Effect of Local Metakaolin Developed from Natural Material Soorh and Coal Bottom Ash on Fresh, Hardened Properties and Embodied Carbon of Self-Compacting Concrete

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Abstract

The carbon dioxide emissions from Portland cement production have increased significantly and Portland cement is the main binder used in self-compacting concrete, so there is an urgent need to find environmental friendly materials as alternative resources. In most developing countries, the availability of huge amounts of agricultural waste has paved the way for studying how these materials can be processed into self-compacting concrete as binder and aggregates compositions. Therefore, this experimental program was carried out to study the properties of self-compacting concrete (SCC) made with local metakaolin, coal bottom ash separately and combined. Total 25 mixes were prepared with four mixes as 5,10, 15 and 20% replacement of cement with metakaolin, four mixes as 10, 20, 30 and 40% of coal bottom ash as partial replacement of fine aggregates separately and 16 mixes prepared combined with metakaolin and coal bottom ash. The fresh properties were explored by slump flow, T_{50} flow, V-funnel, L-box, J-Ring sieve segregation test. Moreover, the hardened properties of concrete were performed for compressive, splitting tensile and flexural strength and permeability of SCC mixtures. Fresh concrete test results show that even if no viscosity modifier is required, satisfactory fresh concrete properties of SCC can be obtained by replacing the fine aggregate with coal bottom ash content. At 15% replacement of cement with local metakaolin is optimum and gave better results as compared to control SCC. At 30% replacement of fine aggregate is optimum and gave better results as compared to control SCC. In the combined mix 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash is optimum and gave better results as compared to control SCC.

1. Introduction

Self-compacting concrete (SCC) is a highly workable concrete that can be spread over the packed reinforcement bars, seals overall corners of the formwork and attains compacted situation under its self-weight. Hence, there is no any vibrator is used for the compaction of concrete. To accomplish such conduct, the principle necessities of fresh properties of SCC are filling capacity, passing capacity and more segregation obstruction. The initial two assets can be accomplished by utilizing a chemical admixture (such as super plasticizer). To protect the cohesion of the SCC mixture, an enormous amount of supplementary cementing material (SCM) and viscosity-modifying admixture (VMA) is needed (EFNARC, 2005).

The construction industry is increasingly using the concepts of sustainability and durability. Cement is the most frequently utilized building ingredient in the construction engineering. It is a vitality comprehensive constituent and liable for high content of CO_2 discharge. Hendricks et al detailed that the measure of CO_2 discharges from cement production relies upon the manufacturing technology, procedure, clinker or cement proportion and fuel utilized. It presumed that the utilization of alternative fossil fuels and mixed cement may diminish CO_2 releases by 20% to 40% and 20% correspondingly (Hendriks et al., 2004). Moreover, Hwang et al estimated the consumption of lime stone, electrical energy and fossil fuels to create one ton of OPC ranges from 1.19 tons to 1.47 tons, from 96.30 kWh to 119.60

kWh and 68.10 kg to 97.30 kg respectively (Hwang et al., 2015). The use of augmented energy, alternate raw constituents and decrease amounts of cement clinker will reduce CO_2 emanations from the cement manufacturing (Damtoft et al., 2008). The use of pozzolanic ingredients increases the concrete durability and reduces CO_2 emissions, since robust constructions structure want less repair and preservation, so it can also extend the life of the structure (Guneyisi et al., 2008). The use of volcanic ash is a trend that is attracting more and more attention, as well as increasing awareness of people about ecological protection and sustainable construction (Papadakis and Tsimas, 2002). Therefore, in the long term, there are good reasons to expand the use of any by-products or pozzolanic materials to partially replace cement in mortar and concrete. It is generally believed that volcanic ash significantly improves the resistance to chloride ions through a combination of chloride ions and pour filling (Rafik et al., 2010). The addition of pozzolanic materials to SCCs can improve strength, durability, lower costs and avoid side effects caused by improper compaction (Eva et al., 2011).

The durability of the pozzolanic concrete is improved owing to the pozzolanic response of different mixes existing in the concrete throughout the hydration cycle (Poon et al., 2001). The most usually utilized pozzolanic constituents are fly ash, silica fume, MK and rice husk ash. However, the calcium hydroxide (CH) and calcium silicate hydrate (C–S–H) are framed during the hydration of OPC in concrete. Besides, the calcium hydroxide is the greatest solvent hydration item, and it is a poor connection in concrete and cement in terms of durability perspective. Thus, the concrete is showing to water, the calcium hydroxide would disintegrate, expanding the permeability and in this manner, the production of concrete is more susceptible due to leaching and chemical attack. However, the pozzolanic MK reaction will form other cemented C-H-H gels and crystalline products, including calcium aluminate hydrate and aluminosilicate hydrate (C2ASH8, C4AH13, and C3AH6). These products of volcanic ash contribute to the narrowing of common pores (Badogiannis and Tsivilis, 2009). Wild et al., (1996) reported that the improved pore system makes the concrete denser, making it much more difficult to transport water and other corrosive chemicals, thereby reducing the diffusion frequency of injurious ions. Huang et al., (2015) assessed carbon dioxide emissions from cement production. Ordinary Portland cement is producing carbon dioxide by calcining limestone and silica reaction at temperatures below 1500 °C.

In this regard, it is conveyed that the utilization of MK in concrete makes it possible to improve the compressive strength of the mixture, particularly in the early stages of hydration. Kim et al., (2007) was stated that the strength of the concrete was measured using a Korean MK and it was recommended that a 10% MK replacement would be a suitable replacement. In terms of durability, the literature has reported a positive effect of MK. Recently Shekarchi et al., (2010) states that when the amount of replacement MK was 15%, concrete transport performance, recorded in terms of water permeability, gas permeability, water absorption, resistivity and ion diffusion rate, increased by 50%, 37%, 28%. 450% and 47% correspondingly. Researchers have reported an optimistic influence of adding MK on the corrosion resistance of samples (Parande et al., 2008; Batis et al., 2005). For example, Batis et al., (2005) showed that the use of MK, regardless of whether it is used as a substitute for sand or cement, can improve the corrosion performance of mortar samples.

The increase in the use of concrete has led to an increase in cement volumes and a gradual increase in demand for fine aggregates, which negatively affected the environment. In terms of reducing environmental pollution, the use of industrial waste may be a suitable solution for achieving sustainable development and solving the growing problem of carbon dioxide (CO_2) invention (Mangi et al., 2018). The CBA is measured as a green and ecologically friendly construction substantial that can reduce the cement content in concrete production. It is a waste ingredient which has introduced by the Construction Industry Development Board (CIDB) for the use of recycled materials in concrete production (Dwikojuliardi, 2015). Moreover, the CBA is formed by burning coal in thermal power plants and is measured the main waste of fly ash (FA). The CBA contains pozzolanic properties due to the existence of silicon oxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). During cement hydration, calcium hydroxide reacts with CBA to form additional calcium aluminate hydrate (CAH) and calcium silicate hydrate (CSH). Cheriaf et al., (1999) was argued that proper grinding can develop the pozzolanic activity of CBA, and six hours of grinding CBA can increase the strength activity index by 27% after 28 days. Hence, in concrete, it is partially replaced by fine aggregate and cement.

The use of CBA in the construction industry is one of the best possible options for reducing the environmental problems caused by lack of discharge sources and increased CBA productivity. Overall, India produces about 105 million tons of CBA per annum from various thermal power plants, which generate 68% of the country's electricity. Because CBA has the same particle size distribution and additional pozzolanic properties as NFA, CBA is promoting its use in the current and future construction industry (Lauritzen, n.d.; Yogesh and Rafat, 2014). Thus, the SCC has been studied many times and it is possible to replace NFA with CBA. In some studies (Abidin et al., 2014; Aswathy & Mathews, 2015; Ibrahim et al., 2015; Jamaluddin et al., 2016; Ratchayut & Somnuk, 2008), in the production of SCC, the bottom ash of coal was also mixed with cement additives such as FA and MK. But, the NFA was replaced by 10% -30% of CBA along with FA and a water reducing agent were added simultaneously (Rafat et al., 2012; Rafat et al., 2012). It was observed that SCCs with CBA and FA could be designed to meet the compulsory requirements of the fresh SCC. For green concrete requirements, the best CBA content to replace NFA has been found to be 10% (Ibrahim et al., 2015). Taking into account the mechanical properties of SCC mixture in the literature studies, it was found that the optimal percentage of CBA can replace NFA up to 20%. Furthermore, the advantageous effects of CBA have also been observed in some important studies, as most of the mechanical properties of SCCs obtained by adding only 10% -15% CBA instead of NFA improved overall performance (Aswathy & Mathews, 2015). Likewise, it was observed that SCC obtained by replacing 10% NFA with CBA has the same behavior. The compressive and indirect tensile strength is increased about 20% with the assimilation of 15% CBA (Abidin et al., 2014; Jamaluddin et al., 2016). Few authors have investigated the tensile strength of SCC and it was perceived that NFA can be effectively replaced by CBA without compensating the overall performance at various curing periods (Dwikojuliardi, 2015). In reference to durability, the water absorption rate is reduced up to 15% replacement levels of NFA with CBA (Abidin et al., 2014; Ratchayut & Somnuk, 2008). The optimum level of CBA was found to be 10% for SCC and in NVC in most of the earlier investigations (Abidin et al., 2014; Jamaluddin et al., 2016). Similarly, an improvement in durability properties has been observed in terms of capillary water absorption, electrical resistivity, carbonation resistance and chloride penetration of concrete blended with 10% of CBA instead of NFA (Cheriaf et al., 1999).

