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TECHNICAL, ECONOMICAL AND ENVIRONMENTAL VIABILITY OF MASONRY GROUT MADE OF RECYCLED MASONRY

M. Shokry Rashwan[1] and Simaan M. AbouRizk[2]

ABSTRACT

An extensive study was conducted to evaluate the technical, economical and environmental viability of using grout made of recycled concrete blocks and clay brick. The recycled material was obtained from waste generated on construction sites. The waste was then processed into aggregate on the same site, using a compact processor developed for this purpose. Recycled material was used, in different proportions, to make concrete suitable for grouting masonry block walls. The technical investigation has focused on studying the properties of original material (i.e., before recycling), the recycled aggregates and the grout made of such material. Test results have shown that recycled aggregates possess higher absorption capacity and lower density than natural aggregates. Depending on the cement: aggregate ratio, grout samples made of such aggregate had compressive strength that complies with code requirements. Masonry prisms filled with grout made with recycled aggregates have also attained compressive strength values within the code requirements. Thermal conductivity coefficients of samples made with recycled aggregate were much lower than those obtained for control mixes. The economic investigation has focused on comparing the cost of on-site recycling process with the ever-increasing cost of disposing of such waste. The environmental study, on the other hand, was a simple task due to the immense benefits that can be gained from such a process. The paper presents the results of part of such investigations and the recommendations of how to maximize the benefits gained from on-site construction and demolition masonry waste recycling process.

1 President, CADR Technologies Inc. 21010-108 Avenue, Winterburn, Edmoton, Alberta Canada T5S 1X4

2 Alberta Construction Industry Professor of Construction Engineering & Management, 220 Civil/Electrical Building, University of Alberta, Edmonton, Alberta T6G 2G7

INTRODUCTION

Disposing of waste generated on construction sites is becoming an increasingly costly option for both building contractors and the environment. Increased prices for hauling this waste, compounded by increasing landfill fees, represent an economical burden not only on contractors, but also on building owners. The hazardous conditions created, and the frequent removal and transferal of waste, affect overall productivity on construction sites. Overcrowded landfills and lack of new sites have forced public authorities to look for alternate ways to remove the waste.

One viable solution to these problems is to recycle the waste generated and re-use it on the same site. This solution might be accomplished by transforming the waste into products with applications on-site. The properties of such material and the products made from it, however, must fall within acceptable boundaries set by building codes and standards. In addition, to be an economically viable option, the on-site recycling cost must be less than, or at least equal to, the cost of disposing the waste. The immense environmental benefits gained by recycling may in fact contribute significantly to such economic assessment

Although the concept of using recycled material in construction is relatively new to North America, it is a well-known process in European construction. Perhaps due to the high cost of clearing and the shortage of new materials following the mass destruction of the Second World War, much of the rubble was recycled into new construction. Research work conducted in this area has since focused on both the properties of the recycled materials and the recycling process. Due to the properties investigated for such recycled materials, their use was limited to a small number of applications (mainly the bases and sub-bases for roads). Making concrete with the recycled material, on the other hand, was suggested after stringent measures were applied to ensure acceptable qualities. The recycling processes themselves were done in centrally located, large plants that required both hauling rubble for recycling, and then transporting recycled material to construction sites.

Even with the added cost of hauling the material to and from recycling plants, it was found in many cases that such a process was more economical than using new materials. Table 1 (Hansen T.C., 92) presents a comparison between the cost elements in the processing and handling of natural aggregates and recycled aggregates in a central crushing plant, and the requirements for recycled aggregates to be competitive with natural aggregate. The cost items of C_4 and C_6, in Table 1 can be eliminated by on-site recycling processes, which would not only achieve higher cost savings than central recycling plants, but would also provide better control over the qualities of the recycled materials.

