Experimental Study on Fresh, Mechanical Properties and Embodied Carbon of Concrete blended with Sugarcane Bagasse Ash, Metakaolin and Millet Husk Ash as Ternary Cementitious Material

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Abstract

In recent years, there has been great concern about introducing new supplementary cementitious materials (SCM) in place of Portland cement (PC) in concrete. This study aims to investigate the behavior of sugarcane bagasse ash (SCBA), metakaolin (MK) and millet husk ash (MHA) as SCM with various proportions in concrete. The SCBA, MK and MHA are available in abundant quantities and considered as waste products. On the other hand, cement production emits a lot of toxic gases in the atmosphere which causes environmental pollution and greenhouse gases. Thus, SCBA, MK and MHA might be utilized as cementitious material in concrete for sustainable development. The effect of SCBA, MK and MHA as SCM on the fresh, mechanical properties and embodied carbon of concrete was evaluated experimentally. A total of 228 concrete specimens were prepared with targeted strength of 25MPa at 0.52 water-cement ratio and cured at 28 days. It is found that the compressive strength and split tensile strength were enhanced by 17% and 14.28% respectively at SCBA4MK4MHA4 (88% PC, 4% SCBA, 4% MK and 4% MHA) as ternary cementitious material (TCM) in concrete after 28 days. Moreover, the permeability and density of concrete are being reduced while utilizing of SCBA, MK and MHA separately as SCM and combined as TCM increases in concrete at 28 days respectively. Moreover, the workability of fresh concrete was decreased with the increase of the percentage of SCBA, MK and MHA separately as SCM and together as TCM in concrete. In addition to that, the use of SCBA, MK and MHA individually as SCM and combined as TCM in concrete can reduce the total carbon footprint while reducing the overall cost of concrete manufacturing.

Keywords: Sugarcane Bagasse Ash; Metakaolin; Millet Husk Ash, Supplementary Cementitious Material; Fresh and Mechanical Properties; Reduce Embodied Carbon of concrete.

1. Introduction

Concrete is the most versatile and most widely used construction material worldwide. Concrete is the best building material as compared to stone, brick or steel etc. (Akyuncu 2012). Civilizations as old as 6500 BC have used non-hydraulic cement in the past. Greeks and Romans developed hydraulic cement afterward (Li 2011). It is the most used construction material these days because of its numerous merits which encircle but are not limited to its moldability, adaptable nature, fire resistance and affordability. Concrete is used in many types of construction like houses, roads, bridges, hospitals and commercial centers etc. Concrete is the combination of cement, coarse aggregate, fine aggregate, water and admixtures. More than 10 billion tons of concrete are produced annually (Evi Aprianti S 2017). With the rise in demand for other basic needs of human like clothing, energy, food and water. Similarly, the demand for concrete is also expected to rise by the year 2050 by which the estimated the production of concrete is about 18 billion tons annually (Evi Aprianti S 2017).

Due to significant use of concrete, the demand for cement is also increasing with every passing day. The present use of cement is evaluated to be around 12 million tons per year and is yet expanding day by day (Khitab 2020). The production of cement is very hazardous to the environment as it produces heat and an excessive amount of CO_2 (Bheel et al. 2020). Carbon dioxide emission is a serious environmental problem in cement production. It is a well-known fact that the production of one-ton cement exhaust around one ton of carbon dioxide directly into the atmosphere. In addition, it is accused of producing cement for 5-7% of carbon dioxide emissions from industrial sources (Bheel et al. 2020). Similarly, the other materials required to produce the cement also pollute the environment and cause the depletion of our natural resources. Coarse aggregates are the key constituents of concrete which are obtaining by cutting and blasting hills and mountains and can also pollute the environment. . Previously a number of researchers have already worked a lot to reduce the use of concrete and replace concrete with sustainable materials, which give the properties like concrete. The emphasis is being put forth on the utilization of industrial and agricultural wastes, as they are the environmental burden (Batayneh et al., 2007; Senthamarai and Manoharan 2005).

It is difficult to dispose of agricultural waste because it still creates an environmental burden. However, it is beneficial when used in concrete. It will not only save money, but it will also cause a reduction in the use of cement in the concrete structure which will reduce the carbon dioxide emissions associated with cement production, and the stability of the building must be taken into account (Hanle et al., 2004; Ma et al, 2007; Aitcin 2011). Partial replacement of cement by a combination of materials for the replacement of cement (CRM) is not only economically advantageous but also can be beneficial due to its mechanical, durable and microstructural characteristics (Gruber et al. 2001). The use of CRM’s in concrete has attracted attention of researchers, and its focus is on extending the life of concrete structures (Kumar et al. 2017). There are many CRMs available in the market for concrete production. Some of the most common materials are sugarcane bagasse ash (SCBA), metakaolin (MK), limestone powder (LSF), rice husk ash (RHA), coal bottom ash (CBA), wheat straw ash (WSA) and silica fume (SF), etc. (Ghosal 2015). In this research project, SCBA and metakaolin (MK) are used as supplementary cementitious material (SCM) in concrete. Those wastes are readily available as there is no other use of those except for landfilling. Owing to the environmental issues associated with cement, the partial replacement of cement by a local waste material will not only lessen the requirement of cement in construction projects but also the corresponding dumping of the waste in landfills will be reduced. However, the Bagasse is an essential by-product of the sugar factory that is utilized as an energy fuel for sugar production in the same factory (Ismail et al., 2008). 25-30% bagasse obtained from sugarcane, while factory processed sugar makes up about 10%. Bagasse is utilized as a raw source for paper production due to its fibrous appearance and can give output about 0.3 tons of paper from one ton of bagasse (Xie and Xi, 2001). Around 70 sugar factories producing 14 million tons of bagasse per annum also used as energy sources. No other uses than landfills, as burning bagasse leaves 3% ash (Amin, 2010; Ramesh et al., 2013). Production of additional calcium silicate hydrate (CSH) due to the result of silica content in pozzolana reacts with free lime released during cement hydration (Mangi et al., 2017), which enhances the hardened characteristics of concrete.

Moreover, the metakaolin (MK) is obtained from kaolin clay which is burnt under controlled temperature ranges from 650-800 ^{0}C. Though the MK is a natural pozzolanic material and it can be used as SCM in concrete. Besides, the utilization of metakaolin in concrete which provides greater strength development of interfacial transition zone as compared to the other constituents

(Duan et al., 2013). Over the past decades, the metakaolin has been utilized commercially in the construction industry (Brooks et al., 2000). Most of the studies were performed on concrete containing MK as SCM which shows the considerable improvement in the hardened properties of concrete.

Poon et al., (2006) conducted experimental work on concrete blended with MK as SCM which increases the mechanical properties of the mixture and reduces the porosity of concrete. It is noted that the concrete inclusion with MK as SCM performs better strength development while using a 0.5 w/b ratio than that of 0.3 w/b ratio and pore spaces are reduced with increase in the dosages of MK in concrete after 28 days. However, Jin and Li, (2003) described the related trend. Ahmed et al., (2012) stated that the compressive and flexural strength of concrete is improved while using 15% of MK as SCM in concrete.

Furthermore, millet husk ash (MHA) is obtained from the burning of millet husk under control temperature ranges from 500-850 ^{0}C for six hours to produce ash. This ash has the potential to be utilized as a supplementary cementitious material in concrete, in order to decrease the usage of PC and increase the utilization of agricultural wastes materials for commercial purposes in the construction industry. However, millet grows all over the world is about 28.38 million tons of which 11.36 tons are generated in Africa and 4.53 tons are generated in Nigeria (Belton et al., 2002). It has been observed that approximately 6.7 million tons of millet yield were produced in the area of 5.8 million hectares (USDA, 2005), and it is mostly grown in the northern region due to low rainfall and unfavorable weather conditions exceed 80% (Food and agriculture organization, 2007). Besides, the millet seeds/grains are extracted from the millet husk (Akande, 2002) and there is no further use of millet husk without landfilling therefore the husk is burnt under controlled temperature to reduce the capacity of waste material and used as SCM in concrete.

A few studies were performed by using SCBA and MK as supplementary cementitious material in concrete mixture individually and combine as binary cementitious material but there is no research work investigated on the SCBA, MK and MHA as ternary cementitious material (TCM) in the mixture. Hence, the main objective of this research work is to investigate the fresh, mechanical properties and embodied carbon of concrete including various content of SCBA, MK and MHA as SCM separate and TCM in concrete.

2. Materials and Experimental Program

2.1 Materials

Sugarcane bagasse ash (SCBA) was obtained from Sugar Mill with prior permission and then it was dried under the atmosphere for 24 hours. After drying ash, it was sieved from #300 sieve to eliminate the large particles and then it can be utilized as supplementary cementitious material (SCM) in concrete. However, the metakaolin (MK) is produced from kaolin clay which is burnt under controlled temperature ranges from 650-800 ^{0}C for two hours. After obtaining MK, it was sieved from #300 sieve to extract out large particles and then it can be utilized as SCM in concrete. Though the MK is a natural pozzolanic material and it is available in huge quantities in the District Thatta, Sindh, Pakistan. Moreover, the millet husk ash (MHA) was obtained from the burning of millet husk under control temperature ranges from 500-850 ^{0}C for six hours to produce ash. This produced ash was sieved form the #300 sieve to remove the huge particles and then it can be utilized as SCM in concrete. It is available in huge quantities in the District of Tharparkar, Sindh, Pakistan. **Figures 1, 2 and 3** indicate the scanning electron microscope (SEM) of SCBA, MK and MHA respectively. The Portland cement (PC) was served as binding material for this experimental work and it is collected from Hyderabad, Pakistan. The oxide composition of SCBA, MK, MHA and PC are mentioned in **Table 1**. According to ASTM C618, the sum of SiO_2, Al_2O_3 and Fe_2O_3

is greater than 50% in materials which is categorized as pozzolanic material. Moreover, hill sand was served as fine aggregates (FA) which passed from #4 sieve and coarse aggregate (CA) was used for research work that possesses 20 mm in size. The properties of FA and CA are given in **Table 2**. The sieve analysis curve for CA and FA is shown in **Figures 4 and 5** respectively. In addition, the drinkable water was served for mixing and curing of this investigational study.

