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An Investigation of the Suitability of Pottery Cull for Aggregate Replacement in Concrete

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ABSTRACT

The Kohler Company manufactures a wide range of kitchen and bathroom fixtures around the world. The Kohler Company only produces products that are the best possible quality; all less desirable products become waste products are collected in a Kohler-owned landfill at a rate of nearly 3,300 metric tons per month. This waste is called pottery cull. The purpose of this paper is to determine if pottery cull's physical and chemical properties make it a practical substitution for fine and coarse aggregate in concrete. Both coarsely crushed and more finely ground pottery cull were compared to natural coarse limestone and sand, respectively. Examined were pottery cull's cementitious characteristics, alkali silica reaction potentials, and costs compared to natural aggregates. This research showed that crushed and ground pottery cull can be used as either fine or coarse aggregate, or both.

Keywords. Pottery cull, aggregate, concrete, sand, limestone

INTRODUCTION

Kohler Company in Kohler, Wisconsin, is a world-known manufacturer of kitchen and bathroom fixture products. The Kohler Company strives for customer satisfaction and maintains high quality control. Roughly 30% of all pottery pieces produced for kitchen and bathroom products do not meet Kohler quality standards (Lieffring, 2010) and are discarded. This discarded material is called pottery cull and is sent to company owned landfills. The Kohler-owned landfill ships out the majority of its waste to assist as a sub-base layer for roadways, parking lots, concrete slabs, and backfill (Wisconsin, 1998). Kohler engineer, Craig Lieffring, explains that they have found other companies that will take landfill pottery cull, and crush it themselves for use in their own production of concrete block (Lieffring, 2010). The Kohler Company also owns multiple landfills throughout the world, and only a few recycle the pottery cull shipped there (Lieffring, 2010). This results in the use of more landfill space, and does not contribute towards bettering the environment. Pottery Cull's current usage as a sub-base layer reflects on the location of the landfills; it is too cost prohibitive for Kohler to crush and ship cull to the job site as needed. As a result, a new method of using manufactured aggregates must be discovered, tested, and implemented for concrete mix designs.

Concrete construction has been used for centuries and will certainly continue to be used in the future. In today's industry, the use of recycled materials in concrete has evolved and they have become common admixtures in concrete mixes. If pottery cull were to replace coarse and fine aggregate within concrete, there would be a new market for this Kohler byproduct.

LITERATURE REVIEW

Physical Properties of Pottery Cull.

It has been found that pottery cull can be ground down to a powder to be used as a replacement for portland cement in mortar (Lieffring, 2010). Because the cost of producing this fine material is more than the item being replaced, it is not economical to use it as a cement replacer. Cull has more potential to be used as coarse and fine aggregate replacement in concrete because it does not require as much grinding and preparation.

Figure 1 and 2 show the physical characteristics of both fine and coarse aggregate, respectively. Fine pottery cull aggregate consists of grains ranging between 0.0625 and 0.2 millimeters. Coarse pottery cull aggregate consists of particles having a size range between 4.75 and 19.10 millimeters.

Figure 1: Fine Pottery Cull Sample.

Figure 2: Coarse Pottery Cull Sample.

Both fine and coarse pottery cull have angular characteristics that closely resemble some natural aggregates like crushed limestone. Because alkali silica reactions (ASR) occur inside the sharp crevices in coarse aggregates there is a potential that fine pottery cull may have a less deleterious ASR potential than coarse pottery cull.

The Wisconsin Department of Transportation has used pottery cull on many of their highway projects near Madison, WI (Wisconsin, 1998). Other uses include base gravel for slabs on grade, fill for landscaped berms, and backfill for retaining walls (Lieffring, 2010).

Before cull is used for these types of projects, it is placed in a nearby landfill on a storage pad owned by the Kohler Company. While in the landfill, cull is crushed by bulldozers until it reaches a size range of 75 [3 inches] to 150 [6 inches] millimeters. This may be a simple process, but it is an effective way to prepare cull to be used as a sub-base layer for roadway projects. As discussed earlier, if there is no market for the pottery cull, it is buried in a landfill and capped off.

Chemical Properties of Pottery Cull

The Kohler Company has performed numerous tests to determine the properties of pottery cull (Lieffring, 2010). After extensive research and testing, they have classified pottery cull as a ceramic material that exhibits pozzolanic properties. Table 1 shows results of an X-Ray Fluorescence (XRF) test conducted by the Kohler Company showing the chemical composition of pottery cull (Krause, 2010).

Table 1. XRF Analysis of Pottery Cull (Krause, 2010)

Oxides, Wt.	Pottery Cull (%)
Quantitative XRF Analysis	
SiO_2	67.7
Al_2O_3	25.9
Fe_2O_3	0.57
MgO	0.28
P_2O_5	0.07
TiO_2	1.10
CaO	0.90
K_2O	1.58
Na_2O	1.84
Semi-Quantitative XRF Analysis	
ZrO_2	0.40
Cr_2O_3	0.09
ZnO	0.08
BaO	0.06
SrO	0.04
HfO_2	0.01
PbO	0.01
Total	100.6
Moisture*	0.01

Further examination of Table 1 shows that pottery cull contains many oxides that can be classified as part of the ternary diagram CaO – SiO_2 – Al_2O_3 (Bentur, 2002). Because pottery cull contains oxides such as silicone oxide and aluminum oxide, there is a high chance of alkali-silica reactions (ASR) to occur, especially for coarse pottery cull.

