# Mechanical and Microstructural Properties of Self-Compacting Concrete by Partial Replacement of Cement with Marble Powder and Sand with Rice Husk Ash

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***Abstract***
*Industrialization, on the one hand, eased mankind's work while on the other hand, it has some drawbacks, i.e., the use of cement widely pollutes the environment with $CO_2$ emission, the usage of cement and fine aggregate (FA) leads to scarcity of their natural resources and the solid waste from industries which occupies land in the form of landfills. To reduce the use of natural resources and prevent the environment from various industrial wastes, the replacement of the constituents of concrete is eagerly necessary. The central theme of this investigation was the use of solid waste (industrial) in concrete, i.e., the substitution of some portion of cement by marble powder (MP) and sand by Rice Husk Ash (RHA), and their fresh and mechanical characteristics were examined. Five types of mixes were prepared, including the control mix without any incorporation. In the rest four types of mixes, cement was replaced by 0, 10, 20, and 30% MP while sand was replaced only with 20% RHA by weight. Fresh and hardened self-compacting concrete (SCC) properties for all the mixes have been evaluated. Fresh concrete properties (workability, density, and air content, and hardened properties (compressive, splitting tensile and flexural strength) were investigated. The workability and concrete density were enhanced with the rise in the content of MP and RHA. Compressive, splitting tensile and flexural strength, were significantly improved at a mix proportion having 20% MP and 20% RHA substituted by cement and sand, respectively. However, no additional improvements were identified in the hardened concrete characteristics when the sand replaced by RHA was 20%, and the substitution of cement increased up to 30% of MP. Accordingly, industrial waste material can play a significant part in replacing part of the concrete, acquiring eco-friendly concrete, and with enhanced mechanical characteristics, it may also significantly decrease ecological pollution.*

***Keywords:*** SCC, industrial waste, MP, RHA, fresh properties, mechanical properties.

## Introduction

Concrete, commonly called composite material, is varyingly utilized worldwide in almost all construction industries. It comprises of cement,

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fine aggregate, coarse aggregate (CA), and water. In addition to all these constituents, admixtures are used to attain a suitable mix design. Concrete main constituent is cement, which acts as a binder. Besides several advantages, its extensive utilization has several drawbacks, i.e., around 7% of $CO_2$ emission in the atmosphere is due to cement (Imbabi, Carrigan, & McKenna, 2012). The manufacturing of 1 ton of cement requires 4GJ energy. In response, it emits 1 ton of $CO_2$ into the atmosphere (Mansoor et al., 2018). Concrete can attain any shape depending on the mold used (Zain, Safiuddin, & Mahmud, 2000). The whole weight of concrete is mainly due to the aggregate utilized in it, i.e., 60 to 70% of the weight of concrete is covered by aggregate (Devi & Gnanavel, 2014, Al-Jabri et al., 2009). Modern industrialization provides ease to mankind, resulting in several aspects that create problems for them and nature, i.e., solid waste production, reduction in natural resources, atmospheric pollution, etc. (Berndt, 2009, Xiao et al., 2015). In order to limit and handle these problems, several types of research have been done to overcome this problem. Cement was replaced effectively by pozzolanic material for a more extended period around the globe (Benzaid & Benmarce, 2017).

Specific customization of normal concrete results in a type of concrete called SCC. In this study In SCC, the flow is mainly due to the self-weight of the concrete. It does not need any vibrator for its flow. It acquires the shape of the mold very quickly without bleeding and segregation. The requirement of SCC is increased in modern construction (Gill & Siddique, 2017). All the SCC ingredients are the same as that of ordinary concrete, apart from the difference in the ratio of FA and CA. In SCC, the amount of FA is more than that of CA, while for ordinary concrete, it is otherwise. SCC is used widely nowadays everywhere around the world because of its several advantages over ordinary concrete, i.e., it is most efficient, it is highly workable, it gives high strength, it requires less workforce and reduces the construction time (Diederich et al., 2013). SCC is more economical than ordinary concrete because cement is too costly. Usually, the workability of SCC is enhanced by introducing filler materials into it (Valcuende et al., 2012). The generation of solid wastes from various industries and environmental problems, including a reduction in natural resources and emission of $CO_2$ from cement making, can be reduced if some of the concrete's constituents are replaced by suitable industrial wastes. Many researchers have replaced various constituents of concrete with industrial wastes in various percentages. The use of MP seems to be an excellent replacement for cement, surrounding environmental balance, and the economy as a whole (Kumar & Dhaka, 2016).

