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# UTILIZATION OF SLAG POWDER AND RECYCLED CONCRETE WASTES IN REACTIVE POWDER CONCRETE

## UPORABA ŽLINDRNEGA PRAHU IN RECIKLIRANIH BETONSKIH ODPADKOV ZA REAKTIVNI BETONSKI PRAH

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Using recycled wastes and industrial by-products in construction materials has become mandatory to conserve the natural resources and manage waste-disposal environmental problems. This experimental work investigates the workability and strength properties of reactive powder concrete (RPC), utilizing slag powder and finely ground recycled concrete waste as the partial substitutes for cement and quartz sand, respectively. The results for the slump flow, flexural strength, compressive strength, split-tensile strength were analysed for varying contents of the recycled concrete waste in RPC, i.e., (0, 5, 10, 15, 20, 25 and 30) % and a constant slag-powder addition of 20 %. Furthermore, water absorption of the hardened specimens of 28 d of curing was also examined. The results indicated a rise in the water absorption and reduced workability with the increase in the content of recycled concrete in RPC. This was due to porous inter-particle voids in recycled concrete wastes. The strength properties of RPC exhibited superior performance for the substitution of 15 % of quartz sand with recycled concrete waste. A low water-cement ratio and a steel-fibre addition to RPC play an important role in the strength development and durability properties of RPC.

Keywords: slag, concrete, waste, reactive powder, recycled concrete

Uporaba recikliranih odpadkov in industrijskih stranskih proizvodov postaja obveza pri izdelavi gradbenih materialov. S tem se ohranja naravne vire in poizkuša uspešno obvladovati okoljske probleme ob nastajanju prekomerne količine odpadkov. V članku je opisana eksperimentalna raziskava lastnosti (obdelovalnosti in trdnosti) reaktivnega betonskega prahu izdelanega iz žlindrinega prahu in fino zdrobljenega recikliranega odpadnega betona, ki naj bi služil kot delna zamenjava za cement oziroma kvarčni pesek. Določili so sipkost, tlačno, cepilno-natezno in upogibno trdnost preizkušancev z različno vsebnostjo recikliranega odpadnega betona v reaktivnem betonskem prahu: (0, 5, 10, 15, 20, 25 in 30) % ter s konstantnim 20 % dodatkom žlindrinega prahu. Prav tako so določili absorpcijo vode v utrjenih preizkušancih po 28-dnevnem utrjevanju. Rezultati analize so pokazali, da se povečuje absorpcija vode in zmanjšuje se obdelovalnost mešanic s povečevanjem vsebnosti recikliranega betona v reaktivnem betonskem prahu. Vzrok za to je poroznost oziroma mikro praznine nastale med delci recikliranih betonskih odpadkov. Trdnostne lastnosti preizkušancev so boljše pri dodatku reaktivnega betonskega prahu kot pri enakem (15 %) dodatku kvarčnega peska. Za razvoj trdnosti in trajnosti preizkušancev sta pomembna predvsem ojačitev z jeklenimi vlakni ter nizko razmerje med vsebnostjo vode in cementom v reaktivnem betonskem prahu.

Ključne besede: žlindra, beton, odpad, reaktivni prah, reciklirani beton

## 1 INTRODUCTION

Ultra-high performance concrete (UHPC) is an excellent type of high-strength concrete which possesses enhanced durability, high energy-absorption ability and low permeability. An addition of fibres, especially steel fibres, to UHPC improves the flexural behaviour, transforming it into ultra-high performance fibre-reinforced concrete (UHPFRC).[1] Many experimental attempts to enhance the durable and mechanical properties of concrete are being carried out by the researchers through advanced scientific improvements and techniques. In that category, reactive powder concrete (RPC) is an exceptional type of UHPFRC[2] generally produced with additions of mineral admixtures, elimination of coarse aggregate, a low water-cement ratio, superplasticizer addition and addition of steel fibres, each of which support the advantageous strength properties[3] while the low water-cement ratio and optimization of the particle packing improve the durability properties of RPC.[4]

Today, sustainability is the main problem associated with the cement and concrete industry, and it is one of the major sources of environmental issues like greenhouse gas emission. To provide eco-friendly solutions for the environmental problems, a few researchers recommended certain actions such as: (1) to develop construction materials with high strength and durability, extending the lifecycle of materials,[5] (2) to develop construction materials with low energy consumption, for example, using industrial by-products[6] and, finally, (3) to use the recycled concrete obtained from construction and demolition wastes.[7] From the environmental point of view, the utilization of high-energy constituents in the production shows RPC as a non-sustainable material. Consequently, there is the need to produce an eco-friendly RPC by replacing the high-energy ingredients with lower-energy