Table 1: Oxides of SCBA, MK, MHA and PC

Binding Materials	Oxides (%)						Physical Property
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	SO_3	Specific Gravity
SCBA	76.34	8.35	3.80	2.15	1.98	0.48	1.97
MK	62.18	21.67	3.01	3.22	1.04	0.78	2.60
MHA	69.40	5.80	3.36	10.50	1.10	1.85	2.25
PC	20.78	5.11	3.17	60.22	0.18	2.86	3.13

Binding Materials	Oxides (%)						Physical Property
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	SO_3	Specific Gravity
SCBA	76.34	8.35	3.80	2.15	1.98	0.48	1.97
MK	62.18	21.67	3.01	3.22	1.04	0.78	2.60
MHA	69.40	5.80	3.36	10.50	1.10	1.85	2.25
PC	20.78	5.11	3.17	60.22	0.18	2.86	3.13

Table 2: Physical Properties of Aggregates

S.No	Properties	Coarse Aggregates	Fine Aggregates
1	Water Absorption (%)	0.69	1.32
2	Bulk Density (kg/m^3)	1680	1920
3	Specific Gravity	2.71	2.66
4	Fineness Modulus	----	2.25

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1	Water Absorption (%)	0.69	1.32
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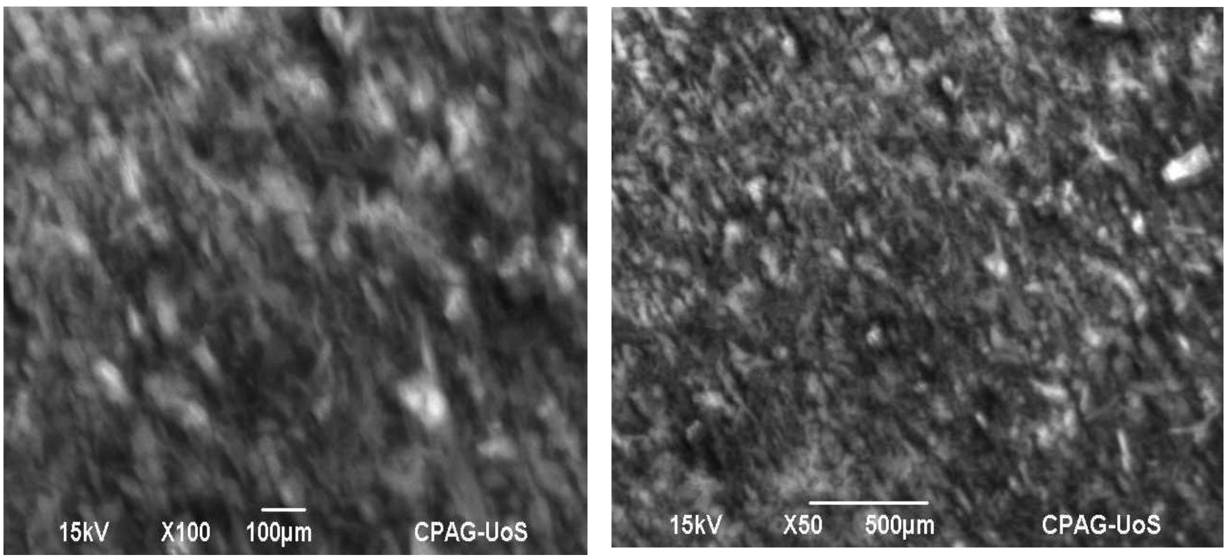


Figure 1: SEM of SCBA at: (a) 100X; (b) 50X

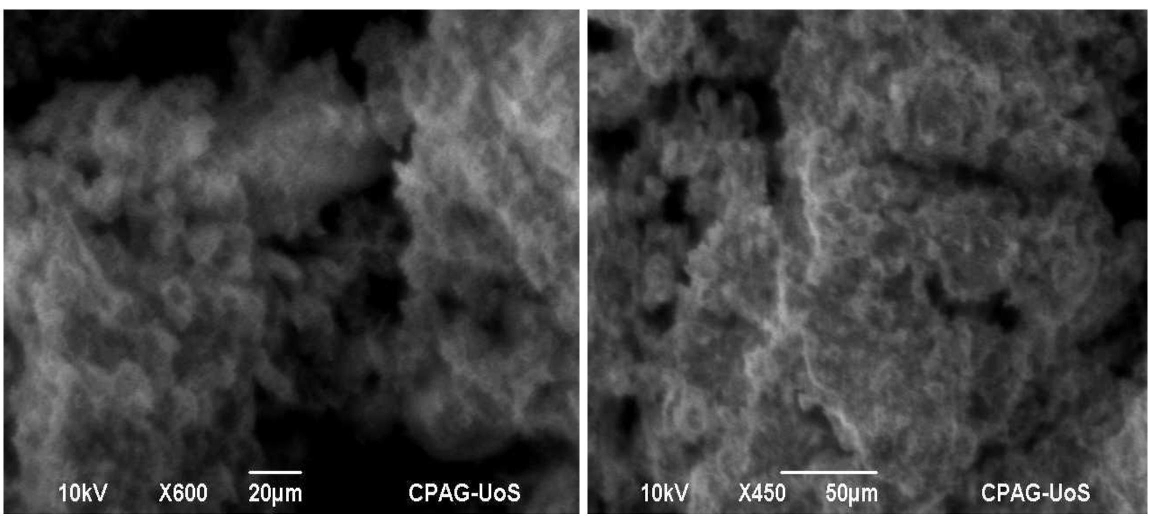


Figure 2: SEM of Metakaolin at: (a) 600X (b) 450X

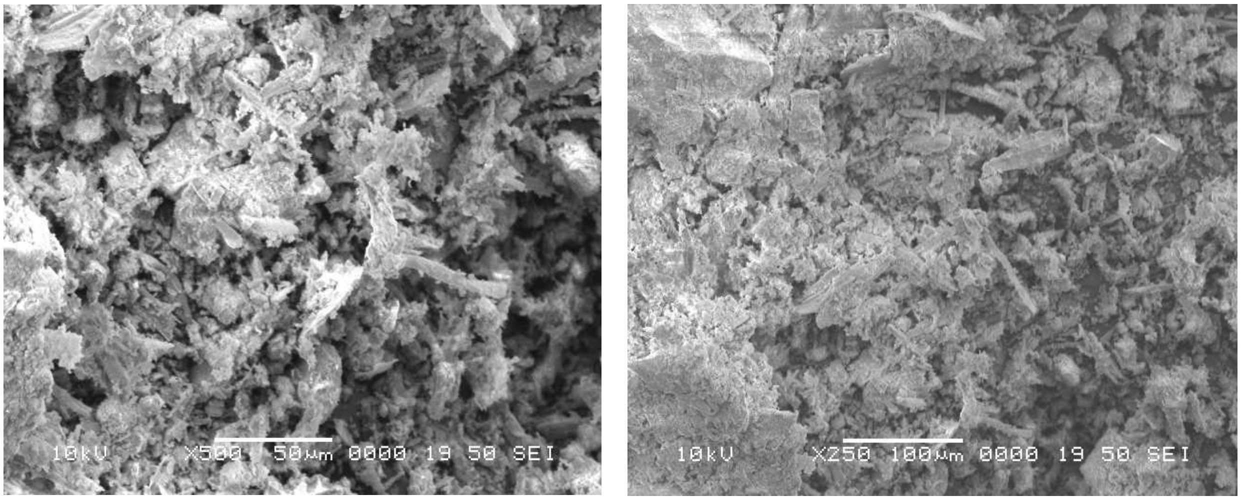
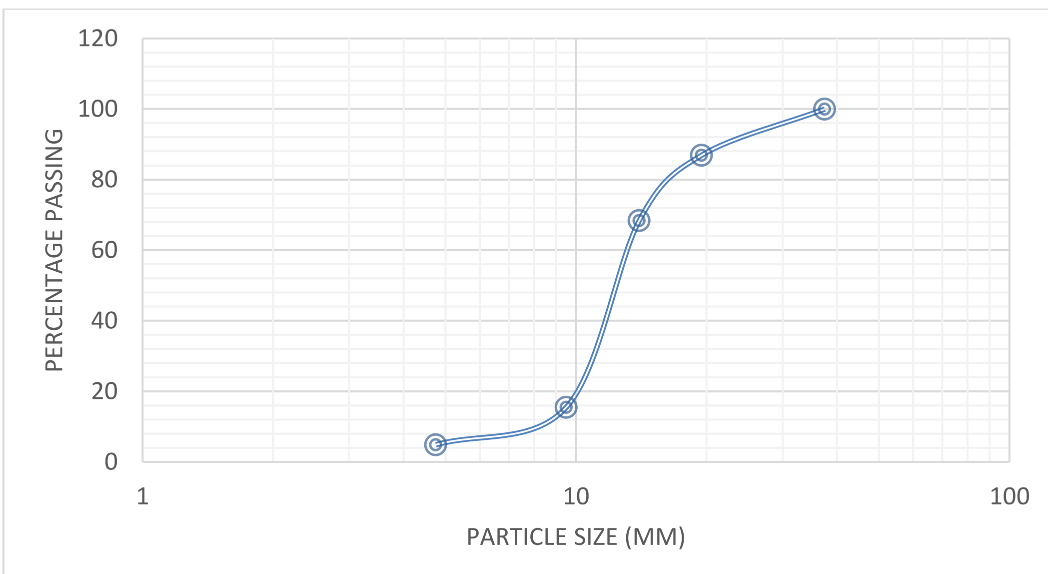


