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Reduction of Cement Consumption, Carbon Foot Print and Improvisation of Durability Performance of Concrete by using High Dosage of High Grade PCE based Superplasticiser

Dr Abdullah Ahmed Laskar[1], Dr Partha Ghosh[2], Gopal Tiwari[3], Anupam Sarkar[4], Vamadev G B[5]
[1]*Dy General Manager (Civil)-BHEL,* [2]*Proffesor Construction Engineering Department-JU,* [3]*Manager (Civil)-BHEL,* [4]*Engineer (Civil)-BHEL,* [5]*General Manager (Technical) - Fosroc Chemicals India Pvt. Ltd*

Abstract: In present world global warming is one of the primary concern of the world community due to continuous increasing of carbon foot print since last few decades. Among the different source of carbon foot print in global atmosphere, cement industry alone contribute nearly 8% to the global anthropogenic CO_2 emissions as 1 MT of cement production is generating nearly 0.87 MT CO_2 to the atmosphere. Hence considering the threat of continuously increasing carbon foot print of the atmosphere number of ways were adopted for reduction of carbon foot print by many researchers in past like using of supplementary cementitious material (SCM) in production of concrete. But in the present research work it has been revealed that by using of high grade PCE based superplasticizer with an increased dosage has shown significant reduction in the consumption of cement with regards to strength requirement of concrete. Thus by reduction of cement consumption in concrete has shown significant reduction of carbon foot print generated from cement industry. On the other side the present research work has also revealed that, by using of high grade PCE based superplasticizer with an increased dosage helps to produce high workability & high performance concrete at very low w/c ratio. Thus because of using very low w/c ratio in concrete without impacting its fresh concrete properties there is a significant improvement has been noticed in hardened concrete properties like increase in strength of concrete, reduction in pore sizes of concrete resulting improvement of concrete durability performance. With regards to cost analysis of the proposal based on the present research work, it is found that using of increased dosage of superplasticiser in concrete is still found to be economic as compared to cost of concrete with high dosage of superplasticiser, as the cost reduction of concrete is higher due to higher amount of cement reduction in concrete as compared to extra cost of Superplasticizer in concrete beyond the optimum dosage of superplasticiser in concrete.
Keywords: Compressive strength, Flexural strength, Workability, Superplasticiser, PCE, MIP, Pore size, CSH, gel pore.

I. INTRODUCTION

The continuously increased global carbon foot print is now became the serious threat to world climatic condition as per United Nation IPCC report of 28 February 2022. According to The World Bank, the global usual carbon footprint in 2014 was 4.97 MT CO_2 per capita. [1]. The European Union usual per capita CO_2 is about 13.8 tons as per 2007 record, while for the U.S, Australia and Luxembourg and it was more than 25 MT CO_2 per capita. In previous record of 2017, the average CO_2 per capita is 20 MT in US. However the carbon footprints per capita of countries in Africa and India were well below average. To establish these numbers into background, supposing a global population of about 9 to10 billion by 2050 and per capita carbon footprint of about 2 to 2.5 tons CO_2 is needed to stay within a 2 °C target. According to the report [2], it is only possible to avoid warming of 1.5 °C or 2 °C if enormous and abrupt cuts in global carbon foot print of the atmosphere. Since 1850–1900 to 2011–2020the average Global temperature rose by 1.1°C. Thus considering threat of global warming there are many ways has been implemented globally to cut down the carbon foot print & as a target it has decided to cut the GHG emissions by 50% by the year 2030. [3]. Among the different sources of carbon foot print cement industries plays a contribution of about 8% of the total global anthropogenic CO_2 emissions, as 1MT cement production generate nearly 0.875 MT CO_2 to the atmosphere. Thus the present research work is mostly focus on the reduction of carbon foot print by reducing the cement consumption of infrastructure industries by using high grade of PCE based superplasticiser in concrete.