MP is acquired from the marble tiles cutting and grinding process. During this process, 40 to 50% of marble is wasted in MP form. The workability of SCC is increased while the fresh concrete density is decreased while substituting MP partially with cement (Boukhelkhal et al., 2016, Praveenkumar & Murugesan, 2017). Cement, when swapped by MP in an amount 5 to 30% enhanced fresh concrete properties (Gesoğlu et al., 2012). By substituting cement with MP, the workability is increased, the fresh concrete density is reduced, and the compressive strength is enhanced up to 20% of substituting cement by MP (Alyousef et al., 2018). By the substitution of cement with 0 to 25% of MP and 25% fly ash, the compressive strength rises to 10% of substituted MP (Pala et al., 2015). MP is substituted with cement in percent from 0 to 20 % with an increment of 5% splitting tensile strength boosted up to 15% of MP substitution, and it starts reduction at 20% of MP substitution (Praveenkumar & Murugesan, 2017). The swapping of cement by MP implies the enhancement of splitting tensile strength. The highest strength enhancement was reported at 15% substitution of cement by MP whereas, beyond this percentage, the strength reduces (Ulubeyli & Artir, 2015).

RHA is acquired from burning rice husk in a blast furnace, which is obtained from the rice industries. If RHA is used as a substituent for FA, then after burning in the blast furnace, the residue should not be passed through the grinding process and should be left as granular (Khan et al., 2012). From the chemical composition, it is concluded that RHA has 85% of silica content, which makes it the super pozzolan (Chindaprasirt et al., 2009). In SCC, the other important material after the cement is sand possessing a rough texture and is used a lot in concrete production, thus causing the depletion of its natural resources. Many researchers have already identified its replacements in concrete to limit its usage and overcome its depletion in the future, and many researchers are seeking to find additional material that could replace it in concrete. Some researchers have utilized RHA to substitute sand in concrete (Chopra & Siddique, 2015). RHA replaces FA in 0%, 10%, 20%, 30%, 40%, and 50%, and the results indicate that the fresh properties of concrete are enhanced by up to 20% of RHA's substitution of sand (Samantaray et al., 2016). The workability increases when RHA swaps sand up to 25% in replacing sand by RHA in a range from 0 to 30% with a 5% increment, while with a further increase in RHA%, the workability starts decreasing (Safiuddin et al., 2010). The fresh concrete density is decreased while replacing cement with metakaolin and sand by RHA up to 10% (Gill & Siddique, 2017).

The air content decreases in SCC when cement is substituted by RHA in the range of 0 to 30% with a 10% increment (De Sensale, 2006). With the replacement of sand by RHA in a range of 0 to 25% with a 5% increment, enhancement is found in the compressive strength of the SCC up to 15% of MP, while beyond this percentage, the strength is reduced (Obilade, 2014). During the substitution of sand by RHA in a range of 0 to 50% with the increment of 12.5%, up to 37.5% of increase in the flexural strength was found, while beyond this percentage, the strength decreased (Kunchariyakun et al., 2015). Substituting the sand with RHA in a range of 0 to 20% with an increment of 5%, the splitting tensile strength boosted up to 10% while beyond this percentage, the reduction in the strength was recorded (Nithyambigai, 2015). SCC acquires a high amount of powder content thus, using only cement makes it costly. Other fillers need to be used in SCC instead of cement to make it economical. Similarly, abundant aggregate usage is causing the depletion of its reservoirs, so an alternative for aggregate, especially for FA, is advantageous to overcome its depletion (Wu et al., 2010). There is much literature on the MP and RHA separately or in combination with other materials; this work explores the combined impact on fresh and hardenend properties of SCC when MP and RHA partially substitute cement and sand.

