# Study on the admixing of recycled C&D waste fine aggregates for partial replacement of sand and ceramic waste tile powder for partial replacement of OPC in foam concrete mixes

# फोम कंक्रीट मिश्रण में रेत के आंशिक प्रतिस्थापन के लिए पुनर्चक्रित सी एंड डी अपशिष्ट महीन समुच्चयों और ओपीसी के आंशिक प्रतिस्थापन के लिए सिरेमिक अपशिष्ट टाइल पाउडर के मिश्रण पर अध्ययन

**Thesis submitted in partial fulfilment for the**
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**By**

**Rohit Rodhia**

**DEPARTMENT OF CIVIL ENGINEERING**
**INDIAN INSTITUTE OF TECHNOLOGY**
**(BANARAS HINDU UNIVERSITY)**
**VARANASI – 221005**
**INDIA**

**Roll No- 19061009**

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# CHAPTER 7 : CONCLUSIONS AND SCOPE FOR FUTURE WORK

## 7.1 CONCLUSIONS

The efficacy of utilizing the recycled fine aggregate from construction and demolition waste (CD-RFA) as partial replacement to sand fraction finer than 1.18 mm and ceramic waste tile powder (CWTP) for partial replacement of OPC in production of foam concrete (FC) mixes was studied. The investigations on foam concrete outlined in this research essentially encompass stages as discussed below:

### 7.1.1 CD-RFA and CWTP as admixtures in FC mixes

(i) CD-RFA has particle sizes that are finer than river sand. Its particles had irregular and angular shape with sharp edges. Specific gravity was lower than sand owing to the attached mortar over its surface. It has higher water absorption as compared to sand.

(ii) CWTP has particle sizes close to OPC and has good composition of $SiO_2$ to function as a pozzolana.

### 7.1.2 Optimization of dilution ratio of FC mixes admixed with CD-RFA

(i) The dilution ratio had a statistically significant effect on the measured concrete properties ($F = 6.95$, $p = 0.0033 < 0.05$), indicating that different replacement levels of CD-RFA influence the overall performance of FC mixes.

(ii) The factor encompassing strength, abrasion resistance, water absorption, sorptivity, porosity, volume of voids, and % CD-RFA showed a very strong statistical influence ($F = 20.66$, $p = 0.0001 < 0.01$), highlighting the sensitivity of concrete behavior to these performance parameters.

(iii) An increase in dilution ratio of foaming agents leads to a higher volume of the fresh mix and subsequently lower dry density.

(iv) Dilution ratio of foam (water: foaming agent) when studied for three proportions viz 1:20, 1:40 and 1:60 reveals that the proportion of 1:40 is best suited for FC mixes by virtue of better physical, mechanical and durability properties which is a novel finding.

### 7.1.3 Fresh properties and hardened density of FC mixes admixed with CD-RFA and CWTP

(i) Flowability indicates the workability of the freshly casted FC mixes and synonymous with its self-compaction behavior. The flowability of control mix prepared with foam was measured as 470 mm at dilution ratio of 1:40; while that of CD-RFA admixed (@ 10%) and CWTP admixed FC mixes (@ 30%) at same dilution ratio were 395 mm and 337.5 mm, respectively. Reduction in flowability of waste admixed mixes were attributable to stiffness imparted to the aggregate proportion due to enhanced fineness.

(ii) The dry density of control FC mixes at dilution ratio of 1:40 was obtained as 1647.84 kg/m$^3$, while that of CD-RFA (@ 10%) and CWTP (@ 30%) admixed FC mixes were 1669.65 and 1612.69 kg/m$^3$, respectively at the same dilution ratio.

A slightly higher density of CD-RFA FC mix than control FC mix may be attributed to pore filling. With this, both FC mixes have almost similar water absorption of 13% by weight of dry sample. Also, lower density of CWTP FC mix is attributable to admixing of particles of lower specific gravity as compared to OPC at replacement level of 30% by weight of OPC.

