Masonry rubble for innovative concrete block production in Tanzania

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Abstract

In Tanzania, concrete and masonry rubble are not recycled and knowledge on how they can be recycled especially into valuable products like building materials, is still limited. This study aimed at reusing concrete/masonry rubble in Tanzania for innovative concrete block production. Eight rubble samples of construction and demolition waste were processed to produce aggregates (fine and coarse) that were used for concrete block production. Aggregates were analysed in the laboratory in order to understand their quality characteristic and how they can affect the building material products. Fuller’s maximum density theory was applied for concrete block production. Analytical method was used for combining aggregates. In each experiment, recycled aggregates replaced natural aggregates by 100\% for both fine and coarse portions. The processes for concrete blocks production were: batching, mixing that was done manually to get homogeneous material mixture, compacting and moulding by a hand machine and curing in water. After 28 days of curing, the concrete blocks were tested on compressive strength, water absorption ratio and density in the laboratory. The results showed that the blocks produced with recycled aggregates by 100\% replacement were weaker than those with natural aggregates. However, the current results show the possibility of recycling the construction and demolition (C&D) waste into building materials because 85\% of tested concrete blocks produced from recycled aggregates, have achieved 7 N/mm\textsuperscript{2} as a minimum strength for load bearing capacity in Tanzania. Therefore, the masonry rubble could be a potential resource for building materials production for sustainable construction in Tanzania rather than throw them away or dump in the dumping site. Further work should focus on the study of chemical–mineralogical composition, contamination, and on economic feasibility for production of concrete blocks with recycled aggregates in Tanzania.

Keywords: Concrete and Masonry Rubble, Recycling, Building Materials, Concrete Block, Innovative, Tanzania

1. Introduction

Shelter is one of the basic needs of human beings. Certainly, in order to construct a house, building materials are needed. Throughout the ages, people have exploited natural resources to provide shelter. Even nowadays, almost all locally available natural building materials are derived from natural resources (Lowton, 1997). This practice continues today despite the many challenges facing current and future generation regarding the availability of building materials. The share of locally available material used to produce building materials in Tanzania is 47\% (NCC, 1992); the rest is imported, which puts significant strain on the country’s economic situation. Importation of building materials is encouraged by the Tanzanian Government, given the fact that there is a deficit of materials like cement (The Guardian (Tz) newspaper of December 29\textsuperscript{th}, 2007). The importation of materials reveals that there is a huge shortage of building materials in Tanzania. While building materials are already limited in many countries, their demand increases daily. In Tanzania, for example, the aggregate demand is approximated to be 2 tonnes per capita annually (Sabai et al 2011). Other countries are showing 11 tonnes per capita in New Zealand, 5 tonnes/ca in the UK and 8 tonnes/ca in the US (Kirby and Gaimster, 2008). The average aggregate demand globally is 3.8 tonnes/ca yearly (WBCSD, 2009). This indicates that Tanzania’s aggregate demand of 2 tonnes/ca is still lower than the global average of 3.8 tonnes/ca. This relatively low use may be attributed to the fact that about 80\% of the population live in rural areas (URT, 2003), whereas studies show that aggregates are consumed mostly in urban
rather than rural areas (Kimambo, 1988). It is estimated that the current population of Tanzania (approximately 43 mil.) will triple by the year 2050. Moreover, 75% of the population will by then live in urban areas (PRB, 2009). This condition suggests that the dramatic growth of population will put pressure on the provision of shelter and the availability of building materials in the future.

In addition, the construction industry is a wasteful sector: it is responsible for generating construction and demolition (C&D) waste of approximately 40-50% of the total amount of waste (McDonald, 1996; Dolan et al, 1999; Macozoma, 2002; Oikonomou, 2005). It is also estimated that for every 1kg of cement produced, 1kg of CO₂ emission is released (Mora, 2007). The amount of C&D waste generated could be estimated from normal construction and demolition activities. But can be witnessed nowadays natural disasters like, earthquakes (e.g. in Italy (2009), Haiti (2010), Chile (2010), New Zealand (2011), Japan (2011) etc), avalanches, and tornadoes events are increasing. On other hand, man-made causes like war, bombing, and structural failures are also often reported in different areas. All in all, it indicates that the construction industry will continue to be wasteful sector. Tanzania is also vulnerable to these natural disasters like, the bomb blasts which occurred recently at Mbagala (2009) and Gongolamboto (2011) in Dar es Salaam, which left hundreds of houses demolished. At the same time, new buildings are needed to cut off housing problems in which building materials are extracted from natural resources (Lowton, 1991). And the construction of these new houses resulting construction waste generation. Apart from the human distress a challenging question remains how to deal with this massive amount of waste issue.

