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Analysis of PCE-based Superplasticiser for the Different Types of Cement using Marsh Cone Test

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Abstract: The Marsh cone test is a direct and straightforward technique for examining the fluidity of cement paste using a superplasticiser. Polycarboxylate ether (PCE) based Auramix 400 superplasticiser, portland pozzolana cement, and ordinary Portland cement are used for finding the optimum dosage of superplasticiser with specific cement. The optimum dosage and the superplasticiser's efficiency are determined by the marsh cone test for two types of cement. The fresh and mechanical properties and non-destructive testing of the concrete mixes made by two cement types have been compared. The water-cement ratio is kept constant for both types of cement. Results show that the optimum dosage of superplasticiser depends upon the different types of cement. After the saturation point, the fluidity of cement paste doesn't affect increasing the quantity of superplasticiser. Both concrete mixes' fresh and mechanical properties of the same grade are similar, but the fine aggregate and coarse aggregate requirements are higher in OPC (Ordinary Portland Cement) mix concrete than in PPC (Portland Pozzolana Cement) mix concrete. The requirement of superplasticiser is more when used with PPC than the OPC concrete mix.

Keywords: Mechanical Properties; Marsh cone funnel; Workability; Superplasticizer; Saturation point.

1. Introduction

The need for good workability is the primary goal of the concrete. Different conditions necessitate varying degrees of workability in concrete. Structures where thin walls are required, beam-column joints, roof and foundation systems with congestion of reinforcement, deep beams, and columns or pillar junctions all need a high degree of workability [1,2]. In most circumstances, the simple solution is to use more water on the site, but excess water can harm concrete's strength and durability. Due to this issue, the SP (superplasticiser) should be used to enhance the workability of the concrete. The use of SP can permit water reduction by up to 30 percent without dropping the concrete's workability [3–5].

These are some properties of superplasticisers:

- It created significantly more workable concrete than plain concrete at the same w/c ratio.
- For the same workability, it allows the use of a lower w/c ratio.
- It decreases cement content due to greater strength with a reduced w/c ratio.

SP also creates homogeneous, cohesive concrete, i.e., free of segregation and bleeding.

The paste's flow behaviour and the dispersion of cement particles by the SP determine high-performance concrete's fresh properties. Various types and quantities of SP are employed to assess the flow properties of cement paste. “The viscous nature of the paste is characterized using the Bingham and Herschel-Bulkley models. The analysis reveals a consistent pattern across alterations in SP dosage, Marsh cone flow period, mini-slump spread, and rheological parameters” [6]. The marsh cone flow is investigated on glycerol-water mixtures using rheological measurements and digital image analysis [7–10]. The viscous Newtonian fluid used in the computations to solve the flow problem is discussed. It is discovered that flow time is relative to Newtonian viscosity, and the relationship between flow duration and apparent viscosity is only applicable for cement pastes with no yield stress [11]. The investigation is done on the effects of a polycarboxylate SP on the mechanical, mineralogical, microstructural, and rheological properties of Portland cement paste. The SP presence is found to slow down the initial cement hydration processes, and a low polycarboxylate SP dosage resulted in a significant reduction in yield stress [12]. The impact of water/cement ratio, mineral admixture composition, and SP type is analysed on cement pastes with varying SP dosages. It is discovered that there is an SP saturation dosage above which no substantial rise in fluidity occurs [13]. Admixtures in concrete have certain potential benefits with the cement paste, such as air entrainment, water reduction, and plasticity [14]. Furthermore, the use of admixtures may be used to control the setting time, such as acceleration or retardation. Amounts of admixture added beyond a certain point can cause incompatibilities such as concrete's performance characteristics and setting time and strength gain issues [15–17]. The marsh cone analysis finds the admixture's optimum dosage for a given cement [18]. The study is conducted on how mineral admixtures and pozzolanic content are used to produce self-compacting concrete. After lowering the aggregate volume ratio, it is determined that fly ash and the proper quantity of SP are used to create the self-compacting concrete [19]. Polyethylene Glycol 4000 admixture is used to analyse self-compacting self-curing concrete and is found well-performed compared to conventional concrete [10]. "A Marsh cone coupled with a Plexiglas horizontal channel can produce a trend similar to that of a rheometer" [20]. The increase in water temperature resulted in a rise in flow time due to increased plastic viscosity and a faster hydration rate [21]. With increasing temperature, cement paste's yield stress and plastic viscosity improved. Since cement hydration reactions accelerate at higher temperatures, the rate of increase becomes steeper [22].

