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RESEARCH

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The Effect of Partial Replacement of Cement with Diatomaceous Earth (DE) and Polypropylene Fibers (PPF) on Fresh, Hardened, and Durability Properties of Concrete

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Abstract

This research aims to investigate the fresh and mechanical properties of concrete with diatomaceous earth (DE) and polypropylene fiber (PPF). The cement was partially replaced by DE in the concentration ranging from 5 to 20% by weight; whereas, PPF was incorporated in concrete mix as in range of 0.05–0.20% by cement weight. Totally, 25 different mix proportions were developed and their fresh properties were examined using slump, density and compacting factor tests. Besides, mechanical properties were evaluated by. Using compressive, split tensile, and flexural strength analysis at the ages of 7th, 14th and 28th days. Furthermore, concrete durability properties were evaluated using water penetration, chloride permeability as well as sorptivity tests, which have been performed at the age of 28th day. The result exhibits that the incorporation of D.E slightly affects the slump value meanwhile PPF decreases the fresh values. Furthermore, the combination of DE and PPF in concrete significantly enhances the mechanical properties compared to the control mix. The mix proportion of 15% DE and 0.15% of PPF exhibited a noticeable influence on mechanical properties as well as durability properties compare to control concrete.

Keywords Chloride penetration, Diatomaceous earth (DE), Durability assessment, Microstructure, Sorptivity

1 Introduction

Concrete would be one of the most widely consumed construction materials all around the world, considering its economic efficacy, load carrying capacity, wide availability and suitability for different kinds of structural application. On other hand, cement production has resulted in the release of a considerable amount of Carbon dioxide to the atmosphere, which has a negative effect on the global environment. In the near future, such a rise in carbon footprint could contribute to unfavorable climate change (Dinakar et al., 2013; Maguesvari & Sundararajan, 2017; Sata et al., 2016; Sujjavanich et al., 2017; Zaetang et al., 2017). It has been estimated that, for an annual world production of around 4.5 billion tons of cement, 2.7 billion tons of carbon dioxide has been released into the environment (Johannes Gutenberg Universitaet Mainz, 2021). As, Portland cement (PC) manufacturing has the dominant environmental impact on CO_2 emission and energy consumption (Li et al., 2019; Monteiro et al., 2017), several research groups are constantly working on supplementary cementitious

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materials (SCMs) as a partial replacement for cement with the objective of reducing environmental effect and energy consumption. The SCMs are divided into man-made or naturally occurring pozzolans (alumino) silicates, that react with $Ca(OH)_2$ produced by cement hydration to generate the supplementary cementitious materials. The industrial byproducts such as ground granulated blast-furnace slag (GGBFS), fly ash (FA) and silica fume are artificial SCMs, while calcined-clay, rice husk ash, volcanic ashes diatomaceous earth (DE) are natural SCMs (Snellings et al., 2012). These SCMs have cementitious and/or pozzolanic properties making them desirable in the construction industries. GGBFS and FA are the most widely used SCMs blends with typical substitution level of 10–30% and exhibit comparable mechanical properties to concretes with a high content of Portland cement at high ages. SCMs from industrial byproducts generate comparatively low environmental impact from processing compared to PC manufacturing (Lothenbach et al., 2008). The PC blended with high substitution level of SCMs is more favorable to reduce the environmental impact throughout the life cycle (Gursel et al., 2016). However, there is a lack of research on SCM from geographical origin with economy. Vast resources of DE are reported in different places world-wide. DE having chemical formula (SiO, nH_2O) is a siliceous sedimentary rock, which is made up of fossilized skeletal remains of aquatic plants or single-celled algae. Silica is the main component of DE, which makes it possible to use the material as a binder and stable alternative to good pozzolanic material (Celik et al., 2014). Furthermore, DE is very easy to obtain at a comparatively low price (Hasan et al., 2020). The properties, economic benefits make natural pozzolona as one of the best alterative SCMs. DE has been used in different industries like distillery, braveries and agroindustry is deposited by land fill; however, those recycle DE also be used in concrete as partial replacement of Portland cement (PC) (Letelier et al., 2016). According to ASTM C618-15; DE has been classified as Class N natural pozzolana, which is suitable as a cement replacement (ASTM C618-15, 2015). DE exhibits high porosity requiring high amount of water and hence the substitution level was limited ~ 10%, or used along with suitable superplasticizers (Yilmaz & Ediz, 2008).

Conventional concrete shows strong compression behavior but provides weak behavior with respect to tension. The phenomenon can be improved by incorporating a small amount of short discontinuous fibers in the concrete thereby improving the properties of cement. The addition of fibers in concrete could enhance the hardened properties, provides high energy dissipation, and improves strain hardening behavior in tension and crack propagation.

The incorporation of fibers is one of the most predominant methods to improve the tensile capacity of concrete (Ahmad et al., 2020). Studies are done with different types of fibers (both synthetic and natural) as reinforcement in cementitious matrix (Afroughsabet et al., 2016; Azhari & Banthia, 2012; Banthia & Gupta, 2006; Chacko et al., 2007; Chen et al., 2014; Mohseni et al., 2016). Previous studies have stated that the addition of nylon, steel as well as poly propylene fibers (PPF) increases the tensile and shear capacity of reinforced concrete (Ahmad et al., 2021a). Among all those fibers PPF application can be applied more in construction industry due to its low cost, high toughness, peak strain, availability, good soften response and crack resistance (Choi & Yuan, 2005). Furthermore, the mechanical performance of concrete improved considerably up to 2.0% on the addition of PPFs (Yew et al., 2015), indicating that the incorporation of polypropylene fibers in concrete can improve the mechanical properties without increasing the density (Ahmad et al., 2021b). The addition of macro-PPF in reinforced concrete has been reported to significantly increase the toughness and residual strength (Rooholamini et al., 2018). In contrast, another study showed a decrease in compressive as well as modulus of elasticity with increase in polypropylene fiber content (Karahan & Atis, 2011). With the availability of contrasting reports on the use of PPF, only a very limited number of studies have been done in the combination of fibers with SCMs and no report on the investigation of the effect of combination of DE with PPF in concrete properties. The character of combining effects is vital, which can help to improve the rheological, mechanical and durability characteristics of concrete, and it has not previously been broadly examined. The current study is designed to investigate and optimize the effect of various concentrations of DE and PPF on fresh, hardened as well as durability characteristics of concrete with different curing period.

