Investigation on the Appropriateness of Ceramic Waste Materials at Hawassa Ceramics Factory as Partial Replacement of Conventional Aggregate in Concrete Making

Henok Tsegaye Tadesse
Water supply and Environmental Engineering, Institute of Technology, Hawassa University, Hawassa, ETHIOPIA
E-mail: henokhawassa@gmail.com

Abstract. Conservation of natural assets and environment is the core of any development. Nowadays, the waste material disposal is the major problem for the development of any technology and industry. As a researcher found that the constructive waste materials are appropriate for the production of concrete, this brings down the cost of concrete and protected disposal of waste materials can be easily achieved. In ceramic industry factories around 30% to 50% of production goes as waste material, which is not recycled. So in this research paper, a laboratory investigation has been conducted to evaluate the suitability of ceramic waste material at Hawassa Ceramics Factory at Hawassa as the major partial replacement of conventional aggregates in concrete making. In the laboratory, both fine and course aggregates are partially replaced by the ceramic scrap. In the case of fine aggregate substitution, 50% of the fine aggregate was replaced, and in the case of coarse aggregate substitution, 33.3% of the course aggregate was replaced. Totally, there were 6 concrete cubes samples casted for both type of aggregate and laboratory test for compressive strength conducted after a curing period of 3 and 7 days. The effectiveness of the partial replacement of both fine and course aggregates of ceramic waste by 50% and 30% discussed in the research study.

Keywords: Ceramic waste materials, Ceramic quality, Compressive strength, Ceramic tiles, Aggregate replacement

1. Introduction

1.1. Background Information

Concrete is one of the most universally used building materials in the world. Fundamentally, concrete consists of three major components: cement, water and aggregates. Both fine and coarse aggregates occupy 65-75% by volume of concrete and are important ingredients to carry major load in concrete production [1] [4].

Depending on their sources, aggregates can be obtained naturally as well as artificially. Natural aggregates are acquired from quarries by processing crushed rocks and from riverbeds while artificial aggregates are acquired from industries by products such as blast furnace slag. Rapid industrial development causes severe problems all over the world such as depletion of natural aggregates [3][6]. This problem overcomes by the utilization of the waste materials for construction from different industry. The ceramic waste materials are disposed from ceramic factories in a land fill and it contact with ground water, sand causes toxic effects [8]. The
reduction of cost and negative environmental impact can be achieved by the application of crushed ceramics aggregate concrete, produced by aggregate replacing method [2] [5].

1.2. Overview of the Availability of Coarse Aggregate in and around Hawassa Town

Hawassa town has showed rapid development and growth in all societal, financial, political and enriching spheres. Notable investment facility in construction industries, major roads, schooling, housing, tourist resorts and additional marketing infrastructures and services have been carry out in recent years and much more are in the development, currently. As the concrete consumption is directly related to the economic growth of a town, the demand for concrete in Hawassa Town is growing proportionally. The demand of concrete requirement is the direct association with the demand of both fine and course aggregate. There are more than 20 crushing plants in Hawassa owned by privates and governmental body which uses the same quarry source, Monopol Quarry, located at 5 km(South) from Hawassa. The following table 1 shows the current average purchasing cost of fine and coarse aggregate in Hawassa town.

Table 1. Average purchasing cost per m³ of fine and coarse aggregate in Hawassa town

| Description   | Purchasing Cost/m³ (Eth. Birr) | Remark                   |
|---------------|--------------------------------|--------------------------|
| 00 Aggregate  | 600                            | from 0~6mm size          |
| 01 Aggregate  | 450                            | from 6~13mm size         |
| 02 Aggregate  | 350                            | from 13~19.5mm size      |
| 03 Aggregate  | 300                            | from 19.5~37.5mm size    |
| River Sand    | 240                            | sand                     |

1.3. Overview of Hawassa Ceramics Factory

1.3.1. Year of Establishment
Hawassa ceramic factory is established by the Ethiopian government with the purpose of manufacturing ceramic products and began its operation at 1995EC. Since; 2011 the Factory is owned by the private company named “Althet” Plc.

