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Original Research

Effect of Artificial Fibers and Corn Cob Ash on Mechanical Behavior of High Performance Concrete

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Abstract

In this research work, Corn Cob Ash is partially utilized as supplementary cementitious material (SCM) for cement and addition of different percentage of artificial fibers as micro reinforcement has been used to find the effect on fresh, mechanical and microstructural properties of HPC through testing. Firstly, the mechanical properties of HPC with different Corn Cob Ash (CCA) contents of 5, 10, 15, 20 and 25% by weight of cement were tested and the results showed that HPC with 15% CCA is the most economical replacement and it exhibits the better mechanical properties close to the reference concrete. Subsequently, 15% CCA was taken constant for PP and PS series mixes with 0.1, 0.2, 0.3 and 0.4 % addition of artificial fibers (polypropylene and polystyrene fiber by weight of binders) into HPC to evaluate its effects on slump, compressive strength, split tensile strength, flexural strength, modulus of elasticity, ultrasonic pulse velocity and microstructure. The results revealed that 15% of CCA replaced mixes along with 0.4% of artificial fibers showed better in mechanical properties and microstructure. However, above 15% of Corn Cob Ash replacement was showed poor on mechanical properties of HPC, compared to the control mix (C0) without CCA and fibers.

Keywords: Corn Cob Ash, polypropylene fiber, polystyrene fiber, high performance concrete, workability, mechanical properties, microstructure

Introduction

High Performance Concrete (HPC) is one of the most promising types of concrete and now is widely preferred for infrastructure projects around the world [1]. The need for HPC is increasing day-by-day due to rapid development of urbanization and industrialization. The fabrication of billions of tones of concrete throughout the world emits significant amounts of carbon dioxide (7%) during production of cement [2]. Accordingly, the partial replacement of cement is expected to meet the increasing demand for concrete production [3]. Using agricultural wastes in concrete production is an eco-friendly way of disposing of the large amounts of waste, which would otherwise

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damage air, land, and water [4, 5]. The replacement of agricultural wastes in the concrete will not only control the pollution and also contribute to the economy, other than it will resolve the sustainability of natural non-renewable material [6]. Agricultural wastes are used in different ways as aggregates, fibers and supplementary cementitious materials for cement based composites. The agricultural wastes such as rice husk, bagasse ash, and elephant grass ashes are silica rich biomass wastes that have been examined in recent years to understand their behavior as Supplemental Cementitious Materials (SCM) in concrete [3, 7]. Still only few studies available in CCA based HPC [7-10]. The Corn is the world's second most significant cereal crop in terms of area of cultivation. In the 2016-2017, global maize output reached over 1040 million MT, with the United States leading the way with 38%, followed by China with 23% [11]. In 2020, India is at 7^{th} place in the world in the production volume of 28.64 million MT of corn and it's around 2% of the global total [12]. After wheat and rice, maize is the third most important crop in India. This employs more than 650 million person-days in India, with more than 15 million farmers involved in Maize Cultivation. Every ton of corn production generates 170-190 kg of corn cob, which pollutes the environment and health related problem by being dumped in land or open air combustion [4, 5]. Therefore, Corn cob can be recycled into corn cob ash and it can also be used as a replacement for Portland cement. The corn cob ash contains around 60% to 70% of silica (SiO_2) in its chemical composition that directly involves in the pozzolanic reaction [13-16]. Investigation of the influence of Corn Cob Ash on workability, mechanical properties and permeability properties of cement paste, mortar, earth blocks and normal strength concrete (NSC) [17-19]. CCA can be utilized as partial replacement for cement in light weight concrete [20]. Feasibility of CCA as a SCM for normal strength concrete [21, 22]. The replacement of CCA was improved the durability characteristics of self- compacting concrete [9, 23]. CCA replacement increased the flexural strength of geopolymer concrete beams [24]. Still, now only few studies were available in the usage of CCA in HPC. The addition of fibers was essential for HPC to prevent from its brittleness nature under loading and also it improved strength and toughness. The polypropylene and polystyrene fibers are the most popular and it is available in all places, which are chemical resistant, high tensile strength and lightweight. Adding of polystyrene based Recron 3S fibers into NSC can improve the mechanical properties [25]. The performance of colour adsorbed fly ash concrete beams with PP fibers was investigated [26]. The result shows that the PP fibers improve the flexural strength, toughness and the fracture energy of colour adsorbed fly ash concrete beams. The present work aims at investigating the workability, mechanical properties and microstructure characteristics of HPC with partial replacement of CCA and also explores the combined effect of CCA and artificial fibers (polypropylene and polystyrene fiber) in HPC. Furthermore, there is no existing research work on this topic to our knowledge.