According to Conceicao Leite et al’s (2011) from a study that was carried out in Sao Paulo city, it was found that the C&D waste generation was 16,000 tons/day: out of that, one third is landfilled and the rest is illegally disposed of. Rao et al (2007) reported that 30% of recycled C&D waste in Taiwan is used for road construction as road base and the rest is landfilled. Similarly, in the US, up to 70% of C&D waste is recycled while in the European Union (EU) up to 90% (especially in The Netherlands and Germany) is recycled. In most of the developing countries like Tanzania, the disposal of C&D waste remains a challenge because the C&D waste as solid waste is addressed for landfill instead of reuse and/or recycling (URT, 2003; 2004). Even though there is currently no official landfill for solid waste disposal in Tanzania, open air dumping sites are used. Dumping C&D waste puts pressure on acquisition for a large portion of the land in order to accommodate the growing waste generation. Population growth and limitation of land for waste disposal will put extra pressure on C&D waste management in future. All in all, the use of C&D waste for building material production can be the best option not only for waste management but also for providing an alternative building material source. This research aims at recycling C&D waste particularly concrete/masonry rubble into new building materials. The study on recycling concrete/masonry rubble has been influenced by the fact that currently, plastic and metal wastes have started to be recycled in Tanzania but not concrete/masonry rubble (Sabai et al, 2011).

Various research studies have been carried out to find out how the C&D waste can be reused for building material production. Mueller et al (2008) reported that the reuse/recycling of C&D waste depends on quality of constituents and the products. Bianchini et al (2005) studied how best to reuse the recycled aggregates for concrete production; authors they also found out that grain size fraction ranges between 0.125-0.600 mm of recycled aggregates can be directly re-utilized as first order material. Oikonomou (2005) and Limbachiya et al. (2007) reported that using 30% of recycled coarse aggregates to replace natural aggregates, the concrete product can comply with specifications. Husken (2010) used up to 20% fine recycled aggregates to replace natural aggregates for paving block production and produced the paving blocks that fulfill the requirements given by EN 1338 on mechanical resistance and durability. Poon et al (2002) replaced fine and coarse natural aggregates by recycled aggregates at a level of 25% to 100% and they found that up to 50% replacement had only little effect on the compressive strength of bricks and blocks, but above this value the compressive strength starts to lag behind. Poon and Lam (2008), reported that in order to make use of recycled materials to produce eco-friendly concrete blocks with good quality by using 100% recycled materials as aggregates; authors succeeded to obtain these products by using 50% recycled crushed glass (RCG).
and 50% recycled crushed aggregate (RCA) together with an aggregates/cement (A/C) ratio of 4 or below. Debied and Kenai (2008) investigated the possibility to reuse coarse and fine crushed bricks as aggregate in concrete production, and found that the level of substitution should be limited to 25% and 50% for coarse and fine crushed brick aggregates respectively, in order to obtain minimum of compressive strength of 22 MPa. Poon et al’s (2009) study was based on recycling and assessing the low grade aggregates obtained from a construction waste sorting facility for use in the production of concrete blocks. It was reported that the low grade recycled aggregates obtained from the construction waste sorting facility had the potential to be used as aggregates for making non-structural pre-cast concrete blocks. In addition, the optimal percentage of recycled fine aggregates (RFA) that can be used to replace natural fine aggregates by 50% (Poon et al, 2009). These studies show that much effort has been made to recycle the C&D waste into building material particularly concrete products in different places especially developed countries. However, in developing counties, such as Tanzania, the concrete/masonry rubble is still regarded as waste to be dumped into dumping sites or thrown elsewhere, despite its recycling potential (Hansen, 1992; EU Commission, 2000; Masood et al, 2002). Knowledge for recycling concrete/masonry rubble into building materials is still limited in developing countries like Tanzania that facing limited funds and technologies.

This paper aims at using the recycled aggregates from C&D waste as a material resource for building materials production in Tanzania instead of throwing them away or using the lower applications like, material for pothole and foundation backfilling. The hundred percent (100%) recycled aggregates (both fine and coarse) from C&D waste will be used to replace natural aggregates for production of the innovative concrete blocks, and the extent to which the recycled aggregate can produce concrete blocks with load bearing capacity in Tanzania will be investigated. Innovative concrete blocks are those with load bearing capacity. Load bearing blocks are concrete blocks that meet building material standards and specifications (i.e. TZS 283:2002(E)) in the construction industry, in this case in Tanzania. Fuller’s maximum density theory, according to Raju (2002), will be applied to design mix proportions of using recycled aggregates for concrete block production while natural aggregates will be used as the control purpose.

2. Materials and Methods
This section describes the material sampling procedures and concrete block production processes.