Cement production requires huge energy whereas, Pakistan faces acute crises of energy and the cost of cement is rising resulting in an overall rise in the construction cost. Though, there are so many studies performed on MK as cementitious materials and CBA as fine aggregates individually but there is no experimental study conducted on MK as PC replacement and CBA as fine aggregates together in SCC mixture. Therefore, this study proposes a method that increases the properties of SCC and reduces the cement production, and reducing embodied carbon by replacing cement with local MK and sand replacement with CBA separate and combine in the SCC mixture. Moreover, the numerous tests in terms of slump flow, T50 flow, visual segregation index, V-funnel, L-box, J-ring and sieve segregation were performed to measure the workability of SCC mixtures blended with separate and combine local MK as replacement for cement and CBA as fine aggregates. In addition, the hardening performance was evaluated in terms of compressive, tensile, flexural strength and water penetration depth of SCC mixtures blended with separate and combine local MK as replacement for cement and CBA as fine aggregates.

2. Materials And Methods

2.1 Materials

Cement Ordinary Portland cement (OPC) from a brand-named Lucky, has been utilized in this experimental study and its physical properties and chemical composition are summarized in **Table 1**. The fine aggregates are used which composed of hill sand passing from 4.75mm, crushed stone passing from 12mm and retained on 4.75mm sieves. Local Metakaolin Local metakaolin (MK) was produced from local natural material soorh available in billions of tons in district Thatta Sindh, Pakistan, by calcination at 800ºC for 2 hours. The MK was used as cement replacement at various dosages, after sieving it from a sieve No 325. The SEM images of local MK as shown in **Figure 1**. Moreover, the chemical composition and physical properties comparison of OPC, soorh and developed MK are presented in **Table 1.**

2.2 Mix Proportion

The SCC mixtures were prepared with water/binder ratio of 0.38 (EFNARC, 2005). Total five mixtures were made in which one mixture was prepared of only cement while other mixtures were made of 5%, 10%, 15% and 20% of developed MK by the cement’s weight. Furthermore, the detail of mix proportions is exhibited in **Table 3**

2.3 Methods

The fresh properties of SCC have been studied out by using the method specified in (EFNARC, 2005). The filling ability tests respected slump flow, V-funnel and T50 flow time test, while passing capability tests, like J-Ring and L-box, were also performed. Moreover, sieve segregation test was carried out. Various trial mixes with and without superplasticizers were prepared to develop the SCC. However, the hardened concrete tests were conducted after the achievement of early fresh concrete tests and it was dispensed into the molds. Moreover, the concrete samples were removed from mold on one day after casting and then these samples were kept in curing water tank till the testing day. Hence, the five concrete cube samples were utilized for exploring the compressive strength of SCC after 3, 28 and 180 days under EN 12390-3 (2009). Additionally, the five cylinders were cast for splitting tensile strength of SCC at 3, 28 and 180 days as per as per EN 12390-6 (2009).

The flexural strength test on the prism samples of the OPC control mix and metakaolin modified mixes of self-compacted concrete at the age of 28 days was conducted as per BS EN 12390-5: 2009. Specimens of 500 mm x 100 mm x 100 mm were cast, and these specimens were used for the given testing age.

The cubical samples (100 mm x100 mm x 100 mm) were cast and de-molded later 24 hours. After de-molding all samples were kept in curing tank for curing for 28 and 180 days and then the specimens were kept in a pressure cell and subjected to a water pressure of 0.5 MPa for 72 hours duration for water penetration depth as per BS EN-12390-8:2000. After subjecting the required water pressure, the samples were divided into two halves in Universal Testing Machine and a water-penetrated moistened surface was measured as water penetration depth.

2.3.1 Embodied Carbon Assessment

It was utilized to study the sustainability benefits by using MK and CBA for the carbon content of the concrete mix being assessed. The embodied carbon of materials were obtained from literature study as shown in Table 5. The carbon embodied for concrete mixes was estimated by using Equation (1). The $CO2e$, Wi and $CO2i$ in Equation (1) display the embodied carbon of concrete, weight per unit volume of material and embodied carbon of materials respectively.

$$CO_{2e} = \sum_{i=1}^{n} (W_i \times CO_{2i}) \qquad (1)$$

2.3 Fresh concrete results

The results of fresh properties of SCC with inclusion of local metakaolin is tabulated in Table 5.

2.3.1 Slump flow

The fresh properties of SCC with inclusion of MK were investigated and the outcomes were given in **Table 6**. The recommended values of slump flow are 650- 850mm (EFNARC, 2005). Without using superplasticizers and using 1% superplasticizers, the observed slump flow of control and MK SCC was less than the recommended values. By using 2% and 3% superplasticizers the slump flow of control and

MK SCC was within the recommended range. As the quantity of MK increased the slump flow decreased due to MK's more specific surface area than that of cement, this outcome of the study is corelated to Guneyisi and Gesoglu, (2008). However, in liquefying action, the use of SP enhances the flowability by dropping plastic viscosity and yielding stress. Moreover, a high slump flow can be accomplished owing to the dissolving action of SP by reducing the water demand which entrapment among flocculated particles. Using 2% superplasticizer, the observed value of slump flow of control mix within range while CBA SCC has been less than the required slum flow i.e., 650mm. By using 5%, 9%, 13% and 17% superplasticizer the slump flow of CBA10, CBA20, CBA30, and CBA40-SCC has been observed within the required range of (EFNARC, 2005). As the magnitude of CBA enhanced the slump flow has been reduced due to the porosity of CBA, which saturate more water with a higher content of CBA. The outcome achieved indicated the CBA structures, which have a rough form that decreasing interparticle abrasion among aggregates contrasted with the control mix. This trend has been observed by other researchers (Aswathy & Mathews, 2015). In the combined utilization of local metakaoiln and CBA, as the quantity of MK and CBA increased more quantity of SP is needed to satisfy the required range of Slump flow. Maximum 22% SP is used to satisfy the requirment of slump flow of MK20CBA40 mix.

2.3.2 V Funnel

The recommended values of the V-funnel are 6-12sec (EFNARC, 2005). Without using superplasticizers and using 1% superplasticizers, the observed V-funnel flow of the control and the MK SCCs exceeded the recommended range. By using 2% and 3% superplasticizers the V-funnel of the control and the MK SCC were within the recommended range. As the quantity of MK increased, the V-funnel time decreased. The V-funnel time displays a distinct tendency to rise with growing in the content of MK. This outcome was deemed that the accumulation of MK in concrete made the mixtures extra viscous. This finding is related to the other research investigations (Guneyisi and Gesoglu, 2008; Hassan et al., 2010). Finally, it was revealed that there is no need of any viscosity modifying agent in concrete mixtures while using MK in concrete. By using 2% superplasticizer, the observed value of V-funnel test of control mix within range while CBA SCC has been more than the required V-funnel i.e. 12-seconds. By using 5%, 9%, 13%, and 17% superplasticizer the value of V-funnel test of CBA10, CBA20, CBA30, and CBA40-SCC has been observed within the required range of (EFNARC, 2005). As the quantity of CBA increased the V-funnel has been increased owing to the porosity of CBA contrasted with the control mix. CBA saturate more water with a higher content of CBA. The outcome achieved suggested the CBA structure, which have a rough form that decreasing interparticle abrasion among aggregates and showed the excessive inclusion of coal bottom ash has declined the viscosity of SCC mixtures. This trend has been observed by other researchers (Aswathy & Mathews, 2015). In the combined utilization of local metakaoiln and CBA, as the quantity of MK and CBA increased more quantity of SP is needed to satisfy the required range of V funnel. Maximum 22% SP is used to satisfy the requirment of V funnel of MK20CBA40 mix.

3.1.3 T50 flow

The recommended values of T50 flow time are 2-5sec (EFNARC, 2005). **Table 6** indicates the T50 flow time was estimated in the range of 2.80 sec to 4.6 sec. As the quantity of MK is increased the T50 flow increased. The outcome was cleared that the T50 flow time of SCC was augmented with addition of 20% MK. This observation was related to Guneyisi et al., (2009). From Table 4, it was indicated that the T50 flow possessed higher plastic viscosity for a given MK content. With using 2% superplasticizer, the observed T_{50} flow time of control mix within range while CBA SCC has been less than the required value of T_{50} flow time test i.e., more than 5 seconds. By using 5%, 9%, 13%, and 17% superplasticizer the T_{50} flow time of CBA10, CBA20, CBA30, and CBA40-SCC has been observed within the required range of (EFNARC, 2005). As the quantity of CBA enhanced the T_{50} flow time has been improved owing to the porosity of CBA contrasted with the cement because CBA saturated more water with a greater content of CBA. The outcome achieved denoted of the CBA structures, which have the rough form that decreasing interparticle abrasion among aggregates and directed the excessive inclusion of coal bottom ash declined the viscosity of SCC mixtures. This trend has been observed by other researchers (Aswathy & Mathews, 2015). In the combined utilization of local metakaoiln and CBA, as the quantity of MK and CBA increased more quantity of SP is needed to satisfy the required range of T50 flow. Maximum 22% SP is used to satisfy the requirment of T50 flow of MK20CBA40 mix.

3.1.4 Blocking ratio (L-box test)

It is utilized to evaluate the flow of SCC concrete and the level by which it is subject to blocking by reinforcement. The results of L-Box tests are shown in **Table 6**. The recommended values for the L-Box test are 0.8-1.0. Without using superplasticizers and using 1% superplasticizer, the observed values of control and the MK SCC exceed the recommended range. By using 2% and 3% superplasticizers the L-box value of control and the MK SCC were observed within the recommended range. As the quantity of MK increased the L-box is decreased, due to MK's more specific surface area than that of cement. This observation is corelated to Guneyisi and Gesoglu, (2008). By using a 2% superplasticizer, the observed value of L-box test of control mix within range while CBA SCC has been more than the required value of L-box {blocking ratio) i.e., less than 1.0. By using 5%, 9%, 13%, and 17% superplasticizer the value of L-Box ratio of CBA10, CBA20, CBA30, and CBA40-SCC has been observed within the required range of (EFNARC, 2005). As the quantity of CBA increased the L-box ratio has also been increased due to a decrease in cohesiveness and a lack of a lack in paste volume of CBA contrasted with the control mix. This trend has been detected by other researchers (Aswathy & Mathews, 2015). In the combined utilization of local metakaoiln and CBA, as the quantity of MK and CBA increased more quantity of SP is needed to satisfy the required range of L-box. Maximum 22% SP is used to satisfy the requirment of L-box of MK20CBA40 mix.

