A review on sustainable concrete mix proportions

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Abstract. The need for reducing the carbon footprint and effect of hazardous gases, etc., released from the construction sectors and other product manufacturing industries on the environment is the need of the hour. In this regard, the construction sector has been utilizing some of the wastes generated from various sources in making concrete. Notable among them is the Ground granulated blast furnace slag (i.e. GGBS) as a partial substitution of cement. Further, waste foundry sand, a by-product of the foundry industry is observed to be an appropriate alternative to partial replacement of fine aggregate and demolition waste as a partial replacement of coarse aggregate. These waste utilizations have addressed some of the global environmental concerns like solid waste management, scarcity of landfilling, sustainability etc. but there is still is inefficient, given the rate at which we are producing waste. This paper presents an overview of some of the recent research published on the utilization of wastes in the production of sustainable RMC/SMC. It also presents the effect of waste utilization in concrete on mechanical, microstructural and durability factors.

Keywords: Ready-mixed concrete, Green concrete, recycled aggregates, Demolition waste, Sustainable concrete.

1. Introduction

Ready Mix Concrete (RMC) is concrete made by simultaneously mixing the ingredients of concrete and transporting the same to work location while maintaining the required workability by adding admixtures and superplasticizers. The time of haul is restricted to 2 hours of the time of loading [1]. RMC is the next widely used construction material when compared with conventional SMC. Worldwide there is a huge concern on reducing the environmental pollution viz. greenhouse gases and the contribution of the construction sector in this aspect is important as most of the industrial wastes can be used as a partial replacement of various ingredients of concrete. Cement Fine Aggregate (FA) and Coarse Aggregates (CA) along with water and admixtures (if necessary) are basic ingredients on concrete. Cement hydration that results in strength attainment of concrete which is accountable in emitting CO₂ into the environment and atmosphere. It is established that 1 Ton production and use of cement in the construction activities emit CO₂ of about 0.9 Ton [2, 3]. The second place in releasing of CO₂ is the construction industry next to the automotive sector. Natural aggregates like fine aggregates (FA)such as Sand and Coarse Aggregate (CA) are reducing at a faster rate on account of abundance
consumption in concrete manufacturing. Due to this, there is an immense outlook for research in looking for substitutes of concrete making constituents. As per the literature study, industrial wastes such as slag (GGBS), waste glass powder, fly ash, silica fume, etc. other than above rice husk ash, sawdust ash, pulverized fuel ash, etc which are known as Supplementary Cementitious Materials (SCM’s). Similarly, FA can be partially replaced with industrial secondary-products like Used Foundry Sand (UFS), M sand (MS), Marble Powder (MP) etc. CA can be partially replaced with Plastic aggregates (HDPE), Rubber Waste (RW), construction debris, Demolition Waste (DW), Recycled Concrete Aggregates (RCA) etc. The suitability of replacing an ingredient of concrete with a waste material depends on the extent of compatibility of their physical and chemical properties. The results of research on the performance of concrete with these replacements initiated the utilization of green materials in the manufacture of cement concrete so that subsidizing to the decrease of environmental contamination. This review paper aims to assess the feasibility of manufacturing RMC with maximum use of green materials.

2. Background
The first RMC industry was established in Germany in the year 1903, whereas the first product of RMC was produced in Turkey in the year 1906. The first commercial product was supplied in Baltimore, the USA in the year 1913. In the year 1926, a first of its kind small transit mixer of revolving type was used for supplying RMC. Later in the 20th century, Europe and the USA have seen remarkable growth in this industry. Currently, USA is consuming 75% and Europe is consuming 47% of cement through RMC plants. In India, RMC utilization was started in the year 1950 for only mega or large-scale projects. Due to rapid growth in industrialization, infrastructure and housing projects, the need for quality, quantity and faster supply of concrete was increasing. Meeting this demand was possible only through RMC. The first commercial RMC plant in India was set up in Pune in 1992. Over the years, the RMC industry has expanded beyond metropolitan cities to smaller cities and towns. Presently it is estimated that in India, around 1000 RMC plants are producing annually 35-40 mm³ of concrete. The projected growth of this industry for the next five years is expected to be above 7%. The existing RMC plants in India are modernized with the automated control system as shown in figure 1.

![Flow Chart-Manufacturing Process of RMC](image)

**Figure 1.** Flow Chart-Manufacturing Process of RMC.
3. Review of Literature
A review of some recent research on utilization of industrial by-products and manufacture of RMC is presented in this section.