Materials and Methods

The Ordinary Portland cement - 53 grade of cement was used conforming to IS 12269-2013 [27]. Table 1 present the physical and chemical properties of binders. The corn cob was crushed to smaller particles and burned using incinerator at 700ºC for 6 hours. After that burned corn cob ash was sieved in 75 µm sieve and only particles pass through 75 µm sieve were used as supplementary cementitious material for HPC and their microstructure is shown in Fig. 1. The commercially available river sand (zone III as per IS : 2386 (Part I) [28]) was used as the fine aggregate, having specific gravity and water absorptions of 2.59 and 0.62%, respectively. The crushed granite stone was used as the coarse aggregate, having the maximum size of 10mm, specific gravity of 2.73 and water absorption of 0.54 %. The Sika ® ViscoCrete ® -20 HE, the polycarboxylate based superplasticizer was used as High Range Water Reducing Admixture (HRWRA), conforming to ASTM C 494 Type F [29]. As per IRC 15- 2011 [30], two types of artificial fibers (Polypropylene and polystyrene) were used as fiber reinforcement for HPC and their properties are present in Table 1. As per ACI 211.4R-08 [31], M70 grade of concrete was designed and optimized based on laboratory trails and error method. Table 2 presents the mix proportions of 14 mixes with different combination of CCA and artificial fibers. The water to binder ratio was fixed 0.36 for all mixes; corn cob ash was added

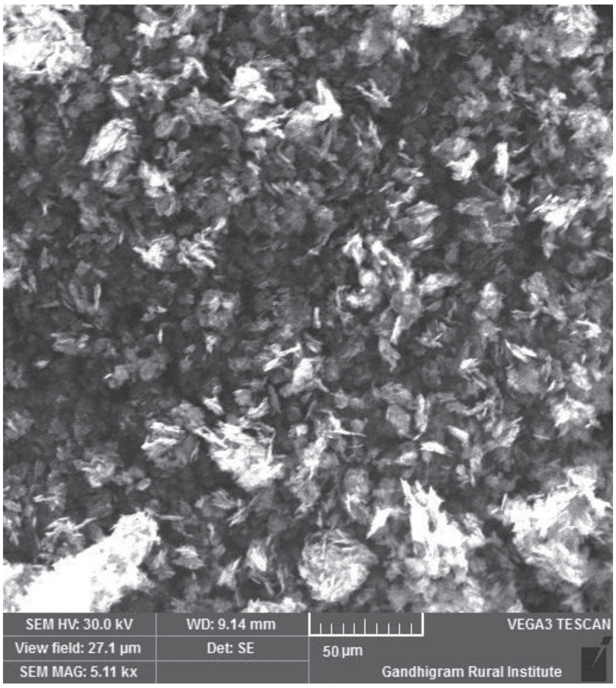

Fig. 1. SEM image of corn cob ash.

Table 1. The physical and chemical properties of cement and CCA.

Material	Chemical properties									Physical properties				
	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	SO_3	LOI	Specific gravity	Fineness (m^2/ Kg)	Average particle size (µm)	Initial setting time (min)	Final setting time (min)
Cement	4.87	61.5	2.36	-	2.73	-	22.3	1.9	1.78	3.12	328.6	7.46	45	325
CCA	8.37	10.7	5.94	2.06	1.88	0.81	64.8	1.52	2.35	2.39	438.53	18.37	-	-

Table 2. The properties of artificial fibers.