1.3.2. Product Range of the Factory
The range of Hawassa ceramic Factory products include:-
- Sanitary Wares (WC, Hand wash Basin, Soap and tissue holder)
- Ceramic Wall tile (Size 15x15x6mm)
- Table ware and Insulators

The above listed products shown in the table 2 and 3 manufactured from locally available raw materials having different physical and chemical properties as described in the following table are brought together with the required proportion and passes different processes in respective plant starting from preparation of raw materials and blending, forming of a desired shape, drying and firing of the piece, selecting, decorating and packaging [9,10].
Table 2. Factory Product Range and Raw Materials Used

| Raw Materials Used   | Sanitary Ware | Table Ware and Insulator | Wall Ceramic tile (6mm thick) |
|---------------------|---------------|--------------------------|-------------------------------|
| Body                | Quartz/Silica Sand | Quartz | Quartz/Silica Sand |
| Feldspar            | Feldspar      | Feldspar      | Feldspar      |
| Kaolin              | Kaolin        | Kaolin        | Kaolin        |
| Ball Clay           | Ball Clay     | Ball Clay     | Ball Clay     |
| Glaze               | Glaze         | Glaze         | Glaze         |
| Quartz              | Quartz        | Quartz        | Quartz        |
| Feldspar            | Feldspar      | Feldspar      | Feldspar      |
| Limestone           | Limestone     | Limestone     | Limestone     |
| Kaolin              | Kaolin        | Kaolin        | Kaolin        |
| Frit Glaze          | Frit Glaze    | Frit Glaze    | Frit Glaze    |
| Glaze binder        | Glaze binder  | Glaze binder  | Glaze binder  |

Table 3. Mineral composition of Raw Materials

| % by weight | Quartz | Feldspar | Kaolin | Mugher Clay | Harar Clay | Limestone |
|-------------|--------|---------|-------|-------------|------------|----------|
| SiO₂        | 99.8   | 64.02   | 46.30 | 66.85       | 63.30      | 5.32     |
| Al₂O₃       | 0.08   | 18.90   | 38.20 | 19.05       | 19.68      | 0.74     |
| Fe₂O₃       | 0.01   | 0.07    | 0.94  | 5.72        | 3.00       | 0.86     |
| TiO₂        | 0.01   | 0.01    | 0.06  | 1.41        | 0.05       | -        |
| MgO         | 0.02   | 0.21    | 0.15  | -           | 1.10       | 0.64     |
| CaO         | 0.01   | 0.02    | 0.08  | 1.95        | 0.01       | 51.46    |
| Na₂O        | 0.03   | 1.24    | 0.05  | 3.01        | 0.30       | 0.12     |
| K₂O         | 0.01   | 12.80   | 0.37  | -           | 3.80       | 0.04     |
| MnO         | -      | 0.03    | -     | -           | -          | 0.04     |
| P₂O₅        | -      | 0.22    | 0.04  | -           | 0.04       | 0.12     |
| BaO         | -      | 0.01    | 0.01  | -           | -          | -        |
| Rb₂O₄       | -      | 0.88    | -     | -           | -          | -        |
| SrO         | -      | -       | 0.01  | -           | -          | -        |
| Others (L.O.I.) | 0.14   | 0.95    | 13.80 | 8.40        | 6.45       | 40.70    |
1.3.3. Production Capacity of the Factory

Table 4. Production Capacity of the Factory

| No | Plant Type                 | Annual Design Production Capacity (ton) | Annual Total Designed Production Capacity (ton) | Actual Production Capacity (ton) |
|----|----------------------------|----------------------------------------|-----------------------------------------------|---------------------------------|
| 1  | Wall tile plant            | 3,000                                  |                                               | 65-70% of designed capacity    |
| 2  | Sanitary ware plant        | 1,000                                  | 6,000                                         | (3,900-4,200)                   |
| 3  | Table ware and Insulation plant | 2,000                                  |                                               |                                 |

1.3.4. Amount of Waste Generated at the factory

Table 5. Amount of Waste Generated at the factory

| No. | Plant Type                 | Designed Wastage (%/ton) | Total Average annual design wastage (%/ ton) | Total Average annual actual wastage (% / ton) |
|-----|----------------------------|--------------------------|---------------------------------------------|----------------------------------------------|
| 1   | Wall tile plant            | 10/300                   |                                             |                                              |
| 2   | Sanitary ware plant        | 10/100                   | 10/600                                      | 13/780                                       |
| 3   | Table ware and Insulation plant | 10/200                 |                                             |                                              |

The above table indicates the ceramic scrap generated from respective products which are found not suitable for recycling constitutes the whole wastage deposits with in the factory compound which is found to be occupying the available free spaces proposed for different factory operation results and has a significantly impact on the activity of the factory and on the environment[11].