2.1. Materials and Materials sampling
Materials used in this study for production of concrete blocks were concrete/masonry rubble recovered from building construction and demolition sites in Dar es Salaam. Concrete/masonry rubble was crushed to produce aggregates both fine and coarse aggregates for concrete block production. Other materials used include cement (Ordinary Portland Cement), water, and aggregates from natural resources. Natural aggregates were used for control purpose. Unwanted waste portions like metals, wood, plastics, gypsum and papers were removed manually during the crushing and screening process. Stratified random sampling was used to select C&D waste sources in Dar es Salaam city. The Dar es Salaam city is made up of three municipalities; namely Temeke, Kinondoni, and Ilala. In order to get representative data, the C&D waste materials for concrete block production were sampled from all three municipalities. The three municipalities share most of the main building materials sources like quarry for aggregates. Therefore, the quality of recovered waste might not be affected by spatial distribution of the sources of natural materials. However, it was assumed that the demolition waste might be weaker than the construction waste and therefore, demolition needs more attention. For this reason, more samples were collected from demolished waste than from construction waste. These samples comprised: three out of ten from multi-storey; three out of ten samples from single-storey demolished buildings. Others include: two out of ten samples from building construction (i.e. multi- and single storey buildings); and two out of ten samples of coarse and fine aggregates from natural resources (for control). In this paper, the materials used are abbreviated as follows: DM1, DM2, DM3 standing for demolished multi-storey buildings; DS1, DS2 and DS3 for single-storey demolished buildings; while CM and CS stand for multi-storey and single-storey construction buildings,
respectively. In addition, NCA and NFA stand for natural coarse aggregate (gravel) and natural fine (sand) aggregates from natural resource, respectively where used also.

2.2 Material processing and volume reduction for laboratory analysis
The heaps of rubble were manually crushed using hammers to get recycled aggregates. Then, 50 kg of aggregates were sampled from each crushed heap. In order to collect the representative sample, the quartering method was applied as recommended in the standard methods (TZS 58 (Part 1): 1980) and shown in Figure 1 below. Next, the reduced sample (50 kg) was sent to the University of Dar es Salaam (Building Material Laboratory) for testing. In the laboratory, the 50 kg sample was further reduced by a sample divider (Figure 1c) to the required amount of materials for a particular test for example, in grading test: 15 kg of aggregates was required for all aggregates except for sand of which only 2 kg was required.

Figure 1 shows a) rubble crushed into aggregates; b) sample reduction through quartering technique and c) Sample Divider (laboratory scale) technique used.

2.3 Aggregate Characteristics
Recycled aggregates and aggregates from natural resources may differ in terms of quality which may have impact to the quality of the product (Mueller et al, 2008). In order to understand the quality of the recycled aggregates generated in Tanzania, the physical and mechanical properties of the samples were analyzed in the laboratory. The tested parameters were: grading (particle size distribution), crushing strength value, ten percent (10%) fines values, density, water absorption ratio, organic impurities, and pH. All these tests were carried out according to standards methods (TZS 58 (Part 1-3):1980; BS 812 (Part 1-3):1975; BS 882 (Part 3): 1975). Two tests were carried out for each experiment and the results presented were the average of two tests and their results of two pairs were relatively similar to each other.

The aggregate grading results were used for the concrete mix design. In order to produce the concrete block with high strength, the particle size distribution curves should correspond to the ideal curve. The ideal curve was obtained by applying Fuller’s maximum density method. According to Raju (2002), Fuller advocates the maximum density theory which states that the greater the amount of solid particles that can be packed in a given volume of concrete, the higher the strength. The dense packing is facilitated by the fact that holes of the large particles are filled with small particles whose voids in turn are filled with smaller ones and so on till the smallest diameter (Brouwers, 2006). Most of the design codes for normal strength and weight concrete use Fuller’s model (Schoner and Mwita, 1987; Husken, 2010). Since the focus of this paper is to explore whether the recycled aggregates can produce building materials which meet building materials standards in Tanzania, the Fuller model was used to determine the ideal curve. Fuller’s ideal grading curve for maximum compaction is based on the equation 1 below:

\[ p = 100 \left( \frac{d}{D} \right)^{1/2} \]  
(Raju, 2002; Husken, 2010) ..............................................eq. 1

Where: \( P= \text{percentage of material smaller than} \ “d \ (mm)”\)
2.4 Characterizing cement and water to be used
In this study, the OPC (extra) cement was used. The cement which, was used complied with Tanzania Bureau of Standards; Twiga Extra (TZS 727:2002, Cem II/A-L/32.5R). The density and particle size distribution was carried out. The Pycnometer method, which using Micromeritics AccuPyc II 1340 is used for density measurement whereby 12 measurements were carried out, and particle size distribution also was measured by a Masterizer 2000 instrument according to ISO 13320-1:1999. Also, water used for mixing and curing processes was tested in the laboratory.

2.5 Requirements for concrete block production from recycled aggregates in Tanzania
The search for requirements of concrete blocks with load bearing capacity as per Tanzania was first conducted. This was carried out in order to establish the minimum material requirements that have to be met while using recycled aggregates for concrete block production with load bearing capacity. The stakeholders were identified; these includes concrete block manufacturers, contractors and consultants, Tanzania Bureau of Standards (TBS) and research institutions (i.e. University of Dar es Salaam, Ardhi University, and National Housing and Building Research Agency, National Construction Company) and clients which were represented by National Housing Cooperation (NHC). From TBS, the Tanzanian standard for concrete blocks (TZS 283:2002(E)) was purchased. The structured and non-structured questions were used to 58 different building contractors, consultants, and concrete blocks manufacturers/producers. It was learnt that the materials currently used in Tanzania for concrete blocks are extracted from natural sources. So, the use of recycled materials from C&D waste in Tanzania is a new thing and needs attention. Data from field survey were used for planning recycling of concrete/masonry rubble into building materials in Tanzania.