Properties	Color	Tensile strength (Mpa)	Length (mm)	Diameter (micron)	Density (g/cm^3)	Melting point °C
Polypropylene fiber (PP)	White	>500	24	30-35	0.9	160-180
Polystyrene fiber (PS)	White	>500	24	20-25	1.38	250-260

in different contents of 5, 10, 15, 20 and 25% by weight of cement; The polypropylene and polystyrene fiber were added 0.1, 0.2, 0.3 and 0.4% by weight of binders. 14 different HPC mixtures were divided into 4 series, C0 represents the reference concrete; C5 to C25 mixes represents the corn cob ash (different dosage 5, 10, 15, 20 and 25%) blended series; PP1 to PP4 represents the polypropylene fiber (different dosage 0.1, 0.2, 0.3 and 0.4%) blended series; PS1 to PS4 represents the polystyrene fiber (different dosage 0.1, 0.2, 0.3 and 0.4%) blended series. According to mixture proportions in Table 3, for the preparation of fresh concrete, all ingredients were mixed with a total mixing time of 10 minutes in Aimil high shear pan mixer machine having capacity of 150 liters (Fig. 2). At first, cement was dry mixed with sand and coarse aggregate for about 3 minutes and water was added and mixed for 4 minutes. The subsequently superplasticizer and fibers were added and mixed for 3 minutes. After completion of mixing process, the slump flow of fresh concrete was recorded as per BS EN 12350-8:2010 [32] and remaining concrete was poured into steel molds (100 mm cube, 100 x 200 mm cylinder and 100x100x500 mm prism) and the surface was covered with the plastic sheets. All specimens were demoulded after 24 hours and then soaked in water until tests (Fig. 2).

Experimentation Techniques

The Compressive Strength was found with an average of three 100 mm cube specimens as per IS 516-1959 [33] at age of 7, 14 and 28 days. The flexural Strength was found with an average of 3 prism specimens (size of 100x100x500mm), according to the IS 516-1959 [33] at age of 7, 14 and 28 days. The Split Tensile Strength was found with an average of 3 specimens of 100 mm dia. and 200 mm high cylinder as per IS 5816-1999 [34] at age of 7, 14 and 28 days.

Fig. 2. Mixing, casting and curing of HPC.

Table 3. Mix Proportions.

Mix ID	Cement (Kg/m^3)	CCA (Kg/m^3)	PP Fiber (%)	PS Fiber (%)	CA-granite (Kg/m^3)	Sand (Kg/m^3)	Water (litre)	PCE (litre)
C0	470	-	-	-	1065	735	155	6.11
C5	446.5	23.5	-	-	1065	735	155	6.11
C10	423	47	-	-	1065	735	155	6.11
C15	399.5	70.5	-	-	1065	735	155	6.11
C20	376	94	-	-	1065	735	155	6.11
C25	352.5	117.5	-	-	1065	735	155	6.11
PP1	399.5	70.5	0.1	-	1065	735	155	6.11
PP2	399.5	70.5	0.2	-	1065	735	155	6.11
PP3	399.5	70.5	0.3	-	1065	735	155	6.11
PP4	399.5	70.5	0.4	-	1065	735	155	6.11
PS1	399.5	70.5	-	0.1	1065	735	155	6.11
PS2	399.5	70.5	-	0.2	1065	735	155	6.11
PS3	399.5	70.5	-	0.3	1065	735	155	6.11
PS4	399.5	70.5	-	0.4	1065	735	155	6.11

The Modulus of Elasticity was found with an average of 3 specimens of 100 mm dia. and 200 mm high cylinders according to the ASTM C 469-02 [35] for 28 days. The Ultrasonic Pulse Velocity was measured with an average of 3 specimens (100 mm cubes) according to the IS 13311 (Part 1) – 2004 [36] at age of 7, 14 and 28 days. For microstructural analysis, after the 28 days of curing period the small bit of concrete samples were soaked in isopropanol for one day to stop hydration and removal of excess water from sample [37]. After that, the micrograph of dried concrete surfaces was captured from VEGA3 TESCAN instruments as per ASTM C1723–16 [38].