The estimated ceramic waste generated and deposited in the factory compound since factory begins operation assuming that the annual production status were similar is around = 14,040 ton (12,997.35m³)

The ceramic waste deposit and crushed ceramic in the compound of Hawassa ceramic factory are presented by the following figures 1, 2 and 3.
2. Materials and Experimental Procedures

2.1. Material characterization

2.1.1. Cement

The binding material called cement used in all mixtures was commercially obtainable ordinary Portland cement of 42.5 class manufactured by “Derba” cement Factory belongs to ES 1176 was worn in this study. The specific gravity of the binding material was 3.15. According to ES 1176-3, the initial setting time were found as greater than 60 minutes.
2.1.2. Fine aggregates

For fine aggregate, locally available river sand was used and it passed through 4.75mm sieve. The specific gravity and fineness modulus of sand is 2.32 and 2.58. The worth of 1,270 Kg/m$^3$ and 1,351 Kg/m$^3$ are the loose and compacted bulk density values obtained from the laboratory test and a water absorption is 5.38%. The above stated data’s are obtained from records of mix design undertaken for the same sand source under MIDROC construction PLC for the project the company currently engaged in the construction for Hawassa University. The source of the sand used in the experiment is from “Alaba” sand quarry site.

2.1.3. Coarse aggregates

From a local quarry, the Coarse aggregates are obtained called Monopole Quarry. The maximum size of coarse aggregate was 20mm having a specific gravity 2.45 and water absorption of 1.15%. The loose and compacted bulk density achieved and is equal to 1403Kg/m$^3$ and 1443 Kg/m$^3$ respectively. The above data’s are also found from pervious mix design carried out by MIDROC for the same purpose. The parent rock used is Basalt.

2.1.4. Ceramic wastes

Crushed ceramic wastes are obtained from the disposal area of Hawassa Ceramic Factory. The maximum crushed ceramic waste passing through sieve 20mm and considered as (02 locally designated) and crushed ceramic waste (01 & 00 local designation) passing through sieve 13mm are considered as finer ceramic waste. The specific gravity of ceramic scraps is 2.20 (as per the information obtained from the factory). The loose and compacted bulk densities are obtained from the laboratory test result was 1106Kg/m$^3$ and 1158Kg/m$^3$ respectively.

2.2. Concrete Mixture Proportions

Two conventional mixes with different composition were used in these preliminary tests. C-25 grade of concrete implemented for the investigation and the mix proportion of (1:2:3) using box size of 40x50x18cm.

Table 6. Ingredients Proportion while replacing the coarse aggregate

| Mix 1: Cement (1) | Ingredients | Mix 2: Cement (1) | Ingredients |
|------------------|-------------|------------------|-------------|
|                  | Fine Aggregate (2) | Coarse Aggregate (3) | Fine Aggregate (2) | Coarse Aggregate (3) |
|                  | Natural river sand | Natural crushed (2) | Crushed Ceramic (1) | Natural Sand (1) | Crushed Ceramic (1) | Coarse Aggregate (3) (Natural crushed aggregate) |
2.3. Mixing Procedure
The amount of the constituents of the concrete was acquired from the technical specification and method of measurement prepared by BATCODA. The strength variation of hardened concrete using ceramic scrap as partial substitute is investigated by casting of cubes. The concrete was made in the laboratory using hand mix. To obtain uniform color, the cement, fine aggregate, coarse aggregate and ceramic scrap were first mixed in waterless state and designed amount of water attained from the workability test was further added and the entire concrete was mixed in wet state. In the meantime the casting moulds are screwed strongly to avoid leakage. The mixed concrete was decanted into 150mmX150mmX150mm size moulds in three layers and the compaction was achieved by poking of tamping rod[12]. After 24 hours, the casted specimens were detached from moulds and the same detached specimens were engrossed in a clean water tank. After the completion of the curing of specimens for 3 days and 7 days of period, the specimens were taken from the water tank and permitted to dry under shadow and then the specimens were transferred to the laboratory for the compression strength test and the results are compared with the result of the conventional or control concrete mix (previously conducted by MIDROC).