NATURAL AGGREGATES		*RECYCLED AGGREGATES - CENTRAL CRUSHING PLANT*	
Excavation Costs	n_1	Extra Treatment of Debris at the Site	c_1
Production Costs (including interim storage)	n_2	Savings in Dumping Charges for Debris (negative)	$-c_2$
Bulk Transportation Costs	n_3	Savings in Transportation of Debris to Dump (negative)	$-c_3$
Costs of Transport to Building Site	n_4	Costs of Transport of Debris to Processing Plants	c_4
		Processing Costs for Recycled Aggregate	c_5
		Costs of Transport of Recycled Aggregate to Building Site	c_6
		Extra Costs for Inspection, Storage, and Sale of Recycled Aggregate	c_7
TOTAL:	$\sum_1^4 n_i$		$\sum_1^7 c_i$

Requirement for recycled aggregate to be competitive: $\sum c_i \leq \sum n_i$

Table - 1 - Costs of Natural Aggregates and Recycled Aggregates

This paper presents the results of the research conducted to investigate the viability of using recycled materials in making concrete grout adequate to fill masonry concrete hollow-core block walls. The investigation is focused on the on-site recycling process as a means of transforming construction waste into aggregates. The construction waste consisted mainly of intentionally and non-intentionally cut and broken concrete blocks of clay brick. It also consisted of hardened mortar and grout that are in excess of required quantities and most often found on sites.

The tests conducted were divided into two parts, the first, to study the properties of recycled aggregates and the second, to investigate the properties of the cementitious products made of such aggregates.

Economical analysis was also conducted to compare the cost of on-site recycling and the equivalent cost of disposing of the waste. The paper is organized as follows:

I. Recycled Material's Properties Tests
   I-a Aggregates
   I-b Grout and Masonry Prisms
II. Economic and Environmental Assessment
III. Summary and Conclusion

I. RECYCLED MATERIALS PROPERTIES TESTS

In order to control the properties of recycled material, it is very important to know the types of input material and their respective properties prior to the recycling process. The following section gives a brief description of materials used in the experimental program:

I-a A Description of Input Materials.

Concrete Blocks. Masonry concrete blocks used in this investigation were of standard size, conforming to CAN3-A165.1-M85 Standard. Portland cement and aggregate used in manufacturing the block were in accordance to SCA Standards CAN3-A5 and CAN-A23.1, respectively. Compressive strength of individual units was specified at 15 MPa while that for masonry prisms was specified at 7.5 MPa. The unit wt. of the blocks were 2400 kg/m^3. The blocks were locally manufactured using a steam curing process.

Clay Bricks. Bricks used in the investigation were taken from 57 mm (H) * 90 mm (W) * 190 mm (L) red clay bricks conforming to CAN-A82.1-M87 Standard. The compressive strength of bricks was specified at 15 MPa. They were also locally manufactured in Edmonton, Alberta.

Grout & Mortars. Ready mix mortars and on-site prepared grout conforming to CSA Standard A179-75 were the original sources of waste used in this study. Average compressive strength of the grout was specified at 10 MPa.

Impurities. Due to the method adopted in storing the waste (disposal bins) impurities such as wood, paper, clay lumps, silts, glass and finer than 0.85 mm materials were found to be either non-existing or at insignificant levels. Very little effort was made prior to the recycling process to separate noticeable impurities such as wood and paper. It is therefore can be said that waste material investigated was to a large extent clean and uniform.

I-b Results Of Tests Conducted On Recycled Aggregate

An on-site recycling plant (Figure -1-), developed specifically for this investigation, was used to process construction waste into aggregate to be used for grout making. The sizes of out put material (crushed) were adjusted to 12 mm minus (the maximum size is 12 mm). Tests conducted on such aggregate included density, moisture content, gradation, absorption capacity and abrasion. Figure -2- presents sieve analysis of both concrete block and dry brick recycled material samples (CSA A23.1-2A Standard) In general, it was found that recycled material is on the coarser side compared to natural (new) aggregate samples with the same size ranges which is normally used for grouting. It was also found that fines in recycled concrete block aggregate (with sizes less than 5 mm) is only 6%, kg weight, while fines in clay brick recycled aggregate is 17% of sample's weight.