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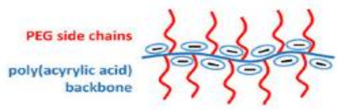
As per the present research development it has been observed that by using high grade of PCE based superplasticiser having high level of water reduction capability due to its long lateral chains steric hindrance mechanism reduces over 35% of the water demand in the mix resulting requires less mixing water to achieve required concrete workability and retention & improved strength. The reduction of water demand in the concrete helps to achieve highest strength and durability at lower cement content of the mix due to significant reduction in porosity and critical pore size diameter of the hardened concrete.

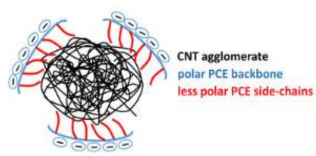
II. LITERATURE REVIEW

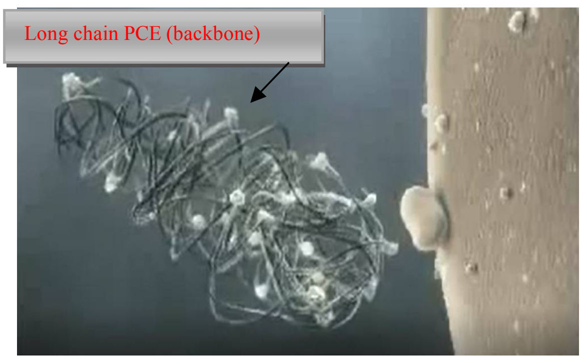
As per the concrete science the water used in the concrete is of two requirement like hydration of cement chemical & to provide the workability of the fresh concrete. According to various past literature the water demand for hydration of cement chemical is 23% & for workability requirement of fresh concrete is 15%, thus total ideal water requirement is 38% by weight of the cement. However the water beyond 23% in concrete occupy some spaces in fresh concrete & leaves once the concrete got hardened resulting various sizes of pore structure in concrete. The higher the water content in the concrete higher the sizes pore in concrete & these pores are the cause of low strength & poor durability performance of concrete. In early 1970 the concrete were produced without using any high range water reducing admixture in Japan and Germany & later on they were made popular in USA ,Europe and even Middle east and far east[4].Till 1985 the using of superplasticiser in India was not popular. The following are the four major types of the superplasticiser are in use globally.

1) Sulphonated Naphthalene Formaldehyde Condensate (SNF).
2) Sulphonated Melamine Formaldehyde Condensate (SMF).
3) Modified Lignosulphonates (MLS)
4) Polycarboxylate ester (PCE)

From the above four major type of superplasticiser PCE based superplasticiser are the new generation high range water reducing admixture even up to 35%. In general the PCE based superplasticiser are of two type's mid-range superplasticiser having water reduction in the range of 20-25% & high range superplasticiser in the range of 30-35%. The new generation high range superplasticiser is unique combination of the of a long chain polycarboxylic ether polymer with long lateral chains. The new generation high range PCE based superplasticiser upon mixing with concrete, at the beginning of the mixing process, occurrence of electrostatic dispersion mechanism as like as traditional superplasticizers, but the long side chains linked to the long chain polycarboxylate polymer known as backbone generate a steric hindrance effect, which is greatly stabilises the cement particles' ability to separate and disperse. This mechanism reduces more than 35% of the water demand in the mix resulting requires less mixing water to achieve required concrete workability and retention. The less water in the concrete helps to achieve higher strength & durability of concrete.







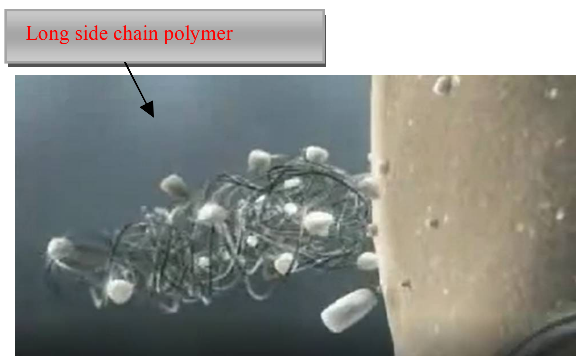


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Fig-1: Chain structures of PCE based super plasticiser & its water reducing mechanism by both electrostatic repulsion of backbone PCE & steric hindrance of side chain.