Figure 3: SEM of MHA at: (a) 500X (b) 250X



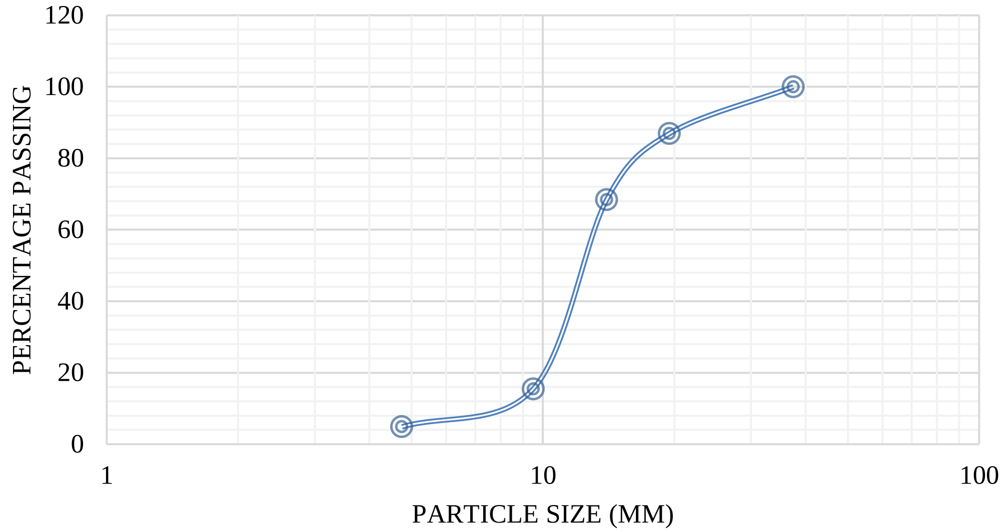
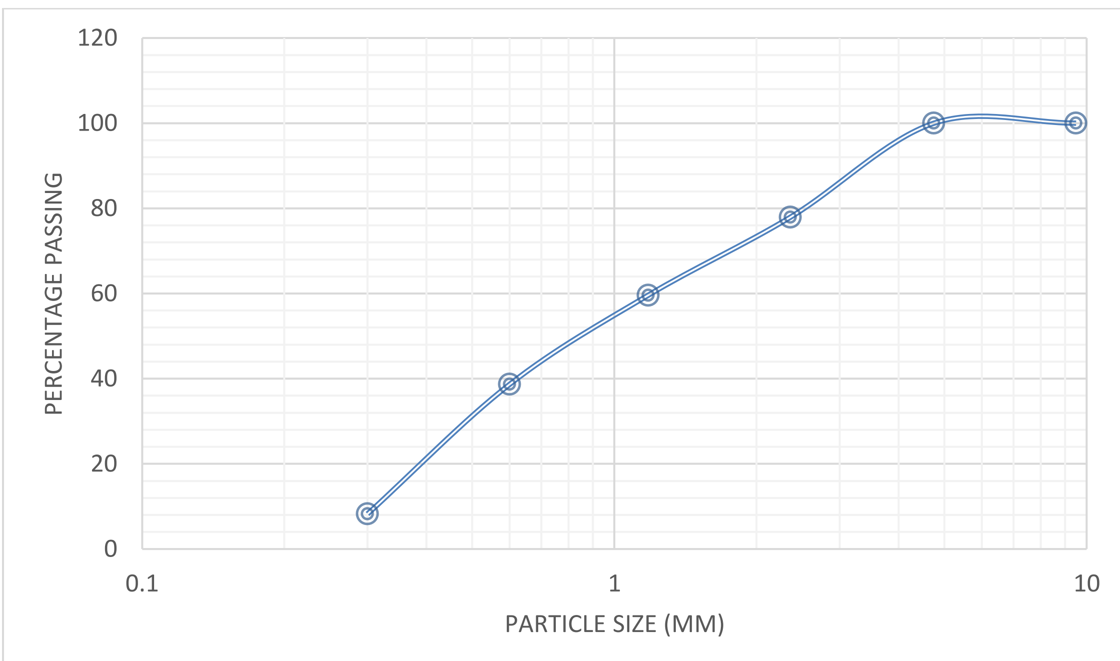


Figure 4: Grading Curve of Coarse Aggregates (C.A)



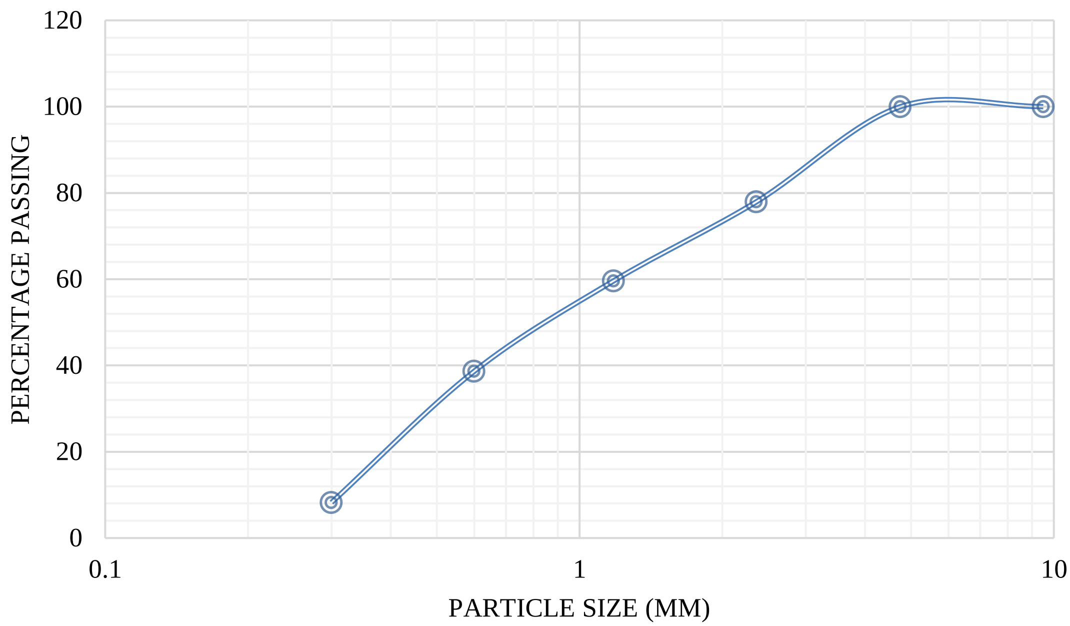


Figure 5: Grading Curve of Fine Aggregates (F.A)

2.2 Experimental Program

This research work was adopted on nineteen mixture of concrete blended with various proportions of SCBA, MK and MHA as SCM in concrete separate and together as TCM for investigating the fresh (slump test) and mechanical properties (density, compressive strength, split tensile strength and permeability) of concrete. From twenty-one mixture, one mixture was made of PC only, four mixes were made with 5%-20% of SCBA, four mixes were prepared of 5%-20% of MK, and four mixtures were equipped with 5%-20% of MHA as PC replacement separate in concrete, and remaining all mixtures were made with various percentages of SCBA, MK and MHA as TCM in concrete. In this investigational study, the concrete specimens (cubes and cylinders) were prod 1:1.62:2.80 mix proportions at a 0.52 water-cement ratio. The details of mix proportions are summarized in **Table 3**.

Table 3: Mix Proportion of Concrete

Mix Proportions	Binder Content (%)				Amount of Material Required to Produce 1 m^3 Concrete (kg)						
	PC	SCBA	MK	MHA	PC	SCBA	MK	MHA	FA	CA	Water
C	100	0	0	0	375	0	0	0	612	1050	195
SCBA5	95	5	0	0	356.25	18.75	0	0	612	1050	195
SCBA10	90	10	0	0	337.50	37.50	0	0	612	1050	195
SCBA15	85	15	0	0	318.75	56.25	0	0	612	1050	195
SCBA20	80	20	0	0	300	75	0	0	612	1050	195
MK5	95	0	5	0	356.25	0	18.75	0	612	1050	195
MK10	90	0	10	0	337.50	0	37.50	0	612	1050	195
MK15	85	0	15	0	318.75	0	56.25	0	612	1050	195
MK20	80	0	20	0	300	0	75	0	612	1050	195
MHA5	95	0	0	5	356.25	0	0	18.75	612	1050	195
MHA10	90	0	0	10	337.50	0	0	37.50	612	1050	195
MHA15	85	0	0	15	318.75	0	0	56.25	612	1050	195
MHA20	80	0	0	20	300	0	0	75	612	1050	195
SCBA2MK2MHA2	94	2	2	2	352.50	7.50	7.50	7.50	612	1050	195
SCBA3MK3MHA3	91	3	3	3	341.25	11.25	11.25	11.25	612	1050	195
SCBA4MK4MHA4	88	4	4	4	330	15	15	15	612	1050	195
SCBA5MK5MHA5	85	5	5	5	318.75	18.75	18.75	18.75	612	1050	195
SCBA6MK6MHA6	82	6	6	6	307.50	22.50	22.50	22.50	612	1050	195
SCBA7MK7MHA7	79	7	7	7	295.50	26.25	26.25	26.25	612	1050	195

Mix Proportions	Binder Content (%)				Amount of Material Required to Produce 1 m^3 Concrete (kg)						
	PC	SCBA	MK	MHA	PC	SCBA	MK	MHA	FA	CA	Water
C	100	0	0	0	375	0	0	0	612	1050	195
SCBA5	95	5	0	0	356.25	18.75	0	0	612	1050	195
SCBA10	90	10	0	0	337.50	37.50	0	0	612	1050	195
SCBA15	85	15	0	0	318.75	56.25	0	0	612	1050	195

SCBA20	80	20	0	0	300	75	0	0	612	1050	195
MK5	95	0	5	0	356.25	0	18.75	0	612	1050	195
MK10	90	0	10	0	337.50	0	37.50	0	612	1050	195
MK15	85	0	15	0	318.75	0	56.25	0	612	1050	195
MK20	80	0	20	0	300	0	75	0	612	1050	195
MHA5	95	0	0	5	356.25	0	0	18.75	612	1050	195
MHA10	90	0	0	10	337.50	0	0	37.50	612	1050	195
MHA15	85	0	0	15	318.75	0	0	56.25	612	1050	195
MHA20	80	0	0	20	300	0	0	75	612	1050	195
SCBA2MK2MHA2	94	2	2	2	352.50	7.50	7.50	7.50	612	1050	195
SCBA3MK3MHA3	91	3	3	3	341.25	11.25	11.25	11.25	612	1050	195
SCBA4MK4MHA4	88	4	4	4	330	15	15	15	612	1050	195
SCBA5MK5MHA5	85	5	5	5	318.75	18.75	18.75	18.75	612	1050	195
SCBA6MK6MHA6	82	6	6	6	307.50	22.50	22.50	22.50	612	1050	195
SCBA7MK7MHA7	79	7	7	7	295.50	26.25	26.25	26.25	612	1050	195

2.3 Procedures for Testing

2.3.1 Slump Test

It was conducted on all mixtures of concrete including different dosages of PC replaced with SCBA, MK and MHA as SCM separate and combined as TCM in concrete by obeying BS EN 12350-2 code.

2.3.2 Mechanical Properties of Concrete

The density of concrete was investigated on concrete specimens blended with various dosages of SCBA, MK and MHA as PC replacement material separate and combine as TCM in the mixture at 28 days by following BS EN 12390–7 code. Besides, compressive strength of mixture was checked on cubical samples (100mm×100mm×100mm) incorporating of SCBA, MK and MHA as cementitious components individually and together as TCM at 28 days under the BS EN 12390-

3 code practice. Similarly, split tensile strength was conducted on cylindrical specimens (200mm×100mm) blended with different dosages of PC replaced with SCBA, MK and MHA separate and together as TCM in mixture by obeying BS EN 12390-6 code. In addition, the permeability of concrete including 5%-20% of SCBA, 5%-20% of MK and 5%-20% of MHA as SCM separate and together as TCM by obeying BS EN 12390-8 code after 28 days.