### 7.1.4 Mechanical characteristics of FC mixes

(i) The compressive strength of control FC mixes at dilution ratio of 1:40 was 22.35 (28-days) and 28.31 (90 days) MPa, while that of CD-RFA (@ 10%) and CWTP (@30%) admixed FC mixes were 14.17 (28 days) and 17.15 (90 days); and 14.94 (28 days) and 17.0 MPa (90 days), respectively at the same dilution ratio.

The compressive strength results indicate the suitability of CD-RFA and CWTP admixed FC mixes for semi or non- structural as well as lightweight applications like partition walls, murals etc. in consonance with ACI 523R; while the control FC mix holds promise for application in structural purposes.

(ii) 28- day flexural strength at the same dilution ratio was 4.68 MPa for control FC mix, while that of CD-RFA (@10%) and CWTP (@ 30%) admixed FC mixes were 4.88 and 4.86 MPa, respectively.

Flexural strength > 4.5 MPa suggests the need for further research on its use for Pavement Quality Concrete (PQC) according to IRC 58; and in certain terms ascertains its suitability for DLC of concrete pavements, encouraging large scale utilisation of wastes. On the other hand, the control FC mix holds promise for their use in parking lots that would keep the surface dry and help groundwater recharge.

### 7.1.5 Water ingression properties of FC mixes

(i) Sorptivity of control FC mixes at dilution ratio of 1:40 was 7.42 mm/sec$^{1/2}$ (28-days), while that of CD-RFA (@ 10%) and CWTP (@30%) admixed FC mixes were 7.50 mm/sec$^{1/2}$ (28-days) and 8.02 mm/sec$^{1/2}$ (28-days), respectively at the same dilution ratio. Increase in sorptivity is visualized as a linear curve between absorbed water volume and the square root of time, with water movement occurring through capillary pressure in air voids larger than 0.3 µm following the Washburn equation.

(ii) Water absorption of control FC mixes at dilution ratio of 1:40 was 12.77% (28-days), while that of CD-RFA (@ 10%) and CWTP (@30%) admixed FC mixes were 12.96% (28-days) and 7.63% (28-days), respectively at the same dilution ratio. Permeable void volume of control FC mixes at dilution ratio of 1:40 was 22.76% (28-days), while that of CD-RFA (@ 10%) and CWTP (@30%) admixed FC mixes were 21.46% (28-days) and 11.77% (28-days), respectively at the same dilution ratio. This justifies the results obtained for dry density.

### 7.1.6 Air-voids in CWTP admixed FC mixes

(i) Foam concrete pore size distribution was found to follow a non-linear pattern with increasing CWTP content, starting from 20 µm to 1200µm for the control FC mix, 250µm at 50% CWTP, 500 µm at 90% CWTP, demonstrating that moderate CWTP incorporation (@50%) produces the smallest pore size.

(ii) The microstructural properties of foam concrete (average pore area, diameter, and Feret diameter) exhibit a U-shaped trend with increasing CWTP content, reaching optimal values at 30% CWTP replacement (107.452µm pore diameter, 108.45µm² pore area, and 107.34µm Feret diameter), indicating this percentage provides the most refined pore structure at dilution ratio of 1:40.

### 7.1.7 Microstructural and crystallography of FC mixes

(i) SEM of FC specimens after 28 days show an irregular distribution of pore-sizes scattered all over the groundmass. Formation of foam bubbles varies noticeably between the control mix and the mix with CD-RFA and CWTP replacement. This is because the admixing CD- RFA results in large surface area of pores/ voids and is adsorptive. SEM of FC mixes admixed with CWTP shows formation of crystals like CH and C-S-H which were found intertwined and filled within cracks, creating a flocky appearance. The $Ca(OH)_2$ crystals were plate-like appearance.