3.1.5 J- Ring

The recommended values of J Ring test (EFNARC, 2005) are 0-10mm. Without using superplasticizers and using 1% super plasticizers, the observed values of the control and the MK SCC exceeded the recommended values. By using 2% and 3% superplasticizers the observed J-Ring values of the control and the MK SCC were within the recommended range as shown in **Table 6**. As the quantity of MK increased, J-Ring decreased due to MK's more specific surface area than that of cement. This similar study is related to Guneyisi and Gesoglu, (2008). By using 2% superplasticizer, the observed value of J-ring test of control mix within range while CBA SCC has been less than the required value of J-ring test i.e., less than 10 mm. By using 5%, 9%, 13% and 17% superplasticizer the J-ring of CBA10, CBA20, CBA30, and CBA40-SCC has been observed within the required range of (EFNARC, 2005; Lauritzen, n.d.). As the magnitude of CBA increased the J-ring has been reduced due to the porosity of CBA contrasted with the cement. As the measure of CBA augmented the J-ring reduced due to a decrease in cohesiveness and lack in paste volume of CBA contrasted with the control mix. This trend has been witnessed by other researchers (Aswathy & Mathews, 2015). In the combined utilization of local metakaoiln and CBA, as the quantity of MK and CBA increased more quantity of SP is needed to satisfy the required range of J-Ring. Maximum 22% SP is used to satisfy the requirment of J-Ring of MK20CBA40 mix.

3.1.6 Sieve segregation

The recommended range of sieve segregation is 0-12% (EFNARC, 2005). Without using superplasticizers and using 1% superplasticizers, the observed values of the control and the MK SCC exceeded the recommended range. By using 2% superplasticizers, the J-Ring values of control and MK SCC were within the recommended range as displayed in **Table 6**. As the quantity of MK increased the sieve segregation increased due to MK's more specific surface area as compared to cement. This similar trend of the experimental study is related to Guneyisi and Gesoglu [29]. By using a 2% superplasticizer, the observed value of sieve segregation of control mix within range while CBA SCC has been less than the required sieve segregation i.e., less than 12%. By using 5%, 9%, 13%, and 17% superplasticizer the value of sieve segregation of CBA10, CBA20, CBA30, and CBA40-SCC has been observed within the required range of (EFNARC, 2005). As the magnitude of CBA increased the sieve segregation has been reduced owing to the porosity of CBA contrasted with the cement. CBA has saturated more water with a greater content of CBA. The outcome achieved suggested the CBA structure, which have a rough form that decreasing interparticle abrasion among aggregates and showed the excessive inclusion of coal bottom ash declined the viscosity of SCC mixes. This trend has been observed by other researchers (Aswathy & Mathews, 2015). In the combined utilization of local metakaoiln and CBA, as the quantity of MK and CBA increased more quantity of SP is needed to satisfy the required range of sieve seggregation. Maximum 22% SP is used to satisfy the requirment of sieve seggregation of MK20CBA40 mix.

The conclusion on the fresh properties of SCC with accumulation of MK exhibited that the use of MK up to 20%, satisfy the performance of fresh-state requirements associated to greater segregation resistance, deformability, passing and filling capabilities using 2 and 3% SP without using VMA. The utilization of CBA as fine aggregate replacement to develop SCC, as the quantity of CBA is increased more SP is needed to satisfy the requirement of all fresh properties of SCC. Maximum 17% SP is used for 40% replacement of fine aggregate with CBA to satisfy the fresh properties of SCC. In the combined utilization of MK as cement replacement and CBA as fine aggregate replacement maximum 22% SP is used to develop the SCC.

3.2 Hardened concrete results

The compressive, tensile, flexural strength and water penetration depth were performed on hardened concrete for all SSC mixes.

3.2.1 Compressive strength

Figure 2 shows maximum compressive strength is increased as 22.6%, 10.39%, and 9.29% more than that of control mix at 15% of MK as cementitious component at 3, 28 and 180 days respectively. However, it was deemed that the compressive Strength of SCC with inclusion of 5% to 15% MK is more than that of the SCC without addition of MK as cementitious substantial. This increment may due to the influence by the active pozzolanic reaction of MK and the silica content in MK particles enhances the development of C-S-H, a gel responsible for strength development (Wild et al., 1996; Guru et al., 2013).The major factors that contribute to the strength of MK SCC are (i) the filling consequence, (ii) the dilution consequence (iii) the pozzolanic response of MK with CH (Wild et al., 1996; Khatib and Hibbert, 2005; Said-Mansour et al., 2011). Besides, the compressive strength of SCC was estimated reduced while utilizing the MK more than 15% (Yasin, 2012). This study is similar to Parande et al., (2008) where it was described that the accumulation of 15% MK as cementitious constituent gives an excellent result than the other substitution levels. The almost same trend of results of compressive strength of concrete using metakaolin has been observed by different researchers (Poon et al., 2006; Mermerdaş et al., 2012). Wild and J M Khatib, (1996) and Ding *et al., (2002) analyzed* that the compressive strength of concrete with inclusion of 20% and 25% MK was lower than that of concrete with accumulation of 15% MK due to the dilution effect of clinker. The dilution effect of clinker is a result of replacement level for cement with an equal extent of MK. In MK concrete, the filler consequence, pozzolanic reaction of MK with CH, and compounding influence respond as opposed to the dilution effects (Wild et al., 1996; Parande et al., 2008; Ding and Li, 2002). Hassan et al., (2010) stated that the compressive strength was enhanced by 22% while using 25% of MK by the weight of cement after 28 days. Vejmelkovaa et al., (2011) conveyed that the MK used in SCC provides compressive strength raises quickly at the initial stage of hardening. Similarly, Melo and Carneiro, (2010) presented that the content of MK increases in SCC that results in reducing the compressive strength of SCC (Okan et al., 2012).

Figure 2 indicates the compressive strength of SCC with accumulation of MK is improved at early age (3–28 days) as well as later age 180 days. Though, the frequency of strength growth was more important at the early age. The latter study was related to the outcomes obtained in earlier studies (Wild et al., 1996; Abidin et al., 2014). Additionally, it was informed that the highest input to the strength progress of concrete on initial periods due to the pozzolanic reaction of MK (Poon et al., 2001).

It is obvious from figure 3 that compressive strength of CBA SCC mix is enhanced as compared to control mix with the replacement of F.A by CBA; with the substitution range 10 % to 30 %. It is oblivious that the optimum compressive strength, 41.56 MPa (i.e. 14.55% increase contrasted with the control mix) at 28 days, has been attained at 30% replacement of F.A with CBA. This has happened due to the permeable refinement and pozzolanic response of bottom ash in the concrete matrix (Norul et al., 2001). On further substitution of F.A by CBA, the compressive strength of SCC mix blended with CBA is reduced than that of concrete without CBA. This indicated that the strength of concrete mixture was declined with enhance in the magnitude of CBA, owing to the substitution of the resilient substantial with the fragile ingredient and enhanced porosity. The reduction in the free water content of concrete with addition of CBA has happened owing to the saturation of part of water by the permeable particles of the coal bottom ash internally also contributed to some extent in excluding adverse the influence of the aspects accountable for decreased compressive strength (Aswathy & Mathews, 2015). In the combined utilization of MK as cement replacement and CBA as fine aggregate replacement maximum compressive strength 44.81 MPa is observed at 10% MK as cement replacement with 30% replacement of fine aggregate with CBA which is 23.51% more than that of control mix at 28 days.

Figure 4 reveled that by the combined use of local metakaolin and CBA maximum compressive strength is 44.81 MPa achieved at 28 days at 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 23.51% more than that of control SCC.

3.2.2 Splitting tensile strength

Figure 5 shows that split tensile strength of SCC with inclusion of 5% to 20% MK is more than that of the SCC without addition of MK as cementitious substantial. As shown in Figure 2, the maximum split tensile strength is increased as 10.43%, 10.19%, and 10.0% respectively than that of control mix at 3. 28 and 180 days respectively at 15% substitution of cement with metakaolin. This may be due to the effect by the active pozzolanic reaction of MK and silica content in MK particles enhances the formation of C-S-H, a gel responsible for strength development (Wild et al., 1996; Guru et al., 2013). On extra substitution of cement by MK the split tensile strength of MK SCC is declined than that of control concrete (Rahmat and Yasin, 2012). This similar trend of this study is related to that where it was observed about tensile strength of SCC with accumulation of 5% to 15% MK is achieved maximum than that of control mixes (Billong et al., 2011).

Figure 6 illustrates that split tensile strength of CBA SCC mixture is enhanced as compared to control mix with the replacement of F.A by CBA; with the substitution limit from 10 % to 30 %. It is oblivious that the optimum split tensile strength, 4.16 MPa (i.e. 14.6% enhanced contrasted with the control mix) at 28 days, has been attained at 30% replacement of F.A with CBA. On further replacement of F.A by CBA, the split tensile strength of CBA SCC concrete is declined than that of control mix concrete. The outcomes proposed that the attachment between cement paste and aggregate has been the most significant aspect in influencing the stability of concrete especially the tensile strength. The enhance in the substitution status of coal bottom ash had formed more permeable concrete with high permeability spread round the CBA aggregate surface, hence decreasing its stability. This trend has been observed by other researchers (Aswathy & Mathews, 2015). M.P. Kadam et al., (2014) have explored that the tensile strength has been enhanced while using 10%-30% substitution and after that it has been reduced for the rest substitution after 7th, 28th, 56th, and 112th days respectively. According to K. Soman et al., (2014) detected that the tensile strength has been enhance by 0.70%, 5.70%, and 12.16% which is recorded for 10%, 20%, and 30 %

substitution after 7 days correspondingly. In the combined utilization of MK as cement replacement and CBA as fine aggregate replacement maximum tensile strength 4.48 MPa is observed at 10% MK as cement replacement with 30% replacement of fine aggregate with CBA which is 23.42% more than that of control mix at 28 days.