Results and Discussion

Slump Flow

Fig. 3 shows the slump spread of fresh HPC mixes with inclusion of CCA and artificial fibers. It clearly shows that the increase of CCA replacement content has reduced the slump spread from 680 mm to 521 mm, which reduced the slump flow up to 23.38% with comparison to control mix (C0) without CCA and artificial fibers. From the results, it could be observed that the inclusion of CCA has reduced the flow, which may be attributed to the angular shape (see Fig. 1) and higher of surface area of CCA reduces the workability caused by high inter particle cohesion and creates the higher water demand. This is in agreement with the findings fro m previous research works [18, 20, 22, 23]. However, 15% of CCA mix is reached flow spread of 617 mm, which decreased slump by 9.26%, in comparison to the C0 mix. Furthermore, the addition of artificial fibers (PP and PS) in 15% of CCA replaced mixes reduced the slump spread. The increasing content of PP fibers 0.1 to 0.4 % in 15% of CCA replaced mixes; the slump was decreased from 609 mm to 561 mm, which reduced the slump up to 17.50%. Similarly, for PS fibers, the slump was decreased up to 15.44%, which reduced from 612 mm to 575 mm. Therefore, it can be concluded that the inclusion of PP and PS fibers reduced workability. However, all values are in acceptable limit only. This may be due to the increase of fiber content leads to even distribution of fiber in cement matrix, which increases friction between the cement paste and fiber and it will increase viscosity of mix [6, 10].

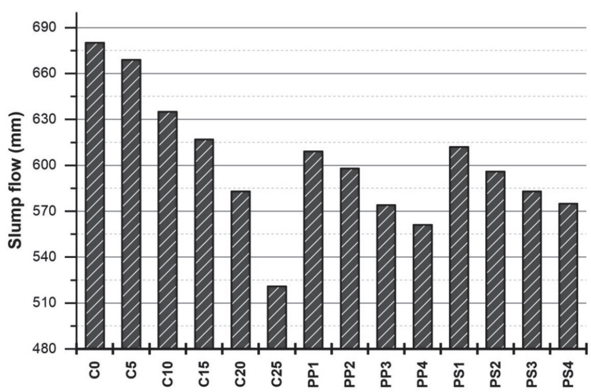

Fig. 3. The effect of corn cob ash and artificial fibers on slump flow of HPC.

Compressive Strength

The effect of CCA, PP fiber and PS fiber content on the compressive strength of HPC is present in Fig. 4. It could be seen that the compressive strength in control mix was 32.93 MPa, 46.06 MPa and 74.23 MPa at the age of 7, 14 and 28 days, respectively. The increasing content of CCA in HPC was reduced the compressive strength about 2.42% to 22.31% at 28th day, except C5 mix, which exhibits higher strength of 75.86 MPa and it's having maximum pozzolanic activity of 102.19% on 28th day. However, the optimum level of CCA replacement for cement in HPC is 15% to attain the better mechanical properties with economical and ecological concern, having pozzolanic activity of 95.56% at 28th day, in compare to C10, C20 and C25. The difference in the microstructure indicates the porous nature (Fig. 5a) of the control mix (C0) specimens without CCA. The replacement of 15% of CCA content in HPC was enhanced dense microstructure and refine pores in the microstructure (Fig. 5b). This enhancement was mainly attributed due to the filler effect and pozzolanic reactivity of CCA [14, 16, 19, 21, 39-41]. Therefore, 15% of CCA replacement was constant for PP and PS series mixes to achieve the maximum gain in mechanical properties. The compressive strength of HPC was increased with every case of artificial fibers (polypropylene and polystyrene) addition into mix. However, the maximum compressive strength observed in PP4 mix was 38.30 MPa, 48.70 MPa and 85.43 MPa at age of 7, 14 and 28 days, respectively for HPC mix with an addition of 0.4% polypropylene fiber along with 15% of CCA, which enhanced the compressive strength up to 15.09%, in comparison to C0 mix. In PS series, the maximum compressive strength observed in PS4 mix was 37.50 MPa, 47.90 MPa and 82.24 MPa at age of 7, 14 and 28 days, respectively. The PS4 mix with 0.4% polystyrene fibers and 15% of CCA increased strength up to 10.07%. It is clear that the combined effect of 15% of CCA and 0.4% of artificial fibers can improve the maximum compressive strength on HPC. This increment may be attributed due to increase in artificial fibers content that were evenly distributed in microstructure [6, 10], which completely sealed the micro cracks and pores, leads to maximum denser microstructure which is observed in micrographs of PP4 and PS4 mix (Fig. 5 (c-d)).

