



## **AN OVERVIEW OF THE RECYCLED WASTE MATERIAL USED AS REPLACEMENTS OF AGGREGATES IN CONCRETE**

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**Abstract:** Solid waste material has been a major concern around the world due to its negative impact on the environment. Over years, there has been a dramatic increase in the amount of solid wastes stored in disposal sites. In an attempt of minimizing the negative impacts of industrial wastes on the environment, many research have been conducted on the effect of these wastes when incorporated in concrete. The majority of the research in this area focused on the partial replacement of cement with these wastes. However, other studies investigated the replacement of fine and coarse aggregates with these wastes. This Paper presents a comprehensive summary for previous studies that focused on the partial replacement of aggregates in concrete with different industrial waste. The paper addresses the findings of these studies in an attempt of assisting future researchers identify useful alternative substitutes for concrete aggregates that enhance its characteristics and contribute to preserving the environment.

### **1 INTRODUCTION**

The construction industry is one of the most demanding and most rapidly expanding industries in the world, as result of the urban expansion, rapid population growth, industrialization and the need to improve the standards of living. This leads to the consumption of humongous amounts of materials, either to create new materials or directly use them for construction. Concrete due its strength to bear large compression loads was determined to be the most effective building material. In the last decade, concrete production has increased from 3,310 million tons to 4,200 million tons annually; and this number is subject to an annual increase. The manufacturing of Portland Cement, which is the main hydraulic binder used for concrete is responsible for huge emission of CO<sub>2</sub> gas that is a main cause of the greenhouse effect. Currently, there are several approaches that can be used to reduce cement consumption. One method is to minimize the concrete cross sections of the load carrying members in the structural designs. Another approach is to substitute portions of the cements needed for manufacturing of concrete with waste materials that have comparable properties to that of cement, such as fly ash. Using recycled wastes as a substitute or replacement for a specific components in concrete has become a great alternative to aid in overcoming pollution and decrease waste. Recycled wastes are analyzed and those that have similar properties as cement, fine aggregates, or coarse aggregate are chosen as replacements for traditional components of concrete. In turn, this reduces the overall cost and pollution in order to produce an efficient material which could be a suitable substitution. This paper presents a comprehensive review of all the studies that focused on the utilization of waste materials as a substitute for portions of the concrete aggregates. done on materials suitable for cement replacement.

## **2 PROBLEM STATEMENT AND OBJECTIVES**

Several studies have been conducted to assess the effect of using waste materials on the properties of concrete when used as partial replacements of aggregates. However, there is not a single paper that provides a comprehensive review of all the work that has been performed. As such, there is a need for a study that succinctly summarize previous studies that investigated effects of utilizing waste material in concrete as a partial replacement of aggregates. This paper sheds the light on previous research attempts in this area. This study presents a concise description of each of the previous studies and highlights the most important findings.

## **3 METHODOLOGY**

The methodology used in this research consists of two main steps. The work started by collecting scholarly articles that addressed previous experiments conducted on the utilization of waste materials in lieu of portions of the aggregates in the concrete mix. The collected papers were classified based on the aggregate type that was replaced in the study. As such, previous studies have been grouped into two categories: fine aggregates and coarse aggregates.

## **4 WASTE MATERIALS IN CONCRETE**

The main objective of all the studies compiled was to explore alternative venues to dispose industrial wastes by utilizing them in concrete in the hope of enhancing or at least maintaining the normal level of the concrete quality. Many studies revolved around substituting either the coarse aggregate or fine aggregate in concrete. The different sizes, shapes and chemical composition of the aggregate have direct impacts not only on the strength and durability of the concrete which may be an engineers' main concern but also on the workability and weight of the concrete. The different aggregates chosen to use in a specific mix also play a huge role in the appearance of the surface being poured.

The materials that were used to substitute fine aggregates in concrete were: waste foundry sand, bottom ash, plastics, crushed glass, waste glass, waste marble aggregates, waste iron, Class F fly ash, scale and steel chips, concrete metallic chips, copper slag, fine crushed bricks, waste tire steel beads, and steel slag. For the replacement of coarse aggregate, the materials used were, coarse rigid polyurethane foam waste, rubber tire particles, crushed concrete, rubber tire waste, oil palm shells, ground coarse fly ash, recycled concrete, and ceramic industry waste.