It is observed from figure 7 that by the combined use of local metakaolin and CBA maximum tensile strength is 4.48 MPa achieved at 28 days at 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 23.42% more than that of control SCC.

3.2.3 Flexural Strength

The figure 8 reveals that the maximum flexural strength is increased as 7.07% more than that of control mix at 15% of MK as cementitious component at 28 days. However, it was deemed that the flexural Strength of SCC with inclusion of 5% to 15% MK is more than that of the SCC without addition of MK as cementitious substantial. This increment may due to the influence by the active pozzolanic reaction of MK and the silica content in MK particles enhances the development of C-S-H, a gel responsible for strength development (Guru et al., 2013; Wild et al., 1996). Moreover, further addition of MK in SCC obtained reducing in flexural strength of SCC as compared to SCC without inclusion of MK.

Figure 9 shows that flexural strength of CBA SCC concrete is enhanced as compared to control mix with the substitution of F.A by CBA; with the substitution limit from 10% to 40%. It is oblivious that the optimum flexural strength, 6.65 MPa (i.e. 14.65% enhance contrasted with the control mix) at 28 days, has been attained at 30% replacement of F.A with CBA. On further replacement of F.A by CBA, the flexural strength of CBA SCC concrete is declined as compared to control mix concrete. The coal bottom ash supplanting (CBA30) provided optimum flexural strength. The reduced flexural strength of the sample as the substitution status of coal bottom ash enhanced has been alleged due to the weak interparticle abrasion among the aggregate, as bottom ash particles has been sphere-shaped. This study is concerned with Bhuvaneshwari *et al* have been stated that concrete with a 30% substitution of bottom ash (BA) with sand indicated more flexural strength for normal samples (Bhuvaneshwari and Murali, 2013). M.P. Kadam et al., (2014) investigated that the flexural strength has been enhanced up to 30% replacement of BA and beyond it gets reduced. Soman *et al., (2014)* has also detected that 30% substitution of fine aggregate by bottom ash contributed comparable flexural strength at the curing period of 28 days. In the combined utilization of MK as cement replacement and CBA as fine aggregate replacement maximum flexural strength 7.17 MPa is observed at 10% MK as cement replacement with 30% replacement of fine aggregate with CBA which is 23.62% more than that of control mix at 28 days.

It is observed from figure 10 that by the combined use of local metakaolin and CBA maximum flexural strength is 7.17 MPa achieved at 28 days 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 23.62% more than that of control SCC.

3.2.4 Water Penetration Depth

The permeability is one of the most important parameters of concrete durability. The less permeability of concrete shows enhanced resistance against chemical attacks. Once water enters into the concrete, various soluble salts together with chloride ions infiltrate into concrete and cause corrosion. In general, it gives the impression that lesser permeability shows improved durability in concretes (Wesche et al., 1989; Ramezanianpour et al., 2011). Permeability of concrete can be evaluated by the water penetration test and the validity of the water penetration test has been approved by BS EN 12390-8 (2000).

The water penetration depth test presented in **Figure** 11 revealed that the water penetration depth of SCC mixtures with accumulation of 5% to 15% MK is decreased than that of SCC without MK at 28 and 180 days. However, the maximum reduction in water penetration depth of SCC mixtures was found as 34.0% and 33% at 15% of MK as cementitious ingredient at 28 and 180 days respectively. This may due to the filling consequence and effect by the active pozzolanic reaction of Metakaolin and the silica content in metakaolin (Parande et al., 2008; Wild et al., 1996). Almost the same behavior in terms of water penetration is reported by Erhan Guneyisi et al*.* that the permeability was reduced by 29% at 15% of MK as cementitious constituent as compared to plain concrete (Güneyisi et al., 2012).

The water penetration test presented in **Figure 12** is covered that the water penetration depth of modified mixes has been reduced contrasted with the CM with the replacement of F.A by the CBA with 10% to 30%. The optimum reduction in water penetration depth was found as 13.5 mm (i.e. 33.49 % decrease compared to control mix mix) at 30% substitution of F.A with CBA. On additional substitution of F.A by CBA, the water penetration depth of CBA SSC concrete has been enhanced contrasted the control mix concrete after 28 days. Almost the same behavior in terms of water penetration has been reported by different researchers (Sirivivatnanon, 1997; Ratchayut & Somnuk, 2008). However, the water penetration test presented in **Figure 12** has shown that the water penetration depth of modified mixes has been declined contrasted with the CM by the replacement of F.A by the CBA with 10% to 30%. The optimum reduction in water penetration depth has been found as 10.2 mm (i.e. 41.04 % decrease compared to control mix) at 30% substitution of F.A with CBA. On additional substitution of F.A by CBA, the water penetration depth of CBA SSC concrete has been increased contrasted with the control mix concrete after 180 days. The same behavior in terms of water penetration has been reported by Yahya et al., (2019) that the substitution of 20% fine aggregate with CBA, the water penetration depth has been enhanced with growing in the extent of CBA as sand substitution. It was identified that the CBA used as sand substitution has declined concrete resistance for water absorption. This similar study has been detected by Marto et al., (2011). Hashemi et al., (2018) described that the growing need for water has happened owing to the permeable texture of CBA causing in enhance the permeability of concrete. Hence, the CBA saturated high amount of water in concrete contrasted with that of the control mix. Therefore, this occurrence illustrates the CBA to have more porous behavior contrasted with the control mix concrete (Hassan et al., 2010). Almost the same behavior in terms of water penetration has been reported by different researchers (Ratchayut & Somnuk, 2008; Khatri and Sirivivatnanon, 1997).

It is observed from **Figure 13** that by the combined use of local metakaolin and CBA, minimum water penetration depth 9.76 mm is achieved at 28 days at 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 36.45 % less than that of control SCC.

3.2.5 Sustainability assessment

Table 4 shows the data of embodied carbon for materials which are used in this investigational study and **Equation (1)** was used to calculate the quantity of embodied carbon content for twenty five SCC mixtures including various percentages of MK as PC replacement and CBA as sand ingredient. **Figure 14** indicates the embodied carbon of SCC mixture inclusion with 0%-20% of MK as cementitious material. The embodied carbon is recorded by 2.72%, 5.44%, 8.10% and 10.72% at 5%, 10%, 15% and 20% of PC replaced with MK is lower than that of control mix of SCC. It was perceived that the embodied carbon is decreased as the dosages of PC replaced with MK increases in SCC mixture. This similar type of trend was performed by Bheel et al. (2021) where the embodied carbon is reduced as the content of coconut shell ash rises in concrete. Related studies were observed by Bheel et al. (2020). However, **Figure 15** represents the embodied carbon of SCC mixture including 10%-40% of CBA as replacement for fine aggregates in mixture. The embodied carbon of SCC mixture is noted by 0.50%, 1.16%, 1.82% and 2.50% at 10%, 20%, 30% and 40% of fine aggregates replaced with CBA is higher than that of control mix of SCC. It can be observed that the embodied carbon of SCC is increased with growing in the extent of CBA as sand replacement in SCC mixture. **Figure 16** displays the calculated quantity of embodied carbon of SCC including 0%-20% of MK as PC replacement and CBA as sand replacement in SCC mixture. The highest embodied carbon is calculated by 450.45 $kgCO_2/m^3$ at control mix of SCC and minimum embodied carbon is noted by 405.15 $kgCO_2/m^3$ at 20% of PC replaced with MK and 10% of fine aggregates replaced with CBA in SCC mixture. From **Figure 16**, it has been observed that the embodied carbon is reduced as the dosages of PC replaced with MK and fine aggregates replaced with CBA increases in the SCC mixture. Therefore, when using environmentally friendly materials (such as recycled waste), the embodied carbon in the concrete mix can be more reduced.

4 Conclusions

It was concluded from the conducted research that:

- It was detected that by using local Metakaolin and CBA resulted increased amount of super-plasticizer to develop the SCC. To develop SCC by using local metakaolin as cement replacement for 5, 10, 15 and 20% metakaolin 2% and 3% SP are used respectively. While to develop SCC with CBA as 10, 20, 30, and 40% fine aggregate replacement 5%, 9%, 13% and 17% superplasticizer is used. . In the combined utilization of MK as cement replacement and CBA as fine aggregate replacement maximum 22% SP is used to develop the SCC.
- The maximum compressive strength is improved as 22.6%, 10.39%, and 9.29% and maximum tensile strength is augmented as 10.43%, 10.19%, and 10.0% more than that of control mix at 15% of MK as cementitious component at 3, 28 and 180 day respectively. It is oblivious that the optimum compressive strength, 41.56 MPa (i.e. 14.55% increase contrasted with the control mix) at 28 days,

has been attained at 30% replacement of F.A with CBA. By the combined use of local metakaolin and CBA maximum compressive strength is 44.81 MPa achieved at 28 days at 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 23.51% more than that of control SCC. By the combined use of local metakaolin and CBA maximum tensile strength is 4.48 MPa achieved at 28 days at 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 23.42% more than that of control SCC.