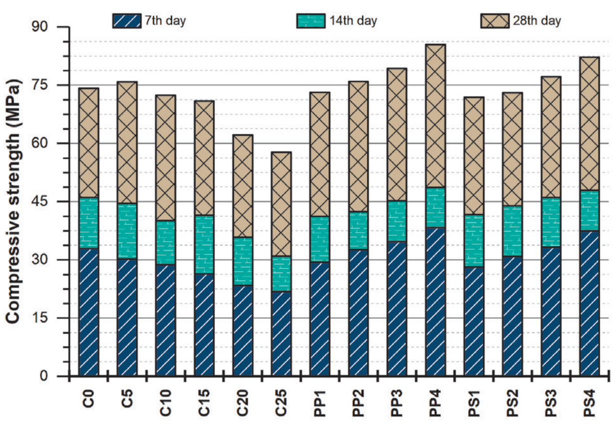

Fig. 4. The effect of corn cob ash and artificial fibers on compressive strength of HPC.

Flexural Strength

Fig. 5 shows the flexural strength of HPC mixes with CCA and artificial fibers. The flexural strength is decreased with increasing percentage of replacement of CCA in HPC at all ages curing period, which perform in the same way to the compressive strength decrement [14, 17, 19]. The test results show that the lowest flexural strength observed was 4.44 MPa, 4.10 MPa, 4.19 MPa, 3.86 MPa and 3.42 MPa for C5, C10, C15, C20 and C25 respectively, at 28th day. The flexural strength was increased with content of artificial fibers (polypropylene and polystyrene) addition into HPC mix. However in PP series, the highest flexural strength noticed in the PP4 mix was 2.78 MPa, 3.85 MPa and 5.77 MPa at age of 7, 14 and 28 days, respectively. This mix with addition of 0.4% polypropylene fiber along with 15% of CCA was enhanced flexural strength by 33.65%, 10.63% and 24.89% at 7, 14 and 28 days compared control mix (C0) without CCA and fibers. Also in PS series, PS4 mix with 0.4% polystyrene fiber along with 15% of CCA was noticed the second highest flexural strength values of 2.85 MPa, 3.89 MPa and 5.41 MPa at age of 7, 14 and 28 days, respectively. It has been observed that the PS4 mix enhanced flexural strength about 37.02%, 11.78% and 17.10% at 7, 14 and 28 days, respectively. This enhancement in flexural strength attribute due to the coupling effect of CCA and fibers, which leads to even distribution fibers inside cement matrix and arrests crack of HPC [7, 24].

Split Tensile Strength

The combined effects of CCA and artificial fibers on split tensile strengths of HPC mixes are shown in Fig. 6. It could be seen that the control mix was achieved the high split tensile strength values of 2.54 MPa, 3.79 MPa and 4.78 MPa at 7, 14 and 28 days, respectively in compared to CCA replaced mixes (C5-25), which gain agreement with compressive strength results. The replacement of CCA was reduced split tensile strength about 4.72-34.25% at 7th day, 4.75-45.91% at 14th day and 6.07-41% at 28th day, respectively at different ages of curing period. On the other hand, the split tensile strength of HPC is increased with every case of both artificial fibers addition (polypropylene and polystyrene) in HPC. In PP series mix, the highest split tensile strength noticed in the PP4 mix (15% CCA and 0.4% PP fiber) was 2.78 MPa, 3.95 MPa and 5.93 MPa at age of 7, 14 and 28 days, respectively. In addition, this enhanced the split tensile