3.1. Fly ash, GGBS and Bottom ash as Partial Replacement of Cement

Some of the by-products in the steel manufacturing industry are fly ash and ground granulated blast furnace slag (GGBS) and shown in figures 2 and 3 respectively. In the Netherlands, due to Greendale initiative, Geopolymer concrete (GC) was manufactured in RMC plant with a combination of GGBS and fly ash, FA and CA which were activated separately with powdered alkalis of sodium silicate and sodium hydroxide called as dry mix and with liquid alkalis called as wet mix. Both were compared with the control mix. It was found that dry binder has good results when compared with the wet binder. After 91 days, the dry binder has shown 1.12 times higher strength than the wet binder which has shown 0.04 times lesser compressive strength than reference concrete. The modulus of elasticity of dry binder is 0.81 times less and wet binder is 0.75 times less than reference concrete. Production of GC in conventional RMC plant by mixing, transporting and casting was successful with minor changes. It was also found that the adopted design mix was workable up to 90 minutes. However, even a single minute delay resulted in difficulty in placing the same. Adjustments may be required in the conventional durability factors while adopting them for special concretes like GC. European codes have not yet standardized the regulations for the designs and construction of structures with concrete made with geopolymer as the binder. It is suggested to use this new type of concrete for the product-based elements like precast slabs, precast fence posts, pavement blocks, tiles etc [9].

GGBFS was added as a part of binder in geopolymer concrete based fly ash. The optimum mixtures of concrete specimens containing 10% GGBFS + 90% Fly ash activated by 40% Na$_2$SiO$_3$ (of total binder content) and 14M NaOH alkali activator solution (with a ratio of Na$_2$SiO$_3$/NaOH 1.5-2.5 without adding any extra water) showed moderate compressive strength under ambient curing. The setting time of binder was comparably same to that of conventional concrete. When Fly ash was replaced with Slag up to 30%, the compressive strength of this geopolymer concrete was nearly 55 N/mm$^2$, and mortar strength was up to 63 N/mm$^2$ after 28 days curing. Beyond this replacement, reduction in strength compared to conventional concrete was observed [10]. Cement with ‘GGBS & bottom ash’ and sand with ‘foundry sand’ (figures 4a & 4b) were partially replaced and tested for mechanical and durability properties. Low concentrations of NaOH i.e., 4M showed satisfactory results under ambient curing. With an increase in density, the grade of concrete, replacements percentages, splitting tensile and flexural strength increased whereas water absorption, weight loss for sulphate and chloride attack reduced [11]. The ready-mix mortar was prepared with three types of cement to study the effect of cement and water content on the plastic or fresh state properties. For maintaining the longer duration of workability for up to 72 hours, the mortar was mixed with hydration stabilizing admixture and air-entrained admixture. The ratio of water to dry material had a substantial influence.
on the air entrainment but the cement types in ready mix mortar and its storage duration have not shown any effect on the same. The consistency of the mix increases with increase in the ratio of water to dry materials. There was no effect for the type of cement used on the consistency index for 12% water to dry materials ratio. The consistency of the mix decreases with increase in storage time. With the increase in cement fineness and storage of the mix, the maximum displacement observed by squeeze flow test increased. The rheological properties of the mix were changed with storage time and cement types. It was also noticed that there was no change in air entrainment and consistency properties [13].

Figure 4. (a) SEM Image of Conventional Mix [12].

Figure 4. (b) SEM Images of Non-Conventional Mix [12].

Ready-mix alkali-activated cement was produced by treating construction waste thermally up to 1200°C and activating it with NaOH solution. This thermally treated construction waste is very stable and can be converted into amorphous form, which when reacts with water forms hard material similar to conventional cement with appreciable compressive strength. With the increase in temperature and NaOH%, the performance of ready-mix alkali-activated cement also increases. It is an eco-friendly material and white in colour. Due to this, it can be used for decorative works and in insignificant projects [14].
3.2 Waste Foundry Sand, Dredged Material and Fine Recycled aggregate as Partial Replacement of Fine Aggregate