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intensive materials and by using industrial by-products and recycled concrete wastes.[8]

Many research studies were carried out across the world to introduce potential mineral admixtures in order to replace the cement and also the silica fume, which possess serious demerits such as high cost, increased water demand and shrinkage.[9,10] The search for cost-effective and efficient substitutes continues day by day. In that way, a past research study attempted to investigate the use of alccofine, an ultra-fine form of slag, in UHPC and found it as an effective pozzolanic material in concrete.[11] On the other hand, several research works were carried out to study the potentiality and usage of recycled concrete wastes in concrete.[12,14] The impact of recycled fine aggregates (RFA) on the mechanical strength and microstructure of UHPC has been studied in a recent research.[15] Furthermore, several research studies suggested the usage of RFA in the concrete production, provided with optimum proportion and better curing conditions.[16–20] A recent research work attempted to study the RPC incorporated with the RFA obtained from two sources, the first source is from the recycled normal concrete and the second source is from the recycled RPC.[21]

The objectives of this present paper are to examine the effects of exploiting the recycled concrete waste and slag powder as partial substitutes of cement and fine aggregate, respectively, on the workability, mechanical strength and water absorption of RPC. The slag powder replaced a constant amount of 20 % of cement in RPC mixes, while the recycled concrete (RC) varied: dosages of (0, 5, 10, 15, 20, 25 and 30) % in RPC were considered.

## 2 EXPERIMENTAL PART

### *2.1 Materials used*

A typical material composition of RPC comprises cement, fine aggregate, mineral admixtures, steel fibres and a superplasticizer to balance the low water-cement ratio considered in the production of a densely packed system. The following materials are used in this study: ordinary Portland cement (53 grade) conforming to IS 12269: 2013,[22] quartz sand with a particle size of 600–750 μm, used as the filler and fine aggregate, slag powder as the cement substitute and recycled concrete (RC) wastes as the partial alternative for quartz sand. The slag powder (alccofine 1203) was manufactured by Counto Microfine Products Pvt. Ltd. and supplied by commercial vendors. The concrete wastes from the construction and demolition activities were collected, crushed and finely ground to a particle size of 300–750 μ. Brass-coated micro-steel fibres were used and their properties are listed in **Table 1.**

A polycarboxylate-based superplasticizer (PCE) was used and its properties are presented in **Table 2.** The chemical compositions of the materials obtained with an X-ray fluorescence (XRF) analysis are presented in **Table 3.**

**Table 1:** Properties of steel-fibres

| Type | Colour | Length | Diameter | Aspect ratio |
|---|---|---|---|---|
| Straight | Golden yellow | 13 mm | 0.3 mm | 43.3 |

**Table 2:** Properties of the polycarboxylate superplasticizer

| State | Solid content (%) | Solubility | Chloride content | pH value |
|---|---|---|---|---|
| Liquid | 50 % | 100 % | = 0.1 | 6.5–8.5 |

### *2.2 Mix design and sample preparation*

The mix proportions for six RPC mixes incorporating recycled wastes and industrial by-products are given in **Table 4**. To simplify the discussion on the test results, the mixes are designated based on the recycled concrete amounts as RC0, RC5 RC10, RC15, RC20, RC25 and RC30. For instance, RC0 denotes the control RPC mix with 0 % of recycled concrete; RC5 denotes the RPC mix with 5 % of recycled concrete. Each mix includes steel fibres, in the amount of 2 % by weight of cement. The water-cement ratio was 0.3 and the PCE dosage was 2 %. The water-cement ratio, dosage of steel fibres and PCE were constant throughout the study. The effects of the varying content of RC on the workability and strength of the RPC were investigated.

The preparation of RPC samples involves batching, mixing, casting and curing. Firstly, the materials based on the mix proportions for each mix were weigh-batched and mixed using a Hobart laboratory mixer. Initially, the base ingredients of RPC were put together and mixed for about three minutes, then the substitute materials were added and mixed in for about five minutes. The addition of one half of the mixture and PCE was done and the duration of 3 min mixing was done. Similarly, The addition