## Objective

Industries produce large amounts of solid waste, acquiring precious land for damping. The ultimate utilization of these waste materials in SCC will limit the environmental issues and result in economic and value-added concrete. Solid wastes from various industries, i.e., MP and RHA, are used a lot by different researchers in their research, but as far as the author's knowledge is concerned, there is no work done on the combined usage of this solid waste in concrete.

This research intends to explore fresh properties and hardened properties of SCC by substituting cement and sand partially with MP and RHA, respectively. Following are the key objectives of this research.

- To explore the impact on fresh properties (workability, density and air content) of SCC, when MP and RHA partly substitute cement and sand, respectively.
- To explore the impact on hardened properties (compressive, splitting tensile and flexural strength) of SCC, when MP and RHA partly substitute cement and sand, respectively.

- To carry out microstructure analysis, i.e., XRD and SEM.

## Materials

The aggregate of sizes up to 16 mm was obtained from the local suppliers. MP was also obtained from the local supplier with a size range of 7 to 50 μm. MP was utilized as a cement substitution as a filler/binder. Rice husk was procured and converted into ash in the furnace. RHA was used as a sand substitution. Cement (Type-1) used in ths research work was acquired from local supplier. Table 1 displays the physical properties of aggregates and MP utilized in this work. Figure 1 displays the MP and RHA. Table 2 displays the chemical properties of cement, MP, and RHA.

***Table 1***
*Physical properties of aggregates and MP*

| Material | Size | Specific gravity | Water absorption (%) |
|---|---|---|---|
| FA | 0-4 mm | 2.89 | 0.83 |
| MP | 7-50 μm | 2.67 | 0.38 |
| CA | 4-16 mm | 2.68 | 0.80 |

***Table 2***
*Chemical properties of cement, MP and RHA*

| Constituents | Chemical composition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $Na_2O$ | $SO_3$ | $Fe_2O_3$ | $SiO_2$ | MgO | $K_2O$ | CaO | $Al_2O_3$ |
| Cement | 0.90 | 3.45 | 3.98 | 20.79 | 1.51 | 1.40 | 62.17 | 5.80 |
| MP | 1.03 | 1.20 | 0.38 | 3.01 | 0.51 | 37.35 | 55.29 | 1.23 |
| RHA | 0.08 | 0.88 | 0.08 | 93.36 | 0.08 | 1.28 | 1.08 | 0.38 |


**Figure 1: MP (left) and RHA (right)**

## Experimental program

*Concrete mix design*

For the control mix, various trials were conducted to acquire 28 days compressive strength of 20 MPa, having a slump flow of at least 650 mm. After finalizing the mix design, five mixes, including the control mix, were prepared with cement replaced by MP with 0%, 10%, 20%, and 30% and sand replaced by RHA with 0% and 20%. Mix design details are mentioned in Table 3.

*Fresh properties of concrete*

Fresh concrete properties (workability, fresh concrete density, and air content) were investigated. The workability includes slump flow, J-ring, L-box, , and V-funnel tests. ASTM and EFNARC (EFNARC, 2002) standards were used for all the workability tests, while for fresh concrete density and air content, ASTM C138/C138M (ASTM C138/C138 M, 2017) standards were used.

***Table 3***
*Mix design proportions*

| **Mix** | **M0R0** | **M0R20** | **M10R20** | **M20R20** | **M30R20** |
|---|---|---|---|---|---|
| W/b | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 |
| Fillers MP (kg / $m^3$) | 120 | 120 | 120 | 120 | 120 |
| Cement (kg / $m^3$) | 450 | 450 | 405 | 360 | 315 |
| MP (kg / $m^3$) | 0 | 0 | 45 | 90 | 135 |
| Water (kg / $m^3$) | 239.4 | 239.4 | 239.4 | 239.4 | 239.4 |
| FA (kg / m3) | 950 | 760 | 760 | 760 | 760 |
| RHA (kg / $m^3$) | 0 | 190 | 190 | 190 | 190 |
| CA (kg / $m^3$) | 700 | 700 | 700 | 700 | 700 |
| Super-plasticizer (kg / $m^3$) | 10.26 | 10.26 | 10.26 | 10.26 | 10.26 |