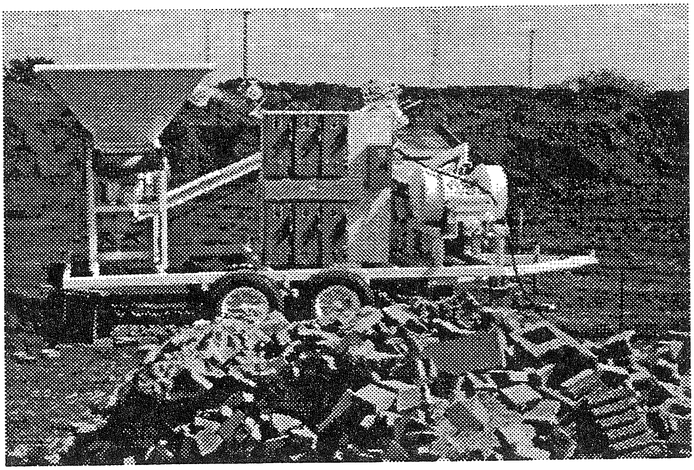


Figure -1- On-Site Recycling Plant

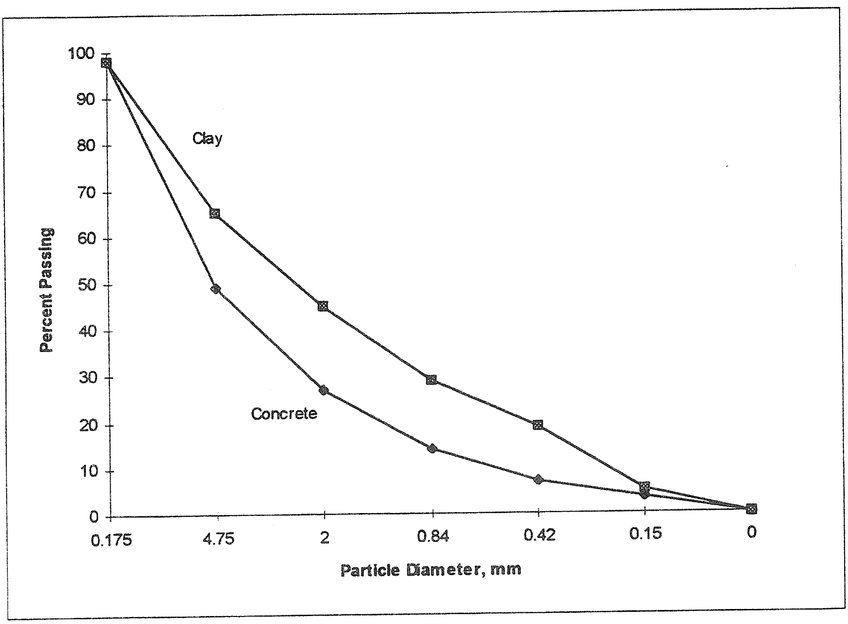


Figure -2- Sieve Analysis of Recycled Aggregates

Table -2- presents results of other tests conducted on both recycled concrete block and dry brick aggregates and also on natural aggregates.

	Concrete	Clay Brick
Loose Density (kg/m^3)	1139	1325
Packed Density (kg/m^3)	1220	1428
Moisture Content (%)	3.4	0.8
Bulk Relative Density	1.71	2.02
SSD Relative Density	1.91	2.21
Apparent Relative Density	2.11	2.45
Absorption (%)	10.4	8.4

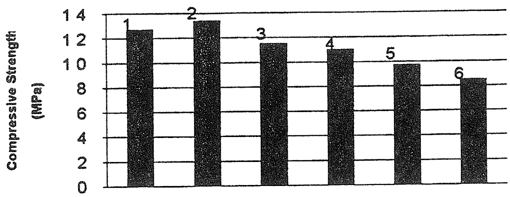
Table -2- Results of Tests Conducted on Recycled and Natural Aggregates

The lower values of densities for recycled aggregates compared to natural aggregate in Table -2- may be attributed to the higher voids content. Such higher volume of voids may, in turn, be attributed to the aggregates particle shapes resulting from the crushing process. Such shapes were found to be mainly angular compared to the generally spherical shape, of control aggregates which contains also sand. Another factor that may have attributed to such higher values of voids, particularly in the concrete block recycled aggregates, is the existence of hardened cement, either in the form of individual particles or as a coat surrounding crushed aggregate particles. Such hardened cement can be relatively porous depending on the age of hydration and the efficiency of the compaction process adopted in the manufacturing of blocks. The higher values of air voids are reflected on the higher values of absorption capacities as shown in the Table. Such combination, of higher voids and absorption values, has a great effect on grout mixing water requirement and the workability of such grout as will be discussed in the following sections.

I-c Results Of Tests Conducted On Concrete Products Made With Recycled Aggregates

Due to the lack of fines in recycled aggregates and poor workability observed in trial mixes made with only recycled aggregates, it was decided to add natural sand to such mixes. In preparing grout mixes for tests, ingredient's proportions limits as outlined in CSA-A179 Standard was used. Different grout mixes were then used to fill masonry prisms. The prisms were tested for 28-d compressive strength according to CAN 3-S304-M84 Standard. Figure -3- presents the results of such tests. The figure shows a compressive strength comparison between masonry prisms filled with grout made of field (natural) aggregates (prism #1) and prisms filled with grout made with recycled aggregates (prisms 2 to 6). Grout mix properties were as shown below the Figure.