**Table 3:** Physical and chemical properties of the materials used

| Materials | Physical properties | | Chemical composition (*w*/%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean particle size (μm) | Specific gravity | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2O$ | $K_2O$ | LOI |
| Cement | 15.4 | 3.15 | 19.84 | 6.50 | 4.72 | 60.20 | 3.42 | 3.51 | 0.19 | 1.04 | 0.47 |
| Slag powder | 2.74 | 2.69 | 40.23 | – | 1.92 | 57.20 | – | – | – | 0.41 | 0.12 |
| Quartz sand | 220 | 2.72 | 99.20 | 0.10 | 0.34 | - | – | – | – | – | – |
| Recycled concrete | 325 | 2.54 | 67.15 | 0.84 | 4.05 | 20.18 | 0.78 | – | – | – | 6.85 |

of the other half of water and PCE was done and the duration of 3 min mixing was done. The addition of steel fibers mixing was done for the duration of 5 min. After assuring a uniform distribution of steel fibres without any further delay, the wet RPC mixes were poured into moulds greased with oil and compaction was done by means of vibration for a period not exceeding 15 s. The entire process of mixing and compaction took around 20 min for each mix. After 24 h, the process of demoulding was done for the casted specimens and subjected to the standard water curing at a temperature of 27 ± 3°.

**Table 4:** Mix design of RPC

| Materials | Weight fractions of materials | | | | | | |
|---|---|---|---|---|---|---|---|
| | RC0 | RC5 | RC10 | RC15 | RC20 | RC25 | RC30 |
| Cement | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Slag powder | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Quartz sand | 1 | 0.95 | 0.90 | 0.85 | 0.80 | 0.75 | 0.70 |
| RC | - | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 |

### *2.3 Test methodologies*

The experimental program investigated the workability, compressive strength (after 7 d and 28 d), split-tensile strength and flexural strength. In addition, the durability of the RPC mixes was tested by means of water absorption. The density and slump flow measurements were carried out for each fresh RPC mix right after the mixing process. The compressive strength and split-tensile strength tests were carried out in a 1000 kN compression testing machine (CTM). The flexural strength of rectangular RPC prisms was determined by subjecting the specimens to three-point loading in the testing machine. The specimen details and the specifications are listed in **Table 5**. Triplicate specimens were used for each testing and the average of the test results was reported as the final result with a deviation of less than ± 15 %.

## 3 RESULTS AND DISCUSSION

### *3.1 Density and slump flow*

Workability plays an important role in the design of ultra-high performance concrete because of the self-compacting nature.[11] The flow characteristics of the RPC mixes were studied based on their slump values. The changes in the density and slump flow of each RPC mix were recorded and the results are listed in **Table 6**. The results show an increase in the density with an increase in the RC content up to RC15 and a decrease with further increment in the RC content for RC20, RC25 and RC30. A maximum density of 2580 kg/m$^3$ was attained by RC15 and a minimum of 2475 kg/m$^3$ was noted for RC30. It was revealed that RC15 possesses effective and densely packed RPC when compared with the other RPC mixes.

**Table 6:** Density and slump flow of RPC

| Mix ID | Density (kg/m$^3$) | Slump flow (mm) |
|---|---|---|
| RC0 | 2523 | 135 |
| RC5 | 2536 | 121 |
| RC10 | 2565 | 108 |
| RC15 | 2580 | 88 |
| RC20 | 2554 | 71 |
| RC25 | 2522 | 52 |
| RC30 | 2475 | 47 |

The slump-flow value of RPC decreased with an increase in the content of RC from 135 mm to 47 mm. This implies that the workability of RPC decreased; when increasing the dosage of the quartz sand. A study by Gautham Kishore Reddy et al.[11] revealed that the incorporation of alccofine increased the workability of UHPC. This denoted the mixed effect of the slag powder and RC on increasing and decreasing the workability of RPC. In addition, the influence of recycled concrete on the workability of RPC was observed to be remarkable.

### *3.2 Strength of RPC*

The average values of the failure load of at least three tested specimens were obtained for the compressive strength, split-tensile strength and flexural strength and listed in **Table 7**. When increasing the RC content about 15 %, the compressive strength at 7 d and 28 d is increased. When increasing the RC content about 20%, the compressive strength at 7 d and 28 d is decreased. A similar trend in the variation was observed for both the split-tensile strength and flexural strength of RPC.

#### *3.2.1 Compressive strength*

The control RPC mix RC0 attained compressive-strength values of 98.14 MPa and 118.72 MPa after 7 d and 28 d, respectively, the split-tensile strength of 10.40 MPa and flexural strength of 34.12 MPa. The maximum compressive strength of 134.25 MPa was exhib-

**Table 5:** Specification and specimen details

| Tests | Testing time | Standards | Specimen type and size (mm) |
|---|---|---|---|
| Slump flow | – | IS 1199:2018 [23] | Fresh mix |
| Compressive strength | 7 d and 28 d | ASTM C 109 [24] | Cube: 50 × 50 × 50 |
| Flexural strength | 28 d | ASTM C293 [25] | Rectangular prism: 160 × 40 × 40 |
| Split-tensile strength | 28 d | ASTM C 496 [26] | Cylinder: 100 × 200 |
| Water absorption | 28 d | ASTM C 642 [27] | Cube: 50 × 50 × 50 |

ited by RC15. **Figure 1** graphically represents the variation in the compressive strength of RPC. It was noted that after 7 d and 28 d, the strength showed a similar variation. The rate of change in the compressive strength with respect to the age of curing was significant for RC0, RC5, RC10 and RC15 when compared with RC20, RC25 and RC30.