2 Materials and methods

2.1 Materials

Locally produced 43 grade cement conforming Indian Standard (IS8112, 1989) and DE containing class N pozzolana (ASTM C618-15, 2015) were adopted to be binder. The chemical constituents of OPC and DE are given in Table 1. The average particle (d_{50}) size of OPC and DE are 22 μm and 12 μm, respectively, and with the specific gravity of 3.15 and 2.21, respectively. Natural river sand and single sourced crushed hard blue granite particles having nominal size of 19 mm were used as fine and coarse aggregate, respectively. Fig. 1 represents the gradation curve of fine and coarse aggregates fulfilling the requirements of IS-383 (1970), IS-2386 Part-1 (1963). Different properties of aggregates have been examined as per

Table 1 Chemical composition of OPC and DE

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	SO_3	LOI
DE (% in mass)	82.00	< 0.01	2.00	0.22	0.30	0.10	0.20	0.06	0.34	0.19	1.15	–	14.18
OPC (% in mass)	18	6.4	2.8	69	–	0.46	0.79	–	–	1.53	8.9	1.64	1.28

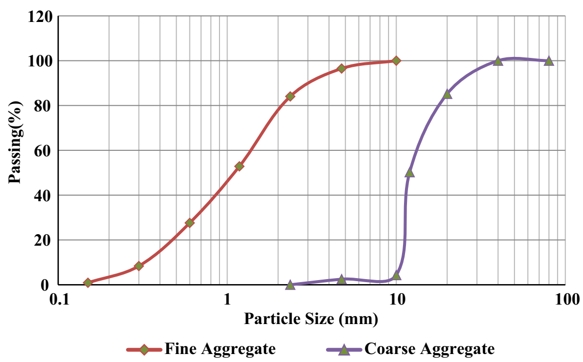


Fig. 1 Particle size distribution of aggregates

IS 2386 Part-III (1963). Virgin polypropylene (PP) fibers with the length of 12 mm, the average diameter of 26 µm and specific gravity of 0.91 were used. Portable fresh water was used for the preparation of all the concrete samples. In this study, 17 different concrete mix proportions were casted including DE and PPF with one control mix. Cement was partially replaced by DE with different percentages of 5%, 10%, 15% and 20% on other hand PPF was added at 0.05%, 0.10%, 0.15% and 0.20% by the total volume of control mix. The control mix code of samples was denoted by the symbol of $D_0P_{0,}$ wherein D represent diatomaceous (DE), P represents polypropylene fiber (PPF) the numeric indicating DE partial replacement percentage and PPF addition. Table 2 represents the detailed mix proportion of concrete.

2.2 Preparation of Concrete Specimens and Testing Methods

The concrete mixing and curing procedures were followed by the procedure of ASTM C192 (2019) for all concrete specimens. Concrete were placed in steel molds, which are properly lubricated before placing. The 100 mm × 200 mm cylindrical specimens ware used for finding the compressive and tensile strength, and all the specimens are kept in a water tank for a period of 7th, 14th and 28th days for curing. Fresh properties of concrete were examined at 28 days according to ASTM C143 (2015), BS 1881-103:1993 (1993), ASTM C360 (1992), ASTM C138 (2017), ASTM C 1202 (1997), ASTM C1585 (2011), respectively, using slump analysis, compaction factor analysis, Kelly ball penetration test, density test and durability properties tests like rapid chloride permeability, sorptivity and water penetration depth were determined.

3 Results and Discussion

3.1 Fresh Properties and Density

The slump value of fresh concrete was gradually decreased when increasing the concentration of PPF, meanwhile, the partial replacement of DE also exhibited the same trend. The variation of slump value and density of concrete are presented in Fig. 2. The maximum slump value of 132 mm was obtained for D_0–P_0 mix (control), the minimum slump value of 13 mm was obtained for D_{20}–P_{100} mix. According to IS 456 (2007), the minimum slump value for reinforced concrete application is 40 mm, so beyond 15% PPF and 0.15% of PPF replacement is not suitable for a reinforced concrete application. The decreasing trend of slump value is due to the incorporation of PPF in concrete that makes interlock between the aggregate particles (Hossain et al., 2019), on other hand, the cohesion and bond between the fiber can reduce the workability of fresh concrete (Fallah & Nematzadeh, 2017). In the same way, the partial replacement of DE also significantly affects the workability with increase in concentration and the range of workability is within the acceptable limit until 15% replacement. It is because of the porosity and finesse of the DE particles. It has been reported that the use of diatomites generates high water demand due to the porous structure of diatomite particles (Gerengi et al., 2013), which directly affects the workability of concrete. In high range of partial replacement, high amount of air bubbles was observed, which may be because of the high loss of ignition. Among all the mixtures, the control mix of D_0–P_0 exhibited highest density of 2436 kg/m^3. The mix D_{20}–P_{100} had the lowest density of 2371 kg/m^3, which was around 2.66% lower than control samples. The reduction in density in concrete is due to the low specific gravity of DE and PPF compared to OPC.