3 Results and Discussions

3.1 Slump Test

Figure 6 indicates the workability of the green mixture including 5%-20% of SCBA as PC replacement material to determine slump with the help of standard slump cone. The optimum slump was measured by 66 mm at the control mix and the minimum slump of the green mixture was recorded by 27 mm at 20% of PC replaced with SCBA. It can be observed that the slump of green mixes is declined as the dosages of SCBA rises in the mixture. This aspect of research investigation was achieved by Bheel et al. (2019) in which the slump of green concrete is reduced while the level of PC replacement with SCBA increases in the mixture. Dayo et al. (2019) reported that the slump is dropped with growth in the percentages of SCBA in concrete. Similarly, the workability of green mixture blended with 5%-20% of MK as SCM in the mixture as describes in **Figure 6**. The optimum slump of the green mixture is noted by 66 mm at the control mix and the lowest slump is calculated by 32 mm at 20% of MK as SCM in concrete. It has been detected that the slump of green concrete is reduced as the quantity of replacement of PC with MK in the mixture. This opinion was linked with Bheel et al. (2020) in which the workability of concrete is dropped with growing in the percentages of PC with MK and GGBFS in concrete. Moreover, the slump of green mixture blended with 5%-20% of PC replaced with MHA in concrete as shown in

Figure 6. The highest slump is noted by 66 mm at the control mix and the minimum is detected by 24 mm at 20% of MHA as SCM in concrete. It can be observed that the slump of green mixes is declined as the dosages of SCBA rises in the mixture. A similar type of study was performed by Bheel et al. (2020) that the workability is plummeted with growth in the proportions of MHA as SCM in concrete. Furthermore, the workability of green mixture inclusion with various percentages of SCBA, MK and MHA as TCM in the mixture is shown in **Figure 6**. The maximum slump is estimated by 66 mm at the control mix and the minimum slump is recorded by 18 mm at SCBA7MK7MHA7 as TCM in the mixture. The outcomes have been perceived that the workability of the green mixture is dropped as growing the quantity of PC replacement with SCBA, MK and MHA as SCM or TCM in concrete. This drop-in slump is owing to the porous particles of SCBA, MK and MHA as compared to PC which absorbs more amount of water with increasing the content of SCBA, MK and MHA in the mixture. The research investigation was performed by Bheel et al. (2020) stated that the slump has plummeted as the content of PC replacement with MK and GGBFS in the mixture.

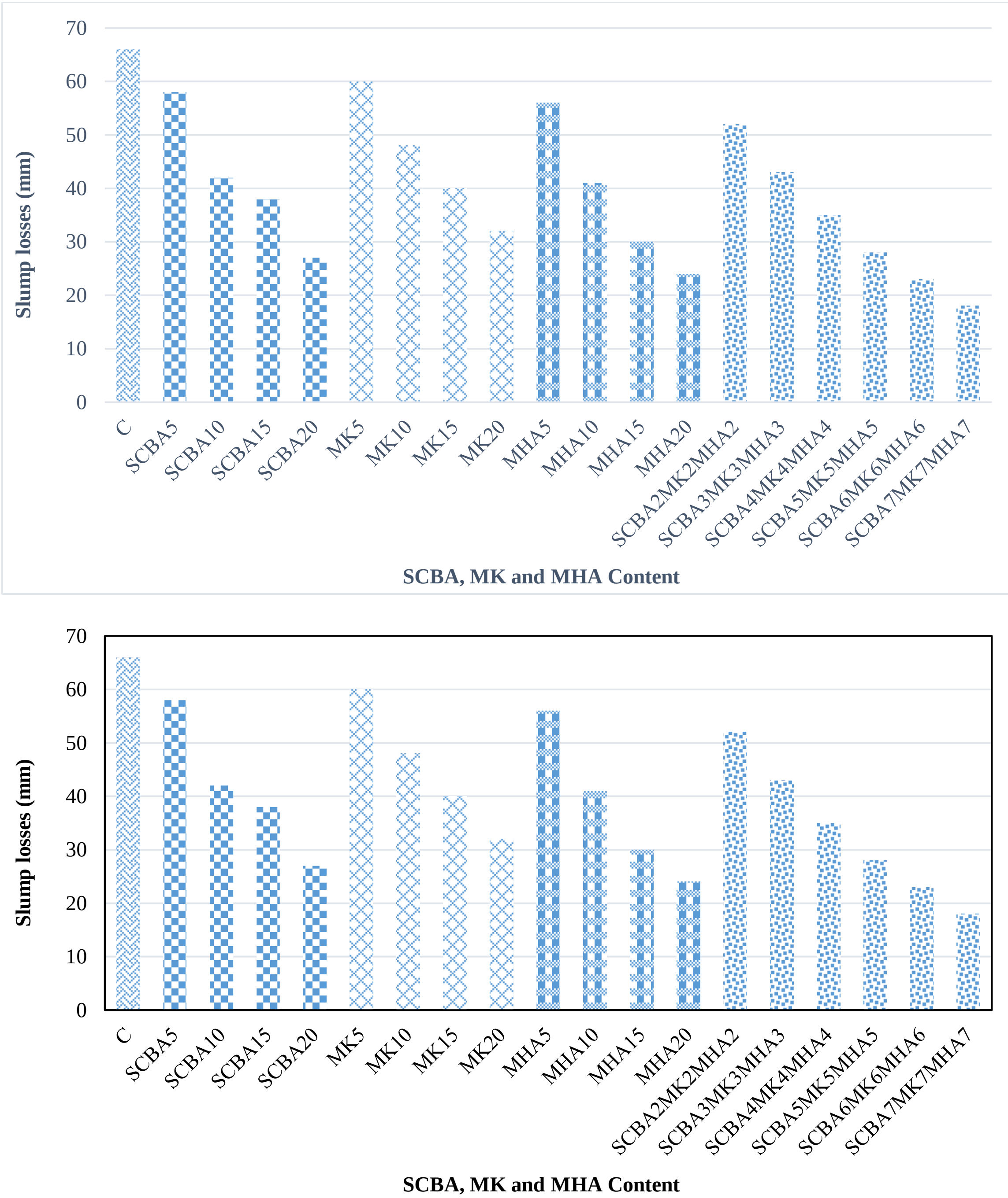
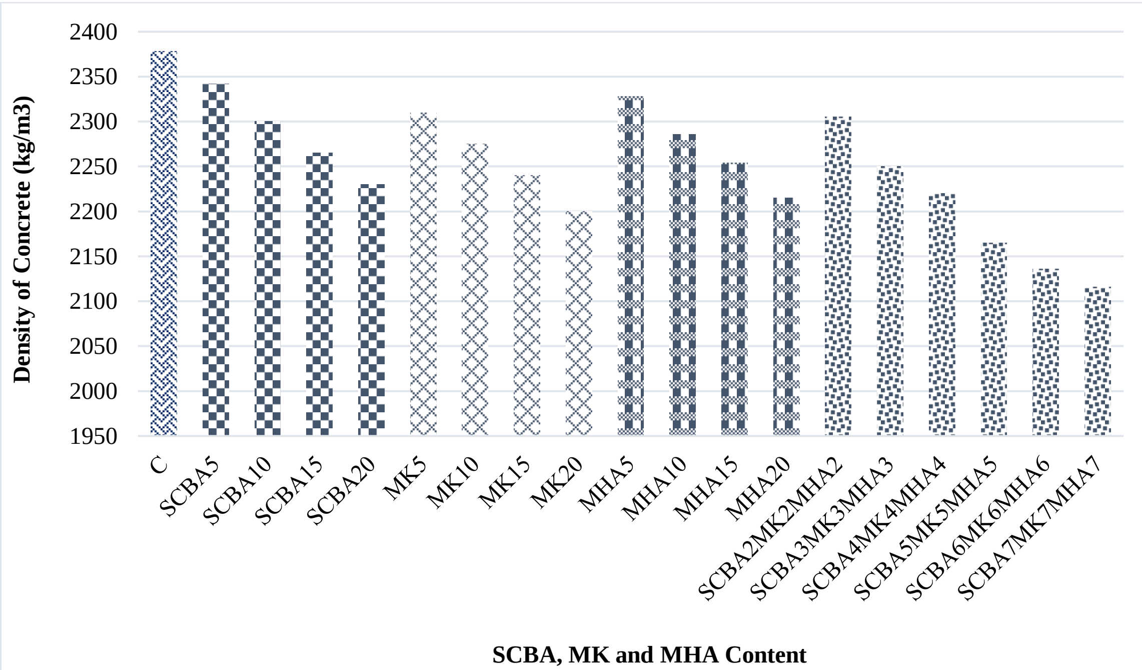


Figure 6: Slump Test of Fresh Concrete

3.2 Density of Concrete

Figure 7 indicates the density of the mixture including 5%-20% of SCBA as PC replacement material after 28 days. The density of concrete was measured by 2342 kg/m^3, 2300 kg/m^3, 2265 kg/m^3 and 2230 kg/m^3 at 5%, 10%, 15% and 20% of PC replaced with SCBA is smaller as compared to control mix after 28 days consistently. It can be perceived that the density of concrete is dropped as the dosages of PC replaced with SCBA rises in the mixture. This observation was correlated with Bheel et al. (2020) in which the density of concrete is dropped with growth in the percentages of SCBA and limestone fines in concrete. Similarly, the density of concrete mixture blended with 5%-20% of MK as SCM in concrete is describes in **Figure 7**. The density of concrete was measured by 2310 kg/m^3, 2275 kg/m^3, 2240 kg/m^3 and 2200 kg/m^3 at 5%, 10%, 15% and 20% of MK as SCM is lesser as compared to control mix at 28 days consistently. It has been detected that the density of concrete has plummeted as the extent of replacement of PC with MK rises in the mixture. This aspect of the research study was done by Ikponmwosa et al. (2020) informed that the density of alkali-activated concrete is dropped with growing in the percentages of CSA in the mixture. Moreover, the density of concrete mixture blended with 5%-20% of PC replaced with MHA as SCM in concrete as shown in **Figure 7**. The density of concrete was measured by 2328 kg/m^3, 2286 kg/m^3, 2254 kg/m^3 and 2215 kg/m^3 at 5%, 10%, 15% and 20% of PC replaced with MHA are smaller as compared to control mix after 28 days consistently. It can be observed that the density of concrete is dropped as the dosages of PC replaced with MHA rises in the mixture. This remark was associated with Bheel et al. (2020) in which the density of concrete is dropped with rising in the percentages of MHA as SCM in concrete. Furthermore, the workability of green concrete blended with SCBA, MK and MHA as TCM in concrete as shown in **Figure 7**. The maximum density is estimated by 2378 kg/m^3 at the control mix and minimum density is recorded by 2116 kg/m^3 at SCBA7MK7MHA7 as TCM in mixture on 28 days respectively. The outcomes has been perceived that the density of the concrete mixture is dropped as growing the quantity of PC replacement with SCBA, MK and MHA together as TCM in concrete. This drop-in density is owing to the specific gravity of SCBA, MK and MHA is lower as compared to PC which causes the reduced weight of concrete with incorporating SCBA, MK and MHA separate as SCM and together as TCM in concrete. The research investigation was performed by Bheel et al. (2020) stated that the density of the mixture is fallen as the content of PC replacement with MK and GGBFS in the mixture after 28 days.