The proportion of mixes by weight in respective ingredients is in table 7:-

**Table 7. Details of Mix designations and specimens**

| Proportions of Ingredients for Mix 1 (M-1) | Proportions of Ingredients for Mix 2 (M-2) |
|------------------------------------------|------------------------------------------|
| Cement (kg) | Water (Kg) | W/C Ratio | Fine Aggregate (Natural sand) (kg) | Coarse Aggregate (1035kg/m^3) | No. of Specimen |
| 14.4 | 6.18 | 0.43 | 27.4 | 27.6 | 13.8 | 6 |
| 14.4 | 6.48 | 0.45 | 41.4 | 13.7 | 13.7 | 6 |

2.4. Tests

2.4.1. Properties of Fresh Concrete
lump test was conducted for each batch of concrete to check their workability. To perform this test, a unique apparatus called slump cone with an combined arrangement of mould, frustum and flat base plate was used. Each bunch of concrete was compacted using tamping rod of 16mm diameter into the mould in three equal layers giving 25 tamps per layer. Top exterior is stroked off and completed with trowel. Then the mould was lifted upright and the concrete was permitted to slump shown in figure 4.
Figure 4. Slump Test for M-1 Mix and M-2 mix respectively

2.4.2. Properties of Hardened Concrete

There are cubes of 150mmX150mmX150mm size were tested in the laboratory for each bunch of concrete to calculate the compressive strength of concrete is shown in figure 5.

Figure 5. Concrete Mixing and Cube preparation

3. Results and Discussions

3.1. Workability

The dissimilarity in height among the molded and slumped condition was calculated and recorded. The results are tabulated below in table 8.
Table 8. Slump Test Results

| S No. | Mix Designation | Height Difference (mm) | Remark        |
|-------|----------------|------------------------|---------------|
| 1     | M-1            | 8                      |               |
| 2     | M-2            | 0                      |               |
| 3     | Conventional   | 20                     | Control test  |

3.2. Hardened Concrete compressive Strength

Table 9. Average compressive strength of hardened concrete in respective mix for 3 and 7 days respectively

| Test No | Mix Designation | W/C ratio | Average compressive strength of hardened concrete |
|---------|----------------|-----------|-----------------------------------------------|
|         |                |           | 3 day (Max. load (KN), Stress (N/mm²)) | 7 day (Max. load (KN), Stress (N/mm²)) |
| 1       | M-1            | 0.43      | 430.93 (19.15) | 543.6 (24.16) |
| 2       | M-2            | 0.45      | 661.8 (29.41)  | 701.77 (31.19)|
| 3       | Control Mix    | 0.52      | 453.43 (20.15) | 476.2 (21.16)|

3.3. Cost Comparison

- Cost of Conventional Aggregates at Hawassa
  Fine Aggregate = 240 birr/m³
  Coarse Aggregate = 350 birr/m³
- Estimated cost of Crushed Ceramic Waste = 95.76 birr/m³
- At 30% substitution of conventional coarse aggregate by crushed ceramic waste material,
  30% (95.76) + 70% (350) = 273.73 br
  Hence, cost of coarse aggregate will decrease by 21.79%
- At 50% replacement of conventional fine aggregate by crushed ceramic waste,
  50% (95.76) + 50% (240) = 172.88 br
  Hence, cost of fine aggregate (sand) will decrease by 30%
4. Conclusions and Recommendations

Source of quarries in and around Hawassa town for aggregate production are vanishing due to rapid infrastructure development in Hawassa and their exhaustive utilization therein. On the other part, the Hawassa Ceramic Factory, in the course of production, releases significant amount of ceramic wastes and the executives are worrying about disposal area of the upcoming wastes because the land in the compound is occupied by the already produced wastes.