The majority of the studies focused mainly on the effect of incorporating these wastes in concrete; however, some studies considered other properties of concrete such as tensile and flexural strengths as well as the ability for the concrete mixes to shield radiation.

## **5 FINE AGGREGATES**

The review of the literature shows that there are seven studies that have been conducted to evaluate the quality of concretes made with waste material used as partial replacement of fine aggregates. The main measure of quality used in these studies was the concrete compressive strength.

Siddique (2003) used Class-C fly ash to partially replace fine aggregate in concrete. Class-C fly ash was used in the increments of 10%, 20%, 30%, 40% and 50% as a replacement of sand in the concrete mix. Cube specimens (150 mm) were casted for compressive strength testing in this study. The concrete was cured for 7, 28, 91, and 365 days. The compressive strength of concrete increased with the increasing the percentage of the Class-C fly used as a replacement of the fine aggregate in the concrete mix (Siddique, 2003).

Aggarwal et al. (2007) investigated the effect of use of bottom ash and waste foundry sand in equal quantities as partial replacement for fine aggregates in various percentages from 0% to 60%. Bottom ash

is a substance produced when coal is burned off; it is heavier than fly ash that is why it settles at the bottom of the boiler. When replacing fine aggregate with waste foundry ash and bottom ash the mechanical behavior of concrete showed strengths comparable to that of conventional concrete. Furthermore, it was observed that the greatest increase in compressive, splitting tensile strength and flexural strength was achieved by substituting 30% of the natural fine aggregate (Aggarwal et al., 2007). The maximum acceptable replacement was at 50% as increasing the percentage of fine aggregate replacement beyond this point would result in a decrease in its compressive strength (Aggarwal et al., 2007).

In 2007, Batayneh et al. studied the properties of concrete made with recycled construction material from constructions sites. The recycled materials used composed of plastics and crushed glass and were used as a substitute for the sand in the concrete mix. Different mixes incorporating the waste materials were made. Waste plastics were reused by grinding them into small particles. A concrete mix was made using the fine plastic particles as 20% replacement of sand (Batayneh et al., 2007). The crushed glass was manually crushed and sieved replacing from 0% to 20% of the sand in the concrete mix. After 28 days, the results show that the compressive strength of concrete mixes was improved by the partial replacement of the fine aggregates with crushed glass; however, when replacing the fine aggregates with 20% of plastics with crushed concrete, the compressive strength of concrete exhibited lower values than the compressive strengths of the control mix (Batayneh et al., 2007).

Debieb and Kenai (2008) also conducted a study in which fine aggregate was replaced in concrete using fine crushed bricks. Cubes of 100 mm were casted and tested for 3, 7, 28, and 90 days (Debieb & Kenai, 2008). The finer crushed aggregates were used, the more decrease in the compressive strength of concrete (Debieb & Kenai, 2008).

Ismail and Al-Hashmi (2008) completed a second study by replacing fine aggregate in concrete with waste iron. The procedure for the study was executed by comparing the compressive strength of a control concrete mix to different concrete mixes that contained waste iron in the increments of 10%, 15%, and 20% as replacement of fine aggregates. Both the control and incremental replacement mixes were cured for 3, 7, 14, and 28 days. A total of 115 cubes of concrete were used for compressive strength testing and 87 prisms for flexural strength (Ismail and Al-Hashmi, 2008). The results show that the compressive and tensile strength improved with the addition of the waste iron.

Ismail and Al-Hashmi (2009) conducted a second study where they replaced fine aggregates in concrete with waste glass. Waste glass can be produced in many such as packaging or container glass, bulb glass, flat glass, and cathode ray tube glass. A control mix was compared to several concrete mixes that contained waste glass as 10%, 15%, and 20% replacements of fine aggregates. The results show a decrease in the slump by increasing the percentage of the waste glass in the mix. However, the compressive strength increased by 4.23% when replacing 20% of fine aggregates with waste glass (Ismail & Al-Hashmi, 2009).