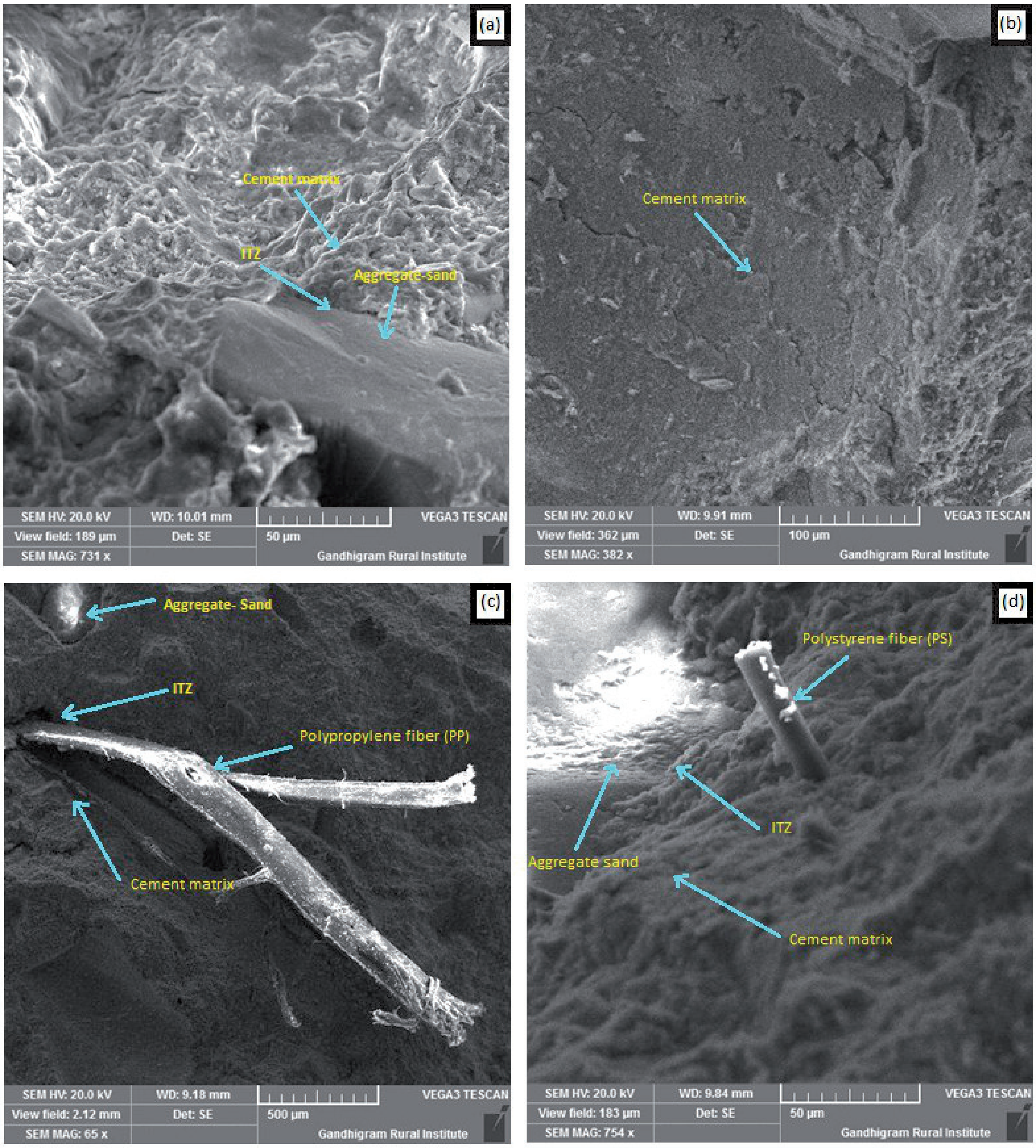

Fig. 5. 28th day microstructure of HPC mixes a) C0, b) C15, c) PP4 and d) PS4.

strength by 9.45%, 4.22% and 24.06% at age of 7, 14 and 28 days, respectively. Furthermore in PS series mix, the highest split tensile strength noticed in the PS4 mix was 2.81 MPa, 3.80 MPa and 5.65 MPa at age of 7, 14 and 28 days, respectively. The replacement of 15% CCA and 0.4% of PS fiber was enhanced the split tensile strength about 10.63%, 0.26% and 18.20% at age of 7, 14 and 28 days, respectively. This mainly attributed due to the inclusion of CCA and artificial fibers can reduce the interconnectivity of pores in cement matrix [40-42] and also enhance denser microstructure through even distribution of fibers [18, 24]. Consequently, this process enhanced friction coefficient between fiber and cement matrix, which leads to improve the tensile strength by arrests cracks and interlocking of slip planes.