Waste foundry sand (WFS) is the by-product of the foundry industry. After repeated use of high-quality silica in the foundry process, it is discarded and sometimes used as landfills. It was showed that it can also be used as a replacement of fine aggregate [15]. WFS was used in the manufacturing of RMC by replacing sand at various percentages by its weight. Solidification and stabilization were done for all concrete mixtures by which the properties were improved. The mechanical, leaching and microstructural properties of WFS-RMC’s final product was studied as per the standards of Turkey and environmental concerns. When compared with control mix, it was observed that as per the Turkey standards “TS 706 EN 12620+A1:2009-Coarse aggregates” [16], WFS has shown similar physical, geometrical and chemical properties on par with conventional sand. When WFS was partially replaced with regular sand, there was a decrease in strength properties when compared with the control mix. Optimum results in compression and splitting tensile strengths were observed up to 20% replacement. With the increase in replacement percentages, water absorption increased, but the density of the mix decreased. Non-conventional mixes cured for 56 days showed results similar to 90 days. The eluate concentrations (Ni, Zn, Cr, F, TDS, DOC, TOC) of WFS treated with solidification and stabilization under different pH conditions were incompatible with EULFD limits. 20% WFS mix and control mix are almost same in the microstructural and morphological properties. To utilize the WFS in RMC, its replacement should be 20% by weight of regular sand. Further, it should not show any adverse effect on mechanical, microstructural and environmental factors. It was also observed that WFS properties may vary from foundry to foundry. It was also found that corrosion effect has to be studied when WFS is used [17]. Dredging is the process of removing silt and other sediment materials from the water bodies. The removed material is called as Dredged Material (DM). DM samples were dredged from Istanbul Ambarlı Port (DM1), Mersin Erdemli Fishery Harbour (DM2), Izmir PETK_IM Container Port (DM3), and Samsun Port (DM4). This DM was used as fine aggregate by treating and without treating the same at various percentages (0%, 25%, 75%, 100%) in RMC as shown in figures 5a & 5b. As per the Turkey standards (17 05 06), DM was identified as “non-hazardous waste”. The leaching characteristics of DM according to “ADDDY – Appendix 2: The acceptance criteria of landfilling waste”, were above the limits of Class III – inert waste as landfill material. The fresh and hardened state properties of treated and untreated DMs of concrete were compared and found that treated DM1 and DM2 performed better than treated DM3 and DM4, the untreated DMs also showed the results like treated DMs. Due to this, the treated and untreated DMs were transformed to form composite treated and composite untreated DMs. The composite treated (untreated) DMs consists of treated (untreated) DMs of 40% each of DM1 and DM2 and 10% each of DM3 and DM4 were mixed as per Turkey’s gradation distribution. As per “TS 706 EN 12620 + A1:2009” [16], the composite treated DMs showed that the fine aggregate properties are similar to silica sand. From the experimental results, it was observed that RMC2 (50% Composite untreated) and RMC8 (100% composite treated) had shown minimum strength as per the requirement.

The composite treated DMs had shown better physical and mechanical properties than composite untreated. On testing the RMC0 (control RMC), RMC2 (SEM showed in figures 6a & 6b) and RMC8 when tested for durability, it was found that higher w-c ratio results in higher permeable voids and permeability.

The leachable properties (eluate concentrations) of RMC2 and RMC8 are observed to be under limits according to “ADDDY-Appendix 2” [18]. The RMC2 had shown similar chemical and mineralogical properties when compared with RMC0 than RMC8. This may be due to the low percentage of replacements. From this study, the author concluded that treated DM can be used as a partial replacement of fine aggregate in RMC or concrete manufacturing locations [19].
Figure 5(a). SEM image of silica sand [19].

Figure 5(b). SEM image of Dredged material Samples [19].

Figure 6. SEM images/EDS spectra of (a) RMC-0 (b) RMC 2 concrete [19].
Fine Recycled aggregate (FRA) was collected from the demolition and construction wastes of the structures. In this study, two types of FRA were used as shown in figures 7a & 7b. One is FRAL (Fine Recycled Aggregate with Lower water absorption ratio of 5.83%) and FRAH (Fine Recycled Aggregate with Higher water absorption ratio of 7.95%). Conventional sand was replaced with FRAL at various percentages (0, 30, 60, 100) and FRAH with 35 and 70% and their effect was studied when used in the RMC. From the experimental study, it was observed that with the increase in replacements, the slump of the RMC was reduced and regardless of FRA replacements and its types, the air content of the RMC was almost similar to that of conventional concrete. With an increase in the replacement percentages of FRA, there was a decrease in compressive strength. As per the Korean standards “KS F 2573” [20], and replaced with 100% FRA, there was a 13% decrease in compressive strength when compared with conventional concrete. With 100% FRAL and 70% FRAH, no significant effect was observed on the splitting tensile strength and modulus of rupture when compared with the conventional mix. With an increase in replacements when compared with conventional concrete, the shear and flexural capacity of RCC beams have not shown any significant decrease. However, deflection values noted during flexure test increased. There was a decrease in 28 days of bond strength also. It was concluded that a 30% replacement of FRA in RMC gives moderate compressive strength [21].