2.6 Building material testing at site in Tanzania
Only about 20% of the building contractors do test the quality of their materials in the laboratory. Most of them do not. About 80% reported that they use simple tests at site. The first method reported being used is lifting up and dropping the concrete block down to the ground. The outcome of the experiment is expected that the block will break into two pieces only if it is strong. But if it disintegrates into more pieces, it is disqualified. The second test is by scratching on the surface of the block by using fingers; if it erodes easily, it is disqualified. The third test is cutting it by using an axe; if it breaks easily, it is disqualified. But, these methods depend on the person’s energy and power as well as whether the surface where the blocks fall either is soft or hard surface. So, these methods are not reliable for concrete blocks control quality. It indicates that laboratory testing and analysis are required for quality control to ensure the quality of the concrete products produced especially these newly concrete blocks to be developed from recycled C&D waste in Tanzania. The main reasons mentioned why a laboratory is not used for testing were lacked of equipment and limited funds. This implies also that there is lack of enforcement, technical personnel etc. For those who test, they reported that their samples are tested at Tanzania Bureau of Standards (TBS) Laboratory and/or at the University of Dar es salaam Building Materials’ laboratory.

2.7 The Concrete block production processes
The concrete blocks production process starts when materials are acquired and continues until the concrete block has been produced, tested, and found fit for building construction. This section presents different processes that were carried out in this study in order to produce the concrete blocks from recycled aggregates in Tanzania. These include resource inputs, production processes, and product (output) as illustrated in Figure 2 below and in the detailed descriptions that follow.
From Figure 2 above, the terms used were defined as follows:

- **Resource input**
  The resource input includes materials such that concrete and masonry rubble, natural aggregates, water and cement. Other inputs are labour, energy and information. Labour and energy are mostly labour-based (i.e. manual). Information includes structural requirement, age at which strength is required, concrete block specifications, standards and codes of practice. In this study, concrete blocks with load bearing capacity that produced from recycled C&D waste after 28 days of curing are focused. The load bearing capacity in Tanzania can be defined as the concrete blocks with minimum strength of 7 N/mm² (TZS 283:2002(E); Sabai *et al.*, 2011, Jackson and Dhir, 1988).

- **Production process**
  i. **Water-cement** ratio. According to interviews made in Tanzania, the water-cement ratio which is normally used for stiff concrete (i.e. concrete blocks) ranges from 23% to 30% (by weight). Husken (2010) reported that the water-powder ratio for stiff concrete mixtures is 0.35 by weight. Concrete blocks are one of the stiff concrete materials (Koski, 1992). In this study, the water/cement ratio of 0.35 (by weight) was used. The difference from that is normally applied in Tanzania may be caused by the nature of the material used (i.e. recycled aggregates, which are more porous than the natural aggregates).

  ii. In this study, the *aggregates/cement* ratio of 1:9 by volume suggested by Schoner *et al.*, (1987) was used. By applying an analytical method of combining aggregates (Raju, 2002; Schoner and Mwita, 1987), the fine and coarse aggregates fractions were estimated. Out of *nine parts of aggregates*, the fine/coarse aggregates ratios were in the ratio of 5:4. This shows that the cement-aggregates ratio used was 1:5:4 (cement: fine (sand): gravel parts in volume). This ratio is equivalent to 1:4:3.3 parts in weight, respectively. The weights of water, fine, and coarse aggregate in a batch were obtained as the product of 50 kg (1 beg) of cement. On other hand,
according to data collected through field visit conducted in Tanzania (2010), cement to aggregates ratios ranging from 1:7 to 1:14 by volume were found. This shows that the mix design applied in this study was within the Tanzanian practices. However, the mix ratios described were for natural aggregates, while in this study, the same ratios were applied for recycled aggregates. The fine aggregates used were those that passed through 5 mm sieve size and coarse aggregates ranging from 5 mm to 12 mm (Jackson and Dhir, 1988; GTZ, 1991).

iii. Material characterization. Materials such that recycled aggregates, natural aggregates, water, and cement were tested and analyzed in the laboratory as described in previous sections (2.3 & 2.4) above. This paper is limited to physical and mechanical characterization as directed in TZS 58 (part 1-3): 1980, chemical-mineralogical characteristic is beyond the scope of this paper.

iv. After determining mix proportions and the compaction method as well as having the equipments, the conventional production processes of concrete blocks were adopted. These processes include batching, mixing, compacting, moulding, and curing. As shown in Figure 3 below, the manual compaction machine was used to mix materials until the homogenous mixture was obtained. The manual compaction machine was applied because it is cheap and easily to access. It is the method which is commonly used by concrete block producers in Tanzania as shown in Figure 3 below. Of course, the method is weaker compared to the mechanical compaction method. However, it is assumed that if the load bearing concrete blocks are produced by using weaker method that satisfy minimum requirements, it is possible to produce concrete blocks on a large scale by using mechanical and other sophisticated equipment with the same or higher quality concrete block products in future. During compaction process, the mixed materials were compacted firstly, by a wooden handle and subsequently, by a steel machine cover. After moulding, the concrete blocks were covered with a plastic sheet for 24 hours to prevent rapid hardening. After 24 hours, the concrete blocks were cured in water (immersed) for 26 days. Then they were taken out of the water for surface drying for one day before the laboratory testing.