**Table 7:** Compressive strength, split-tensile strength, flexural strength, MPa

| Mix ID | Compressive strength (MPa) | | Split-tensile strength (MPa) | Flexural strength (MPa) |
|---|---|---|---|---|
| | 7 d | 28 d | | |
| RC0 | 98.14 | 118.72 | 10.40 | 24.12 |
| RC5 | 105.06 | 126.33 | 11.85 | 27.75 |
| RC10 | 112.12 | 130.56 | 13.22 | 32.64 |
| RC15 | 118.04 | 134.25 | 15.05 | 34.12 |
| RC20 | 101.48 | 110.28 | 12.14 | 26.06 |
| RC25 | 94.88 | 102.31 | 10.02 | 22.18 |
| RC30 | 89.39 | 97.05 | 8.53 | 18.22 |

The elimination of coarse aggregates and use of fine materials in RPC enhanced the homogeneity of the packed materials in each RPC mix. This homogeneity of the RPC matrix, which contributes to stronger bonding between the materials, is one of the major reasons for the strength enhancement up to the 15 % replacement. About a 13 % increase in the compressive strength was exhibited by RC15 when compared with that of RC0. Furthermore, the slag powder acting as the supplementary cementitious material contributes to a higher production of calcium silicate hydrates (C-S-H), which was confirmed by a higher content of CaO (57.20 %) in the slag powder, being almost similar to that of cement (60.20 %).

*3.2.2 Split-tensile strength*

The resulting 28-day split-tensile strength of the RPC specimens is graphically shown in **Figure 2**. Initially the increment of tensile strength occurred and attained its maximum split-tensile strength of 15.05MPa, which was 44.7 % greater than that of the control RC0 specimens. When the RC content exceeded 15 % in RPC, the tensile strength decreased. However, RC20 exhibited a greater

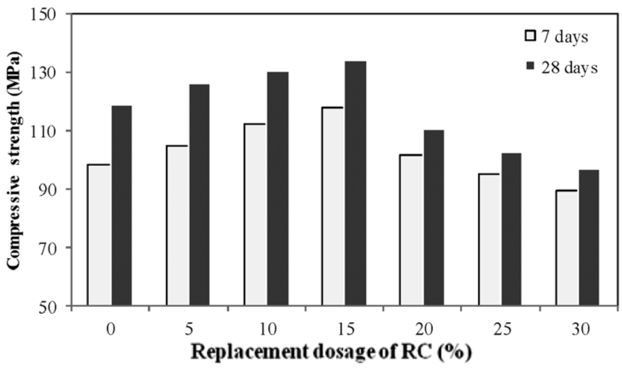


**Figure 1:** Compressive-strength test results

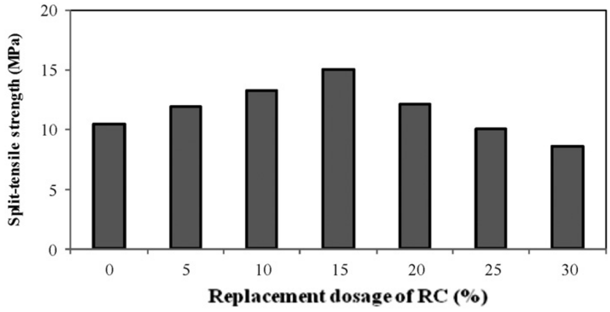


**Figure 2:** Split-tensile strength test results

strength compared to RC0. A minimum split-tensile strength of 8.53 MPa was noted for RC25, which allowed a greater replacement of quartz sand by RC.

It is known that concrete is brittle, breaking into pieces when subjected to compression, tension or flexural loading. This explains the poor strength behaviour of concrete, especially under tensile and flexural loads. To make a control in crack formation and to minimize the brittleness, steel fibres were incorporated in RPC. This resulted in a ductile failure of the RPC specimens without any sudden failure.[28] Furthermore, the bonding of steel fibres with the RPC matrix was comparatively significant at 20 % slag powder and 15 % RC incorporation in RPC.