3.2 Kelly Ball Test and Compaction Factor

The Kelly ball test, an assessment method for freshly mixed concrete workability, utilizes a device shown in Fig. 3a. This device includes a 30-pound spherical metal ball measuring approximately 15 cm in diameter, affixed to a graduated stem with a handle. A frame permits

Table 2 Mix proportions of concrete (one cubic meter)

Sl. no.	Mix ID	Partial replacement of DE (%)	Addition of PPF (%)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Course aggregate (kg/m^3)	Water (kg/m^3)
1	D_0–P_0	0	0	383	658	1298	196
2	D_5–P_0	5	0	383	658	1298	196
3	D_{10}–P_0	10	0	383	658	1298	196
4	D_{15}–P_0	15	0	383	658	1298	196
5	D_{20}–P_0	20	0	383	658	1298	196
6	D_0–P_{25}	0	0.05	383	658	1298	196
7	D_0–P_{50}	0	0.10	383	658	1298	196
8	D_0–P_{75}	0	0.15	383	658	1298	196
9	D_0–P_{100}	0	0.20	383	658	1298	196
10	D_5–P_{25}	5	0.05	364	658	1298	196
11	D_5–P_{50}	10	0.10	345	658	1298	196
12	D_5–P_{75}	15	0.15	326	658	1298	196
13	D_5–P_{100}	20	0.20	307	658	1298	196
14	D_{10}–P_{25}	5	0.05	364	658	1298	196
15	D_{10}–P_{50}	10	0.10	345	658	1298	196
16	D_{10}–P_{75}	15	0.15	326	658	1298	196
17	D_{10}–P_{100}	20	0.20	307	658	1298	196
18	D_{15}–P_{25}	5	0.05	364	658	1298	196
19	D_{15}–P_{50}	10	0.10	345	658	1298	196
20	D_{15}–P_{75}	15	0.15	326	658	1298	196
21	D_{15}–P_{100}	20	0.20	307	658	1298	196
22	D_{20}–P_{25}	5	0.05	364	658	1298	196
23	D_{20}–P_{50}	10	0.10	345	658	1298	196
24	D_{20}–P_{75}	15	0.15	326	658	1298	196
25	D_{20}–P_{100}	20	0.20	307	658	1298	196

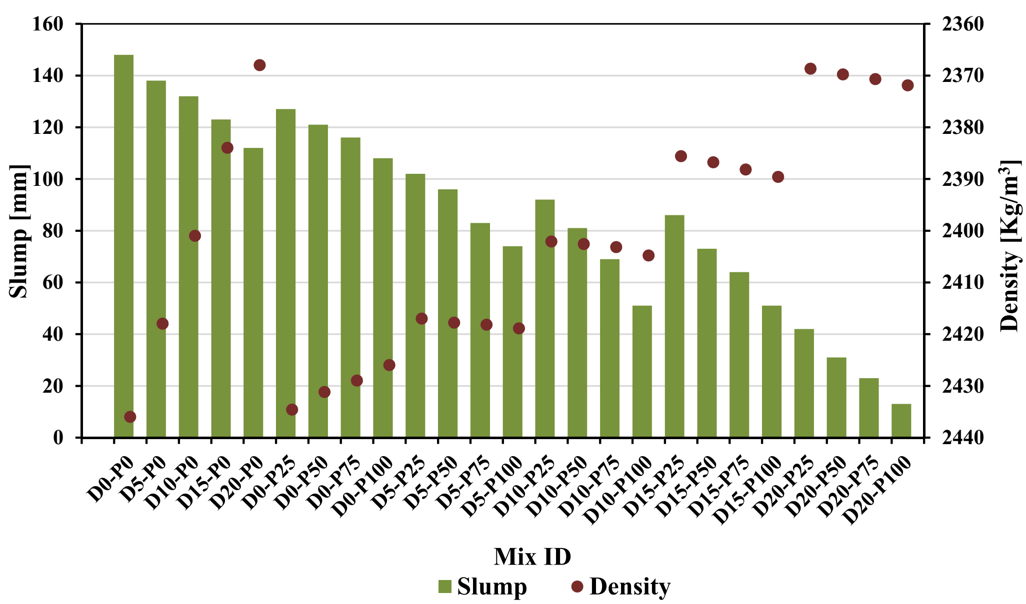


Fig. 2 Slump and density of different concrete mixers

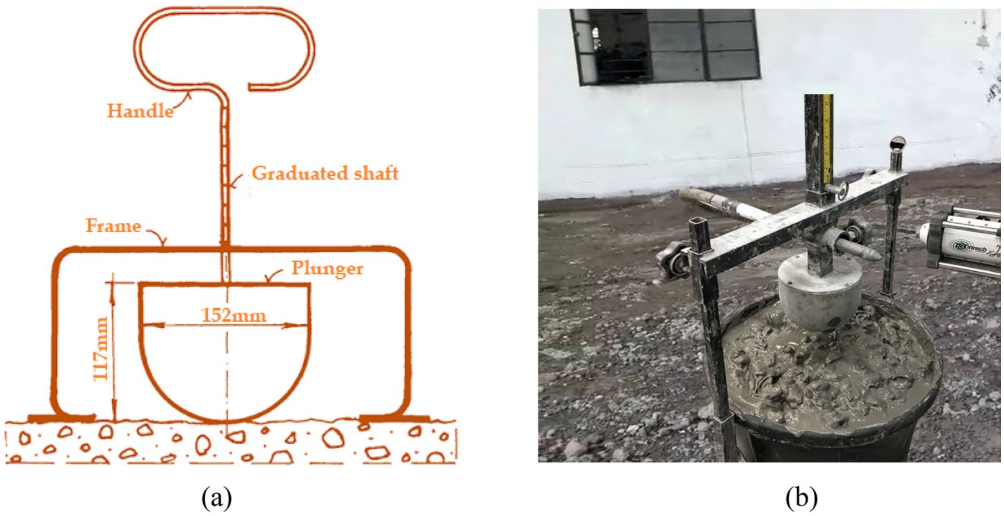


Fig. 3 **a** Kelly ball apparatus schematic, **b** Kelly ball test on DE with PPF sample

vertical movement of the stem, resting on the concrete surface during testing. To ensure accuracy, the rectangular container and equipment must be free from gritty particles. Concrete should fill the container to a depth of at least 20 cm, leveled, with the Kelly ball positioned precisely at the center and 23 cm from each side. Measurements from three consecutive tests on the sample should be recorded, and their average value calculated. Fig. 3b shows the ball pentation test on concrete sample with PPF. The Kelly ball test result and compaction factor test results are shown in Fig. 4. The ball penetration depth was decreased upon increasing the amount of PPF, and the partial replacement of DE. The maximum penetration depth of 69 mm was measured in the control mix (D_0–P_0), while the D_{20}–P_{100} mix exhibited the lowest penetration depth of 36 mm, which was around 47.82% lower than the control mix. The 15% DE replacement mixers exhibited a penetration reduction around 30.43–40.58% range compared to the control mix. The penetration decrement might be due to the interlocking nature of fiber