- By the combined use of local metakaolin and CBA maximum flexural strength is 7.17 MPa achieved at 28 days 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 23.62% more than that of control SCC.
- The water penetration depth of SCC mixtures with accumulation of 5% to 15% MK is decreased than that of SCC without MK and with 20% MK after 28 and 180 days. However, the maximum reduction in water penetration depth of SCC mixtures was found as 34.0% and 33% at 15% of MK as cementitious ingredient after 28 and 180 days respectively. The optimum reduction in water penetration depth was found as 13.5 mm (i.e. 33.49 % decrease compared to control mix mix) at 30% substitution of F.A with CBA. By the combined use of local metakaolin and CBA, minimum water penetration depth 9.76 mm is achieved at 28 days at 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash which is 36.45 % less than that of control SCC.
- The embodied carbon is reduced with growing in the dosages of MK as PC replacement in SCC mixture. However, the embodied carbon of SCC mixture is increased as the extent of CBA as sand ingredient replacement rises in mixture. Moreover, the embodied carbon of SCC mixture is reduced while the increasing of MK as cementitious ingredients and CBA as fine aggregates replacement in mixture.
- Based on investigated parameters, it can be concluded that at 15% replacement of cement with local metakaolin is optimum and gave better results as compared to control SCC. At 30% replacement of fine aggregate is optimum and gave better results as compared to control SCC. In the combined mix 10% replacement of cement with metakaolin combined with 30% replacement of fine aggregate with coal bottom ash is optimum and gave better results as compared to control SCC.

Declarations

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None

Author Contributions

Manthar Ali Keerio: Data Analysis, Validation, Writing – Original Draft.

Abdullah Saand: Supervision, Methodology, Writing - Original Draft, Funding Acquisition.

Aneel Kumar: Formal Analysis, Validation.

Naraindas Bheel: Conceptualization, Investigation, Data Analysis, Validation, Writing - Original Draft, Writing – Review and Editing.

Karm Ali: Data Analysis, Validation, Writing – Original Draft

Availability of data and material

The data used in this study will be made available upon the request.

Compliance with ethical standards/Conflict of interest

None

Consent to participate

Not Applicable

Consent for publication

Not Applicable

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Tables

Table 1: Physiochemical Properties of Binder (OPC, Soorh and Developed Metakaolin)

Constituent	OPC (%)	Soorh (%)	Metakaolin (%)	CBA (%)
SiO_2	20.78	55.89	62.18	36.67
Al_2O_3	5.11	23.51	21.67	26.131
CaO	60.89	-------	3.01	5.107
MgO	3.0	3.53	3.41	1.757
Fe_2O_3	3.17	8.15	3.01	14.022
K_2O	-----	5.89	1.85	0.927
Na_2O_3	-----	1.89	1.03	2.535
TiO_2	-----	1.14	1.03	2.535
In_2O_3	-----	-----	0.80	
LOI (%)	1.71	7.40	0.50	1.064
Specific gravity	3.15	2.64	2.60	

Table 2: Constitute composition of natural material Soorh and developed metakaolin

Components	Soorh (%)	Developed metakaolin (%)
Quartz	47.1	36.3
Illite	27.4	42.9
Stevensite	12.1	16.5
Kalonite	11.9	--
Calcite magnesium	0.8	4.3
Hematite	0.7	--

Table 3: Chemical composition of CBA

Constituents	**Percentage by weight of CBA Lakhra power plant**
SiO_2	36.67
Al_2O_3	26.131
CaO	5.107
MgO	1.757
Fe_2O_3	14.022
K_2O	0.927
Na_2O_3	2.535
TiO_2	2.535

Table 4: Details of mix proportions (Kg/m3)

Concrete Mix	Cement	MK	CBA	W/B (%)	Water	FA	CA	SP (%)
CM	500	0	--	0.38	190	900	650	2
MK5	475	25	--	0.38	190	900	650	2
MK10	450	50	--	0.38	190	900	650	2
MK15	425	75	--	0.38	190	900	650	3
MK20	400	100	--	0.38	190	900	650	3
CBA10	500	--	90	0.38	190	810	650	5
CBA20	500	--	180	0.38	190	720	650	9
CBA30	500	--	270	0.38	190	630	650	13
CBA40	500	--	360	0.38	190	540	650	17
MK5CBA10	475	25	90	0.38	190	810	650	5
MK5CBA20	475	25	180	0.38	190	720	650	9
MK5CBA30	475	25	270	0.38	190	630	650	13
MK5CBA40	475	25	360	0.38	190	540	650	18
MK10CBA10	450	50	90	0.38	190	810	650	5
MK10CBA20	450	50	180	0.38	190	720	650	12
MK10CBA30	450	50	270	0.38	190	630	650	16
MK10CBA40	450	50	360	0.38	190	540	650	20
MK15CBA10	425	75	90	0.38	190	810	650	7
MK15CBA20	425	75	180	0.38	190	720	650	13
MK15CBA30	425	75	270	0.38	190	630	650	17
MK15CBA40	425	75	360	0.38	190	540	650	22
MK20CBA10	400	100	90	0.38	190	810	650	7
MK20CBA20	400	100	180	0.38	190	720	650	13
MK20CBA30	400	100	270	0.38	190	630	650	17
MK20CBA40	400	100	360	0.38	190	540	650	22

Table 5: Embodied carbon of materials

Materials	Embodied carbon ($kgCO_2/kg$)	“References”
Cement	0.82	(Flower and Sanjayan, 2007) (Meddah et al.,
MK	0.33	2018)
CBA	0.015	(Kalaw et al., 2016)
Super	0.72	(Long et al., 2015)
Plasticizer	0	(Yang et al., 2013)
Water	0.0139	(Turner and Collins, 2013)
FA	0.0408	(Turner and Collins, 2013)
CA		

Table 6: Fresh properties of SCC

Concrete Mix	Filling Ability Properties			Passing Ability Properties		Segregation Resistance Property	SP (%)
	Slump Flow (mm)	V-funnel (Scec)	T_{50} flow (Scec)	L-Box (Ratio)	J- Ring (mm)	Sieve Segregation (%)	
CM	740	7.4	2.8	0.83	2.5	8.43	2
MK5	710	9.8	3.6	0.95	6	5.11	2
MK10	695	11.2	4.8	0.97	7.5	4.88	2
MK15	635	9.1	3.4	0.88	3.8	10.1	3
MK20	580	11.4	4.6	0.98	8.3	6.78	3
CBA10	735	11.2	4.98	0.85	4.5	5.26	5
CBA20	760	11.89	4.89	0.92	7.4	4.56	9
CBA30	755	10.22	4.8	0.87	8.7	7.23	13
CBA40	750	12	4.3	0.89	6.8	7.35	17
MK05CBA10	745	8.39	3.4	0.89	3.8	8.45	5
MK05CBA20	750	10.22	3.8	0.92	7.8	6.67	9
MK05CBA30	750	9.84	4.3	0.9	8.1	5.72	13
MK05CBA40	752	11.42	4.8	0.88	8.6	6.82	18
MK10CBA10	760	8.4	3.7	0.88	3.8	6.24	5
MK10CBA20	745	9.5	4.4	0.89	4.2	7.18	12
MK10CBA30	755	10.3	4.9	0.95	5.6	6.38	16
MK10CBA40	730	10.2	4.1	0.91	8.4	6.1	20
MK15CBA10	745	9.7	3.9	0.91	4	5.27	7
MK15CBA20	750	10.3	4.3	0.94	4.2	6.91	13
MK15CBA30	755	10.5	4.8	0.9	7.3	5.79	17
MK15CBA40	750	8.7	4.2	0.94	6.9	7.35	22
MK20CBA10	750	9.6	4.4	0.85	5	6.39	7
MK20CBA20	720	10.2	4.8	0.87	6.3	5.71	13
MK20CBA30	725	11.1	3.9	0.91	6.8	6.4	17
MK20CBA40	745	11.66	4.3	0.95	6.2	6.24	22