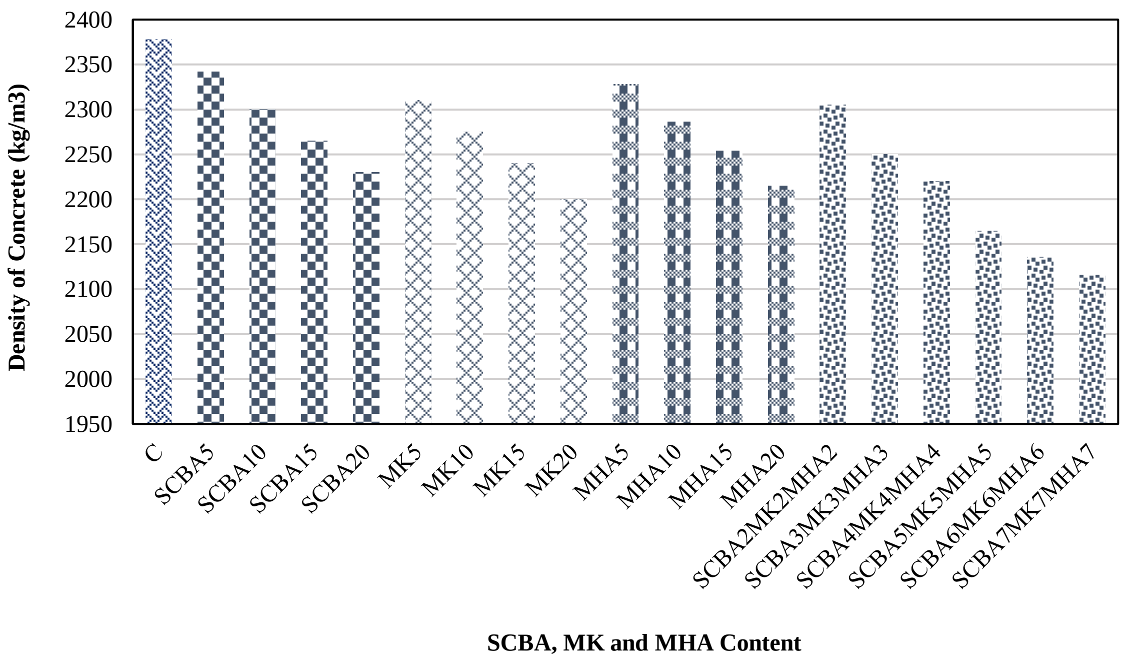
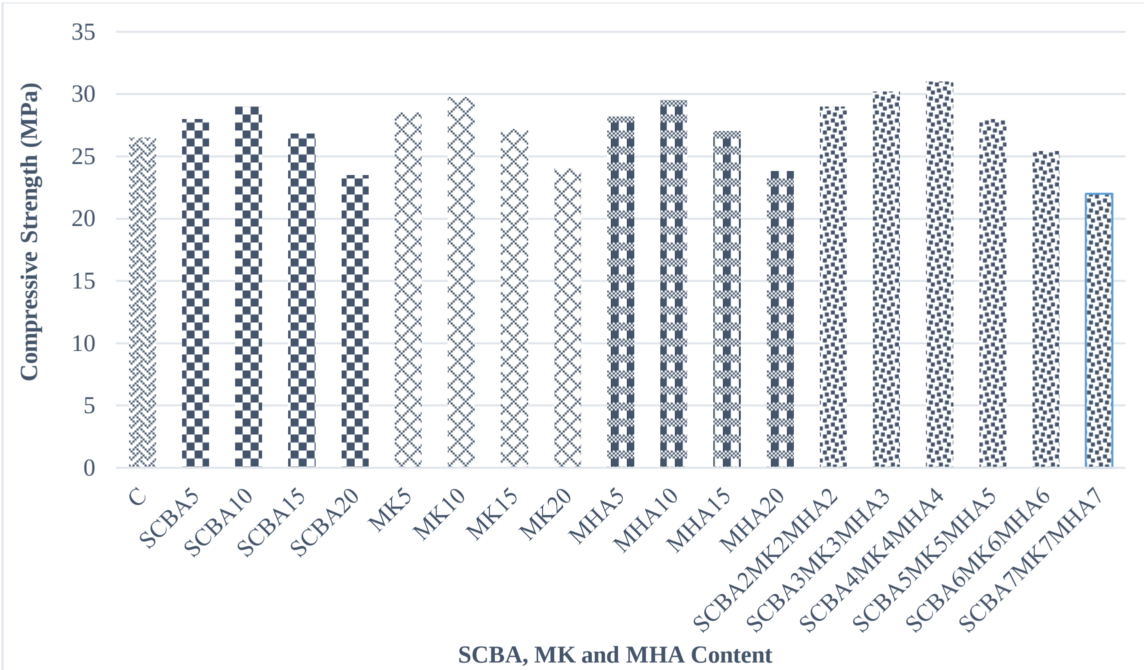


Figure 7: Density of Hardened Concrete

3.3 Compressive Strength

Figure 8 displayed the mixture of concrete including several proportions of SCBA as PC replacement material for determining the compressive strength at 28 days. The best compressive strength was estimated by 29MPa at 10% of PC replaced with SCBA and the lowest strength was noted by 23.50MPa at 20% of SCBA as PC replacement material in concrete on 28 days consistently. It can be detected that the compressive strength is boosted while consuming SCBA up to 10% as PC replacement in the mixture and further addition of SCBA in concrete, the compressive strength starts reducing. This opinion was accompanied by Bheel et al. (2019) where the compressive strength is boosted as the content of PC replacement with SCBA up to 10% at 28 days. Dayo et al. (2019) presented a report that the compressive strength is augmented while the amount of replacement material with SCBA up to 10% in the mixture at 28 days. Similarly, **Figure 8** directs the compressive strength of the mixture blended with several percentages of MK as a replacement for PC in the mixture after 28 days. The maximum compressive strength was recorded by 29.75MPa at 10% of PC replaced with MK and minimum strength was estimated by 24MPa at 20% of MK as SCM in the mixture after 28 days consistently. It has been noted that the compressive strength is augmented as the extent of PC replacement with MK up to 10% in the mixture. This aspect was performed by Parande et al. (2008) where the compressive strength is boosted while the replacement level of MK as SCM increases up to 15% and further addition, it starts reducing after 28 days. A similar type of investigational study was done by Keerio et al. (2021). Moreover, **Figure 8** demonstrates the mixture blended with 5%-20% of PC replaced with MHA as SCM in concrete at 28 days. The greatest compressive strength was estimated by 29.50MPa at 10% of PC replaced with MHA and the lowest strength was noted by 23.80MPa at

20% of MHA as SCM in concrete on 28 days consistently. It can be observed that the compressive strength is heightened while consuming MHA up to 10% as PC replacement in the mixture and with further addition of MHA in concrete, the compressive strength starts reducing. This judgment was convoyed by Bheel et al. (2020) where the compressive strength is enhanced as the content of PC replacement with MHA up to 10% at 28 days. Furthermore, **Figure 8** shows the concrete mixture inclusion with various proportions of SCBA, MK and MHA as TCM in the mixture for investigating the compressive strength after 28 days. The best value of compressive strength was observed by 31MPa at SCBA4MK4MHA4 as TCM and the lowest value was recorded by 22MPa at SCBA7MK7MHA7 as TCM in the mixture at 28 days individually. It can be observed that the compressive strength is improved while utilizing of PC replacement with SCBA4MK4MHA4 as TCM in the mixture and then it starts reducing. This improvement in strength is due to the high amount of silica present in SCBA, MK and MHA and finest particles of SCBA, MK and MHA than that of PC which increases the transition zone concrete and further addition of SCBA, MK and MHA in concrete, it starts reducing owing to the dilution effect of SCBA, MK and MHA on PC that results in reducing the calcium hydroxide which is present for product formation. A similar trend of research work was conducted by Bheel et al. (2020) where the compressive strength is boosted while using 10% of PC replaced with MK and GGBFS together in the mixture at 28 days.