Figure 3 shows mixed materials, compaction technique and moulding machine applied for concrete block production

- **Concrete block product**
  Quality control: After the 28 days of curing, the concrete block specimens were taken to the laboratory at the University of Dar es Salaam for testing. The density, water absorption ratio,
and compressive strength were tested. The analysis was carried out according to the standard methods which are specified in the TZS 283:2002(E) and NEN-EN 772-1:2000. The following is a summary of how the analysis was carried out.

a. Compressive strength test: The concrete block specimen was placed and centered on the platen of a compression testing machine. The compaction machine (MFL Systeme-PRUF UND MESS) with a maximum of 3000 kN was used. The gross area of the loaded surface was length-width i.e. 450x230 (mm) bed face according to TZS 258:2002(E); NEN-EN 772-1:2000. Two soft sheets of plywood were placed under and above the specimen to reduce friction. Poon et al (2009), also applied the same technique on compressive testing. To calculate the compressive strength, equation 2 was used. The compressive strength result reported is an average over five specimens and the results were relatively similar to each other.

\[
CompressiveStrength = \frac{1}{n} \sum_{i=1}^{n} \frac{Failure\ -\ load\ ,\ N}{Area\ of\ base\ face\ (Length \times Width), \ mm^2} \quad \text{...eq. 2}
\]

Mean strength and standard deviation for the 45 concrete block specimens were analyzed. The standard deviation (s) were estimated by using eq. 3 below.

\[
s = \sqrt{\frac{1}{n+1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \quad \text{...eq. 3}
\]

Where:
- \(x_i\) = compressive strength of individual specimen \(i\)
- \(\bar{x}\) = mean of compressive strength of total specimens, \(n\)
- \(n\) = total number of concrete blocks specimens.

b. Density: Concrete block specimens were weighed by SOEHNLE-Wagebereich 0.5 bis 55 kg and the dimensions were measured by veneer caliper with 50 cm and 100 divisions. The density was calculated using equation 4 below. For each sample type, the average of the five 5 specimens was calculated.

\[
Density = \frac{Mass\ (Kg)}{Length \times Width \times Height\ [m^3]} \quad \text{...eq. 4}
\]

c. Water absorption ratio: The wire basket method was used for water absorption analysis for aggregates larger than 10 mm size (TZS 58 (Part 3): 1980). Two specimens each having one-eighth the size of a concrete block (i.e. cut from concrete blocks) was tested. Firstly, they were dried in the oven (105°C) for 24 hours and then cooled at room temperature for about 4 hours. After that, they were immersed in water for another 24 hours. Then, they were dried (surface drying, enhanced by towels - absorbent cloths) and weighed (Mass A). Then, the specimens were immersed in water was placed in wire mesh basket and then weighed by a digital balance. After that, the specimens were placed in the oven at 105°C for 24 hours. Next, they were removed from the oven and cooled in an airtight container and then weighed (Mass D). The water absorption ratio was calculated by using equation 5 and the average results of the two specimens were calculated.

\[
WaterAbsorption = \frac{(A - D)}{D} \times 100\% \quad \text{...eq. 5}
\]

3. Results
3.1. Results of aggregates’ characteristics
The results of the laboratory tests and analysis of both recycled and natural aggregates are presented in Table 1 and Figure 4(a&b) below.
Table 1 presents characteristics of recycled aggregates in Tanzania

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gross density (g/cm³)</th>
<th>Water absorption (%)</th>
<th>pH</th>
<th>Aggregate crushing strength value (%)</th>
<th>Organic impurities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fine</td>
<td>Coarse</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DS1</td>
<td>2.5</td>
<td>2.2</td>
<td>10.3</td>
<td>9.7</td>
<td>58.5</td>
</tr>
<tr>
<td>DS2</td>
<td>2.4</td>
<td>2.2</td>
<td>13.0</td>
<td>8.8</td>
<td>71.5</td>
</tr>
<tr>
<td>DS3</td>
<td>2.5</td>
<td>2.2</td>
<td>8.1</td>
<td>11.0</td>
<td>47.9</td>
</tr>
<tr>
<td>DM1</td>
<td>2.5</td>
<td>2.1</td>
<td>5.6</td>
<td>11.1</td>
<td>38.2</td>
</tr>
<tr>
<td>DM2</td>
<td>2.4</td>
<td>2.2</td>
<td>10.7</td>
<td>8.8</td>
<td>57.8</td>
</tr>
<tr>
<td>DM3</td>
<td>2.5</td>
<td>2.2</td>
<td>7.6</td>
<td>9.4</td>
<td>49.1</td>
</tr>
<tr>
<td>CS</td>
<td>2.5</td>
<td>2.5</td>
<td>9.1</td>
<td>9.6</td>
<td>49.3</td>
</tr>
<tr>
<td>CM</td>
<td>2.4</td>
<td>2.3</td>
<td>6.2</td>
<td>11.5</td>
<td>30.4</td>
</tr>
<tr>
<td>NCA</td>
<td>na</td>
<td>2.4</td>
<td>1.8</td>
<td>8.8</td>
<td>28.6</td>
</tr>
<tr>
<td>NFA</td>
<td>2.5</td>
<td>na</td>
<td>na</td>
<td>8.8</td>
<td>na</td>
</tr>
</tbody>
</table>