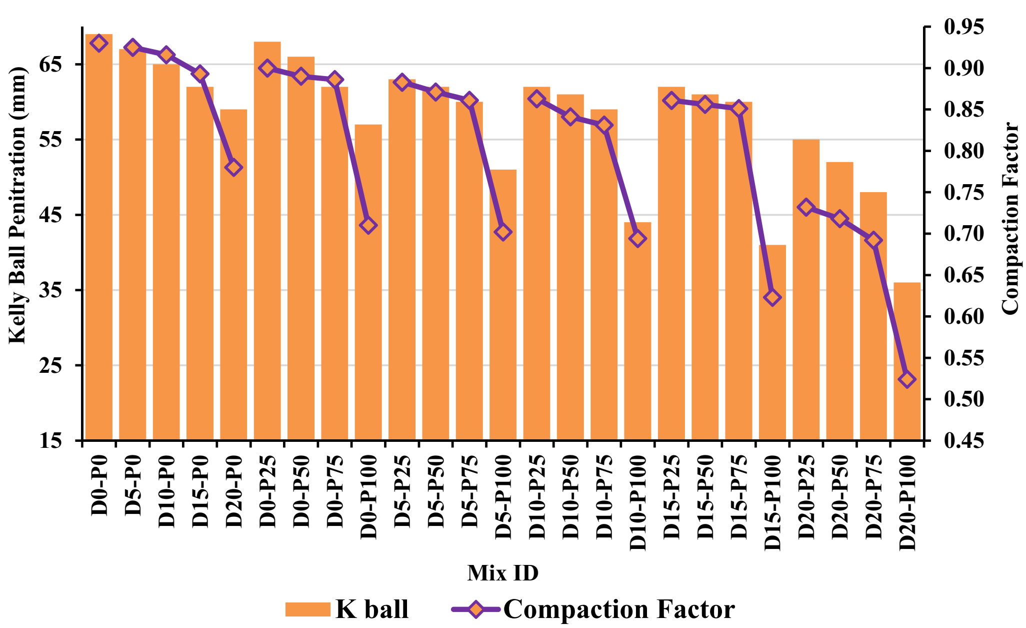


Fig. 4 Kelly ball penetration and compaction factor

between aggregates as well as the highwater absorbing nature of DE particles. The observed ball penetration test pattern is comparable with results from prior investigations (Akid et al., 2021).

The compaction factor test evaluates concrete workability by comparing the weights of partially and fully compacted concrete. The test apparatus includes trowels, a 15.2 cm hand scoop, a 61 cm steel rod (1.6 cm diameter) with a rounded end, and a balance. The procedure involves carefully placing the sample in the upper hopper, allowing it to flow down, trimming excess concrete, and measuring the weight of partially compacted concrete (W_1). Then, the cylinder is refilled, compacted thoroughly, and reweighed to find the weight of fully compacted concrete (W_2), using the initial empty cylinder weight (W) as a reference. The compaction factor is calculated as $(W_1 - W)/(W_2 - W)$.

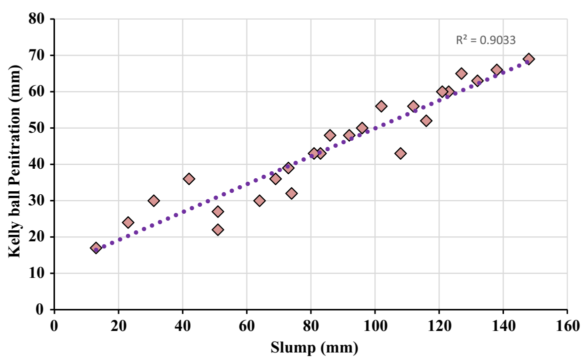


Fig. 5 Relation between ball penetration and slump value

When cement is replaced by DE beyond 15% the water demand is drastically increased, which significantly affects the workability. Upon further examination, the incorporation of PPF and increase in DE concentration decreased the compaction factor of the concrete mix. The compaction factor values ranged from 0.52 to 0.93 for all the concrete mixers. The D_0–P_0-mix scored the highest value of 0.93, and D_{20}–P_{100} scored the lowest compaction factor of 0.52. All the mixers having more than 15% cement replaced by DE exhibited a very low compaction factor, which is not suitable for reinforced concrete applications as per IS-1199-1959 (1959). The experimental relationship between Kelly ball penetration and slump values are presented in Fig. 5. It should be noted that experimental produced values with high co-efficient relationship ($R^2 = 0.9033$).

3.3 Mechanical Properties of Concrete

3.3.1 Compressive Strength Test

The compressive strength results of all the concrete mixers at the age of 7th, 14th, and 28th days are presented in Fig. 6. The mix with PPF and partial replacement of cement by DE had increased the strength compared to the control samples. The strength increment was due to the interlocking mechanism of fiber and aggregates as well as the amorphous silica present in the DE that can form C–S–H by reacting with water and calcium oxide leading to the strength increment while, fibers can prevent the extensive generation of micro cracks. The strength increment was noted while incorporating fibers in concrete (Rostami et al., 2019). However, beyond 0.15% of PPF incorporation showed strength decrement,