(ii) The XRD reveals hydrated products such as portlandite (CH), calcium silicate hydrates (CSH), and unreacted calcite and dicalcium silicate. Samples with higher level of CD-RFA replacement show higher intensity of calcite, which resulted from carbonation of hydrated products as compared to control FC mixes. Also, as the percentage of CD-RFA increases in foam concrete, the concentration of $CaCO_3$ increases in the mix at every dilution ratio along with increase in porosity. XRD of mixes admixed with CWTP exhibits the hydration and pozzolanic crystalline phases.

With the exposure to air and allowing $CO_2$ to enter the pores of CWTP mixes, the formation of $CaCO_3$ was noticed. CWTP being high on alumina, the formation of ettringite (Aft) was noticed which peaks at 90 % CWTP incorporation. CWTP reacts with CH and sulphate ions during hydration to produce calcium aluminate hydrate (C-A-H) and calcium sulfoaluminate hydrates crystals, and its peak increases as incorporation of CWTP increases in FC mixes. The Aft crystals and CSH gels significantly help in the strength development of FC mixes.

### 7.1.8 Durability characteristics of foam concrete mixes admixed with CD-RFA and CWTP

(i) Loss in mass due to abrasion of control FC mix at dilution ratio of 1:40 was 15.96% (28-days), while that of CD-RFA (@ 10%) and CWTP (@30%) admixed FC mixes were 18.43% (28-days) and 23.1% (28-days), respectively at the same dilution ratio. A linear inverse relationship between dry density and loss in mass is proposed in this research for FC mixes.

(ii) FC mixes subjected to 28 days curing and 56 days exposure to 2% sulphuric acid and 2% hydrochloric acid solution exhibited the following:

  a. Gain in mass of 8.42 and 4.61%, respectively for control FC mix; while it was 9.61 and 5.29%, respectively for CD-RFA (@ 10%); and 6.92 and 3.71%, respectively for CWTP (@30%) at dilution ratio of 1:40. This gain in mass is attributed to the formation of gypsum and ettringite in presence of sulphate ions, and soluble salts in presence of chloride ions. All these remain within the pores of the FC mixes, thereby increasing the mass.
  b. Compressive strength was 14.40 and 17.65 MPa, respectively for control FC mix; while it was 9.17 and 11.58 MPa, respectively for CD-RFA (@ 10%); and 10.55 and 10.83 MPa, respectively for CWTP (@30%) at dilution ratio of 1:40. This loss in compressive strength is attributed to surface erosion; spalling of concrete; liberation of hydrated products of expansive nature like ettringite and gypsum; and formation of soluble salts ($CaCl_2$) which get preserved in the layered structure of foam concrete matrix, thereby decreasing in compressive strength. Loss in compressive strength of CWTP FC mixes exposed to HCl is lower than as compared to $H_2SO_4$ due to higher concentration of H+ ions in sulphuric acid. FC mixes admixed with CWTP has higher acidic resistance as CWTP has alumina content, which forms calcium aluminate hydrates, which is more stable than calcium silicate hydrates.

## 7.2 SCOPE FOR FUTURE WORK

This study represents an initial phase in the ongoing extensive investigations into foam concrete through the integration of CD-RFA and CWTP. Further exploration can be pursued in the following areas to enhance comprehension of the material, thereby increasing its utility for the construction sector:

1) Investigation may be done using CD-RFA and CWTP simultaneously.
2) Investigations can be conducted on methods to mitigate the shrinkage of foam concrete through the addition of CD-RFA and CWTP.
3) Microstructural analysis of FC mixes can be performed after exposure to varying acidic conditions for different durations.
4) Research on the optimal dosage of fibers to improve the tensile and flexural strength of foam concrete without compromising its fresh state properties can be conducted.
5) Research on identifying more compatible chemical admixtures in foam concrete to decrease the water-solids ratio requirement may be conducted. The impact of superplasticiser on shrinkage and sorption behaviour can also be examined.
6) Further research is recommended to validate the utilisation of waste materials in foam concrete, considering different foam volumes. Thorough analysis of the structural and durability properties is crucial for semi-structural and structural applications.
7) Future engineers can work towards the integration of light weight FC mixes into engineered mechanical arrestor system for runway end safety areas.