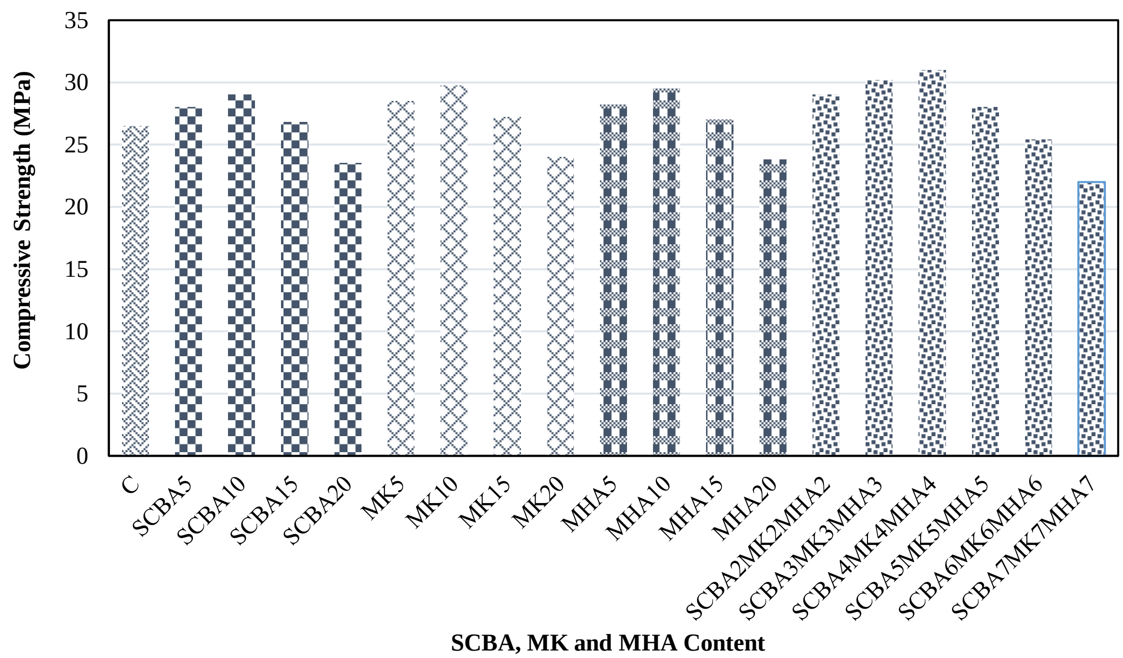
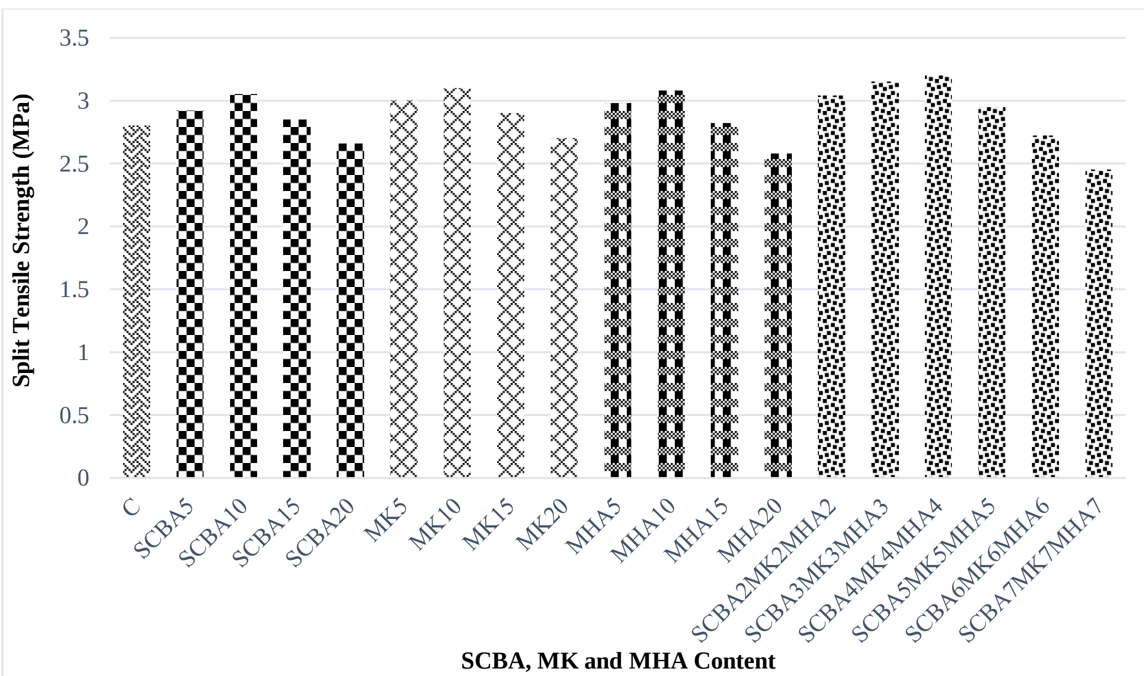


Figure 8: Compressive Strength of Concrete

3.4 Splitting Tensile Strength

Figure 9 displayed the mixture incorporating several proportions of SCBA as a PC replacement material for determining the split tensile strength at 28 days. The highest split tensile strength was estimated by 3.05MPa at 10% of PC replaced with SCBA and the lowest strength was noted by 2.66MPa at 20% of SCBA as PC replacement material in concrete after 28 days correspondingly. It can be identified that the split tensile strength is improved while utilizing SCBA up to 10% as a PC replacement in the mixture and further addition of SCBA in concrete, the split tensile strength starts reducing. This opinion was accompanied by Bheel et al. (2019) where the split tensile strength is boosted as the content of PC replacement with SCBA up to 10% and then it starts reducing after 28 days. Dayo et al. (2019) stated that the split tensile is augmented while consuming in the dosages of SCBA as SCM in concrete. Similarly, **Figure 9** directs the split tensile strength of mixture combined with several percentages of MK as SCM in mixture on 28 days. The maximum split tensile strength was recorded by 3.10MPa at 10% of MK and the lowest strength was assessed by 2.70MPa at 20% of MK as SCM in the mixture at 28 days correspondingly. It has been noted that the indirect tensile strength is augmented as the extent of MK as SCM up to 10%. Al-Sibahy and Edwards, (2012) and Mo et al. (2018) reported that the split tensile strength is amplified while the 10% of replacement material with metakaolin in mixture on 28 days. Moreover, **Figure 9** indicates the split tensile strength of concrete including various percentages of MHA as SCM in concrete. The optimum strength was recorded by 3.08MPa at 10% of PC replaced with MHA and minimum strength was noted by 2.58MPa at 20 of MHA as SCM in concrete at 28 days individually. It has been observed that the indirect tensile strength is improved as the replacement level of PC with MHA increases up to 10% and then it get reduce. This opinion was accomplished by Bheel et al. (2020) where the indirect tensile strength is boosted while the replacement level of PC with MHA increases up to 10% and further addition, it starts reducing at 28 days. Furthermore, **Figure 9** demonstrates the mixture blended with various proportions of SCBA, MK and MHA together as TCM for investigating the splitting tensile strength. The best split tensile strength was observed by 3.20MPa at SCBA4MK4MHA4 and the lowest value was recorded by 2.45MPa at SCBA7MK7MHA7 as TCM in the mixture at 28 days respectively. It can be observed that the indirect tensile strength is improved while utilizing of PC replacement with SCBA, MK and MHA as TCM up to 12% in concrete and then it starts reducing after 28 days. This development in strength is owing to the high specific surface area of SCBA, MK and MHA than that of PC which increases the interfacial transition zone of concrete up to a certain limit and then strength starts reducing due to the slower pozzolanic reaction of SCBA, MK and MHA as compared to hydration reaction of PC in the mixture. A similar trend of research work was conducted by Bheel et al. (2020) where the split tensile strength is boosted while the using PC replaced with MK and GGBFS up to 10% together in the mixture at 28 days.



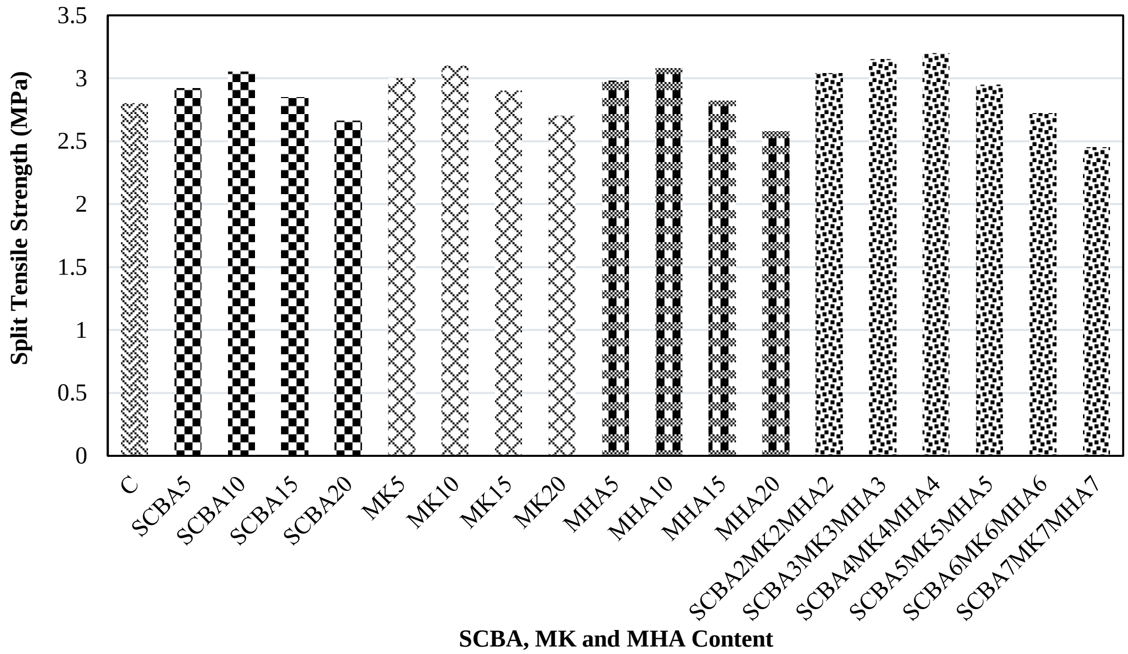


Figure 9: Split Tensile Strength of Concrete

3.5 Permeability of Concrete

Figure 10 indicates the permeability of the mixture including 5%-20% of SCBA as PC replacement substantial in the mixture at 28 days. The optimum permeability of the mixture was noted by 24 mm at the control mix and minimum permeability of mixture was recorded by 17 mm at 20% of PC replaced with SCBA on 28 days consistently. It can be observed that the permeability of mixes is declined as the dosages of SCBA rises in the mixture. This aspect of the research study was done by Bheel et al. (2021) in which the permeability of concrete is dropped with growing in the percentages of fine aggregates with wheat straw ash in the mixture. Similarly, the permeability of concrete mixture blended with 5%-20% of MK as SCM in mixture on 28 days as describes in **Figure 10**. The optimum permeability of mixture is noted by 24 mm at control mix and lowest permeability is calculated by 10 mm at 20% of MK as SCM in the mixture at 28 days consistently. It has been detected that the permeability of the mixture is reduced as the quantity of replacement of MK as SCM in the mixture. This opinion was interconnected with Keerio et al. (2021) informed that the permeability is dropped with growing in the percentages of metakaolin up to 15% in mixture. Guneyisi et al. (2012) in which the permeability of concrete is reduced while the level of PC replacement with metakaolin increases up to 15% in the mixture at 28 days. Moreover, the permeability of mixture blended with 5%-20% of PC replaced with MHA as SCM in concrete. The optimum permeability of the mixture was noted by 24 mm at the control mix and the minimum permeability of the mixture was recorded by 14 mm at 20% of PC replaced with MHA on 28 days consistently. It can be observed that the permeability of mixes is declined as the replacement level of PC with MHA rises in the mixture. This aspect of the research study was done by Bheel et al. (2021) in which the permeability of concrete is dropped with growing in the percentages of fine aggregates with wheat straw ash in the mixture. Furthermore, **Figure 10** indicates the permeability of concrete including various percentages of SCBA, MK and MHA together as TCM in concrete. The highest permeability is assessed by 24 mm at the control mix and the lowest permeability is recorded by 6.50 mm at SCBA7MK7MHA7 as TCM in the mixture after 28 days respectively. The outcomes have been perceived that the permeability of mixture is dropped as growing the quantity of PC replacement with SCBA, MK and MHA together as TCM in concrete. This drop-in permeability of concrete is owing to the finest particles of SCBA, MK and MHA as compared to PC which seals the remaining porous left by other constituents of concrete with increasing the level of SCBA, MK and MHA in concrete. The research investigation was achieved by Bheel et al. (2020) in which the permeability of the mixture is dropped with rising in the dosages of PC replacement with MK and GGBFS in concrete.