*Mechanical properties*

The mechanical properties (compressive, splitting tensile and flexural strength) of concrete, were investigated. A 75 mm diameter and 150 mm height cylindrical specimens were casted for compressive and splitting tensile strength test as per ASTM C192/C192M (ASTM C192/C192 M 16a, 2016). Wet curying of the samples were done for 7 and 28 days. Three samples of each mix were tested for compressive strength and splitting tensile strength as per ASTM C39/C39M (ASTM C39/C39 M, 2018) and ASTM C469/C469M (ASTM C496/C496 M, 2017). For flexural strength assessment, prisms (100 mm × 100 mm × 350 mm) were casted as per ASTM standard C192/C192M (ASTM C192/C192 M 16a, 2016). Three samples of each mix were tested at 7 and 28 days of curing age under a 4-point bending test mechanism (as shown in Figure 2) as per ASTM standard C78/C78M (ASTM C78/C78 M, 2018).

***Table 4***
*Fresh properties of concrete*

| Mix | Slump flow (mm) | J-ring flow (mm) | V-funnel (s) | L-box value | Density (kg/m$^3$) | Air content (%) |
|---|---|---|---|---|---|---|
| M0R0 | 705 | 691 | 8.5 | 0.88 | 2428 | 3.42 |
| M0R20 | 714 | 694 | 8.1 | 0.90 | 2424 | 2.91 |
| M10R20 | 719 | 699 | 7.5 | 0.94 | 2418 | 2.52 |
| M20R20 | 727 | 702 | 6.9 | 0.96 | 2411 | 2.26 |
| M30R20 | 735 | 707 | 6.2 | 0.99 | 2403 | 1.9 |

**Figure 2: Flexural strength test setup**

*Microstructure analysis*

Microstructure analysis, including the morphology, framework, and porosity of selected mixes was performed through scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis. For XRD and SEM analysis, a piece of 2 to 4 mm each in size was taken from the compressive strength cylinders tested at 28 days of curing for M0R0 and M20R20. The sample specimen was dipped in acetone to end the hydration reaction and grounded for XRD and SEM analysis.

## Results and discussion

*Fresh mix properties*

Examining fresh mix properties includes workability, fresh concrete density, and air content. Workability was enhanced while the fresh mix density and air content were decreased with the rise in the content of MP and RHA. The reduction in the density and air content is because the substituted materials in SCC have less specific gravity and low densities. While investigating the fresh properties of the concrete, the density and air content decrease with the addition of the substitutive MP by cement, i.e., from 5 to 30% with an increment of 10 (Gesoğlu et al., 2012). In previous research, the sand was replaced from 0 to 10% by RHA, and concrete density and air content were reduced with a percent increase of RHA (Gill & Siddique, 2017). Fresh concrete properties are listed in table 5. The slump and J-ring flow enhanced with the rise in the percent of MP and RHA. Utilizing too fine and less viscous materials in SCC enhances the slump and J-ring flow. With the increase in the percent of substitutive materials, i.e., MP and RHA, there is an increase observed in the blocking ratio from the L-box test.

The increase in the blocking ratio is due to the usage of less viscous material in concrete. The results from V-funnel showed that there is a decreased time duration of escaping of concrete from the V-funnel. The decrease in the time for V-funnel is due to the use of less dense materials in concrete. Previous study shows that cement substituted by MP in a range of 150kg/m$^3$ to 350kg/m$^3$ improved the workability as the percent of MP increased (Tayeb et al., 2011). The concrete workability is enhanced due to the addition of the substituted MP by cement (Sharifi et al., 2015). Figure 3 expresses the slump flow as well as the L-box test.

**Figure 3: Slump flow and L-box test**

*Hardened properties*

For the assessment of hardened concrete properties, all mixes were cured for 7 and 28 days. Tests results for 7 and 28 days strength for all mixes are given in table 5.