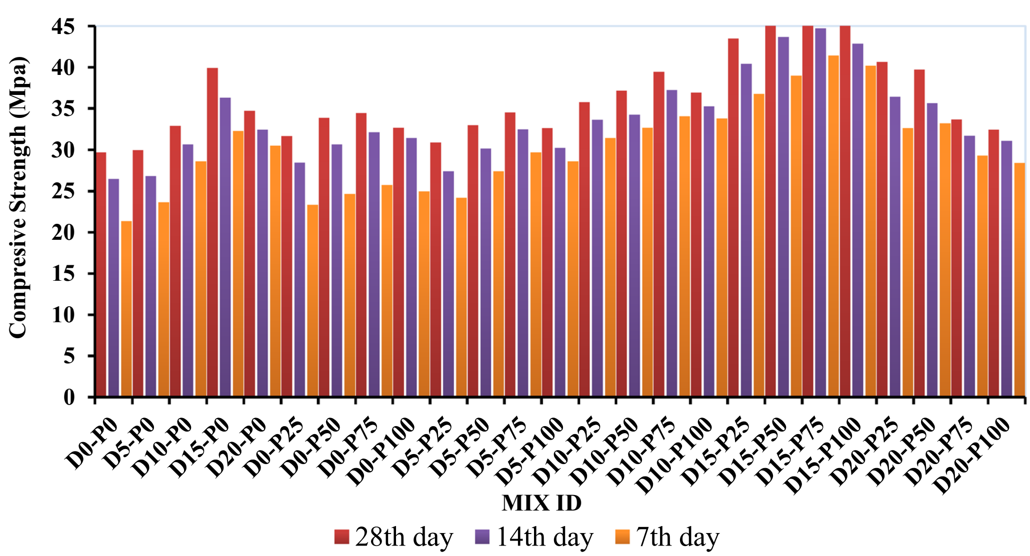


Fig. 6 Compressive strength of different replacements

which might be because of the high amount of PPF that can lead to enhanced air entrapment in concrete. On the other hand, concrete with DE showed higher early age strength growth rather than the control mix compared later age strength growth. This significant strength increment is due to the pozzolanic reaction of high surface DE particles. The compressive strength of concrete mixes with only PPF was in the range of 9.2–17.2%, 7–16.04%, 6.22–16.22% at the age of 7th, 14th and 28th days, respectively, compared to control mix. Previous studies have also reported on the strength growth of 5–8%, 10–13%, 12–15% at 7, 14th and 28th days, respectively, compare to control mix (Afroughsabet & Ozbakkaloglu, 2015) upon incorporation of PPF fibers in concrete. The compressive strength growth of 33.84%, 37.11%, and 34.68% at the age of 7th, 14th, and 28th days, respectively, was observed upon partial replacement of cement by DE.

It is important to mention that the partial replacement of cement by DE (15%) along with 0.15% PPF exhibited the maximum compressive strength at 28th day. The strength improvement ranged between 19.28 and 44.66%. The maximum compressive strength improvement was observed due to the high amount of the amorphous silica present in DE that reacted with CaO and water and enhanced the cement hydration and interlocking effect of PPF.

3.3.2 Split Tensile Strength Test

The split tensile strength results of all the concrete mixers are shown in Fig. 7. The cement partially replaced by DE with the incorporation of PPF achieved higher tensile strength than the control mix. This strength enhancement is due to the high amount of CaO from cement that can produce $Ca(OH)_2$, which react with amorphous silica from DE and alumina thereby producing extra C–S–H, that may fill the pore hole in the concrete mix and densify the interfacial transition zone (ITZ) between paste and aggregate. Meanwhile, PPF can resist the opening and growth of early and macro cracks as well as prevent crack formation and propagation. Previous studies have also revealed similar kind of tensile strength improvement with the incorporation of fibers (Afroughsabet & Ozbakkaloglu, 2015).

On other hand, decrement of tensile strength was noted beyond 15% partial replacement of cement by DE in the absence of PPF (16.12%) compared to the control mix. It may be because of the low availability of hydrated product so that, the excess amount of $Ca(OH)_2$ will act like a byproduct of hydration, which easily leaks out from the inner matrix leading to an increase in the amount of pores thereby affecting the tensile strength.

It has to be noted that there was a significant enhancement in the tensile strength of concrete with the increment of PPF concentration with or without DE. Compared to control mix, at all the testing age the tensile strength was substantially enhanced for the mix P_{100} with DE. Concrete mix having D_{20}–P_{100} mix achieved 37.56%, 23.58% and 17.39% higher tensile strength at the age of 7th, 14th and 28th days. Concrete with steel fiber has been previously reported to obtain an increasing in tensile strength of 11–15% and 15–55% at 7th and 28th days ages, respectively, than the control mix (Atis & Karahan,

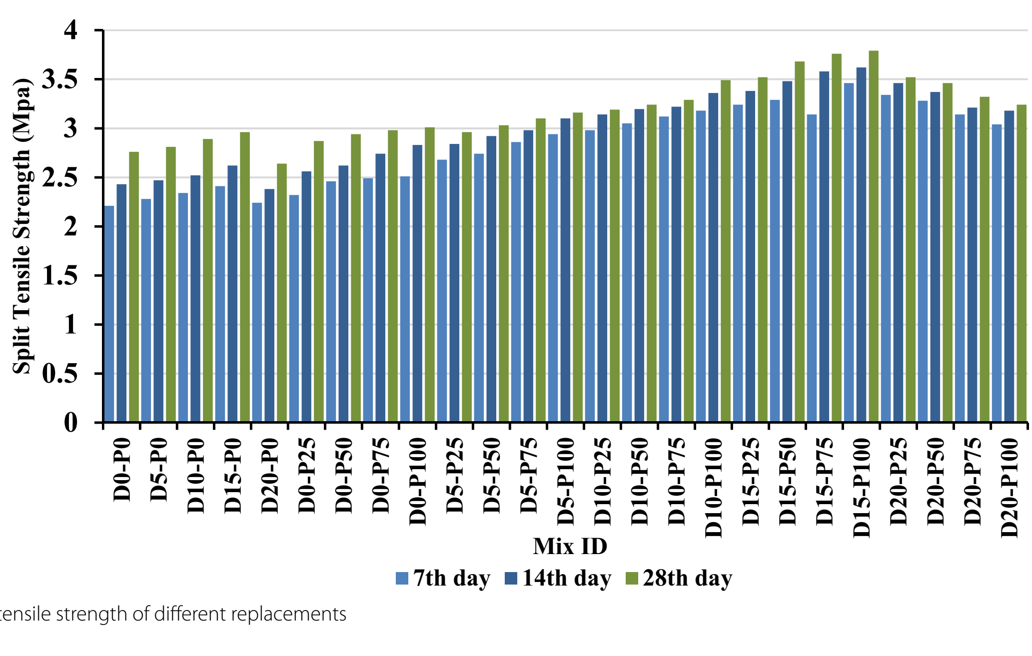


Fig. 7 Split tensile strength of different replacements

2009). The maximum strength gain was observed with mix of $D_{15}–P_{100}$ at the age of 28th day which was around 37.31% higher than the control mix; however, the concrete containing 20% DE with all the PPF dosage levels exhibited lower strength than 15% replacement, and meanwhile, it was still around 7–27% higher than control mix. The possible reason of this reduction can be due to the low amount of hydrated product availability beyond 15% DE replacement rather than ordinary Portland mix.