Alwaeli and Nadziakiewicz (2012) also replaced fine aggregate in concrete using scale and steel chips. In this study, two distinct types of concrete were made with steel chips scale (ScC) and (SchC). The sand was replaced in proportions of 25%, 50%, 75%, 100%. The concretes were produced in accordance with the Polish standards. Cubes of 100 mm length were used for gamma radiation testing, 84 slabs were casted with measurements of 250 x 250 x 26 mm. The results were the following: the compressive strength of concrete containing steel chips is better than ordinary concrete when used as fine aggregate replacement of up to 25% (Alwaeli & Nadziakiewicz, 2012). At the same time, addition of scale and steel chips enhances the shielding of gamma radiation (Alwaeli & Nadziakiewicz, 2012).

A summary of different waste materials used as a replacement of fine aggregates in concrete and their effect of on the compressive strength is shown in Figure 1.

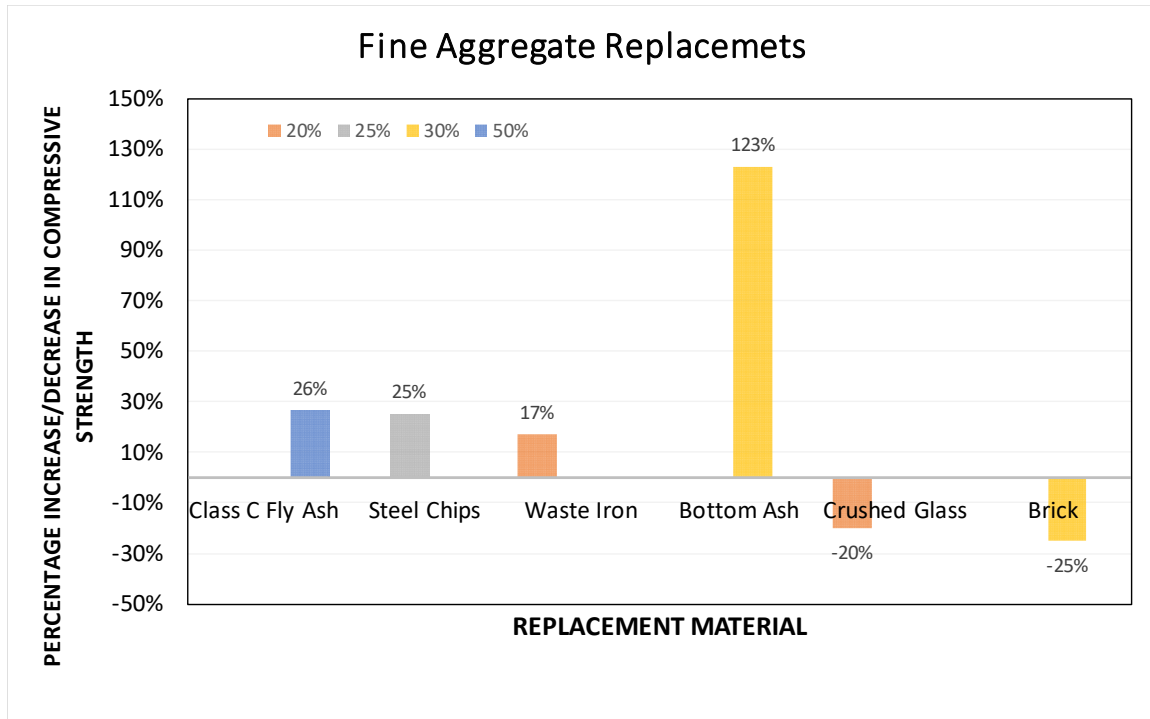


Figure 1: Comparison of the compressive strength of with different fine aggregate replacements

## 6 COARSE AGGREGATES

The literature included only four studied that explored the utilization of waste materials as partial replacements of coarse aggregates. The waste materials used in these studies included: ceramic industry waste, recycled concrete, rubber chips, and oil palm shells.