2. Materials

2.1 Cement

JK Laxmi Pro+ (fly ash) pozzolanic material-based PPC and Wonder cement OPC, both types of cement, are purchased from a material plant located alongside Delhi, India, which are used in this analysis[3,23]. The PPC and OPC are subjected to various methods of testing based on several IS codes (Indian Standard). The outcomes from the PPC and OPC are presented in Table 1.

Table 1. Characteristics of PPC (J.K Laxmi pro+ cement).

Cement type	Cement properties	Results
PPC	28 days compressive strength	42 MPa
	Normal consistency	33%
	Sp. Gr.	2.97
	Setting time (Initial)	90 min
	Setting time (Final)	155 min
	Cement expansion (soundness)	3 mm
OPC	28 days compressive strength	44 MPa
	Normal consistency	29.5%
	Sp. Gr.	3.14
	Setting time (Initial)	93 minutes
	Setting time (Final)	182 minutes
	Cement expansion (soundness)	2 mm

2.2 Aggregates

"FA (Fine aggregate) in the form of crushed stone (stone dust) and CA (Coarse aggregate) in 10 mm and 20 mm sizes are purchased from a building material plant located alongside Delhi, India. The testing of FA and CA are done within standard parameters specified in the IS code, and all outcomes associated with properties of aggregate are available in table 2. The sieve analysis method is used to find FA's gradation and particle size distribution, and the results are demonstrated in Fig 1" [14–17,24,25].

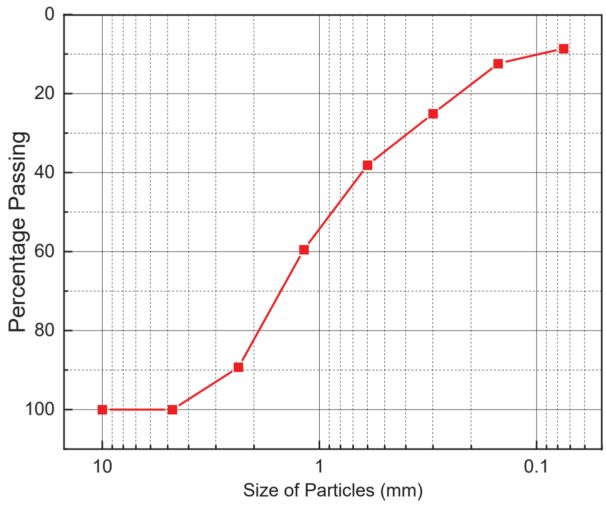


Fig. 1: Grain size distribution curve of fine aggregate

Table 2. Properties of FA and CA.

Material	Properties	Results
FA	Zone	II
	Fineness modulus	2.756
	Sp. Gr.	2.62
	Water absorption	1.21 %
CA	Sp. Gr.	2.79
	Water absorption	0.2 %
	Fineness modulus	7.29
	Impact value	26.3 %
	Loss angel abrasion Value	36 %

2.3 Superplasticiser

Fosroc Chemicals (India) Ltd. provides Auramix 400, a PCE (polycarboxylate ether) based SP that is used to provide concrete with the appropriate workability. SP has an Sp. Gr. of 1.09 and a pH value of 6, according to the Fosroc Chemicals. SP's optimal dose and efficiency are obtained with marsh cone equipment using a nozzle aperture diameter of 8 mm [26–28].

3. Mix Proportions

Based on trial results, a water-to-cement (w/c) ratio of 0.38 was chosen for the concrete in this investigation. The concrete's workability and compressive strength were both evaluated as part of the examination. The Marsh cone test recommends a dose of 1.4 percent for Portland Pozzolana Cement (PPC) and 1 percent for Ordinary Portland Cement (OPC) in order to ensure a moderate degree of workability. The marsh cone test determines the optimum dosage of SP[4,5]. Proportions for the mix design of M40 grade concrete are presented in Table 3. Mix R1 is made by PPC, while R2 mix is made by OPC. In this analysis, a mechanical vibrator is used to achieve perfect compaction, minimise voids in the concrete, and ensure a consistent mix throughout. The concrete mixtures are prepared at a temperature of 29 degrees Celsius and under a relative humidity of 36%. Afterward 24 hours, the samples are demoulded and placed into the curing tank to achieve the strength of concrete at different ages [23,29]. The curing water is free from oils and other chemicals. The curing water is changed after every seven days to maintain the pH of the water. The mix proportion of M40 and all the materials used are presented in Table 3.