*3.2.3 Flexural strength*

The obtained test results for the flexural strength of the RPC specimens at the age of 28 d are shown in **Figure 3**. It was observed that the flexural strength also increased with the increase in the RC content up to 15 % and decreased at 20 % and greater levels of the replacement. A maximum flexural strength of 34.12 MPa and minimum flexural strength of 18.22 MPa were exhibited by RC15 and RC25, respectively. Similar trends in the variation of the compressive strength and split-tensile strength were observed in the flexural-strength results. Also, a maximum increase in the flexural strength of 41.5 % was noted for RC15 compared to the flexural strength of RC0. This revealed that the mix composition of RC15 was more efficient in enhancing the mechanical strength of the RPC incorporating slag powder and RC under the normal curing conditions than that of the control mix.

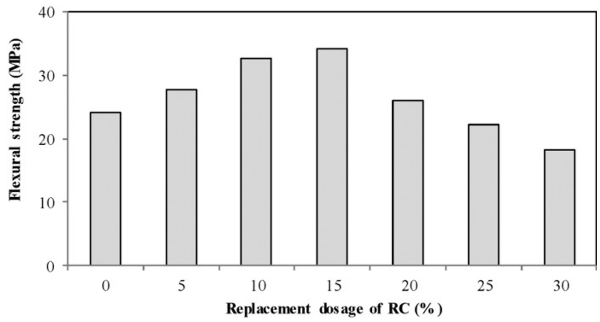


**Figure 3:** Flexural-strength test results

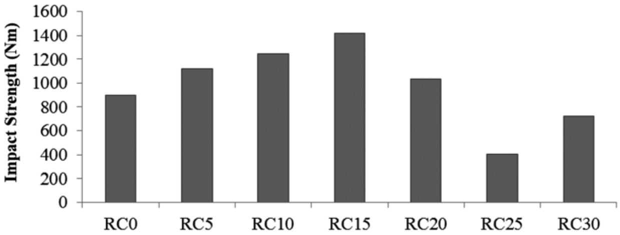


**Figure 4:** Impact strength test results

The addition of 2 % of micro-steel fibres has great influence on improving the flexural strength by providing ductility and increasing the energy absorption capacity of RPC. The role of steel fibres also includes the ability to resist and bridge the cracks when subjected to flexural loading. The research work by Kannan Rajkumar et al.[2] explained that RPC specimens without fibres result in a brittle failure under increasing flexural loading. The ductile failure pattern observed during the flexural strength testing confirmed the ductility provided by the inclusion of steel fibres in RPC.

*3.2.4 Impact strength*

For the mix RC15, the highest impact strength value was obtained which has 15 % replacement of RC. The impact value of RC15 mix is 57 % more than control mix RC0. And the second mix which has the highest impact value is RC10 mix. It has the impact value 38% more than control mix RC0. For the mix RC25, the lowest impact strength value was obtained which has 25 % replacement of RC. The impact value of RC25 mix is 55 % less than control mix RC0. And the second mix which has the lowest impact value is RC30 mix. It has the impact value 20 % less than control mix RC0. From the test results, it is observed that the addition of RC is more than 15 %, the impact strength is decreased because of the loose packed concrete mixture. The impact strength values are displayed in **Figure 4**.

*3.2.5 Bond strength*

From the **Figure 5**, it is observed that the highest bond strength was obtained for the mix RC10. The bond strength for the mix RC10 is 9 % more than the control mix RC0. The reason for the maximum bond strength was the particle size distribution of RC with optimum content 10 %. This leads to form the better bond between

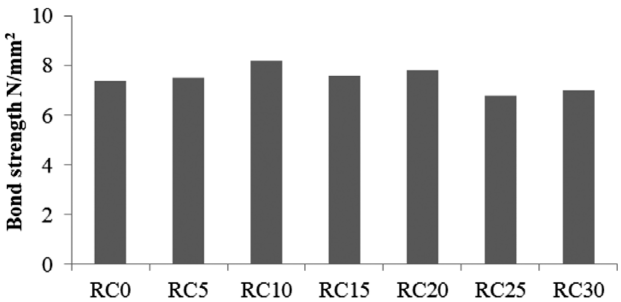


**Figure 5:** Bond strength test results

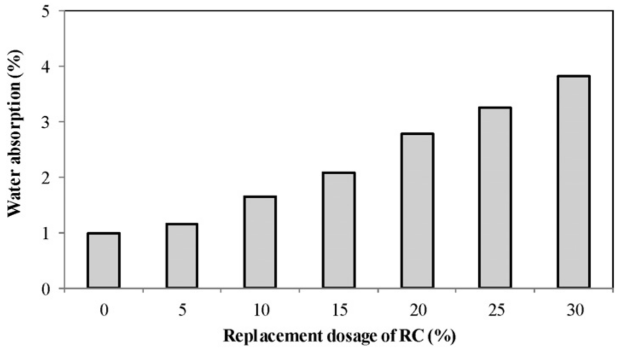


**Figure 6:** Water absorption test results

the concrete and the bar. Up to 10 % replacement of RC, the mechanical interlocking characteristic of concrete mix was enhanced. After that 10 % RC replacement, the bond strength was reduced than the normal mix.