Figures

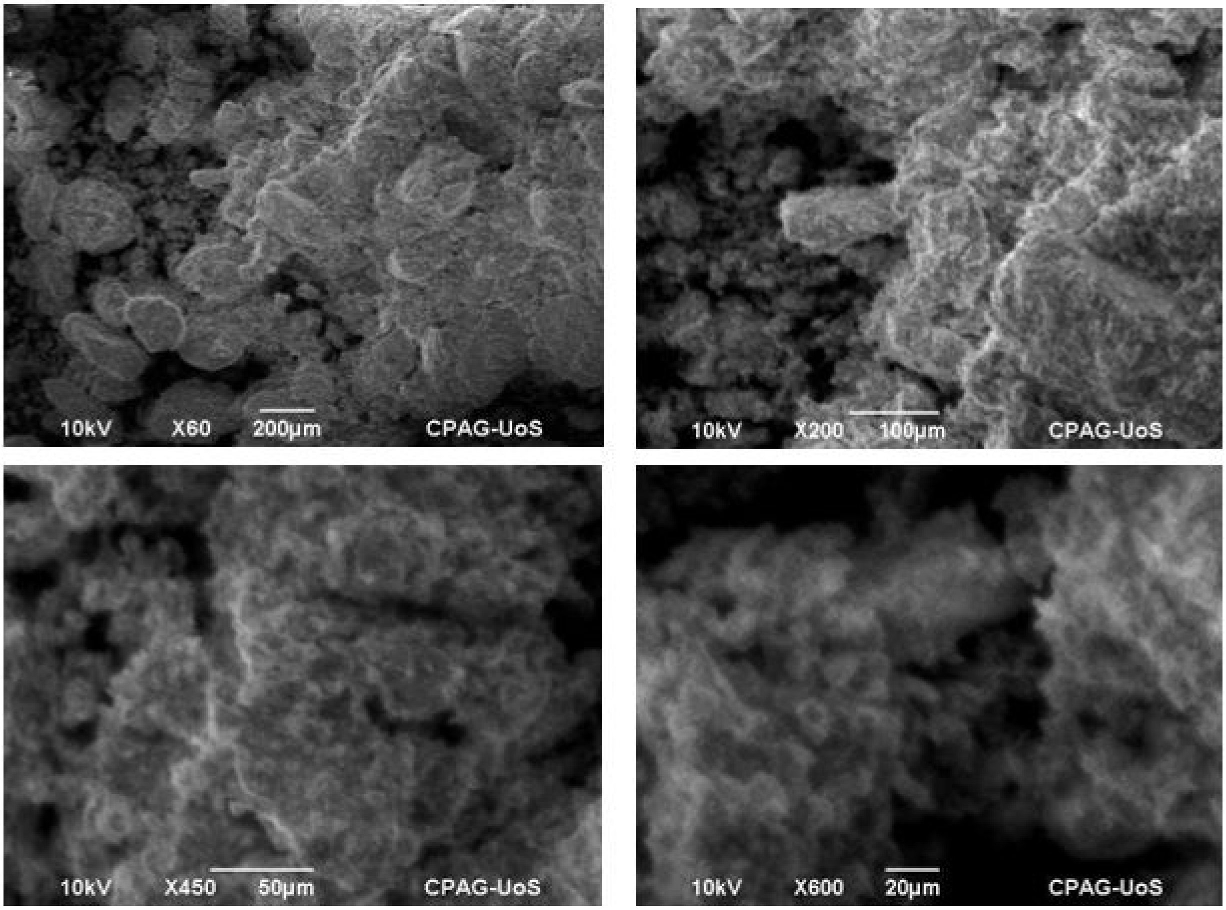

Figure 1

SEM images of local developed metakaolin

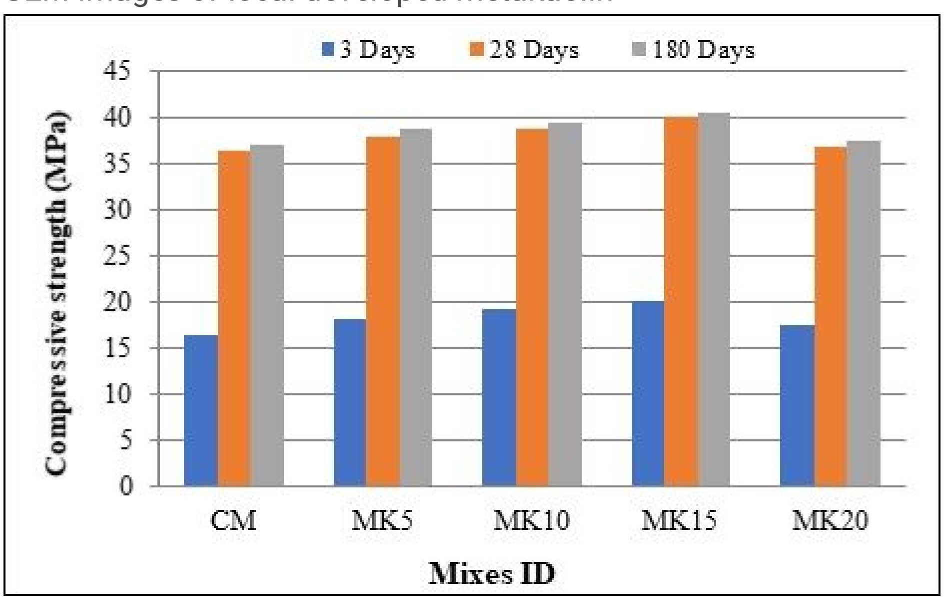

Figure 2

Compressive strength of MK SCC at 3, 28 and 180 days

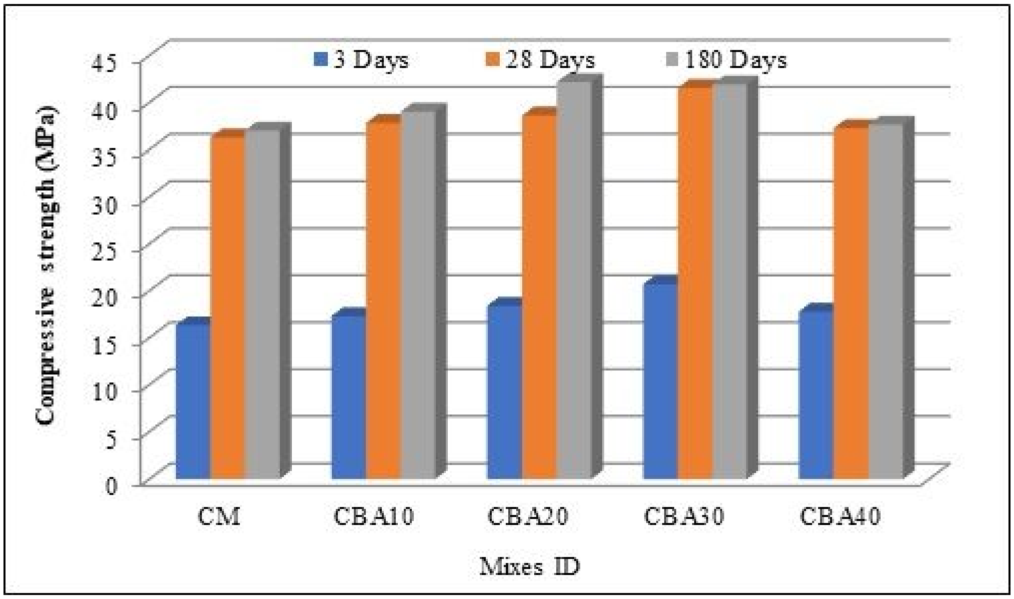

Figure 3

Compressive strength of CBA SCC at 3, 28 and 180 days

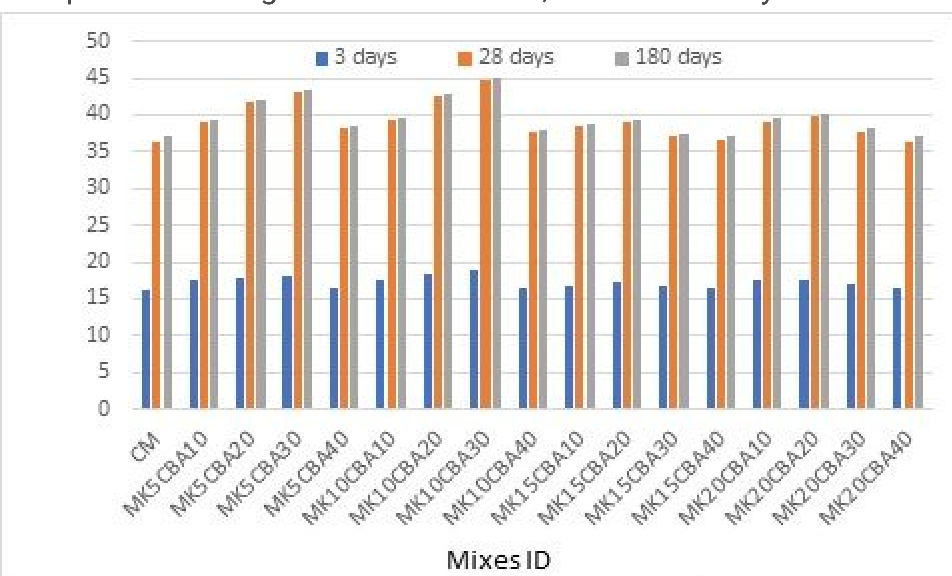

Figure 4

Compressive strength of MK CBA SCC at 3, 28 and 180 days

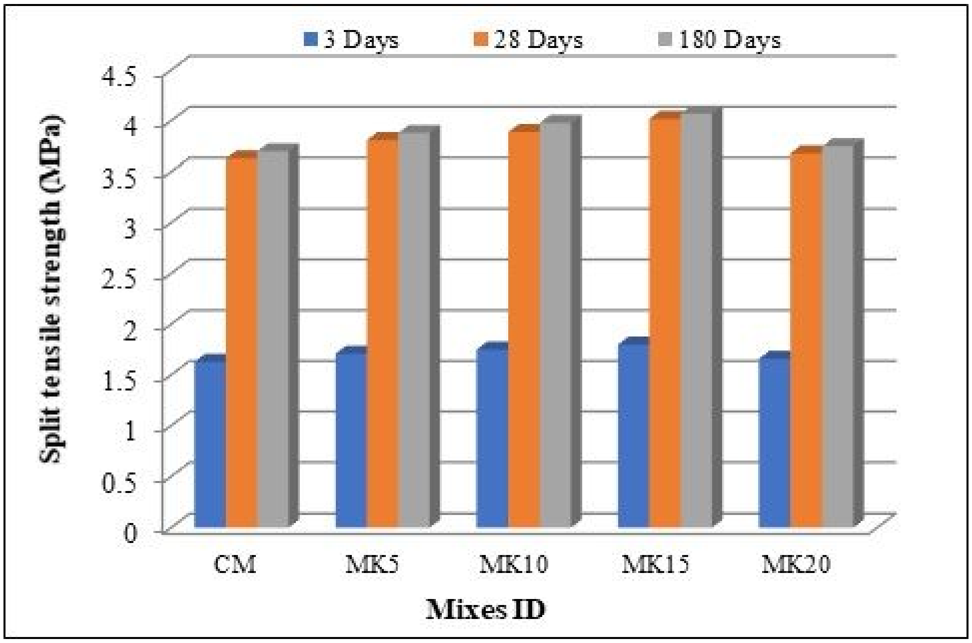

Figure 5

Tensile strength of MK SCC at 3, 28 and 180 days