Table 3. Mix proportion for concrete.

Mix No.		**R1**	**R2**
Cement (kg/m^3)		390	390
FA (kg/m^3)		666	676
CA (kg/m^3)	(20 mm)	769.8	781.2
	(10 mm)	513.2	520.8
w/c ratio		0.38	0.38
SP (%)		1.4	1.0
Slump (mm)		97	99

4. Testing Procedure

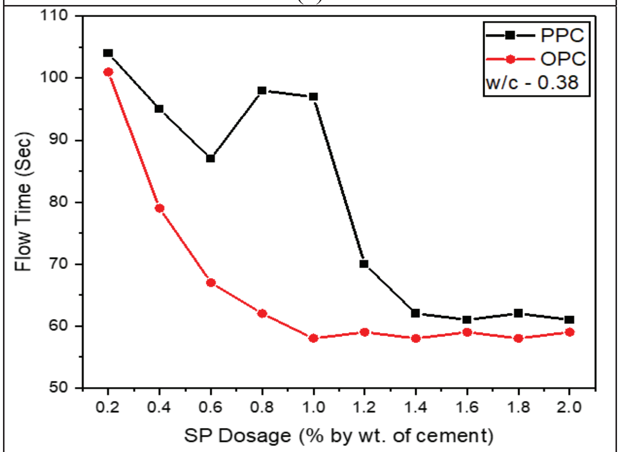
Concrete's fresh and hardened properties are evaluated in this study, such as workability, compressive strength, and flexural strength non-destructive tests. For testing the hardened properties of concrete, three specimens are prepared for both sets of the mix. A UTM (universal testing machine) with a maximum loading capacity of 2000 tons is utilised to assess concrete's compressive and flexural strength. The specimen's dimension for compressive strength is 150X150X150 mm and for flexural strength is 100 mm x 100 mm x 500 mm as per IS code [30]. 140 kg/cm^2/min gradual loading rate is applied to the sample for testing compressive strength, and the 180 kg/min gradual loading rate is applied for flexural strength.

5. Results and Discussion

5.1 The Optimum dosage of superplasticizer

With the use of a marsh cone apparatus, the optimal amount and efficacy of SP are determined. The diameter of the nozzle aperture is 8 mm. There are many aperture sizes available, say 5, 6, 8, and 11 mm, to perform this test; however, the selection of the appropriate nozzle is based on cement paste fluidity. Other attachments with a bigger diameter aperture can be used according to different slurry types and different w/c ratios. In this test, w/c is taken 0.38 according to the prescribed mix design of concrete. The dosage of SP is taken 0.2% in the first test, then increased with an interval of 0.2% until the flow time becomes almost constant. Mix them thoroughly in the Hobart mixer for 2 min to avoid the lumps in the mixture. If hand mixing is done, then the slurry should pass through a 1.18 mm sieve before the marsh cone test to avoid lumps in the slurry. The SP's optimum dosage is selected when the slurry takes minimum time to complete out from the marsh cone. After the SP's optimum dosage (saturation point), the slurry's outcome time becomes almost constant for the particular cement and specified w/c ratio. After the saturation point, the addition of SP doesn't influence the fluidity of cement paste. The testing setup for determining the optimum dosage of SP is illustrated in Fig. 2(a). The slurry's flow time with different dosages is shown in Fig. 2(b). SP dosages of 1.4 percent for PPC and 1% for OPC are determined to be the most effective.

(a)



(b)

Fig. 2: a) Testing setup of marsh cone apparatus; **b)** The optimum dosage of superplasticizer with different cement

5.2 Efficiency of Superplasticiser

The marsh cone apparatus with an 8 mm aperture diameter is used for finding the SP's efficiency. The efficiency of the SP is essential for making the mix design of desired strength. SP's efficiency indicates that the required amount of water for the concrete design mix can be reduced up to a specific limit. The test procedure for finding the SP's efficiency is taken from the book concrete technology (theory and practice)[31]. In this process, the cement quantity remains constant, but the water amount is changed in all the tests. The flow time of slurry without SP, having 1100 gm of water should be the same as another slurry with 1% of SP dosage having a less amount of water, as shown in Fig 3. The efficiency of the auramix-400 SP for PPC and OPC permits the decrement of 22.73% of water. Different kinds of SP may be used for the same nature of cement, and the SP efficiency will be dissimilar. To find the efficiency of the SP flow table test can be used in place of the marsh cone apparatus.