The purpose for the research is to use the ceramic wastes disposed from Hawassa Ceramic Factory partial as a replacement of fine and coarse aggregate in concrete casting. The make use of ceramic scraps in concrete has helpful effects on the surroundings and gaining lower costs. From the above examination conceded out, the ceramic scrap from Hawassa ceramic factory can be used as partial replacement of fine and coarse aggregate. The fine aggregate was replaced up to 50% and the coarse aggregate up to 33.3% of ceramic waste. The following are the conclusions obtained after performing the above experiments.

- As we have observed above, in the application of ceramic waste material as the partial replacement of coarse aggregate, no additional cost is incurred. Therefore, using ceramic waste material as the partial replacement of conventional course aggregate has economic significance.
- On top of the awareness about its significant role in the conservation of the diminished natural aggregate resources, the factory executives will stop worrying about disposal area since it has a role in the reduction of the space required for land fill disposal.
- Better results would be obtained if more test inclusive of different combination including from complete replacement of coarse aggregate as well as the fine aggregate to partial replacement in concrete.
- Since the natural materials for making of concrete are depleted from time to time and increasing
huge demand; paves the way to recommend to use and search for other industrial wastes which may be suitable for making of concrete.

- It has been shown in this paper that ceramic waste materials can be used as a partial replacement for conventional coarse aggregate with regards to technical and environmental benefit; and the owner of the factory should give due attention to utilize and use the opportunity.
- Further tests should be undertaken to assess the detail chemical composition and resistance to different environmental and chemical attacks for better utilization of the waste.

References

[1] Steven HK, Beatrix K and William CP 2003 Design and Control of Concrete Mixtures, Fourteenth Edition International Journal of Engineering and Advanced Technology Vol. 2 Issue 1.

[2] Sekar T 2011 Studies on Strength Characteristics on Utilization of Waste Materials as Course Aggregate in Concrete International Journal of Engineering Science and Technology Vol. 3 No. 7.

[3] Bahoria BV, Parbat DK and Naganaik PB 2013 Replacement of Natural Sand in Concrete by Waste Products: A State of Art Journal of Environmental Research and Development Vol. 7 No. 4A.

[4] Dhavamani DS and Gobinath D 2013 Chemical Resistance of Concrete with Ceramic Waste Aggregate International Journal of Current Engineering and Technology Vol.3, No.3.

[5] Veer Singh Ceramics: Manufacturing, Properties and Applications Vani ITM, Department of Applied Science and Humanities 31-34.

[6] Mohd Mustafa Al Bakri A, Norazian MN, Kamarudin H and Che Mohd Ruzaidi G 2008 The Potential Of Recycled Ceramic Waste As Coarse Aggregates For Concrete Malaysian Universities Conferences on Engineering and Technology.

[7] V.S. Sethuraman, L.K. Rex, D.S.Vijayan, A.P. Aroumugame, A.Vallavan, “Study on Utilization of Burr Wastes as Micro-Reinforcements in Concrete to Overcome Disposal of Hazardous Materials in Environment”, Journal of Green Engineering (JGE), Volume-10, Issue-8, August 2020, Page No: 4353-4364.

[8] D.S.Vijayan, C.Nivetha, P.Dinesh Kumar, B.Saravanan, V.Gogulnath, “Green Composite Form of Eco-Friendly Concrete by Adding PVA Fiber”, Journal of Green Engineering (JGE), Volume-10, Issue-6, June 2020.

[9] S.Aravindan, D.S.Vijayan, K.Naveen Kumar, B.Saravanan, Characteristic Study of Concrete by Replacing Glass Cullet and Ceramic Tiles over Conventional Aggregates, INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH, VOLUME 8, ISSUE 10, OCTOBER 2019, Page no – 1802 – 1805.

[10] P. Subathra et.al, “Experimental investigation on concrete with marble dust and steel fiber”, AIP Conference Proceedings 2271, 030016 (2020); https://doi.org/10.1063/5.0024779

[11] R. Sanjay Kumar et al, “Effect of silica fume on strength of glass fiber incorporated concrete”, AIP Conference Proceedings 2271, 030020 (2020); https://doi.org/10.1063/5.0024775

[12] M. Kalpana, D. S. Vijayan and S. R. Benin, Performance study about ductility behavior in electronic waste concrete, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.07.049