3.3.3 Strength Relationship (Analytical)

The properties of concrete specimens can be determined from experimental investigations, while executing large scale experiment need large area, long time duration and high cost. In this regard, analytical relationships can be important to determine the properties for further use for making new concrete with various combinations of ingredients. The analytical correlation of this investigation with different codes of practices for split tensile strength and compressive strength of concrete are presented in Fig. 8. The parameters of each other's relationships will determine how well one strength may be measured from the other parameters. From the various code of practices, such as CEB–FIP (1), AS 3600 (2), ACI 318 (3) and ACI 363R (4), the following equations were recommended to predict the alternative strength:

$$f_{sts} = 0.3\ (f_{cs})^{2/3}, \tag{1}$$

$$f_{sts} = 0.4\ (f_{cs})^{0.5}, \tag{2}$$

$$f_{sts} = 0.56\ (f_{cs})^{0.5}, \tag{3}$$

$$f_{sts} = 0.59\ (f_{cs})^{0.5}, \tag{4}$$

where f_{cs} and f_{cst} represent the compressive and split tensile strength in MPa.

The projected data points of strength derived from ACI 363R were the closest to the tested findings among the four standards. The anticipated strength values obtained with AS 3600, in contrast, were found to be the farthest from the measured results. The experimental relationship between the strength values produced a strong prediction with a moderately high correlation of coefficient determination ($R^2 = 0.772$). Among all the standards AS3600 and ACI 318 underestimated the prediction line of compressive and tensile strength, while CEB–FIP and ACI 363R overestimated the prediction line of tensile strength. It should be observed that when compressive strength increased, the experimental tensile strength data points diverged more from the usual prediction line. From this experimental investigation, the following prediction equation can be suggested:

$$\mathbf{f_{sts} = 1.786e^{0.0158fcs}}$$

3.4 Durability Tests

3.4.1 Water Penetration Test

The water penetration test results of blended concrete mixers of 28th day are presented in Fig. 9. The partial replacement of DE and addition of PPF decreased the water penetration depth than the control specimens. Specimen having mix id $D_{15}–P_{75}$ gained the lowest penetration, which was around 24% lower than the control mix. The water penetration deduction could be because of the reaction of amorphous silica with cement that makes a coating around aggregates, leading to the reduction of OH—ions pathway. Fig. 10 shows the diamond-blade-cut sample of $D_{15}–P_{75}$ after water penetration. Meanwhile beyond 15% DE showed more absorption, which might be because of the less amount of hydrated product when increasing the amount of DE on other hand excess amount of calcium hydroxide leak out from the matrix, it led to the increasing amount of pores. The addition of PPF also inhibited crack propagation, reduced the micro cracks as well as flow of water in concrete. The similar kind of water penetration reduction trend was also observed when PPF was incorporated with silica

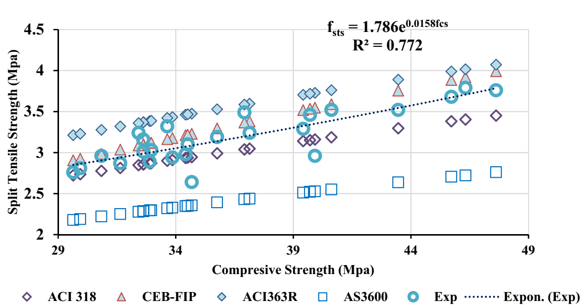


Fig. 8 Analytical relationship between compressive and split tensile strength

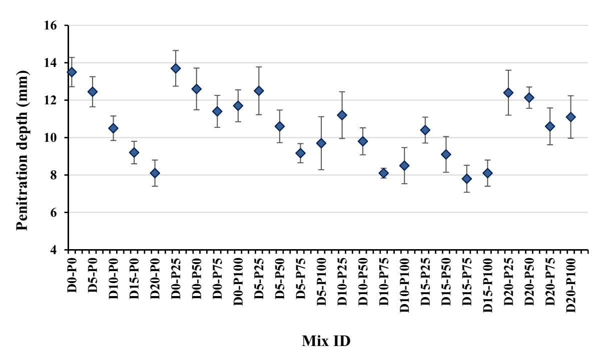


Fig. 9 Water penetration test result

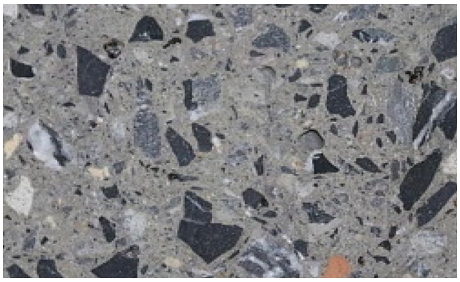


Fig. 10 Diamond-blade-cut sample of D_{15}–P_{75} after water penetration

fume in concrete (Zhang & Li, 2013). It should be noted that the water penetration depth decreased for both concrete with and without DE up to a concentration of 0.75% polypropylene fiber; after that point, it increased once again, which is in line with the previous study (Ramezanianpour et al., 2013). This tendency could be the result of concrete becoming more porous and entrapment of more air due to the addition of higher amount of PPF.

3.4.2 Rapid Chloride Penetration Test

The rapid chloride penetration test (RCPT) results of blended concrete mixers at the age of 28th day is presented in Fig. 11. The partial replacement of cement with DE and incorporation of PPF substantially decrease the chloride iron penetration rather than the control mix. This decreased chloride penetration resistance could be due to the internal void connectivity decrement as well as decreased capillary pores of concrete made with PPF. However, all the individual dosage of PPF samples scored high chloride penetration compared to individual DE samples. This increment is due to porosity development and entrapped air volume while adding PPF in concrete. A similar kind of increasing chloride penetration was recorded while adding PPF in concrete was recorded (Liu et al., 2021). On other hand, all the mix having PPF concentration above 0.75% exhibited an increasing chloride penetration trend, which might be because of the increased air volume in concrete samples beyond optimum level of PPF. To the contrary, the effectiveness of DE was decreasing the chloride penetration. The observed result may be because of high amount of CaO in cement that produces excessive $Ca[OH]_2$, which react with alumina and amorphous silica in DE to generate additional C–S–H. The additional C–S–Hcan fill the pore holes in concrete mix, and also refine and densify the interfacial transition zone [ITZ] between aggregates and cement paste.