The Modulus of Elasticity

Fig. 7 shows the effects of CCA replacement and fibers addition on the modulus of elasticity (MOE) of HPC mixes. It could be seen that the MOE was decreased with increasing content CCA. In comparison to control concrete 28th day result, the lowest MOE values observed in C5-25 series was 38.08 GPa, 38.32 GPa, 34.64 GPa and 32.99 GPa for C10, C15, C20 and C25, respectively. The replacement of CCA reduced MOE up to 1.65-14.80%, with increasing its content 10-25%. In contrast, C5 mix achieved highest MOE of 39.17 GPa, which increased MOE about 1.16%, in comparison to control concrete without CCA. However in PP series, the maximum modulus of

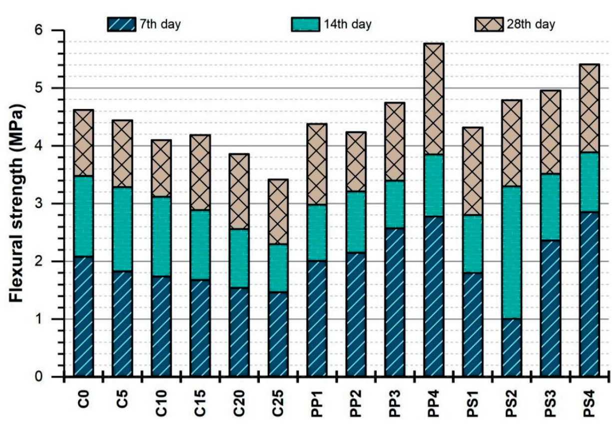

Fig. 6. The effect of corn cob ash and artificial fibers on flexural strength of HPC.

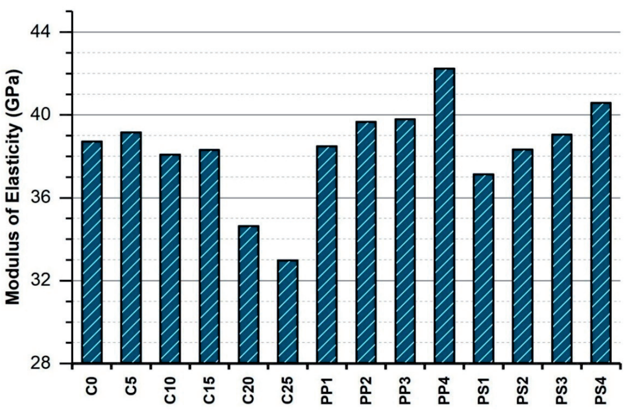

Fig. 8. The effect of corn cob ash and artificial fibers on modulus of elasticity of HPC.

elasticity value was observed in PP4 (with 15% CCA and 0.4% PP fiber) mix was of 42.25 GPa, which increased MOE of HPC up to 9.12% in compared to the control mix (C0). Similarly in PS series, the maximum enhancement in modulus of elasticity was observed in PS4 (with 15% CCA and 0.4% PS fiber) mix was of 4.83%, which reached second highest MOE value of 40.59 GPa. It might be due to the filler effect of CCA and coupling effects of fibers has improved interface between cement and fiber which leads to enhancement the modulus of elasticity of high performance concrete [6, 10].

The Ultrasonic Pulse Velocity Test

The effects of CCA and artificial fibers content on pulse velocity of HPC specimens and their quality as per IS 13311 (Part 1) – 2004 are shown in Fig. 9. It could be seen that the replacement of CCA is reduced the pulse velocity value of HPC specimens. The pulse velocity reduced with every case of CCA increment, which reduced UPV about 4.57-24.19% at 7th days, 2.68-16.78% at 14th day and 3.54-18.75% at 28th day, respectively, in comparison to control mix (C0) results. Conversely, the pulse velocity of HPC is gradually increased with every dosage of artificial fibers. In PP series, the PP4 mix with 15% CCA and 0.4% polypropylene fibers has a greater pulse velocity value of 3.71, 4.63 and 4.85 Km/sec was noticed at 7, 14 and 28 days, respectively and this fostered the pulse velocity value of 0.27%, 3.58% and 1.04% at age of 7, 14 and 28 days respectively in comparison to C0 mix. Similarly in PS series, the PS4 mix (15% CCA and 0.4% polystyrene fibers) observed the higher pulse velocity value was noticed 3.74, 4.55 and 4.78 km/sec at 7, 14 and 28 days, respectively. This blend with 15% CCA and 0.4% polystyrene fibers was enhanced pulse velocity value of 0.27%, 3.58% and 1.04% at age of 7, 14 and 28 days, respectively. It might be due to the pore filling effect of CCA has improved the denser microstructure (Fig. 5 (a, b)) and further increase of fibers content in HPC leads to completely seal the micro cracks