*na=not applicable because analysis was either requiring fine or coarse aggregates*

In Figure 4 (a) below, the results show that grading curves of DS1, DS2, CS and DM2 were above the ideal curve. It is indicating that more cement and/or compaction are needed in order to achieve the maximum density, which will result in greater strength of concrete product. The loads applied for ten percent fines value (TFV) were varied from 400 kN, 100 kN, and 50 kN in order to use graphical approach to estimate the TFV. The results of TFV are shown in Figure 4b below. The results from Table 4b shows that the load required to produce 10% fines were out of range for all recycled aggregates except to construction waste delivered form multi-storey buildings (CM) and natural aggregates which showed that 10% fines values were obtained when 130 kN load was applied.

![Grading/Particle Size Distribution](image)

*Figure 4a shows aggregates particle size distribution (grading) results*
3.2. Characteristics of cement and water used for concrete block production

The density and PSD of the OPC were analyzed according to standard methods (ISO 13320) as described in section 2.4 above, the results for 12 measurements were relatively close to each other and the average density was 3.0127 g/ml. The PSD result is presented in Figure 5 below. Also, before commencing concrete blocks production, water was tested and the results are shown in Table 2.

Table 2 shows the characteristics of water used for concrete block production

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Results</th>
<th>TZ standards*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>8.02</td>
<td>9.2</td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm</td>
<td>404</td>
<td>nm</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/l</td>
<td>2.2</td>
<td>nm</td>
</tr>
<tr>
<td>Salinity</td>
<td>ppt</td>
<td>0.2</td>
<td>nm</td>
</tr>
<tr>
<td>Colour</td>
<td>mgPt/l</td>
<td>0.2</td>
<td>50</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>1.27</td>
<td>25</td>
</tr>
<tr>
<td>SO₄</td>
<td>mg/l</td>
<td>14</td>
<td>800</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>mg/l</td>
<td>0.16</td>
<td>2.0</td>
</tr>
<tr>
<td>PO₄</td>
<td>mg/l</td>
<td>0.11</td>
<td>nm</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/l</td>
<td>0.04</td>
<td>1.0</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/l</td>
<td>194</td>
<td>600</td>
</tr>
<tr>
<td>P. alkalinity</td>
<td>mg/l</td>
<td>0</td>
<td>nm</td>
</tr>
<tr>
<td>Total Alkalinity</td>
<td>mg/l</td>
<td>124</td>
<td>nm</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/l</td>
<td>76</td>
<td>100</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>mg/l</td>
<td>157</td>
<td>600</td>
</tr>
</tbody>
</table>

*Source: TZS 789:2003; nm=not mentioned
TZ=Tanzania
3.3 Survey results on concrete block produced in Tanzania

After the aggregate characterization, the concrete mix design was designed for concrete block production. Prior to doing that, the existing mix ratios in Tanzania were investigated, whereby a total of 58 questionnaires were conducted and six research institutions were interviewed. Mixing ratios for blocks production differ from one producer to another depending on various individual factors such as demand of clients, planned selling price and decision of the producer. It stated that one cement bag can produce 26 to 60 concrete blocks depending on the mixing ratio and targeted customers. They always say that the mixing ratio is confidential information as far as trade is concerned. Mixing ratio is established at site, depending on experience, just by counting the number of shovel/spade full of the required material or basin “karai” or buckets or wheel barrows. The mixing ratios applied according to field survey between cement–aggregate ratios: range from 1:7-1:14 by volume. Furthermore, the compressive strength produced also ranges from 2.1 - 11.6 N/mm² (MPa). According to Tanzanian standards (TZS 283:2002 (E)), the recommended compressive strength ranges from 3.5 - 21 N/mm². Even though not categorized based on load bearing and non-load bearing compressive strength, the contractors and consultants who were interviewed indicated that they categorize concrete blocks with load bearing block as the ones which have a minimum compressive strength of 7 N/mm². This value is reported also by Jackson and Dhir (1988) and Poon et al (2002). And concrete blocks with compressive strength below 7 MPa are mostly used for single storey low cost houses in Tanzania. Since in Tanzania, materials for concrete blocks production is extracted from natural resources; the lower compressive strength obtained i.e. 2.1 MPa was contributed by high mixing ratio used i.e. 50 kg of cement for 60 concrete blocks.