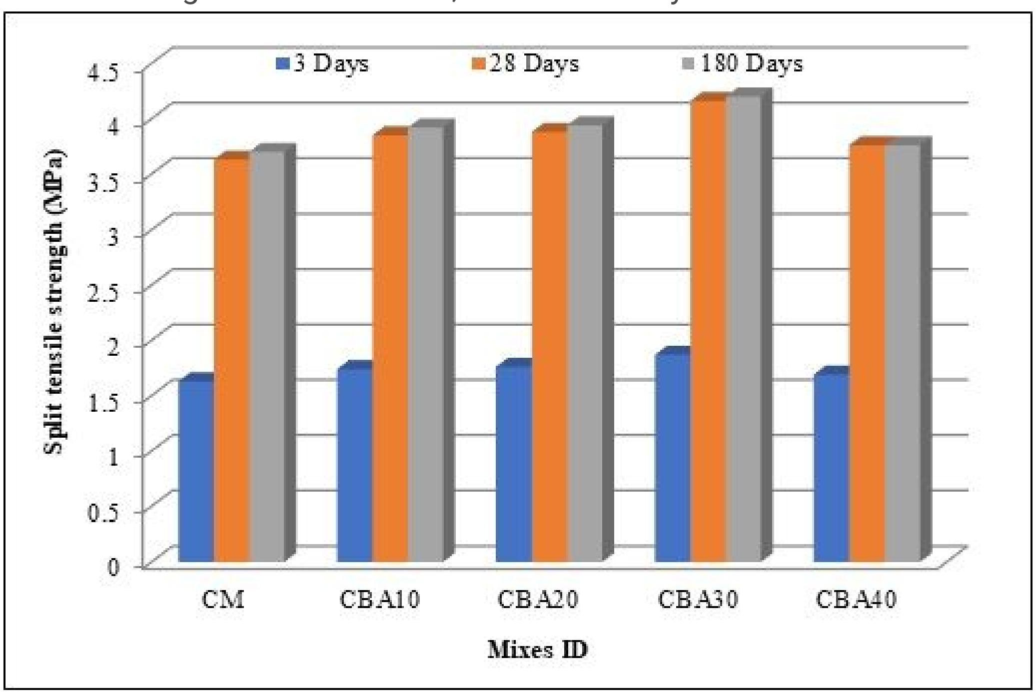

Figure 6

Tensile strength of CBA SCC at 3, 28 and 180 days

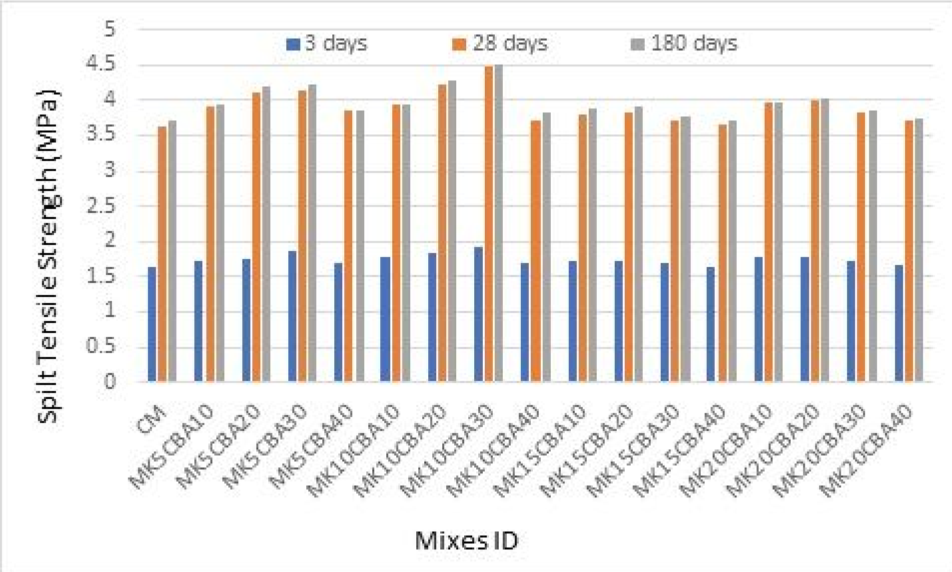

Figure 7

Tensile strength of MK CBA SCC at 3, 28 and 180 days

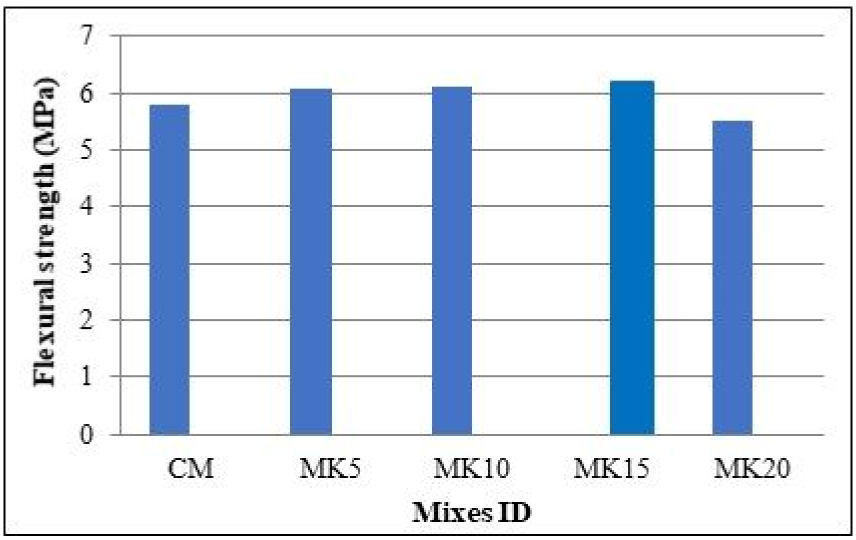

Figure 8

Flexural strength of MK SCC at 28 days

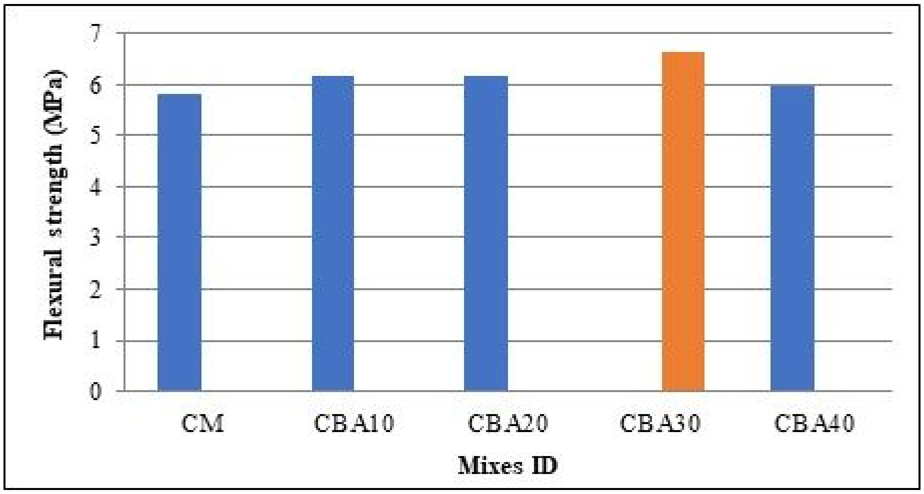

Figure 9

Flexural strength of CBA SCC at 28 days

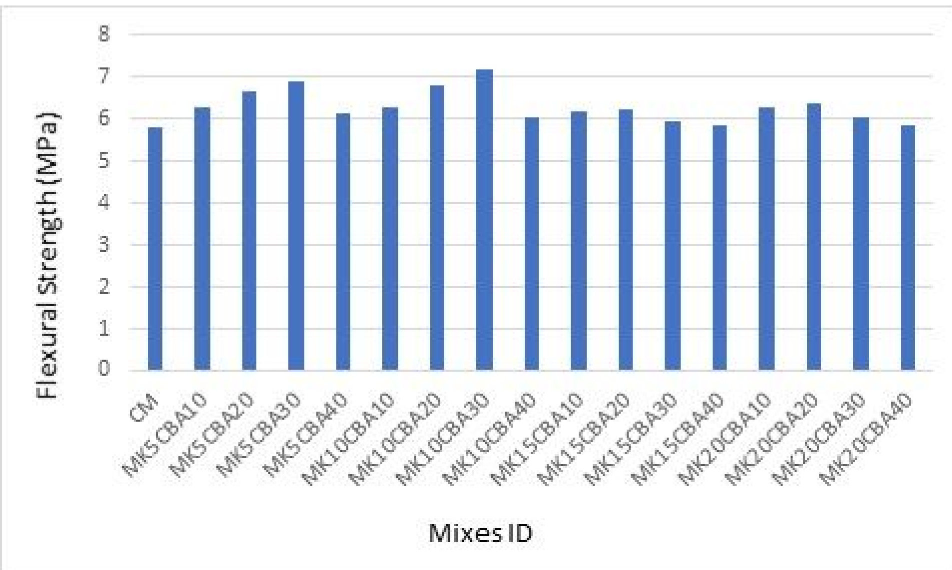

Figure 10

Flexural strength of CBA MK SCC at 28 days

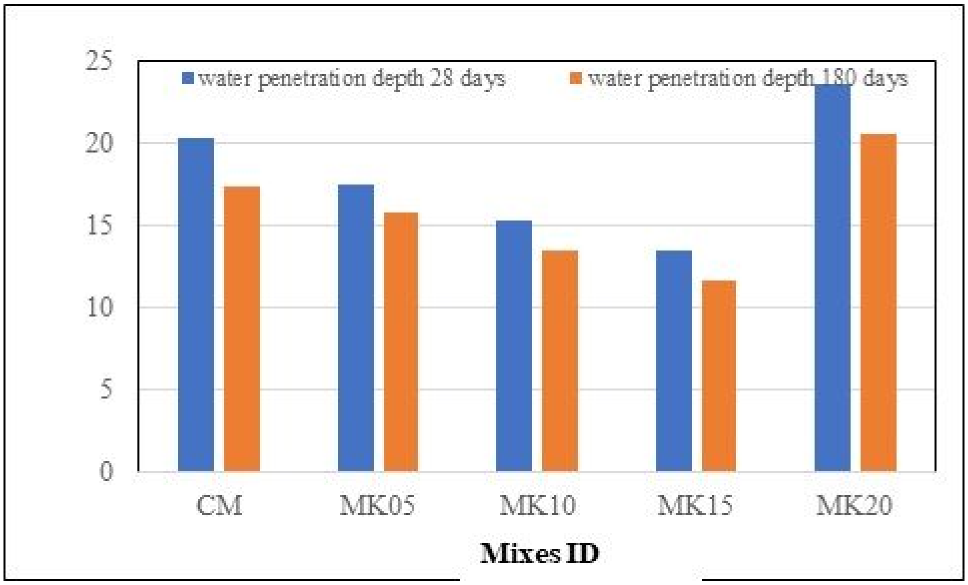