Basri et al. (1999) conducted a study to explore the possibility of using oil palm shells as a partial replacement of the coarse aggregate in concrete. The objective of using oil palm shells is to produce lightweight concrete. The natural thickness of this material ranges from 1.5 – 2.5 mm. Specimens were made using oil palm shells as a partial replacement of coarse aggregates. The concrete was tested for the slump and compressive strength and the results showed that the compressive strength of the oil palm shell specimens was about 41%-51% lower than the regular concrete; however, it was still within the range for structural lightweight concrete (Basri et al, 1998).

In another study, recycled concrete was used as a replacement of the coarse aggregates. The waste was obtained from crushed concrete that had been removed from a demolished structure. The results of experiments conducted showed that the quality of the recycled concrete used as a replacement of coarse aggregate is lower than that of natural aggregate. This is mainly because of the effect of mortar along with the remnants of other reactions and materials attached to the natural aggregates that were used in the recycled concrete. The replacement of the coarse aggregate with recycled concrete showed a reduction in compressive, flexural strength and splitting tensile strength compared to the control concrete mix.

A third study investigated the effect of utilizing waste tire rubber as partial replacement of coarse aggregates in concrete. In preparing rubberized concrete samples, 15% of the volume of gravel was replaced with rubber chips. With this replacement, the compressive strength was reduced by 45% and the indirect tensile strength was reduced by 23%. It was found that the rubber chips' size had a direct impact on the compressive strength. Reducing the size of the rubber chips should result in an increase in its strength. (Huang et al, 2004)

A study investigated the effects of using ceramic industry waste on concrete mix when used as a replacement of the coarse aggregate. This ceramic waste material was broken in 20 mm size to be used as coarse aggregate. Different mixes were made using different water cement (w/c) ratios of 0.35, 0.40, 0.45, 0.50, 0.55 and 0.60. The ceramic waste was used as a 100% replacement of the coarse aggregate, but the sand and cement varied depending on the w/c ratio. The specimens made from different batches were tested for the compressive and flexural strengths and were compared to the control concrete mix. The results show the utilization of ceramic waste as coarse aggregates enhanced the workability of concrete and increased the compressive and flexural strengths as well as the modulus of elasticity of the concrete. (Gobinath et al, 2011)

## 7 FINDINGS

From previous research, some interesting findings can be found about the impact of using waste materials as replacements of aggregates on concrete. The change in concrete properties depend on the type of material used as an aggregate replacement, and the percentage of replacement. A complete summary of the most important findings for each study is summarized in Table 1.

Table 1: Findings of Coarse and Fine Aggregate Replacements

| Type of Aggregate | Material              | Findings   | Source   | Specimen Type | Specimen Size               |
|-------------------|-----------------------|--|--|---------------|-----------------------------|
| Coarse            | oil palm shells       | OPS has better workability, lower compressive strength, light weight concrete                                  | Concrete using oil palm shells as aggregate<br>Basri et al. (1999)   | Cube Molds    | 100x100x100 mm <sup>3</sup> |
| Fine              | copper slag           | increase in density, up to 50 percent replacement had a comparable compressive strength and then it goes down, | Copper slag as sand replacement for high performance concrete , Khalifa S. Al-Jabri ,a, Makoto Hisada, Salem K. Al-Oraimi , Abdullah H. Al-Saidy | Cube Molds    | 150x150x150 mm              |
| Fine              | bottom ash            | density and workability decreased, compressive strength was lower than control                                 | EFFECT OF BOTTOM ASH AS REPLACEMENT OF FINE AGGREGATES IN CONCRETE, P. Aggarwal , Y. Aggarwal, S.M. Gupta  |               |                             |
| Fine              | class F fly ash       | compressive strength increased   | Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete. Rafat Siddique                               | Cylinders     | 150x300 mm                  |
| Fine              | glass aggregate       |  | "Glasscrete" concrete with glass aggregate by Weihua Jin, Christian Meyer and Stephen Baxter   |               |                             |
| Coarse            | rubber tire particles | reduction of both compressive and flexural strength  | The Use of Rubber Tire Particles in Concrete to replace mineral aggregate , H. A. Toutanji   | Cylinders     | 100x200                     |
| Fine              | glass aggregate       | optimum flexural strength was at 20 percent replacement, slump decreased                                       | Recycling of waste glass as a partial replacement for fine aggregate in concrete, Zainab Z. Ismail , Enas A. AL-Hashmi                           |               |                             |
| Fine              | scale and steel chips | better compressive strength until 25 percent, better absorption of gamma radiation                             | Recycling of scale and steel chips waste as a partial replacement of sand in concrete, Mohamed Alwaeli , Jan Nadziakiewicz                       | Cube Molds    | 100x100x100 mm <sup>3</sup> |