*3.2.6 Water absorption*

The results of the water absorption test carried out on the 28th day on cured RPC cubical specimens were plotted graphically and shown in **Figure 6**. From the figure, it is known that the water absorption increases with an increase in the content of RC. The control mix RC0 showed about 0.98 % water absorption, which increased linearly in a gradual manner and attained a maximum of 3.83 %. Because of the usage of fine recycled concrete, the water absorption is increased in RPC was reported by a few past studies.[21] This was because of the presence of adhered cement matrix to the sand surface.

The crushed and finely ground particles of RC, however, possess inter-particle voids in the interface between the cement and sand particles. This allows the RPC to absorb water, retain it in minute voids and increase the water absorption. However, the water absorption of the RPC mixes with a maximum of 30 % of the RC substitution was found to be less than 4 %. This was mainly due to the particle-size distribution and particle-packing efficiency of the material mixture. Furthermore, the role of the superplasticizer is remarkable, balancing the increasing water demand and ensuring the homogeneity while its potential in packing the materials results in a self-compacting nature of the RPC material mix.

*3.2.7 Sorptivity*

From the **Figure 7**, it is known that the least value of sorptivity was obtained for 20 % RC replacement concrete mix. For the addition of more than 20 % RC, the concrete mix forms water channels and internal voids and increases sorptivity. The reason behind this is the closed particle efficiency and the particle size distribution of the replacement material RC. The same trend was obtained for both 15 min and 30 min sorptivity values.

*3.2.8 Porosity*

The minimum value of porosity was obtained for 20 % RC replacement concrete mix. The pore diameter is reduced and ITZ is strengthened because of the parti-

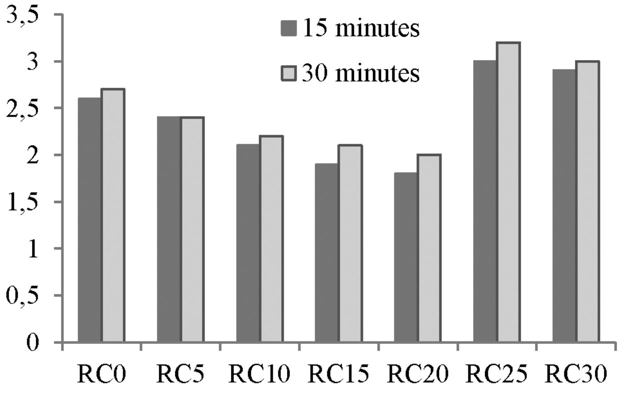


**Figure 7:** Sorptivity test results in $10^{-2}$ mm/$\sqrt{s}$

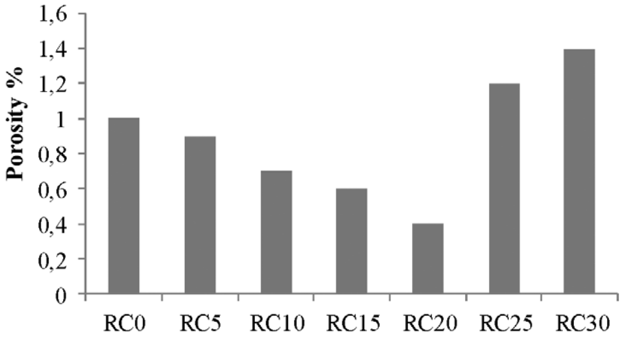


**Figure 8:** Porosity test results

cle size distribution of the replacement material. For the addition of more than 20 % RC, the bleeding occurs in concrete mix which creates internal voids and increases porosity. This is because of loosely packed concrete of RC concrete. The porosity values are displayed in **Figure 8**.

*3.2.9 Acid Attack*

From **Figure 9**, it is indicated that the mix RC5 has the lowest loss of strength value in both HCL and $H_2SO_4$ attack. For the mix RC5, the loss of strength is 82 % less than the normal concrete for HCL acid attack specimen and 34 % less for H2SO4 acid attack specimen. The densified packing capacity of RC replacement concrete generates very denser concrete that prevents the entry of calcium sulphate salts, calcium chloride salts. This leads to reduce the concrete degradation. For the mix RC30, the loss of strength is 16 % more than the normal concrete for HCL acid attack specimen and 17% more for $H_2SO_4$ acid attack specimen. When the addition of RC is beyond 20 %, this will lead to form more free water and bleeding and increase the strength loss in concrete mix.