![Image of Recycled Fine Aggregates](image)

**Figure 7.** Images of Recycled Fine Aggregates (a) FRAL (b) FRAH [21].

In this study, Fly ash bricks were manufactured with cement, sand, sludge lime and gypsum. NCF50 bricks showed better results when compared with NCF100 in the compressive strength, and water absorption. There is no sign of efflorescence in NCF50 and NCF100. With the help of these results, conventional sand can be partially replaced with waste foundry sand up to 50% [22].

### 3.3 Construction Demolition Waste, RMC Waste as Partial Replacement of Coarse Aggregate
In 1999, an earthquake occurred in Taiwan and generated approximately 20 million tons of construction demolition wastes (CDW). The demolished clay brick and tiles (CBT) out of this waste were used as a replacement of coarse aggregate. The RAC (Recycled Aggregate Concrete) made with washed CBT has shown higher values of the slump, compressive strength and flexural strength when compared with unwashed CBT. The low slump value of unwashed CBT is due to impurities present in it[23]. Conventional coarse aggregate was replaced with two kinds of waste generated, one is the initial waste of RMC plant collected from Hormigones Ebro (HE) Company and other was demolition waste from Hormigones Rioja (HR) as shown in figure 8. It was found that HE wastes concrete has yielded lesser strength, whereas HR demolition waste concrete was similar to conventional coarse aggregate concrete. With the prior treatment of HR aggregates, it was shown that up to 50% can be utilized in concrete production by replacing natural aggregates [24].

Figure 8. Image of Recycled Coarse Aggregate derived from concrete waste [24].

To estimate the environmental impact of concrete structures, a wide-range study was carried out on the life cycle assessment of the same grade of recycled concrete and ordinary concrete. Both are commercial products. It was found that recycled concrete has less impact on the environment when compared with conventional concrete. Carbon emissions are slightly less for 1cum of recycled concrete when compared with control concrete [25]. The durability parameters viz. volume of permeable voids (VPV), water absorption and sorptivity of ready mixed concrete of grades G40, G45 and G50 are studied. It was reported that the water absorption percentage increased with decrease in grade of concrete with respect to its curing condition and age. G40 concrete that underwent 28 days S2 (site cured) curing on top zone has 7.12% water absorption value. In the case of G50 concrete that underwent 90 days S1 (sealed cured) curing, the bottom zone recorded the lowest value of 3.59%. G40 has 13.50% VPV when compared with G50s VPV that has 6.17% on the bottom zone. G40 left zone has the highest sorptivity of 0.123 g/mm² /√t for 28 days curing and 0.038 g/mm² /√t on the bottom zone of G50 concrete cured for 90 days. So, the Performance indicators play a vital role in RMC transported to the site [26]. The effect of sustainable materials in the production of micro-concrete is reviewed [27]. Nowadays conventional concrete is manufacturing with wastes generated from demolition and construction which in turn reduces the environmental pollution [28].

4. Conclusion
1. The combination of GGBS and fly ash can partially replace cement in the production of sustainable concrete mixes.
2. For adopting in mix design, the workability of geopolymer Ready Mix Concrete (RMC) is to be retained to up to 90 minutes.
3. When Fine aggregate was partially replaced with Waste Foundry Sand (WFS), it adversely affected the workability and water absorption in the Site Mix Concrete (SMC).
4. WFS up to 20% replacement resulted in similar strength properties as that of control conventional concrete.
5. For minor works where strength required is nominal, WFS can be used as a partial replacement to produce low-strength materials without any major modification or alteration to the SMC.
6. Treated dredged material (DM) can be used as a partial replacement of sand without significant effect in physical, mechanical, environmental, microstructural properties of RMC.
7. For moderate compressive strength, construction demolition waste (CDW) can be used up to 30% as coarse aggregate replacement in RMC.
8. CDW's washed clay brick tile when used as a coarse aggregate replacement showed a higher slump and improved mechanical properties when compared with unwashed clay brick tiles.
9. Natural coarse aggregates can be replaced with Hormigones Rioja (HR) aggregates up to 50% in concrete production.
10. Using these wastes in concrete production, showed a significant reduction in carbon emissions.

5. Scope of the Study

Many of the research studies on sustainable green materials exhibited acceptable performance in terms of strength and durable properties of concrete. On the other hand, there is a requirement for further research work in finding the impact of utilizing sustainable materials on dynamic properties of new-age concretes like sustainable green concrete. Also, the life cycle assessment has to be done based on real-time data on specific and existing market products. Furthermore, the scope of sustainable materials in the production of RMC and SMC needs to be studied extensively.

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