Figure 11

Water Penetration Depth of MK SCC at 28 and 180 days

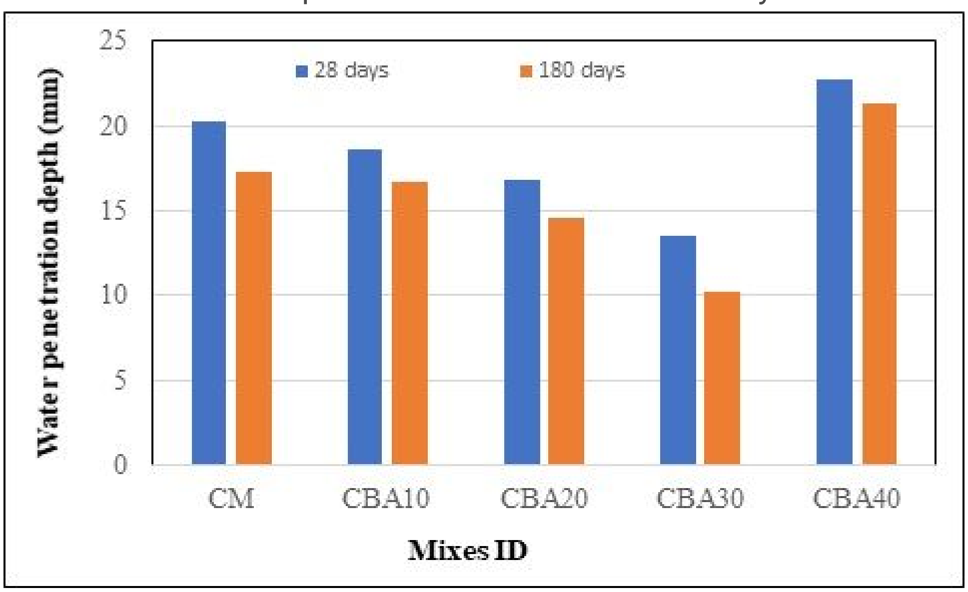

Figure 12

Water Penetration Depth of CBA SCC at 28 and 180 days

Figure 13

Water Penetration Depth of MKCBA SCC at 28 and 180 days

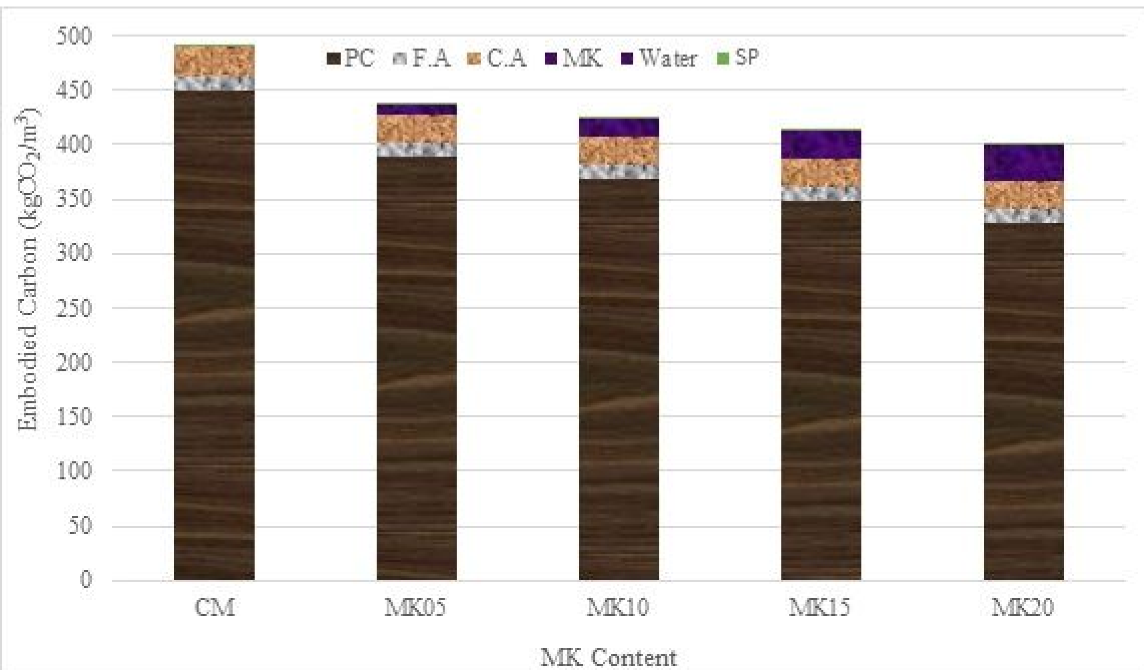

Figure 14

Embodied Carbon of Concrete including MK

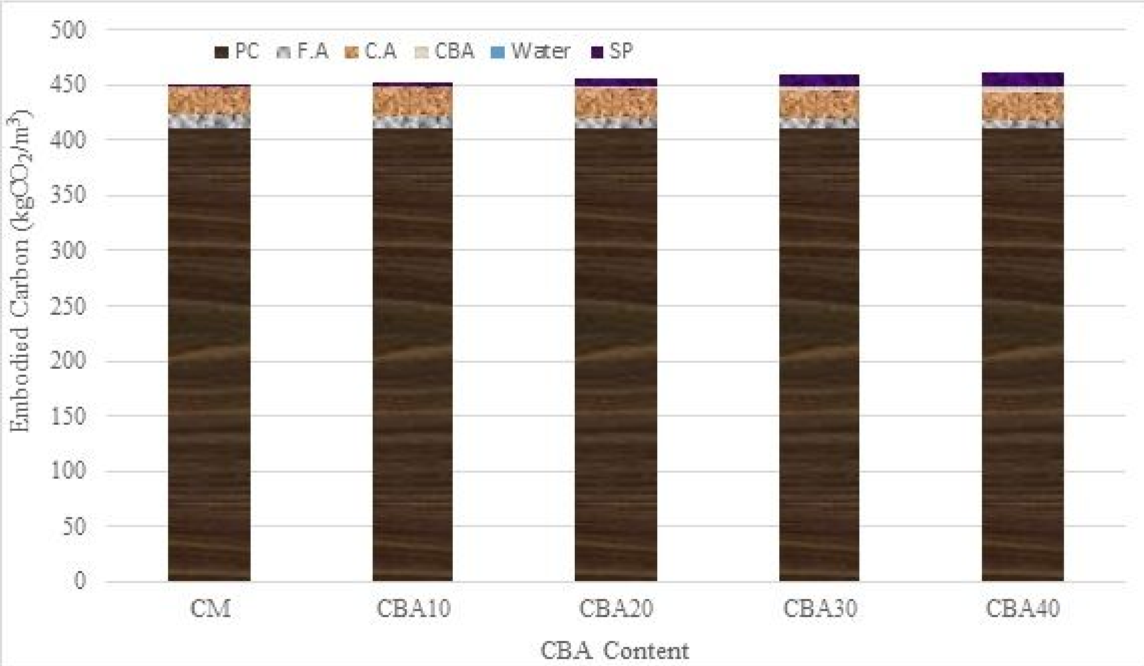

Figure 15

Embodied Carbon of Concrete containing CBA

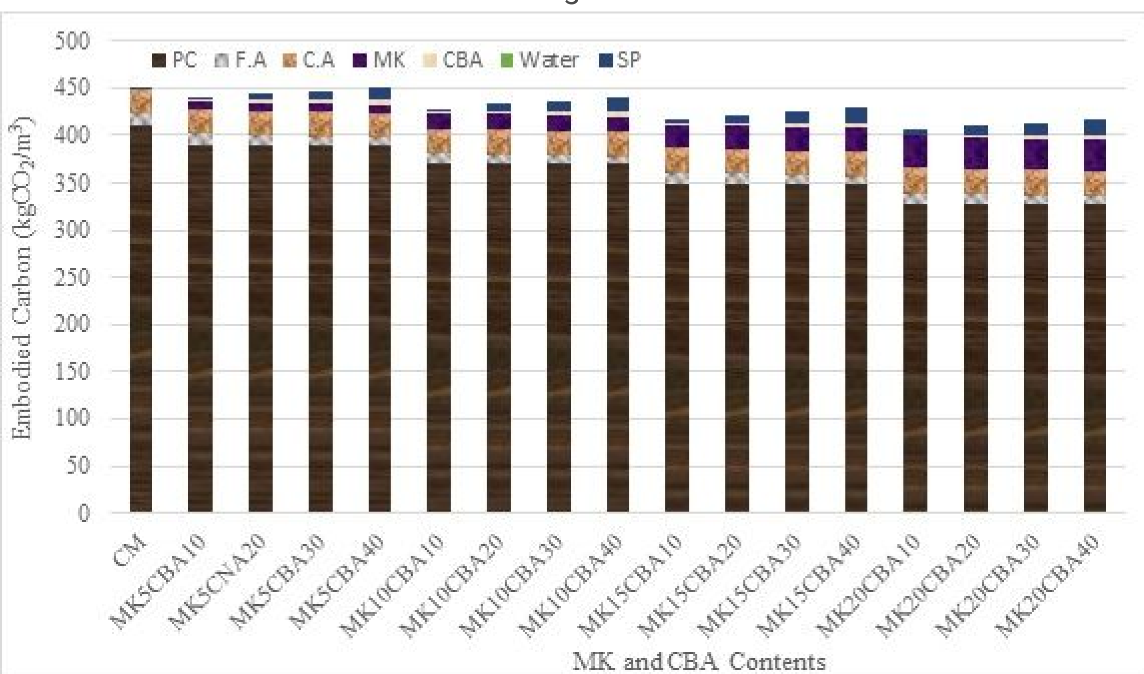

Figure 16

Embodied Carbon of Concrete including MK and CBA