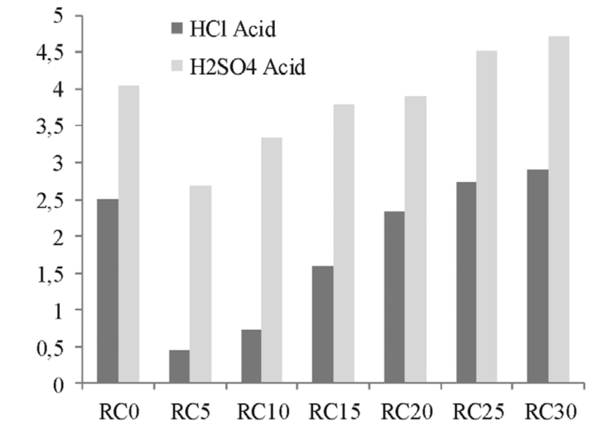


**Figure 9:** Percentage loss of strength due to Acid Attack

## 4 CONCLUSIONS

Based on the results and findings of the current experimental study, following conclusions are drawn:

- The utilization of ultrafine slag powder and fine recycled concrete have decreased the workability and improved the mechanical strength of RPC under normal curing condition when added in optimum proportion. In addition, the maximum density and the strength properties are noted to be highly correlated. This in turn reveals that the particle packing of the RPC ingredients under study, bonding behaviour of the fibers and concrete matrix and the low water-cement ratio considered in the study is the governing factors in the strength development of RPC. A similar strength performance was exhibited by the RPC specimens of different mix combinations under compression, tension and flexural strength testing.
- The addition of micro-steel fibers by 2 % was effective toenhance the mechanical properties of RPC. This was confirmed by the ductile failure pattern of RPC under the application of compressive, flexural and tensile loading conditions. The higher CaO content of the slag powder obtained from the XRF analysis described the role of the fine slag powder as the supplementary cementitious material and formation of C-S-H during the hydration reaction. The addition of RC is more than 15 %, the impact strength is decreased because of the loose packed concrete mixture. The bond strength is enhanced up to 10% RC replacement.
- Recycled concrete possess inter particle voids in the interface between the cement and silica particles which absorbs and retains the water during mixing. This in turn resulted in decreased slump flow and increased water absorption with increasing substitution of recycled concrete. The better results are obtained for sorptivity and porosity values up to 20 % RC replacement. The addition of RC is beyond 20 %, this will lead to form more free water and bleeding and increase the strength loss in concrete mix. However the addition of ultra-fine slag powder in RPC has a significant effect in increasing the workability. It leads the RPC to possess mixed outcome in case of workability and the strength properties with addition of slag powder and recycled concrete.

## 5 REFERENCES

[1] Katrin Habel, Marco Viviani, Emmanuel Denarie, Eugen Bruhwiler, Development of the mechanical properties of ultra-high performance fiber reinforced concrete (UHPFRC), Cement and Concrete Research, 36 (**2016**) 1, 1362–1370, doi:10.1016/j.cemconres.2006.03.009

[2] P. R. Kannan Rajkumar, Durga Prasad Mathangi, C. Sudha, M. Neelamegam, Experimental Investigation of Reactive Powder Concrete Exposed to Elevated Temperature, Construction and Building Materials, 261 (**2020**), 119593, doi:10.1016/j.conbuildmat.2020.119593

[3] H. Yazici, The effect of curing condition on compressive strength of ultra-high strength concrete with high volume mineral admixtures, Building and Environment, 42 (**2007**) 5, 2083–2089, doi:10.1016/j.buildenv.2006.03.013

[4] M. Alkaysi, S. El-Tawil, Z. Liu, W. Hansen, Effects of silica powder and cement type on durability of ultra-high performance concrete (UHPC), Cement and Concrete Composites, 66 (**2016**), 47–56, doi:10.21838/uhpc.2016.87

[5] E. Ghafari, H. Costa, E. Júlio, Critical review on eco-efficient ultra-high performance concrete enhanced with nano-materials, Construction and Building Materials, 101 (**2015**), 201–208, doi:10.1016/j.conbuildmat.2015.10.066

[6] H. Yazici, M. Y. Yardimci, H. Yigiter, S. Aydin, S. Turkel, Mechanical properties of reactive powder concrete containing high volumes of ground granulated blast furnace slag, Cement and Concrete Composites, 32 (**2010**), 639–648, doi:10.1016/j.conbuildmat.2015.10.066