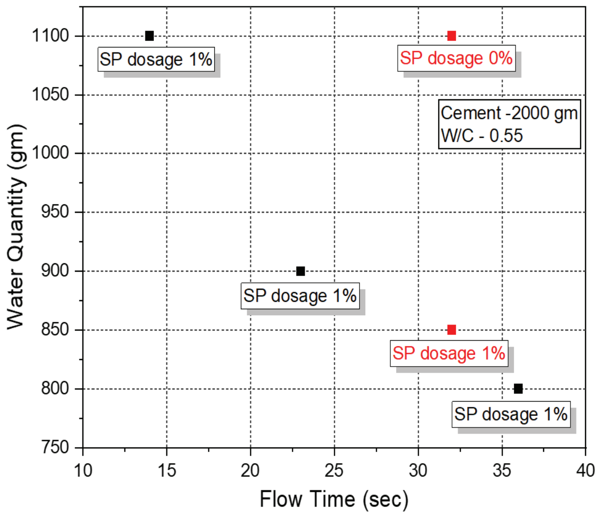


Fig. 3: The efficiency of SP

$$\text{The efficiency of SP} = \frac{\text{The difference in water content}}{\text{Original water content}} X100$$

= 22.73%

5.3 Workability

The slump cone test measures the workability of concrete. SP is utilised by the weight of cement for ensuring the required workability of concrete. The slump cone results of the PPC and OPC mix are revealed in Fig 4. After the outcomes, it is assessed that the concrete workability of both mixes is nearly similar. The concrete mixes of the same grade made by PPC and OPC having the optimum dosage of SP exhibit similar workability. The slump value for medium workable concrete should be 50-100 mm, ensuring that both mixes are workable in the medium range.

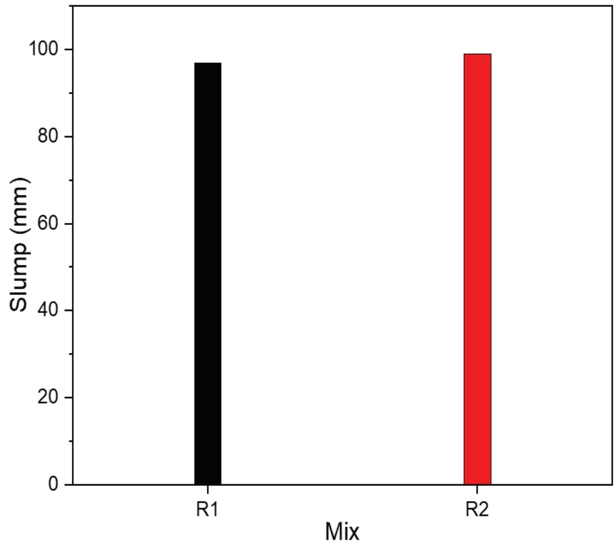


Fig. 4: Results of slump cone for mixes

5.4 Compressive Strength

The compressive strength of concrete is tested according to [32]. The compressive strength results of both mixtures are revealed in Fig 5. After analysing the results, it is found that the OPC mix's compressive strength is slightly larger at 28 days of curing and slightly lower at seven days and 14 days of curing as compared to the PPC mix. Both concrete mixes of the same grade show nearly similar results. The compressive strength of the PPC mix and OPC mix for the same SP would be almost similar, but the dosage of SP varies [33–38]. The dosage of SP in the PPC mix is slightly higher than the OPC mix, but the amount of FA and CA is lower.