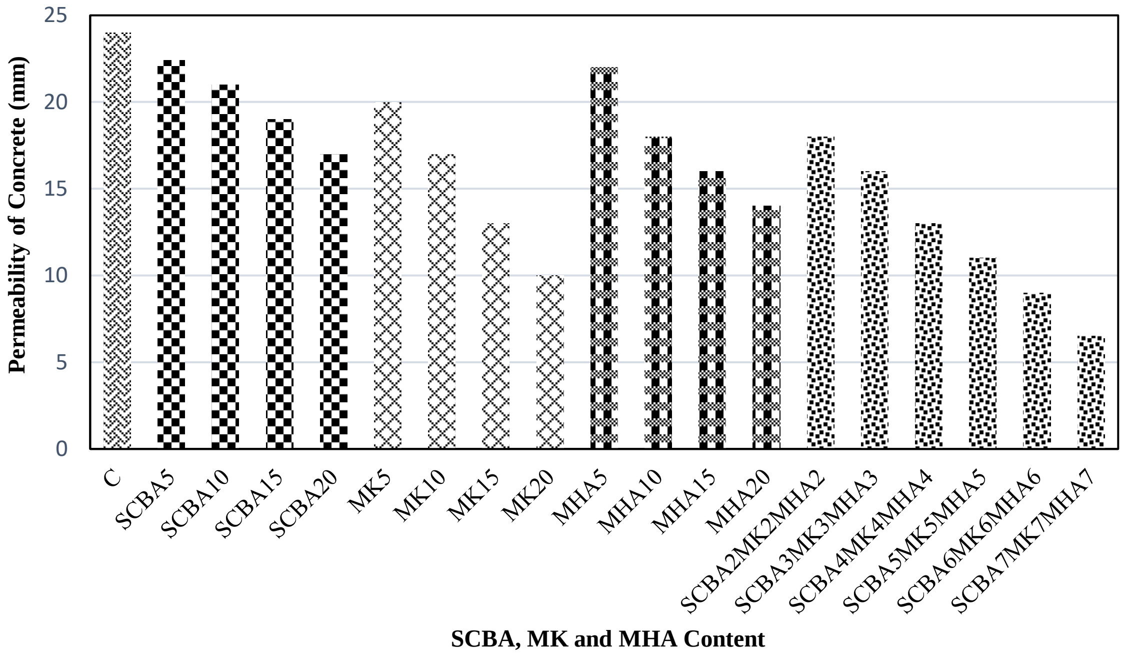


Figure 10: Permeability of Concrete

3.6 Sustainability Assessment

The environmental impact assessment was done for nineteen mixture in this research study to evaluate the embodied carbon of the concrete blended with SCBA, MK and MHA separate as SCM and combine as TCM. The embodied carbon and energy utilized for all components of concrete were taken from literature except SCBA and MHA as displayed in Table 4. Due to the unavailability of the embodied carbon of SCBA and MHA in the literature, the embodied carbon utilized is based on a few assumptions. As for SCBA, since the burning of bagasse is done in the sugar mill to produce electricity, and only residual SCBA was taken, therefore, only the carbon emissions during the transportation and sieving of SCBA is taken into consideration in the current study. The SCBA was collected from a local sugar mill in the Hyderabad division of Sindh, Pakistan, the distance from the sugar mill to the laboratory where the casting and testing were done, was approximately 37 km. Assuming a diesel lorry truck whose capacity was 1000 kg, was utilized to transport the SCBA with 0.92 $kgCO_2$/km emissions factor (Jhatial et al., 2021; Alnahhal et al., 2018). Furthermore, assuming that to sieve the 1000 kg SCBA, approximately 149.7 kWh electricity will be consumed (Jhatial et al., 2021; Alnahhal et al., 2018). Taking the emission factor 0.521 $kgCO_2$ per each kWh consumed (Jhatial et al., 2021; Alnahhal et al., 2018). Based on these emission factor values, it can be estimated that 1 kg of SCBA will have embodied carbon of 0.112 kg. Moreover, the production of MHA involved the transporting and drying of the millet husk before burning at a controlled temperature to produce ash. Let us consider the 1 MJ equals 0.2778 kWh, the equivalent carbon dioxide released for the transporting, and drying of the millet husk was achieved. However, the burning of millet husk was assumed to the similar value of rice husk ash, and the embodied carbon was estimated based on the energy consumption of 0.022 MJ/kg. So, the embodied carbon of MHA is founded on the cumulative embodied carbon as a result of the transporting, burning and drying of millet husk. However, the embodied CO_2 for all mixture of concrete is estimated from **Equation 1**. The symbols of CO_{2e}, i and W_i in **Equation 1** are shown the total embodied carbon and the weight per unit volume (i.e. kg/m^3) for every mixture of concrete. Moreover, the symbol like CO_{2i} has represented the embodied carbon of concrete's constituents indicated in **Table 4.**

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

Table 4: Sustainability of Components of Concrete

Components	**Embodied Carbon ($kgCO_2$/kg)**	**References**
Portland Cement	0.82	(Collins, 2010)
Fine Aggregates	0.0139	(Turner and Collins, 2013)
Coarse Aggregates	0.0408	(Turner and Collins, 2013)
SCBA	0.112	Current Study Estimates
MK	0.33	(Adesina, 2020)

MHA	0.174	Current Study Estimates
Water	0	(Jones et al., 2011)

Components	Embodied Carbon (kgCO₂/kg)	References
Portland Cement	0.82	(Collins, 2010)
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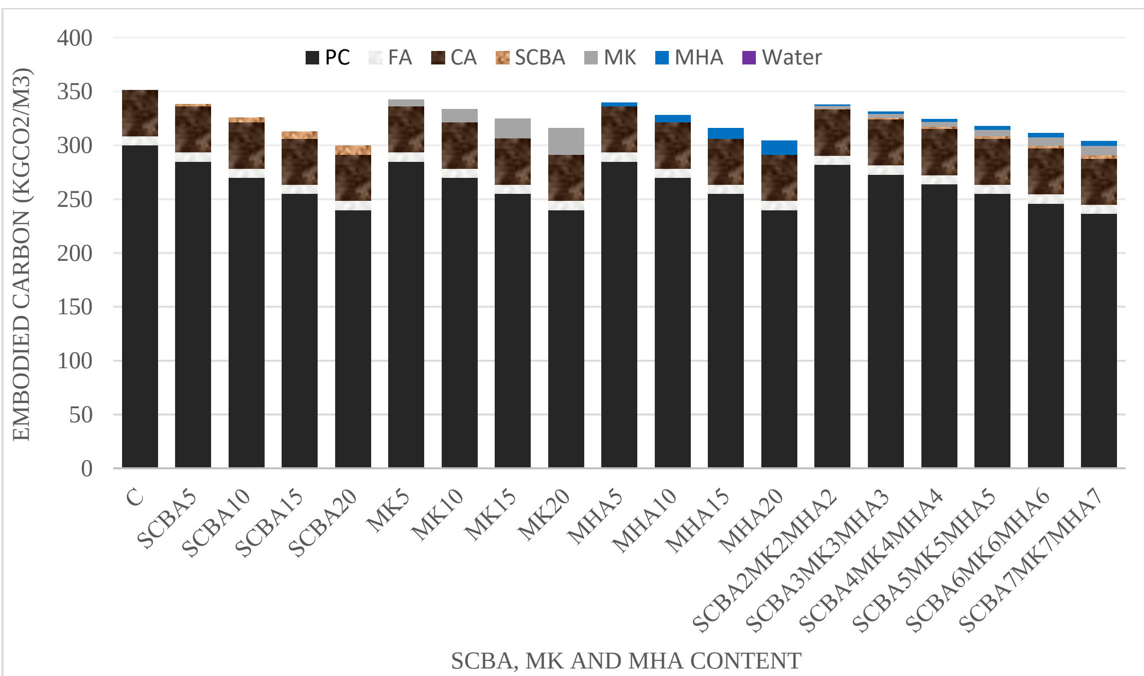
SCBA	0.112	Current Study Estimates
MK	0.33	(Adesina, 2020)
MHA	0.174	Current Study Estimates
Water	0	(Jones et al., 2011)



