causing the premature failures. However it should be noted that the reduction in mechanical properties were not so enormous. Especially for the samples processed under 1400 °C. The strengths are lowered less than 20 %. These materials are apparently feasible for applications such as low level buildings or pavements. The cost will be significantly lower than using raw cement.

![Graph](image1)

**Fig. 3.** a) Compressive strengths; b) tensile strengths of the four mixtures and the control sample.

3.3. Microstructures

The SEM images (SEI mode) of the cement paste are shown in Figure 4. The CSH and CH grains are clearly observed in the sample. The morphology of the hydration products with from the waste materials are similar with the normal pastes. In both samples, the CSH gel can be clearly observed, as well as the CH plates and AFt crystals. Comparing these two samples, it is noticed that the amount of the AFt crystals in the waste concrete sample is much less than the control sample, which may be responsible for the lower mechanical properties. It is also noted that in the sample with the regenerated cement, there is a through crack, which may be due to the weak binding between the CSH gels and other hydration products. This is also a viable mechanism to explain the diminished mechanical properties of the concretes from regenerated cement. Other than that, it seems there are no apparent differences in the microstructures between the two samples verifying the validity of using the dehydrated waste concrete to develop new materials.
Fig. 4. The SEM images of hydrated cement paste at the age of 28 days for (a) control sample and (b) sample with dehydrated wastes at 1400 °C.

4. CONCLUSIONS

In this work, the waste concretes were processed at temperatures of 1280 and 1400 °C. No difference on morphology was observed on the resultant materials. The resulting dehydrated materials were directly added to mix with cement. The resulting mechanical properties are lower than those of normal concrete samples, based on tensile tests. The microstructures and CSH are also similar with the normal concretes, based on the SEM images. It is applicable to use these waste concretes for construction that does not necessitate high strengths, such as pavement and single-story house. This work provides opportunities of using waste demolished concretes, reducing cost while having a positive impact to the environment.

REFERENCES