Further examining the results, it can be noticed that the concrete mixtures with DE and PPF exhibits low chloride penetration rather than control as well as individual dosages. Samples having ID of D_{10}–P_{75}, D_{15}–P_{50} exhibits penetration almost near to the moderate range meanwhile, D_{15}–P_{75-100} are in the range of moderate level of penetration. The control mix of D_0–P_0 achieved the highest chloride penetration value of 8890 C among all the concrete samples while, the lowest chloride penetration value of 3640 C was achieved in the mix D_{15}–P_{75} which, was around 59.05% lower than control mix. The 15% DE

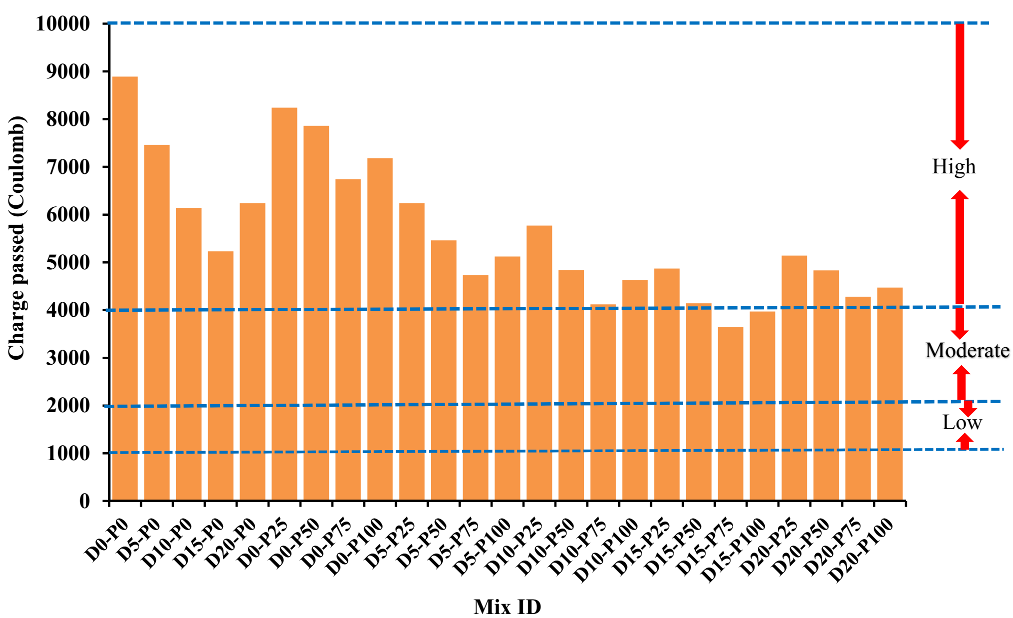


Fig. 11 Rapid chloride penetration test result

dosage with PPF combination mixtures achieved the optimal chloride penetration compared to all the mixtures. However, 20% DE with PPF exhibited higher current passing than the concrete having 15% DE with PPF. The increasing of charge can be ascribed to the reactivity of DE beyond 15% replacement.

3.4.3 Sorptivity Test

The sorptivity test result of concrete mixers at 28th day's age are shown in Fig. 12. The control concrete exhibited the maximum sorptivity co-efficient among all the concrete mixtures. However, the concrete containing DE and PPF showed reduced sorptivity coefficient compared to control concrete D_0–P_0. The lowest sorptivity co-efficient value of 8.2×10^{-5} m/s$^{0.5}$ was achieved in the concrete mix id D_{15}–P_{75}, which was around 24.07% lesser than control mix. The reduction in sorptivity is attributed to the reduction in porosity while cement replaced by DE, pores mean while adding PPF in also helps to reduce the pores in concrete. Another study also proved that the addition of PPF in concrete reduced the sorptivity co-efficient value [59]. It is to be noted that the concrete containing above 0.75% PPF with or without DE exhibited a slight increment in sorptivity co-efficient value (Ramezanianpour et al., 2013) recorded that the incorporation of PPF in concrete up to certain volume fraction can reduce the sorptivity after the rage it will increases.

In this research, DE showed a significant reduction of sorptivity compared to PP fibers, which may due to DE particles filling, and the amorphous silica present in DE promotes the cement hydration as well as densification of the ITZ. It should be noted that beyond 15% partial replacement leads to increase in the sorptivity, which might be due to the shortage of hydrated products, so that the excess amount of $CaOH_2$ will leak out from the inner matrix and enhance the porosity as well as loosen ITZ in concrete. However, the concrete with combination of 15% DE and 0.75% of PPF gives lower sorptivity among all the concrete mixes.

3.4.4 Morphological Examination (SEM)

The effect of DE and PPF on the surface morphology of concrete was examined by SEM (JEOL-JSM-IT 200 with EDS). The specimens were selected based on the optimum strength and lowest strength of blended (DE and PPF) concrete mix. The SEM image of D_{15}–P_{75} and D_{20}–P_{100} is shown in Fig. 13 at different magnifications. The specimen ID of D_{15}–P_{75} exhibited low cracks, low voids with the presence of needle like ettringite crystals throughout the concrete surface which increase the concrete strength. It should be noted that the partial replacement of cement by DE in concrete enhanced the pozzolanic reaction and it led to additional C–S–H production due to its amorphous silica reaction with calcium oxide it leads to filling of voids in ITZ and makes the denser micro structure, which ultimately enhanced the durability of concrete. It can also be noted that the interaction has been developed with DE while adding PPF.