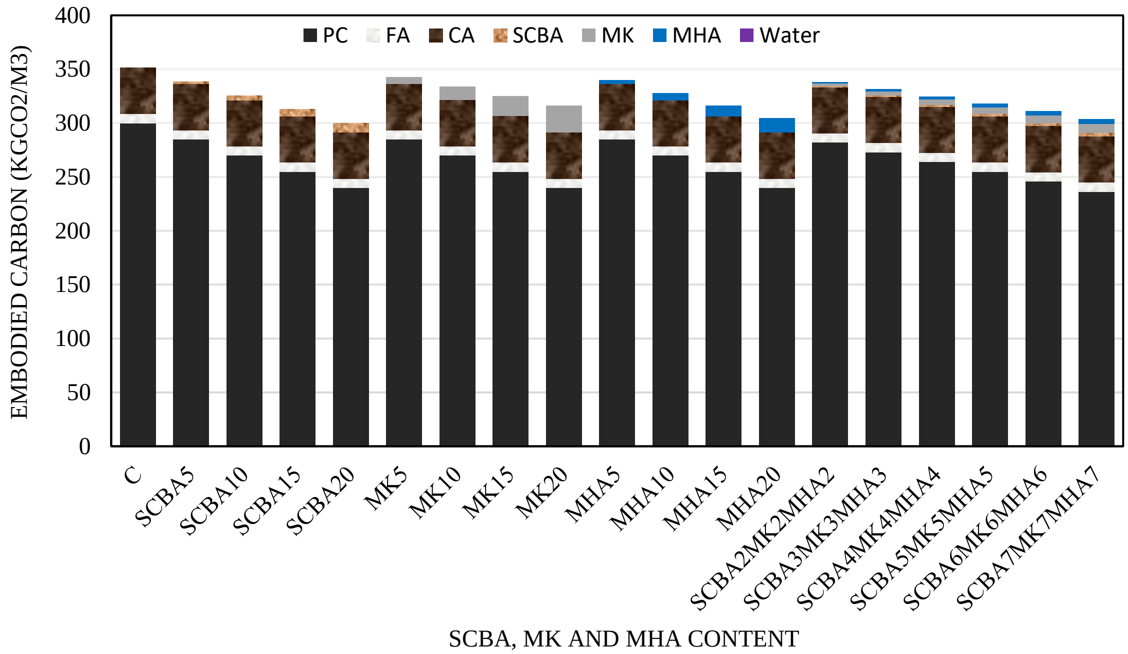


Figure 11: Embodied Carbon of Concrete

Figure 11 indicates the embodied carbon of concrete including SCBA, MK and MHA separate as SCM and combined as TCM in concrete. It has been observed from **Figure 11** that a high amount of carbon is released from Portland cement followed by the coarse and fine aggregate. However, the contribution of SCBA, MK and MHA individually and combine as TCM in concrete is minor shown in Figure therefore the contribution of SCBA, MK and MHA separate as SCM and combine as TCM is very low to the embodied carbon of concrete. The embodied carbon of concrete is noted by 3.67%, 7.34%, 11% and 14.86% at 5%, 10%, 15% and 20% of PC replaced with SCBA is lower than that of the control mix of concrete. It has been observed that the embodied carbon is reduced while increasing PC replacement with SCBA in the mixture. However, the embodied carbon is calculated by 2.51%, 5.02%, 7.53% and 10% at 5%, 10%, 15% and 20% of PC replaced with MK are lower than that of the control mix of concrete. From **Figure 11**, it can be revealed that the utilization of SCBA as SCM in concrete led to a significant decline in the embodied carbon of the mixture. Moreover, the embodied carbon of concrete is noted by 3.34%, 6.68%, 10.02% and

13.36% at 5%, 10%, 15% and 20% of MHA as SCM is lower as compared to the control mix of concrete. It has been observed that the embodied carbon is reduced while increasing PC replacement with MHA in the mixture. Furthermore, the embodied carbon of concrete is recorded by 3.81%, 5.71%, 7.62%, 9.52%, 11.42% and 13.50% at SCBA2MK2MHA2, SCBA3MK3MHA3, SCBA4MK4MHA4, SCBA5MK5MHA5, SCBA6MK6MHA6 and SCBA7MK7MHA7 as TCM is greater than concrete without the inclusion of TCM in concrete. It has been observed from **Figure 11** that the addition of SCBA, MK and MHA together as TCM is reduced the embodied carbon of concrete. However, not only reduction in embodied carbon of concrete should be concentrated but also the reduction in the constituents with replacement level of PC with SCBA, MK and MHA and also effects of these waste materials on compressive strength. To better understand this, an eco-strength efficiency indicator can be used, by using **Equation 2**:

$$Eco-strength\ Efficiency = \frac{Average\ 28\text{–}Days\ Compressive\ Strength\ of\ Concrete}{Total\ Embodied\ Carbon\ of\ Concrete} \quad (2)$$

The eco-strength efficiency of concrete blended with SCBA, MK, and MHA separate as SCM and combined as TCM was estimated by using **Equation 2** and the outcome is shown in **Figure 12**. The optimum eco-strength efficiency was noted by 0.089MPa/kgCO_2.m^3 at 10% of PC replaced with SCBA, 0.089MPa/kgCO_2.m^3 at 10% of MK as SCM, 0.09MPa/kgCO_2.m^3 at 10% of MHA as replacement for PC and 0.096MPa/kgCO_2.m^3 at SCBA4MK4MHA4 as TCM in concrete respectively which is greater than that of control mix concrete. Similarly, the least eco-strength efficiency strength was calculated by 0.078MPa/kgCO_2.m^3 at 20% of SCBA as SCM, 0.076MPa/kgCO_2.m^3 at 20% of MK as cementitious material, 0.078MPa/kgCO_2.m^3 20% of PC replaced with MHA and 0.072MPa/kgCO_2.m^3 at SCBA7MK7MHA7 as TCM in concrete. It was noted that the eco-strength efficiency is improved as the replacement level of PC with SCBA, MK and MHA increases in concrete up to 10% and further addition of SCM individually and TCM, it gets reduced. This can be attributed to lower embodied carbon and the highest compressive strength amongst the different mixes.

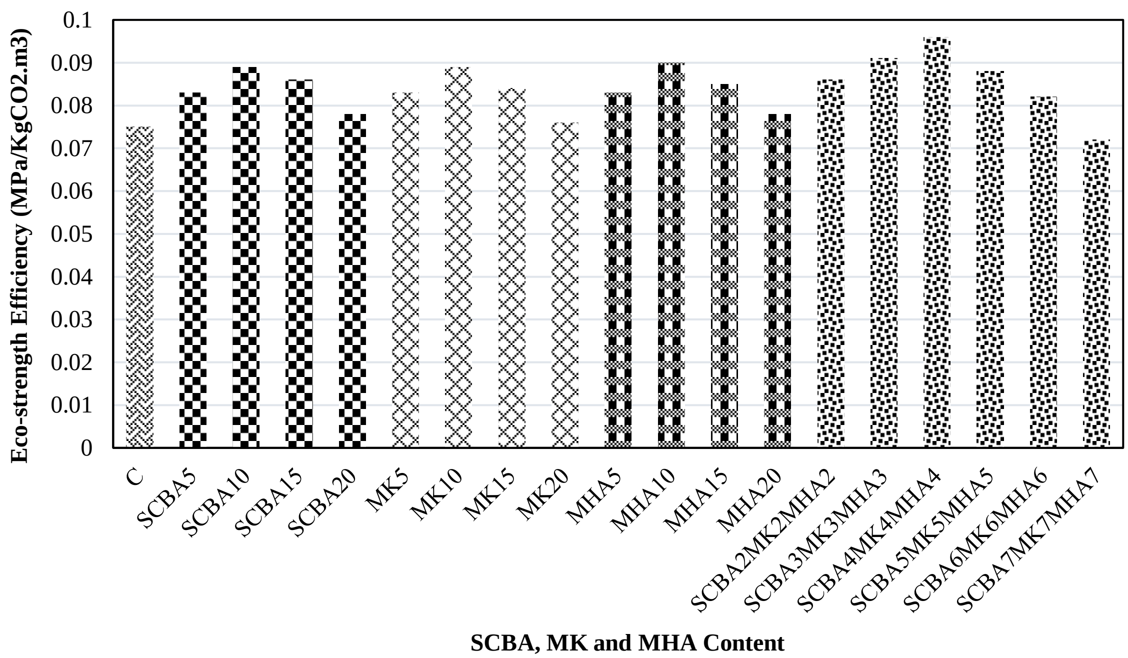


Figure 12: Eco-strength Efficiency for all mixes of concrete

4 Conclusions

The basic aim of this study was the utilization of SCBA, MK and MHA separate as SCM and together as TCM in concrete and determines their effect on fresh, hardened properties and embodied carbon of concrete. From this research study, the following conclusions are drawn:

- The optimum slump was measured by 66 mm at control mix while the minimum slump of the green mixture was recorded by 27 mm at 20% of PC replaced with SCBA, 32 mm at 20% of MK as SCM and 24 mm at 20% of PC replaced with MHA in concrete respectively.

Moreover, the maximum slump is estimated by 65 mm at the control mix and the minimum slump is recorded by 18 mm at SCBA7MK7MHA7 as TCM in the mixture. The outcomes have been perceived that the workability of the green mixture is dropped as growing the quantity of PC replacement with SCBA, MK and MHA separate as SCM and together as TCM in concrete.

- The optimum density was measure by 2378 kg/m^3 at control mix while the lowest density was calculated by 2230 kg/m^3 at 20% of PC replaced with SCBA, 2200 kg/m^3 at 20% of MK as SCM, 2215 kg/m^3 at 20% of MHA as SCM and 2116 kg/m^3 at SCBA7MK7MHA7 as TCM in mixture on 28 days respectively. It has been observed that the density of hardened concrete is reduced as the replacement level of PC with SCBA, MK and MHA separate as SCM and combined as TCM increases in concrete after 28 days.
- The optimum compressive strength was estimated by 9.43% at 10% of PC replaced with SCBA, 12.26% at 10% of MK as SCM, 11.32% at 10% of MHA as SCM and 17% at SCBA4MK4MHA4 as TCM are greater than that of control mix concrete at 28 days respectively. It can be witnessed that the compressive strength is improved while using of PC replacement with SCBA, MK and MHA separate as SCM and together as TCM up to 10% in concrete and further addition of these materials in concrete, the strength gets reduced.
- The maximum split tensile strength was estimated by 8.90% at 10% of PC replaced with SCBA, 10.70% at 10% of MK as SCM, 10% at 10% of MHA as SCM and 14.28% at SCBA4MK4MHA4 as TCM are greater than that of control mix concrete at 28 days respectively. It can be observed that the split tensile strength is improved while using of PC replacement with SCBA, MK and MHA separate as SCM and together as TCM up to

10% in concrete and further addition of these materials in concrete, the strength gets reduced.

- The optimum permeability was calculated by 24 mm at control mix while minimum permeability of mixture was recorded by 17 mm at 20% of PC replaced with SCBA, 10 mm at 20% of MK as SCM, 14 mm at 20% of PC replaced with MHA and 6.50 mm at SCBA7MK7MHA7 as TCM in mixture on 28 days individually. The outcomes have been perceived that the permeability of mixture is dropped as growing the quantity of PC replacement with SCBA, MK and MHA separate as SCM and together as TCM increases in concrete.
- The embodied carbon of concrete is decreased with increasing the replacement level of PC with SCBA, MK and MHA separate as SCM and together as TCM increases in concrete.
- From experimental investigations, it is concluded that the use of SCBA, MK and MHA up to 10-15% separate as SCM and combined as TCM in concrete provides optimum results for structural applications.

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