In concrete, there are many types of mitigation methods used to prevent ASR. Some of the leading mitigation methods include replacing cement with supplementary cementing materials (SCMs) such as fly ash, silica fume, slag, and ternary blends (Fowler, 2010). In turn, this promotes more sustainability for building design within the concrete mix; this becomes a win-win situation. SCMs have been found to reduce three important components that lead to ASR. They include reducing concrete permeability, ionic mobility, and pore solution alkalinity due to pozzolanic reaction and alkali binding (Fowler, 2010). If pottery cull were used to replace natural aggregates, also using SCMs may be the best procedure to reduce any ASR effects.

Availability and Locations of Pottery Cull

The Kohler Company is an international company; therefore, it has many vitreous plants worldwide. Table 2 shows the estimated monthly cull production deposits that can be used for aggregate replacement in concrete. In the near future, Kohler expects to open more vitreous plants worldwide, resulting in more pottery cull deposits (Lieffring, 2010).

Table 2. International Pottery Cull Availability (Lieffring 2010)

	Operations	**Estimated Monthly Cull Production (metric tons)**
Americas	Brownwood	400
	Monterrey	1300
	Spartanburg	500
	WI - Vitreous	150
	Total	2350
Europe	Dole	95
	Tangiers	180
	Zaragoza	70
	Total	345
Asia	Foshan	300
	Thailand	140
	India	140
	Total	580
	Worldwide Monthly Total	3275

Similar Aggregate Byproducts

Experimentally, glass has been used as an aggregate replacement for concrete. A study by Polley *et al.* has looked at replacing both fine and coarse aggregate with glass at different percentage levels (Polley, 1998). Because pottery cull's surface exhibits a glossy, transparent surface like glass, looking at a previous experiment replacing fine and coarse aggregates with glass in concrete could explain what may happen if pottery cull is used to replace aggregate in concrete.

When looking at fine glass particle replacement alone, Polley *et al.* found that when 20% of the fine aggregates were replaced with glass, the compressive strength of concrete was slightly higher. They also found that the compressive strength of concrete when replacing

30% of coarse aggregate with coarse glass particles was roughly 50% lower than a typical concrete mix. The smooth and flat surface of the glass may have resulted in more slippage of the concrete specimen. According to Lieffring, pottery cull exhibits similar characteristics to glass at this size (Lieffring, 2010).

Not only did glass size have an effect on compressive strength, but the color of glass used had a detrimental effect on the test specimens. Polley *et al.* observed that using white glass particles yielded higher 28-day compressive strengths compared to using green and amber colored glass particles. Further investigation discovered that the different chemicals used to produce green and amber glass affected their compressive strengths. Washing the glass was also a factor in the compressive strength. They discovered that washed glass performs better than non-washed glass by 40%. Because all pottery cull would come directly from the Kohler landfill, an effort to wash the cull is recommended based on these glass experiments.

It has been found that recycled glass heavily contributes to Alkali Silica Reaction (ASR) (Polley, 1998). This occurs when a silica aggregate reacts with alkali causing expansion and internal stresses, which ultimately causes the concrete to break apart. The difference between ASR and a pozzolanic reaction is that ASR usually occurs in mature concrete because of its slow reaction period, while pozzolanic reaction occurs within the first few months after mixing (Dyer and Dhir, 2001). Since pottery cull often has remnants of the glass-like porcelain coating it could be assumed that it would also exhibit some ASR reaction.

EXPERIMENTAL TESTING

Physical testing of mix designs with combinations of pottery cull and natural aggregate were performed by the authors as part of a second research paper and the data from that paper is also presented at this conference (Wurtz and Zachar, 2013). Based on that research, the authors found that substituting fine and coarse aggregates with fine and coarse pottery cull respectively maintained the same compressive strength characteristics as a normal mix concrete. As described earlier, fine pottery cull contains angular aggregate and extra finer particles in the form of powder. According to their testing, it can be shown that increasing fine aggregate replacement up to the 100% level has little effect on the concrete's compressive strength. All mix designs tested in their study reached a targeted 41.4 MPa [6000 psi] concrete compressive strength at the 28-day test. Towards the 56-day test, all concrete mix designs seem to converge together, adding an extra 6.9 MPa [1000 psi] to its compressive strength. Please refer to that paper for all of the test specifications and results.

COST ANALYSIS

Our research has demonstrated that pottery cull aggregates may be sufficient enough to be used as an aggregate replacement in concrete, with respect to a compressive strength standpoint (Wurtz, Zachar, 2013). Before this can be considered practical, one also needs to consider the environmental impacts and costs associated with the use of this material.

Figure 3 indicates that about 228 million metric tons of sand and gravel are used per year to make concrete. If pottery cull were to be used to replace natural aggregate, the Kohler Company could contribute about 43,000 metric tons per year. Although the amount of material that can be supplied by the Kohler Company is not comparable to the total demand of aggregate it will be a step in the right direction. Its use will reduce the mining of natural materials. It would also reduce the amount of cull material currently wasted in landfills.