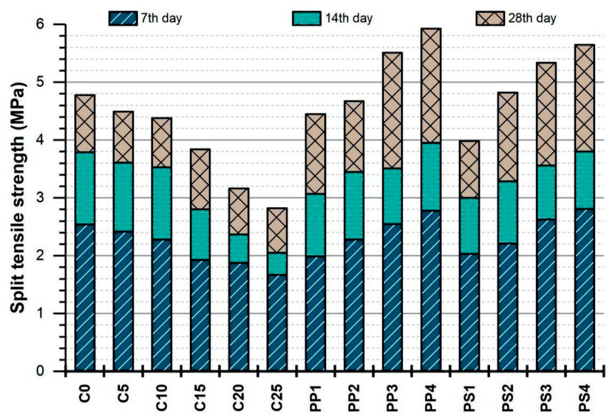

Fig. 7. The effect of corn cob ash and artificial fibers on split tensile strength of HPC.

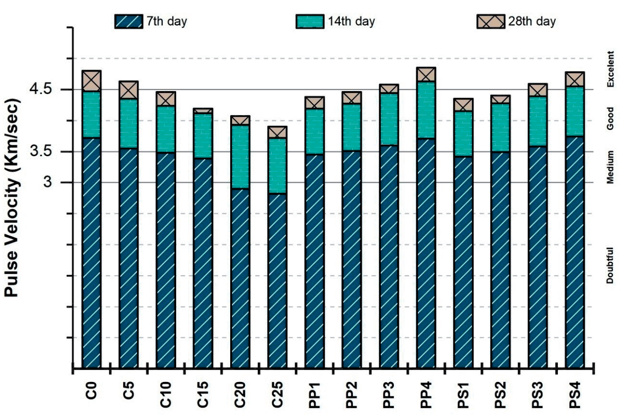

Fig. 9. The effect of corn cob ash and artificial fibers on ultrasonic pulse velocity of HPC.

and pores in HPC matrix (Fig. 5 (c, d)), this reduction pore leads to higher pulse velocity.

Conclusions

From the results of the various tests, the following conclusions can be drawn.

– The increasing content of CCA reduced the slump flow up to 23.38%, addition of 0.4% PP fibers reduced the slump flow up to 17.50% and PS fiber reduced the slump flow up to15.44% in HPC.
– In compressive strength results, the C5 mix was achieved higher strength of 75.86MPa. On the other hand, 15% of CCA replacement was reached 70.92 MPa and it has pozzolanic activity of 95.56% at 28th day. Accordingly, the 15% of CCA was effective replacement level for HPC further improvement with fibers by means of economical and ecological point of view.
– The addition of both PP and PS fibers to CCA blended HPC has improved the mechanical properties and microstructure properties. The maximum compressive strength enhancement in PP4 (0.4% PP fiber content along with 15% of CCA) mix was 15.09%, in PP series. Similarly for PS series, PS4 mix with 0.4% PS fibers and 15% of CCA increased strength about 10.07%.
– The optimum dosage of 15% of CCA along with addition of 0.4% PP fibers in HPC was significantly enhanced the compressive strength about 15.09%, flexural strength about 24.89%, split tensile strength about 24.06%, modulus of elasticity about 9.12% and ultrasonic pulse velocity about 1.02% at age of 28 days.
– Scanning electron-microscopic images reveals development of denser cement matrix with 15% of CCA replacement, compared to C0 mix micrographs. The even distribution of artificial fibers was observed in microstructure of PP4 and PS4 mix, the inclusion artificial fibers was completely seals the micro cracks and pores in matrix, which improves interfacial transition zone lead to denser microstructure. This could be mainly attributed due to pozzolanic activity of CCA and artificial fibers improving friction coefficient between cement matrix and fiber interface of HPC.

Conflict of Interest

The authors declare no conflict of interest.

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