3.4 Results for concrete block produced from 100% recycled C&D waste

The concrete blocks were produced by using both fine and coarse aggregates from the same sample of recycled aggregates except for natural aggregates where sand and gravel were used together as normally done in Tanzania. After 28 days of controlled conditions of curing, the concrete blocks were taken to the laboratory for testing. The compressive strength, water absorption ratio, and density were measured and the results are shown in Figure 6. The results showed that the compressive strength of recycled aggregates range from 5.2 to 10.4 N/mm² but was 14.2 N/mm² for natural aggregates. Moreover, the mean compressive strength of 8.8 N/mm² and standard deviation of 2.1 N/mm² was obtained for concrete block specimens produced from recycled aggregates. While mean compressive strength of 9.4 N/mm² and standard deviation of 2.6 N/mm² were obtained from concrete block specimens produced from recycled aggregates and natural aggregates. This shows that minimum strength was 6.7 N/mm² and 6.8 N/mm² for those concrete blocks produced recycled aggregates only and those from recycled and natural aggregates respectively. The results indicating that all samples have compressive strength higher than 3.5 N/mm² according to TZS 283:2002(E) but, only 85% of specimens is achieved the 7 N/mm² (for load bearing capacity in Tanzania).
Figure 6 show the results for the concrete blocks produced from recycled aggregates in Tanzania

4. Discussion
This section describing detailed discussion of aggregates and concrete blocks products produced from recycled aggregates.

4.1. Aggregates quality
Results for aggregate characteristics are presented in Table 1 and Figure 4a&b in Section 3.1. These indicate that the recycled aggregates were less dense than natural aggregates. In addition, the fine aggregates were denser than coarse aggregates for both recycled and natural aggregates. However, the grading results in Figure 4a, show that curves for CM, DM1, DM3, DS3, and natural aggregates (NCA) comply with Fuller’s ideal curve; on other hand, the DS1, DS2, CS, and DM2 grading curves did not. These results suggest that the use of more fines aggregates and high compaction mechanism may be needed for the DS1, DS2, CS, and DM2 samples in order to produce the concrete blocks with high strength. The concept for using more fine to fill voids of coarse aggregates in production of concrete with high strength is agreed with particle packing concepts in paving block production as reported in Husken (2010).

The results of aggregates crushing values (ACV) as presented in Table 1 showed ACV for recycled aggregates range from 30.4% up to 71.5% compared to natural aggregate ACV is 28.6%. According to TZS 58 (Part 2):1980, the recommended the aggregate crushing value for aggregates to be used for concrete is 45% while for wearing surfaces it is 30%. This indicates that no recycled aggregates qualify to be used for wearing surfaces except natural aggregate with crushing strength value of 28.6%. Only DM1 and CM with crushing strength values of 38.2% and 30.4%, respectively that meets the specification which is required for concrete for all recycled aggregates. This indicates that about 75% of the recycled aggregates samples failed to achieve the recommended standards (TZS 58 (Part 2):1980). Poon et al (2002), reported that the recycled aggregates crushing strength value in Hong Kong range from 21.6% - 24.5%. This showed that recycled aggregates from Hong Kong are stronger than those from Tanzania, and their recycling techniques might vary depending on initial quality of the recovered waste to be recycled. This condition suggests that it is impractical to directly transfer outcomes from developing countries to developing countries like Tanzania.

In addition, the ten percent fines values (TFV) were tested and the results are presented in Figure 4(b). The results show that the TFV for CM and NCA are obtained by applying 130 kN. The rest of the recycled aggregates, the results showed that the TFV is out of range even though, the graphs of
percentage of material passing at 2.36 mm sieve size versus load applied gave high value to the correlation coefficient \((R^2)\) which were greater than 93%. Unlike Poon \textit{et al} (2002) and Poon \textit{et al} (2009) who indicated that the TFV of recycled aggregates range from 72 - 145.1 kN, in this study, the TFV obtained from recycled aggregates from construction waste, and the rest of the recycled aggregates was out of range. The TFV results indicate that the recycled aggregates from demolition (i.e. \textit{DSS} & \textit{DMS}) waste and construction waste from single storey building (\textit{CS}) in Tanzania are very weak. This condition may be caused by low cement content applied in the old concrete rubble or because rubble was dominated mostly by mortar materials.

The water absorption ratio results (Table 1) ranged from 6.2 to 13% of the recycled aggregates while for natural aggregate it was 1.8%. The results suggest that the recycled aggregates were porous about 7 (700%) times more than natural aggregates. Our results are generally in agreement even relatively higher with previous studies conducted in Hong Kong where it was reported that water absorption for recycled coarse aggregates range from 4.2 to 7.6% (Poon \textit{et al}, 2002; Poon \textit{et al}, 2009). This could be caused by the presence of the cement paste/mortar attached to the crushed recycled aggregates.