Figure -3- 28 Days Compressive Strength of Masonry Prisms With Various Grout Mixes



Mix ratio based on cementatious volume

Mix #	Cement	Sand	Recycled Concrete Aggregate	Recycled Brick Aggregate	Gravel	Water	Comp. Strength (MPa)
1	1	3			3	0.96	12.7
2	1	2	3			1.06	13.4
3	1	2	4			1.49	11.5
4	1	3	3			1.62	11
5	1	2	2	3		1.63	9.7
6	1	2	2	2		1.52	8.5

Average air content values for grout mixes made with recycled aggregate were higher than that for control mixes. Average densities of fresh grout made with recycled aggregate, on the other hand, were 70% to 80% of that of grout made with natural aggregate.

Thermal conductivity tests were also conducted on grout specimens made of new aggregates and recycled materials respectively. Test results have shown that grout made with control mixes (density of 2313 kg /m^3) has a thermal conductivity coefficient of 1.35W/m - °K, while that made of recycled materials may achieve values ranging between 0.61 to 0.98 W/m - °K, depending on the mix's density. Such results suggest higher thermal resistivity limits (R-value) for recycled materials.

II. ECONOMICAL AND ENVIRONMENTAL ASSESSMENT OF ON-SITE CONSTRUCTION RATE RECYCLING

For on-site construction waste recycling process to be economically viable, its cost must compete with the cost of other options and specifically the cost of dumping waste in landfills. In order to conduct such assessment, the following factors must be considered:

1. Amount of waste generated;
2. Cost of disposing of waste;
3. Cost of natural aggregates;
4. Cost of recycling.

Table -3- presents the amount of waste generated on construction and demolition sites as well as average costs of disposal in the major Canadian cities.

	Population (million)	Haul per ton	Dump per ton	Haul + Dump per ton	Recycle Tonnage (conc./masonry)	Disposal Costs
Canada						
Toronto	3.431	$6.00	$90.00	$96.00	403,884	$38,772,912
Montreal	2.921	$10.00	$33.00	$43.00	343,849	$14,785,516
Vancouver	1.381	$6.25	$69.00	$75.25	162,566	$12,233,103
Ottawa	0.819	$6.5	$61.00	$67.50	96,410	$6,507,649
Edmonton	0.774	$6.50	$40.00	$46.50	91,112	$4,236,726
Calgary	0.671	$6.25	$50.00	$56.25	78.988	$4,443,053
Winnipeg	0.625	$7.50	$45.00	$52.50	73,573	$3,862,565
Hamilton	0.557	$6.25	$85.00	$91.25	65,568	$5,983,076
St. Catherines	0.343	$4.20	$88.00	$92.20	40,377	$3,722,730
Halifax	0.295	$5.00	$77.00	$82.00	34,726	$2,847,556
Victoria	0.255	$5.50	$75.00	$80.50	30,018	$2,416,421
Oshawa	0.203	$5.50	$50.00	$55.50	23,896	$1,326,250
St. John's	0.162	$6.00	$11.00	$1700	19,070	$324,191
Canadian Major Centre Total					**1,464,037**	**$101,461,748**

Table -3- Amounts of Waste generated from construction and Demolition Work for Major Canadian Cities

Cost of natural aggregates, including transportation, also vary from one city to another, depending on the location of aggregate pits and local market economy.

Cost of on-site recycling, on the other hand, is mainly dependent on the process and equipment used for crushing waste into concrete and also on the condition of waste on the site.

Sorting waste by types (e.g. concrete block, clay brick, etc.) in separate bins would definitely maximize both the technical and economic benefits achieved from the recycling process. Use of small and mobile recycling equipment would reduce both operation and energy costs. A framework for assessing the economical viability of on-site recycling was developed (I.C.E.S. Inc., 1995) which may assist contractors in making the decision whether or not to use such a process.