| Type of Aggregate | Material                             | Findings  | Source   | Specimen Type | Specimen Size              |
|-------------------|--------------------------------------|---|--|---------------|----------------------------|
| Fine              | iron                                 | flexural strength increase, slump decrease  | Reuse of waste iron as a partial replacement of sand in concrete, Zainab Z. Ismail , Enas A. AL-Hashmi   |               |                            |
| Fine & Coarse     | scrap tire rubber                    | compressive strength, modulus of elasticity tensile and flexural strength decreased                   | Scrap-tire-rubber replacement for aggregate and filler in concrete, Eshmaiel Ganjian a, Morteza Khorami b, Ali Akbar Maghsoudi c   |               |                            |
| Coarse            | metallic chips                       | better tensile strength , better compression with small percentage                                    | Strengthening of Concrete Metallic Chips, Y. Bouafia, S. Djebali, D. Atlaoui, and M. S. Kachi  | Cube Molds    | 90x90x100 mm               |
| Fine & Coarse     | crushed bricks                       | lower density, higher water absorption, decrease in compressive strength                              | The use of coarse and fine crushed bricks as aggregate in concrete, Farid Debieb , Said Kenai  | Cube Molds    | 100x100x100 mm & 70x70x280 |
| Fine              | fly ash                              | higher strength and environmental friendly  | Use of ground coarse fly ash as a replacement of condensed silica fume in producing high-strength concrete, Chai Jaturapitakul, Kraiwood Kiattikomol, Vanchai Sata, Theerarach Leekeeratikul |               |                            |
| Fine              | solid waste incineration fly ash     | the physical properties were not deteriorated, it maintained close to the control                     | Use of municipal solid waste incineration fly ash in concrete, J.E. Aubert, B. Husson, A. Vaquier  | Cylinders     | 15x20 cm                   |
|                   | recycled plastic                     | density reduced, compressive strength decreased, decrease in tensile strength,                        | Use of recycled plastic in concrete: A review, Rafat Siddique a, Jamal Khatib b, Inderpreet Kaur   |               |                            |
|                   | steel fibers                         | slightly increased compressive strength, lower workability  | Use of steel fibers recovered from waste tires as reinforcement in concrete: Pull-out behavior, compressive and flexural strength, M.A. Aiello, F. Leuzzi, G. Centonze, A. Maffezzoli        | Cube Molds    | 150x150x150                |
|                   | steel beads                          | decreased workability , reduction in compressive strength, increased tension                          | Use of waste tire steel beads in Portland cement concrete, Christos G. Papakonstantinou, Matthew J. Tobolski   | Cylinders     | 4x8 inch                   |
| Coarse            | coarse rigid polyurethane foam waste | good workability, higher porosity, decrease in compressive strength and dynamic modulus of elasticity | Valorization of coarse rigid polyurethane foam waste in lightweight aggregate concrete, Amor Ben Fraj, Mohamed Kismi, Pierre Mounanga  | Cube Molds    | 50x50x50 mm                |

## 8 CONCLUSIONS

The increment of waste materials and the awareness of waste management and environmental issues had led to a progress in the utilization of various waste materials in concrete cease to be toxic. Concrete mixtures can be made containing a volume fraction of waste materials as a replacement of natural aggregates. This serves as an alternative venue for disposing waste material sustainably. The results show that some materials can have a positive impact on some properties of concrete, such as the compressive strength and workability. While the majority of waste material have negative effect on the compressive strength of concrete, a life cycle cost analysis study is needed to determine the feasibility of this approach.

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