The pH of both recycled and natural aggregates were above 7. This reveals that all aggregates are basic in nature. However, the pH of the recycled aggregates from construction waste (\textit{CM}) had higher pH value than the others. This could be attributed to the nature of its origin. For example, the aggregates recovered from CM originated from granite rock while the rest were limestone (calcium carbonate). Since limestone is composed of carbonates its pH may be lowered when it gets in contact with water.

The results for organic impurities that are presented in Table 1 indicated that almost all recycled aggregates are polluted except the recycled aggregates from construction waste (\textit{CM}) and natural sand (\textit{NFA}). The unpolluted CM sample may be attributed to the fact that the CM sample was mostly composed of residual concrete and broken blocks while other recycled aggregates were sampled and sorted from mixed debris. This indicates that re-utilization of C&D waste as a material input for concrete blocks production will reduce not only the building materials shortage but also the environmental burden to dispose of this polluted material waste and hence to achieve sustainable construction in Tanzania.

From the recycled aggregates quality discussed parameters above, revealed that the recycled aggregates are weaker and less dense than natural aggregates. These conditions are likely to affect the quality of the concrete block to be produced out of them. Also, high percentage of water absorption suggests that the recycled materials composed mostly of cement paste materials i.e. mortar (sand-cement) rather than stone materials. Furthermore, results showed recycled aggregates are contaminated which, further study is required to establish if it’s their contamination have impact on the recycled concrete block product.

### 4.2. Concrete blocks from recycled C&D waste

The results of the concrete blocks presented in Figure 6, showed that the denser concrete blocks (with high density value) are the higher the value of compressive strength. For example, concrete blocks with densities more than 1900 kg/m\(^3\) have a compressive strength of more than 7 N/mm\(^2\) while for DS3 that had a lower density value than others, has a lower compressive strength (5.2 N/mm\(^2\)). These results are generally in agreement with Fuller’s theory that the higher the density, the higher the strength (Raju, 2002). However, the compressive strength of DS3 results is challenging because the results of aggregates grading was corresponding to the ideal curve. And ACV showed that it had lower value (49.1%) compared to DS1 (58.5%); DS2 (71.5%), DM2 (57.8%), and CS (49.3%). This outcome may be affected by the compaction technique (manual) which was used because the water absorption ratios showed that DS3 had a higher value of 15.1% compared to for example that of the CS (8.6%), DM2 (8.8%), DS1 (12.3%). Since it was manual work, may be a worker was tired at the end of the day, or there were chemical contaminations that may have effect to the hydration process.

13
Furthermore, the compressive strength results portray that there is a possibility to recycle the concrete and masonry rubble into building materials because approximately, 85% of concrete blocks specimens tested in the laboratory are attained compressive strength of more than 7 N/mm$^2$. The re-utilization of masonry rubble into building materials could help to solve the problems of solid waste disposal in Tanzania, and also to become an alternative resource for production of new building materials and therefore, contribute to conserve natural resources, increase employment and improve economic of people and nation at large.

5. Conclusion
The aim of this paper was to investigate the extent to which the recycled aggregates from C&D waste can be used to replace natural aggregates from concrete block production in Tanzania rather than dumping them into dumping sites, throwing them away, or utilizing them for less useful purposes for example, pothole and foundation backfilling. By this replacement and reuse of recycled aggregates, the aim is not only to reduce down-cycling but also to solve the rising problem of material shortages. In this research, the recycled aggregates for both fine and coarse replace natural aggregates by 100% in the concrete blocks production. Aggregates were tested to understand their physical and mechanical characteristics, and the results were subsequently applied in design mix in concrete block production. The concrete blocks with dimensions 450 mm in length, 230 mm in width and 150 mm in height were produced by using both recycled aggregates and aggregates from natural resources for control purpose. A hand machine was used for compacting and molding. After 28 days of curing, the concrete blocks were tested in the laboratory. The tests included compressive strength, water absorption ratio and density.

The results of aggregates showed that the recycled aggregates were weaker in strength compared to natural aggregates. Furthermore, the recycled aggregates in Tanzania were weaker compared to those from Hong Kong as reported by Poon et al (2002); Poon et al (2009). The poor (weaker) condition of recycled aggregates in Tanzania compared to those from Hong Kong suggests that the cement content of the old concrete waste was poor as well.

Also, the results showed that the blocks produced with recycled aggregates by 100% replacement were weaker than those with natural aggregates. However, the current results show the possibility of recycling the construction and demolition (C&D) waste into building materials because 85% of tested concrete blocks produced from recycled aggregates, have achieved 7 N/mm$^2$ as a minimum strength for load bearing capacity in Tanzania. Therefore, the masonry rubble could be a potential resource for building materials production for sustainable construction in Tanzania rather than throw them away or dump in the dumping site. Further work should focus on the study of chemical–mineralogical composition, contamination, and on economic feasibility for production of concrete blocks with recycled aggregates in Tanzania.

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