[7] A. Rao, K. N. Jha, S. Misra, Use of aggregates from recycled construction and demolition waste in concrete, Resources, Conservation and Recycling, 50 (**2007**), 71–81, doi:10.1016/j.resconrec.2006.05.010

[8] Sukhoon Pyo, Hyeong-Ki Kim, Fresh and hardened properties of ultra-high performance concrete incorporating coal bottom ash and slag powder, Construction and Building Materials, 131 (**2017**), 459–466, doi:10.1016/j.conbuildmat.2016.10.109

[9] N. A. Soliman, A. Tagnit-Hamou, Development of ultra-high-performance concrete using glass powder – Towards ecofriendly concrete, Construction and Building Materials, 125 (**2016**), 600–612, doi:10.1016/j.conbuildmat.2016.08.073

[10] P. Rougeau, B. Borys, Ultra high performance concrete with ultrafine particles other than silica fume, Proceedings of the International Symposium on Ultra High Performance Concrete, Kassel, Germany 2004, 213–226, doi:10.3390/en14248291

[11] G. Gautham Kishore Reddy, P. Ramadoss, Influence of alccofine incorporation on the mechanical behavior of ultra-high performance concrete (UHPC), Materials Today Proceedings, 33 (**2015**), 789–797, doi:10.1016/j.matpr.2020.06.180

[12] J. Sim, C. Park, Compressive strength and resistance to chloride ion penetration and carbonation of recycled aggregate concrete with varying amount of fly ash and fine recycled aggregate, Waste Management, 31 (**2011**), 2352–2360, doi:10.1016/j.wasman.2011.06.014

[13] C. S. Poon, D. Chan, The use of recycled aggregate in concrete in Hong Kong, Resources, Conservation and Recycling, 50 (**2007**), 293–305, doi:10.1016/j.resconrec.2006.06.005

[14] J. M. Khatib, Properties of concrete incorporating fine recycled aggregate, Cement and Concrete Research, 35 (**2005**), 763–769, doi:j.cemconres.2004.06.017

[15] H. Zhang, T. Ji, X. Zeng, Z. Yang, X. Lin, Y. Liang, Mechanical behavior of ultrahigh performance concrete (UHPC) using recycled fine aggregate cured under different conditions and the mechanism based on integrated microstructural parameters, Construction and Building Materials, 192 (**2018**), 489–507, doi:10.1016/j.conbuildmat.2018.10.117

[16] Y. Kasai, Guidelines and the present state of the reuse of demolished concrete in Japan, RILEM Proceedings, CHAPMAN & HALL, 1993, 93

[17] L. Evangelista, J. De Brito, Concrete with fine recycled aggregates: a review, European Journal of Environment and Civil Engineering, 18 (**2014**), 129–172, doi:10.1080/19648189.2013.851038

[18] L. Evangelista, J. de Brito, Mechanical behaviour of concrete made with fine recycled concrete aggregates, Cement and Concrete Composites, 29 (**2007**), 397–401, doi:10.1016/j.cemconcomp.2006.12.004

[19] J. Geng, J. Sun, Characteristics of the carbonation resistance of recycled fine aggregate concrete, Construction and Building Materials, 49 (**2013**), 814–820, doi:10.1016/j.conbuildmat.2013.08.090

[20] C. J. Zega, Á. A. Di Maio, Use of recycled fine aggregate in concretes with durable requirements, Waste Management, 31 (**2011**), 2336–2340, 10.1016/j.wasman.2011.06.011

[21] Hammad Salahuddin, Liaqat Ali Qureshi, Adnan Nawaz, Syed Safdar Raza, Effect of recycled fine aggregates on performance of Reactive Powder Concrete, Construction and Building Materials, 243 (**2011**), 118223, doi:10.1016/j.conbuildmat.2020.118223

[22] IS 12269: 2013 – Indian Standard Ordinary Portland Cement, 53 Grade – Specification, Bureau of Indian Standards, New Delhi, India

[23] IS 1199: 2018 – Fresh Concrete – Methods of Sampling, Testing and Analysis, Bureau of Indian Standards, New Delhi, India

[24] ASTM C 109/C 109M: 2002 – Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), ASTM International, West Conshohocken, United States

[25] ASTM C 293: 2002 – Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading), ASTM International, West Conshohocken, United States

[26] ASTM C 496/C 496M: 2004 – Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, United States

[27] ASTM C 642: 1997 – Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, West Conshohocken, United States

[28] M. Vigneshwari, K. Arunachalam, A. Angayarkanni, Replacement of silica fume with thermally treated rice husk ash in Reactive Powder Concrete, Journal of Cleaner Production, 188 (**2018**), 264–277, doi:10.1016/j.jclepro.2018.04.008