*Compressive strength*

An average of three samples were taken for each mix at the curing age of 7 and 28 days for compressive strength as per ASTM standard C39/C39M. The results obtained for compressive strength of all the mixes at 7 and 28 days strength are tabulated in table 5. The results dipicts that the compressive strength enhanced significantly with rise in the percentage of MP and RHA. The enhancement in the compressive strength due to rise in the percentage of MP is such that it reaches maximum strength at the mix, having 20% of MP and 20% RHA substituted by cement and sand, respectively. The total increase in the M20R20 mix with the control mix (M0R0) is 13% at 28 days strength. Being of a filler nature, MP reduces pores in the concrete which is the main reason for the enhancement of compressive strength of mix M20R20 compared with the control mix (M0R0) (Alyousef et al., 2018). Also, a previous study demonstrates that the compressive strength of concrete enhances due to the inclusion of MP and RHA up to a certain amount. The compressive strength is enhanced if sand is 20% swapped by RHA due to the pozzolanic action of RHA (Madandoust et al., 2011, Zerbino et al., 2011). Compressive strength test results of all the mixes are expressed in Figure 4.

***Table 1***
*Mechanical properties of concrete mixes*

| Mix | Compressive strength (MPa) | | Splitting tensile strength (MPa) | | Flexural strength (MPa) | |
|---|---|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days | 7 days | 28 days |
| M0R0 | 17.50 | 28.12 | 2.92 | 3.50 | 3.90 | 4.73 |
| M0R20 | 17.70 | 31.25 | 2.98 | 3.72 | 4.06 | 4.99 |
| M10R20 | 18.35 | 31.90 | 3.06 | 3.87 | 4.00 | 4.81 |
| M20R20 | 18.55 | 32.15 | 3.19 | 4.17 | 3.92 | 4.75 |
| M30R20 | 18.53 | 28.21 | 2.84 | 3.39 | 3.79 | 4.66 |

*Splitting tensile strength*

An average of three samples were taken for each mix at the curing age of 7 and 28 days for split tensile strength as per ASTM standard C469/C469M. The results obtained for split tensile strength of all the mixes at 7 and 28 days strength are tabulated in table 5.