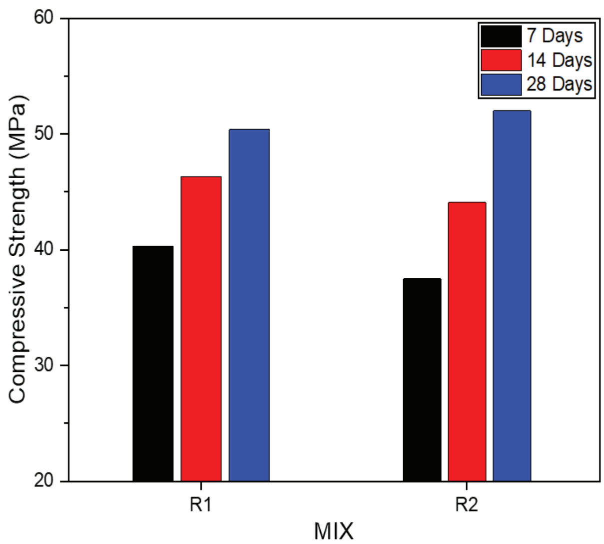


Fig. 5: Compressive strength of standard concrete of different mix

5.5 Flexural Strength

The Flexural strength of concrete is tested according to IS code [32]. The prism specimen's failure pattern is shown in Fig. 6(a), and the failure condition is in the range prescribed in IS code [32]. The results of the flexural strength of both mixtures are revealed in Fig. 6(b). Afterwards, evaluating the results, it is found that the OPC mix's flexural strength is slightly larger at 28 days of curing and slightly lower at seven days and 14 days of curing as compared to the PPC mix [39–41]. Both concrete mixes of the same grade show nearly similar results[42].

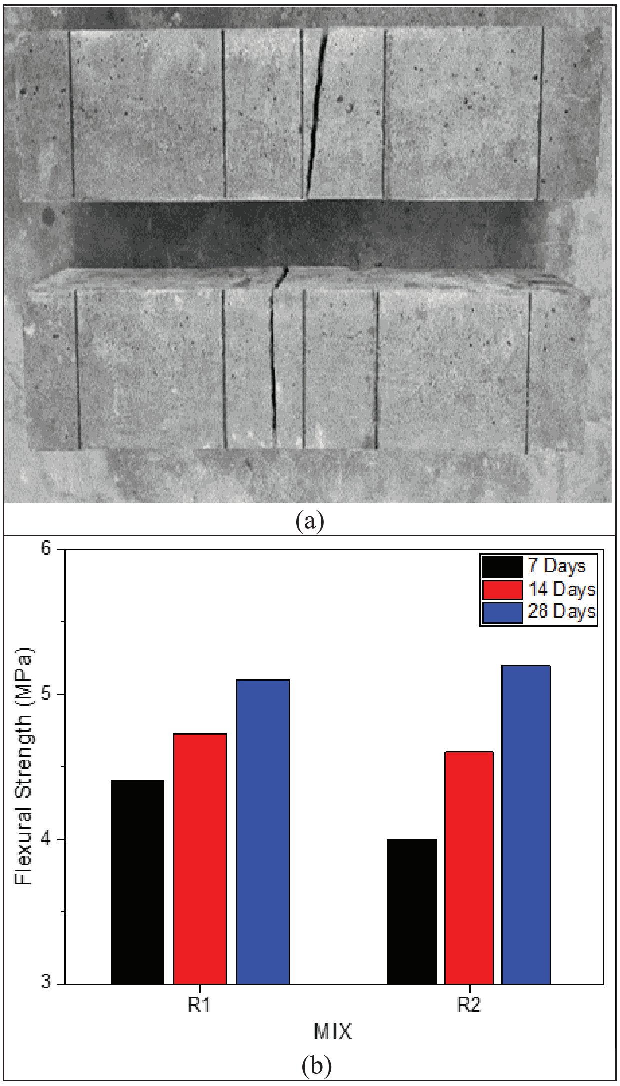


Fig. 6: a) Failure pattern of prism specimen; b) Flexural strength of standard concrete of different mix

5.6 Compressive strength of concrete mixes by Rebound hammer

Fig 7(a) shows the Proceq Schmidt Digital Concrete Test Hammer, utilised to assess the concrete's compressive strength according to [43]. The compressive strength results from the rebound hammer of both mixes are revealed in Fig.7(b). After examining the results, it is discovered that the compressive strength of concrete mixtures measured using a rebound hammer is 2-8 percent higher than the results obtained with UTM.