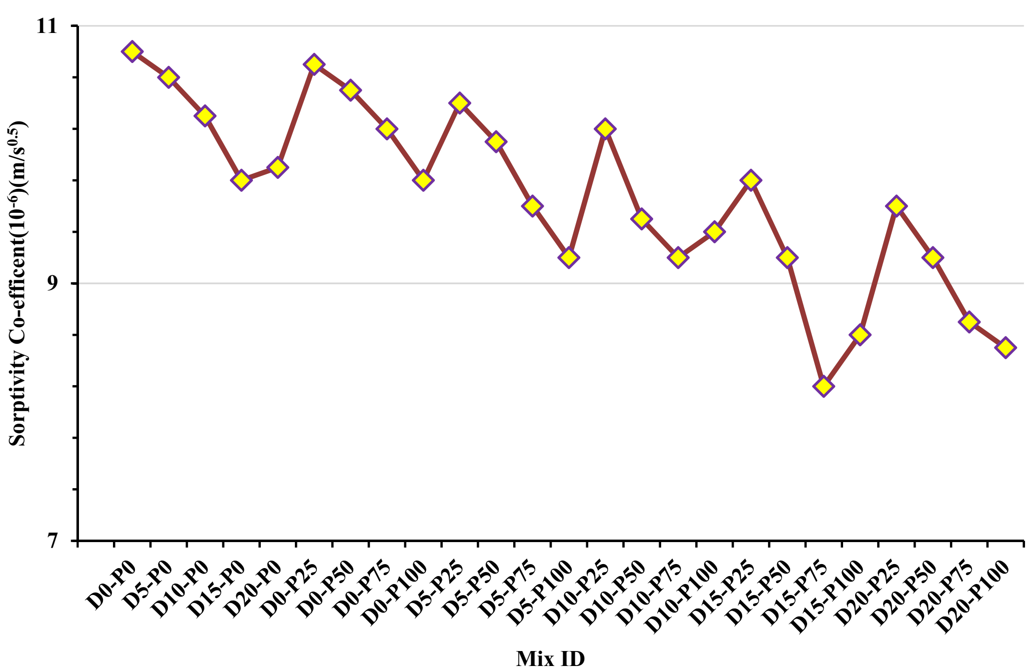
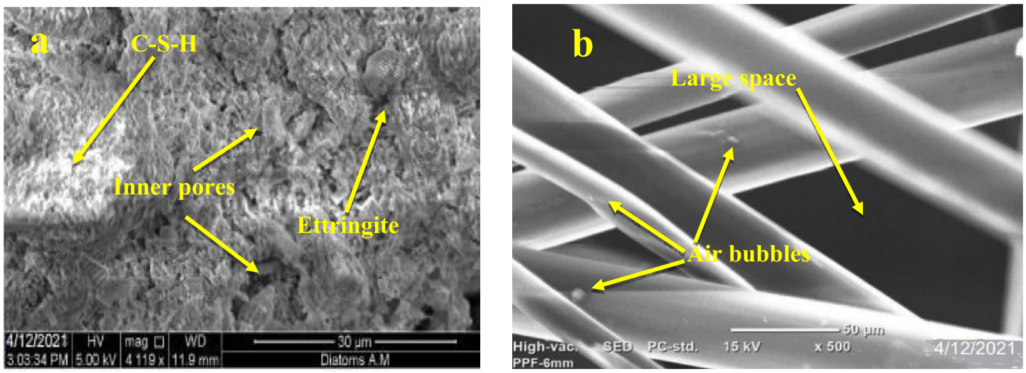


Fig. 12 Sorptivity co-efficient test result



(a) (b)

Fig. 13 SEM image of **a** optimum strength specimen, **b** lowest strength blended specimen

This interaction can transfer the normal axis stress and control the expansion of micro cracks. On the contrary, mix D_{20}–P_{100} SEM image exhibited low amount of ettringite crystals with clustered PPF particles. It should be noted that the high amount of entrapped air bubbles and large space between PPF fibers can be major factor for affecting the strength of concrete mixtures. In addition, high amount of larger size pore holes were also observed, which may be because of the excess amount of $Ca(OH)_2$ leak out from the ITZ that enhanced the number of pores in concrete. This causes the strength reduction as well as low durability.

4 Conclusion

In this study, the varying combinations of diatomaceous earth and Poly Propylene fibers with concrete mixers having fresh, mechanical and durability characteristics were examined. The following findings can be arrived based on the obtained results.

- Increasing the partial replacement of cement by diatomaceous earth and polypropylene fibers has direct influence on fresh properties of concrete mixtures. The incorporation of diatomaceous earth and polypropylene fibers decreases the fresh properties, the partial replacement of cement by diatomaceous earth decreases the fresh properties of concrete rather than the addition of polypropylene fibers.
- Concrete made with DE and PPF shows the strength development rather than control concrete. Diatomaceous earth enhanced the cement hydration and poly propylene fibers controlled and mitigated the growth of initial and macro cracks.
- The analytical relationship between the compressive and tensile strength of concrete showed a good predictive model with varying codes of provisions.
- The water penetration, chloride penetration and sorptivity coefficient in concrete holding diatomaceous earth and polypropylene fibers decrease rather than control mix. It should be noted that the enhancement of the durability properties of concrete by DE was more substantial than PPF.
- The SEM micro structural image exhibited that the partial replacement of cement by DE enhances the cement hydration, fills the voids between aggregates by forming ettringites and makes concrete as stronger and durable.
- The partial replacement of cement by DE beyond 15% exhibits strength reduction due to the insufficient availability of hydrated products. Likewise, PPF also shows the same nature beyond 0.75% due to the entrapped air volume.
- The analysis of all test data indicated that the concrete mix with 15% DE and 0.75% polypropylene fiber had better compressive strength, water penetration, sorptivity, decreased chloride permeability, and strength in comparison to control and other concrete mixtures.

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Author contributions
AGA: writing—review/editing, formal analysis, and data collection conceptualizations, formal analysis, investigation, design, experimentation, writing—original/final draft, writing—review/editing visualization supervision and project administration. JPA: writing—review/editing, formal analysis, and data collection conceptualizations MRA: conceptualizations, formal analysis, investigation, design, experimentation, writing—original/final draft, writing—review/editing visualization supervision and project administration. KD: writing—review/editing, formal analysis. All authors read and approved the final manuscript.

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