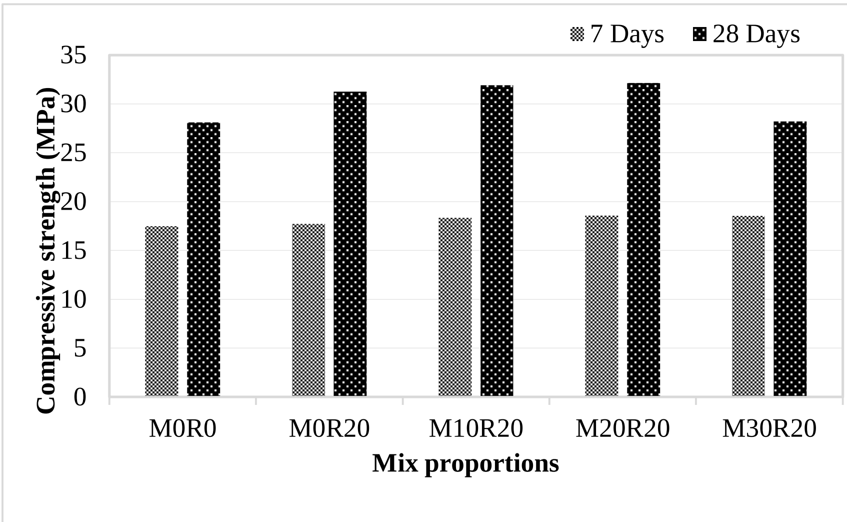


**Figure 4: Compressive strength of concrete mixes**

A substantial increase is found in the splitting tensile strength of concrete with the rise in the percentage of MP and RHA, and maximum splitting tensile strength is gained at a mix having 20% of MP, and 20% RHA replaced by cement and sand, respectively, i.e., M20R20 beyond this mix decrease found in the strength as MP approaching toward 30% replacement. The peak enhancement in splitting tensile strength at mix M20R20 at 28 days is 16% compared to that of control mix. Figure 5 expresses the results for splitting tensile strength. The increase in split tensile strength could be attributed to the reaction of MP and RHA with free $Ca(OH)_2$ to generate calcium silicate hydrates and enhance the quantity of binders, increasing the splitting tensile strength. Previous research also shows that the cement and sand partially substituted by MP and RHA raised the splitting tensile strength (Samantaray et al., 2016). In the assessment of the concrete mechanical properties with cement substituted by MP at 0%, 5%, 10%, 15%, and 20% and fly ash at 20%, the splitting tensile strength increases to 15% (Praveenkumar & Murugesan, 2017). During the study of mechanical properties of concrete having sand partially substituted by RHA, i.e., 0% to 50% with an increment of 12.5%, the results reveal that up to 37.5% of sand substituted by RHA, the splitting tensile strength increases (Kunchariyakun et al., 2015).

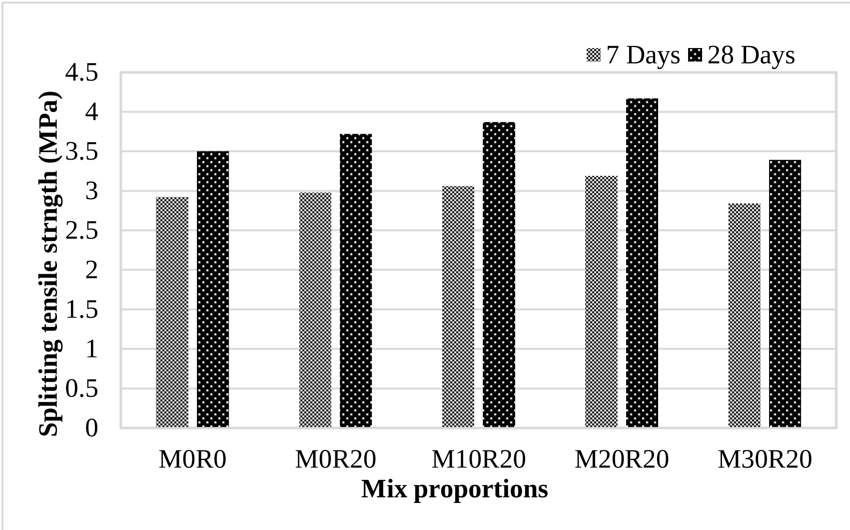


**Figure 5: Split tensile strength of concrete mixes**

*Flexural strength*

For flexural strength assessment three prisms were tested for every mix as per ASTM C78/C78M. All the results for samples for all the mixes at 7 and 28 days tests are given in table 5. With the rise in the percent of RHA, the flexural strength improves while it decreases with the rise in the percent of MP. A maximum increase of 5.21% of flexural strength after 28 days is achieved at a mix having 0% MP and 20% RHA compared with the control mix. Beyond this mix, the flexural strength starts decreasing, but at mix M30R20, the flexural strength still is greater than that of the control mix. Being super pozzolan and the pozzolanic behavior of RHA is the reason for enhancing the flexural strength of mix M0R20 at 28 days strength. Results for flexural strength are shown in Figure 6. Previous research indicates that substitution of RHA for sand improves flexural strength. In assessment of the concrete mechanical properties, sand is substituted by RHA from 0 to 50% with an increment of 12.5%. The results shows that the flexural strength increases up to 25% of substitution of RHA (Samantaray et al., 2016).

***Microstructure analysis***

Control mix (M0R0) and M20R20, a mix with 20% of MP and 20% RHA substituted by cement and sand, were taken for microstructural analysis.