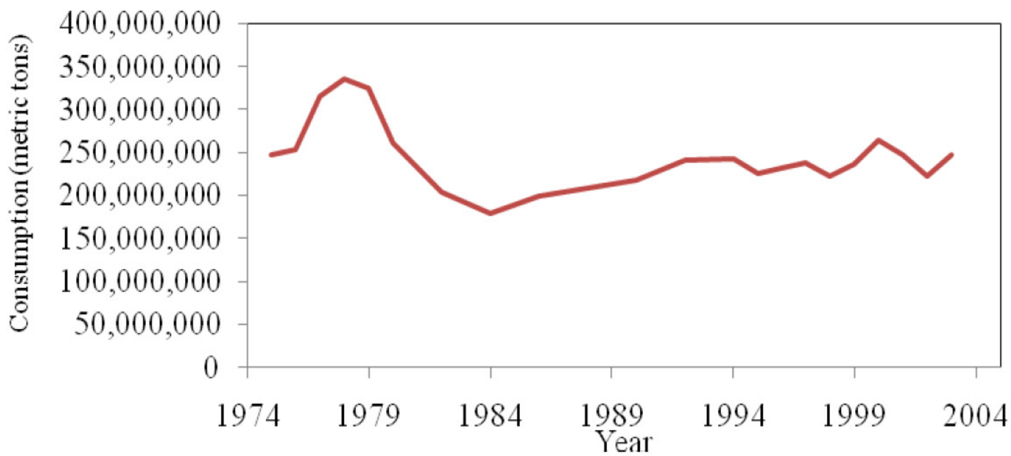

Figure 3. Historical Gravel and Sand for Concrete Consumption (Kelly and Matos, 2010)

Figure 4 shows the historical unit costs of sand and gravel. It shows that the cost of this material, on average, is $5.69 per metric ton. Because pottery cull initially has a size of approximately 75 [3 inches] to 150 [6 inches] millimeters, a local subcontractor would be hired to grind the cull to the specified granular size. The price / ton for grinding reduces with the amount ground. A quoted price to grind 1,000 metric tons of pottery cull to coarse and fine aggregate sizes would be $8 - $10 per metric ton (Wanek, 2011). If the Kohler Company were to supply the local contractor with 10,000 metric tons of pottery cull to grind the cost would reduce to $4 - $5 per metric ton. Based on these costs, if 10,000 metric tons of pottery cull was used as a normal production amount the resulting material would cost less than the averaged historical costs of natural sand and gravel the ground cull would replace. Ultimately, this would reduce the cost to produce concrete.

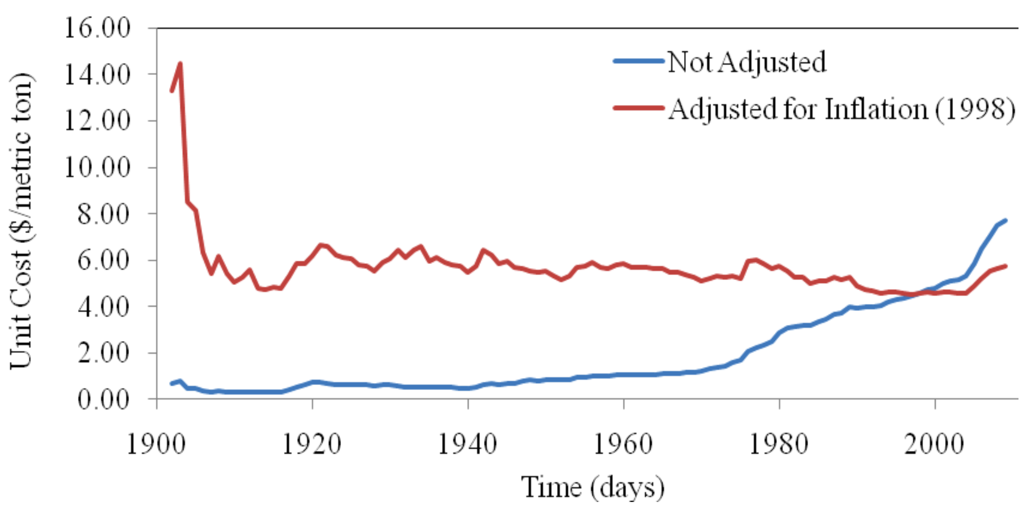

Figure 4. Historical Unit Costs of Sand and Gravel (Kelly and Matos, 2010)

CONCLUSION

Based on the physical and chemical characteristics of pottery cull, and testing done by the authors (Wurtz and Zachar, 2013), it can be shown that concrete produced with aggregate replaced by pottery cull maintained the same compressive strength characteristics as a normal concrete mix. It is recommended that alkali silica reaction tests be performed to further clarify if pottery cull causes any deleterious chemical effects in concrete. Once further testing is completed, additional market research and cost justification can be completed to further determine if this material can serve as a cost effective aggregate replacement on a plant-to-plant basis.

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