The environmental advantages of on-site recycling are so obvious considering the total amounts of waste dumped in landfills every year. For example, the commercial sector in the Province of Alberta accounts for approximately 45% of all wastes going to landfills, 25% of which is construction and demolition waste, while concrete and masonry share is approximately 24% of such amount. This means that 3% of all wastes being deposited of each year in Alberta landfills consists of concrete and masonry waste requiring at least 70,000 cubic metres of space for disposal (about the size of a football field with rubble piled up over eleven metres high each year). It should be noted that such environmental considerations have a significant impact on total construction economy. For example, Ontario landfills have become so congested that waste management costs are running at 5% of any tender's prices. Combining all of such factors may results in a significant gain to on-site recycling users and the environment.

III. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

An extensive testing program was conducted to assess the technical, economical and environmental viability of on-site construction waste recycling process. Test results have shown that such a process may offer a number of benefits, not only to the contractor and building owners, but also to the environment. Results of tests conducted on recycled aggregates and grout made with it are summarized as follows:

Crushing of concrete products results in a wide variety of sizes ranging from 1/2" to fine powder (for specific use of concrete aggregate). Sieve analysis conducted has yielded gradations close to those specified by the Code, however, on the coarser side. Addition of sand was found essential for such gradation to fall within the allowable limits. When used to manufacture concrete, mix proportions suggested by CSA -A179 Standard for masonry grout were used. The Code recognizes two types of grout mixes range, between 1 part cement : 2.25 part aggregate to 1 part cement : 5 part aggregates. Tests conducted have covered a number of different mix proportions. As expected, it was found that the higher the amount of cement the higher the strength. It was also found that the addition of sand is necessary to reach reasonable workability for the mix since the consistency of such mixes is reduced due to the absorptive nature of the crushed aggregate. It was also found that some of the mixes, particularly those with high cement ratios, have higher strength than those made with new material with the same proportions. This phenomena may be attributed to the existence of non-hydrated cement particles in the recycled aggregate which increases the cementatious value of the grout and hence the high strength. More work is currently being done to confirm such phenomena.

Masonry prisms filled with grout made of recycled aggregates have yielded compressive strength ranging from 8.5 to 13.4 MPa. These strength values are acceptable compared to an average compressive strength of 7.5 MPa recommended by CAN3- S304 - M84 Standard. Generally, it became evident that in order to use recycled aggregate for grout, the following ranges of mix proportions, by volume, would be recommended:

Cement		*Sand*		*Crushed Aggregate*
1	:	2 to 3	:	2 to 4

Economical mixes may be achieved by considering the upper boundaries for sand and crushed aggregate, however, a higher water to cement ratio would then be required to attain reasonable workability and hence the strength would drop. Ideal mixes for masonry grout may be made by mixing 1 part cement : 2 part sand : 4 part crushed aggregates.

Blend aggregate (concrete and clay recycled aggregates) may require the lower boundaries of both sand and crushed aggregate to attain acceptable strength.

The high air content indicate that such mixes made with recycled aggregate may be considered good candidates for structures subjected to frequent cycles of freeze-and-thaw. Air entrained admixtures may then not be required for such mixes.

Density test results indicate lower values than those obtained for mixes made with new material. This may be attributed to the higher air content of the recycled aggregates. Such lower density may be advantageous for minimizing the dead loads on supporting structures.

Shrinkage test results indicate insignificant changes in the linear dimensions of hardened concrete made with the recycled aggregate as compared to values allowed by the concrete code.

Thermal tests have also shown significant reduction in the conductivity of grout made with recycled materials compared to that made with new materials. Such reductions can be translated to higher R-values of masonry walls filled with recycled concrete.

For successful and efficient implementation of an on-site recycling process on construction/demolition sites, the following recommendations should be considered in order to achieve the highest possible benefits:

1. Costs of operation of the on-site recycling process should be compared to traditional means to evaluate the economic impact on-site recycling will have on the project's budget.

2. The utilization of the recycling process must be considered during the early planning stages.

3. Lines of communication of all parties involved or affected by the utilization of on-site recycling should be established.

4. The expected use of the materials produced by the recycling process must be identified.

5. The composition and amounts of material to be recycled should be established.

6. Construction waste must be sorted and separated to allow reduce contaminants in the material to be recycled.

7. Tests should be conducted on the recycled material and its products to ensure their conformance to the corresponding Standard.

8. All efforts must be made to encourage building owners, consulting engineers, and contractors to recycle construction/demolition waste. Initiatives must be made by Code and Standard writers to incorporate specifications regarding construction/demolition recycling and reuse of recycled material as building products.

9. Remember, we are all responsible for our environment.

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