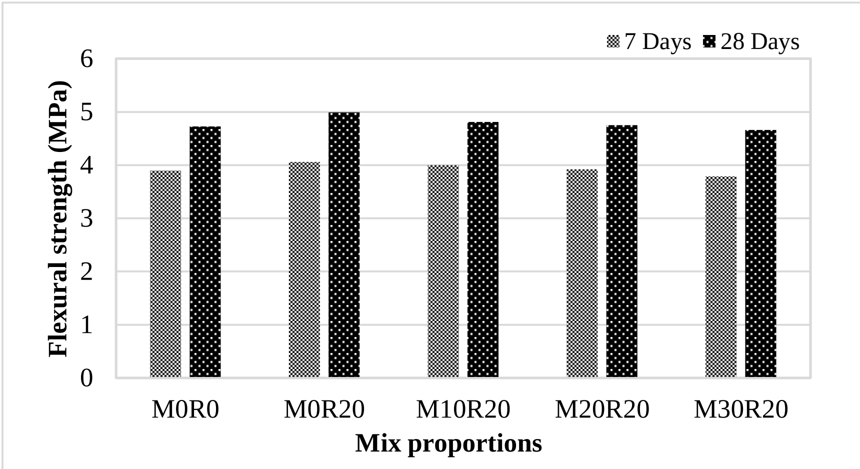


**Figure 6: flexural strength of cocncrete mixes**

*X-ray diffraction (XRD)*

In XRD, the graph shows some humps, indicating that the materials are amorphous, not crystalline. The results of XRD for the mix M0R0 (control mix) and mix M20R20 were compared with each other after 28 days of strength and hydration. The dipping of the sample in acetone solution stopped the hydration. The graph indicates that there exist several peaks in both of the mix proportions with varying intensities. The peaks at given degrees, i.e., 18.09, 34.19, 47.10, 50.79, 54.34, and 64.24, show the Portlandite (P) contents (Singh, B., & Rai, D.C., 2017). The peak in mix M20R20 is of high intensities compared to the control mix. At degrees 29.4, 31.92, and 49.6, calcium silicates (CSH) in M20R20 as shown in the figure, indicate hydration in M20R20. For quartz Q, the degrees that show the occurrence of quartz are 26.65, 59.75, 67.75, and 68.15 degrees (Habib et al., 2016). The diagram also shows some peaks for magnesium oxide at 75.6 and 77.75 degrees. From all the elements shown in Figure 7, it seems that the intensities of these materials in mix M20R20 is slightly higher than that in the control mix, indicating that due to hydration, some additional elements are produced in mix M20R20.

*Scanning electron microscopy (SEM)*

SEM gives observation of the framework and pores in a structure. For SEM analysis, control mix and mix M20R20 of 28 days hydration were compared. The results shown in Figure 8 and 9 indicate that in mix M20R20, there are fewer pores than in the control mix because the mix M20R20 shown in Figure 9 is well compacted and seems non-porous. This is due to the establishment of secondary CSH and CH due to occurrence of pozzolanic activity in mix M20R20. These CSH and CH content replete the pores and thus decrease the porosity of the mix (Iqbal et al., 2022). The previous study also indicates that due to the addition of RHA in concrete, CSH and CH formation occur in the concrete (Xu et al., 2016).

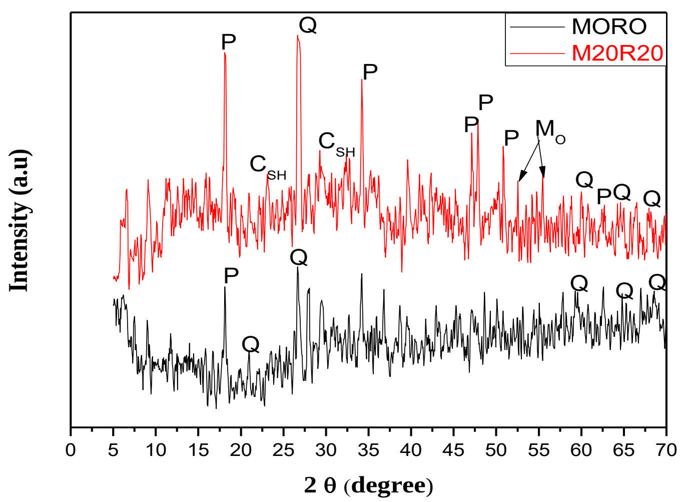


**Figure 7: XRD results of M0R20 and M20R20**

## Conclusions

This research was to examine and explore the impact of MP and RHA on fresh concrete and hardened properties of SCC. The following are the findings of this study.