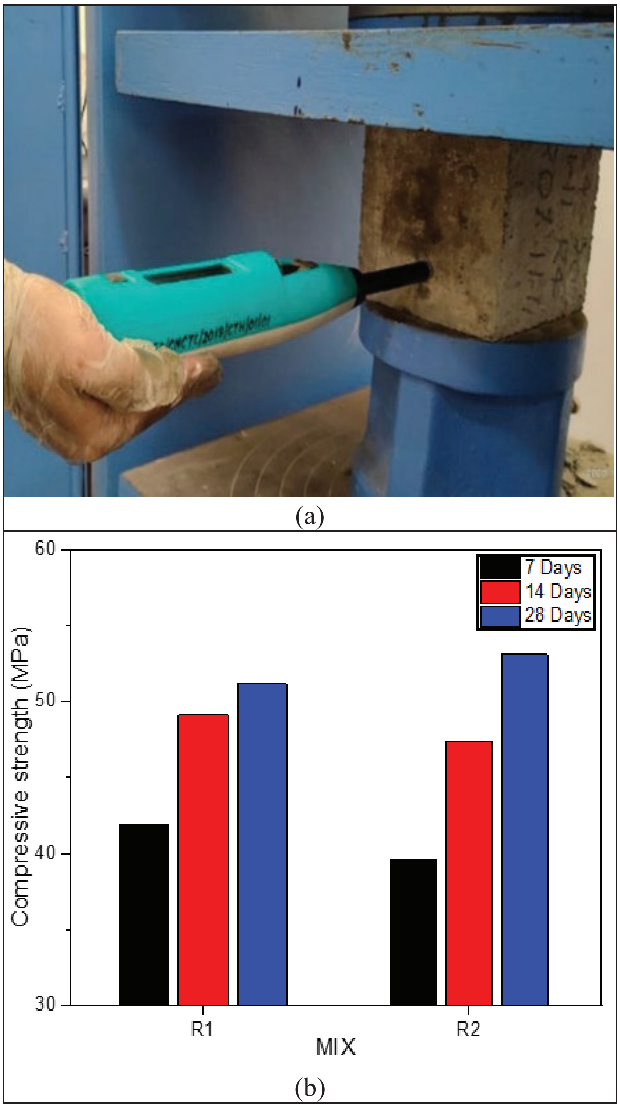
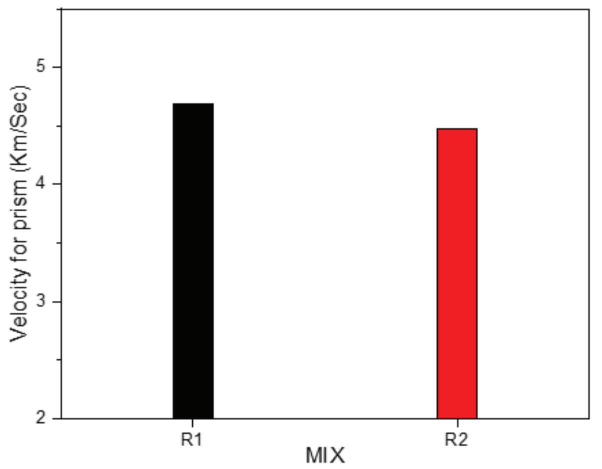


Fig. 7: a) Rebound hammer testing of the cube for the compressive strength test; **b)** Compressive strength of standard concrete by rebound hammer with age

5.7 Ultrasonic Pulse Velocity

The UPV of both concrete mixes is tested by a 'MATEST' UPV tester and 2 transducers with a frequency of 54 kHz on the prism specimens, as shown in Fig. 8(a) according to [44]. An adequate amount of gel is applied between the concrete prism's surface and the transducer to confirm the proper connection. The UPV results of both mixes are shown in Fig. 8(b). The PPC concrete mix has UPV greater than 4.5 km/sec, which shows that the concrete is in excellent condition, but the OPC concrete mix has UPV of less than 4.5km/sec, and it offers good condition [45,46].

(a)



(b)

Fig. 8: a) Ultrasonic pulse velocity test of standard concrete; **b)** Ultrasonic pulse velocity of mixes at 28 days

6. Conclusion

The optimum dosage of polycarboxylate ether-based SP auramix 400 is found 1.4% with PPC and 1% with OPC. The optimum dosage of SP depends upon the type of SP and type of cement. If the cement or SP is different, then the optimum dosage will be changed. The optimum dosage of SP also depends upon the water-cement ratio. If the water ratio is changed, the optimum dosage will be different. If the SP is used with PPC, it requires more SP than the requirement of SP with OPC. However, FA and CA's requirement is more in OPC mix concrete than PPC mix concrete. The fresh and mechanical properties of concrete mixes of the same grade of concrete made by PPC and OPC with the SP's optimum dosage are approximately similar. The UPV is slightly higher in PPC concrete than in OPC concrete.

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Competing Interests
All authors have no financial interests.
Author contributions
The authors were involved in all parts of the manuscript preparation.

Nomenclature

FA- Fine aggregate
CA- Coarse aggregate
SP- Superplasticizer
PPC- Portland Pozzolana Cement
OPC- Ordinary Portland Cement
IS code- Indian Standard code
ASTM- American Society for Testing and Materials
Sp. Gr.- Specific gravity

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