- SCC can be produced using MP and RHA as partial replacement of cement and sand respectively.
- Workability is enhanced when MP and RHA partially replace cement and sand.

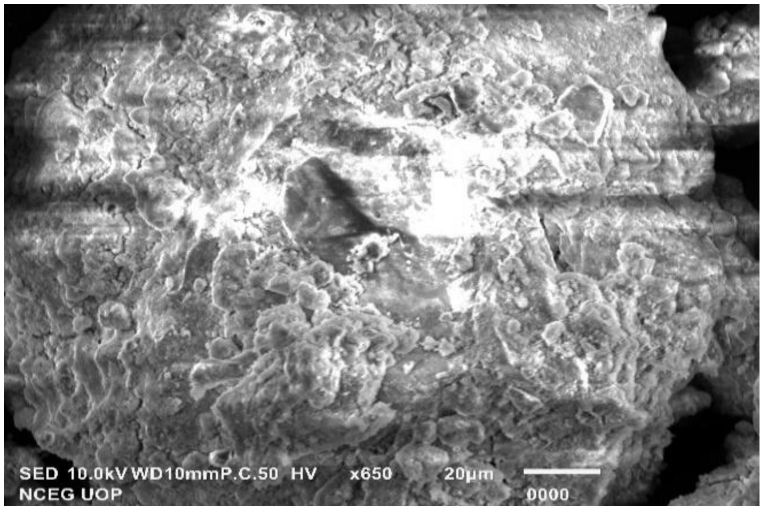


**Figure 8: SEM image of M0R0 of 28 days strength**

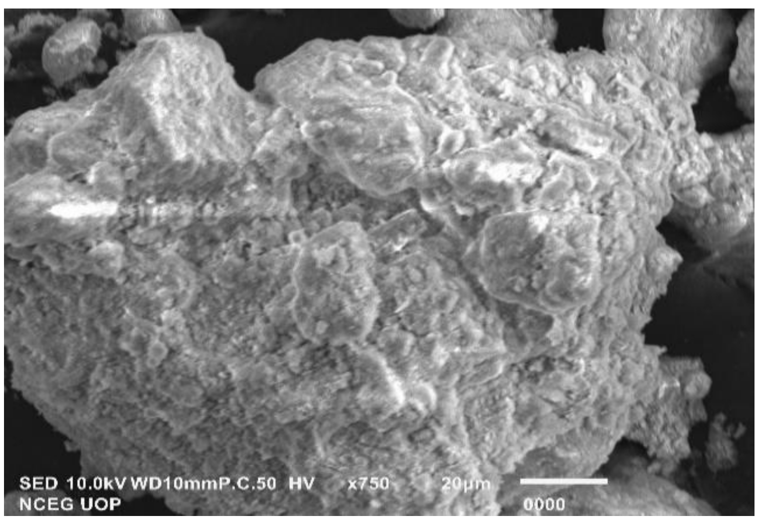


**Figure 9: SEM image of M20R20 of 28 days strength**

- The air content of concrete is reduced as there is a rise in the percent of MP and RHA when they are substituted with cement and sand, respectively.
- The hardened concrete properties (compressive and splitting tensile strength) are enhanced when MP and RHA partially replace cement and sand and achieve maximum enhancement at a mix with 20% substituted MP and RHA.

- Among hardened properties, flexural strength increases only because of the substitution of RHA by sand, so flexural strength enhanced up to mix having 0% MP and 20% RHA substituted by cement and sand, respectively, but still mix M20R20 has greater strength than control mix.
- The concrete formed when MP and RHA partially replace cement and sand will cost meager.
- Microscopic characteristics of concrete are also enhanced when MP and RHA partially replace cement and sand.
- The concrete formed when MP and RHA partially replace cement and sand, respectively, will be environmentally friendly.
- These solid waste materials, i.e., MP and RHA, can be utilized in large amounts in industries to produce concrete, thus limiting the environmental issues due to these solid wastes.

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