III. MATERIALS

In the present research work a reference concrete were used as C-30/37grade of concrete with 440 kg CEM-I, 52.5N grade cement [5] per cum with w/c ratio 0.45 & superplasticiser dosage 0.6% by weight of cement. The aggregate used in the experiment were crushed basalt stone of 19 mm nominal size & fine aggregate used in the experiment were river sand of FM 2.51[6]. The following are the different properties of various ingredient of concrete which are used in the experimental work.

A. Cement

Table-I
Physical and Chemical analysis of cement

SL No	Test parameter	Unit	Test Results
1	Sp gravity	-	3.15
2	Blaine Fineness	m2/Kg	342
3	45 micron retain	%	2.65
4	IST	minute	128
5	FST	minute	245
6	C_3A	%	7.04
7	C_3S	%	55.25
9	C_4AF	%	10.76
10	LSF	Ratio	0.93
11	SR	Ratio	2.47
12	AR	Ratio	1.37

B. Mixing Water

Table-II
Mixing water physical & chemical analysis

SL No	Test parameters	Unit	Test Results
1	pH	-	7.1
2	Chloride content	ppm	47
3	Sulphate content	ppm	225
4	Alkalies (Na_2O_{eq})	ppm	135

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C. The Superplasticiser characteristics from FTIR spectrum Analysis

The C=O stretching vibration band at 1730 cm−1 in the FT-IR spectra of PCE indicated that they were ester-based superplasticizers. Also, it is estimated to consist of an ether structure because of the asymmetric stretching of C-O-C at 1030 cm−1. This indicates the superplasticiser is the combination ether and Easter based PCE admixture. The physical & chemical analysis of superplasticiser & its FTIR spectra is shown below.

Table-III
Physical and chemical analysis of Superplasticiser

SL No	Test parameters	Unit	Test Results
1	Relative Density	g/cc	1.064
2	pH	-	6.45
3	Chloride content	%	0.032
4	Total alkali (Na_2O_{eq})	gm	1.5
5	Water Reduction	%	35
6	Dry material content	%	30.97

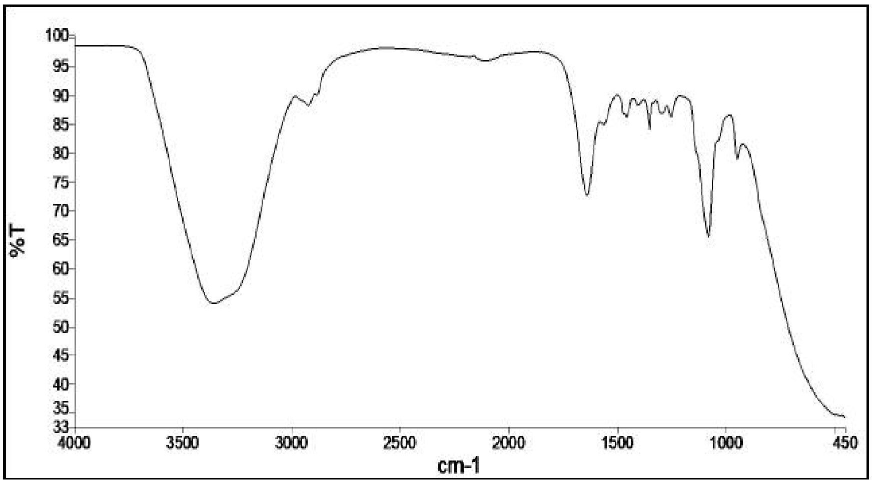

Fig-2: FTIR spectra of PCE -based superplasticizers.

D. Coarse Aggregate

Table-IV
Physical properties of coarse aggregate.

Combined graded coarse aggregate 19 mm + 9.5 mm (60:40)			
SL No	Test parameters	Unit	Test Results
1	Sp gravity	-	2.82
2	Flakiness Index	%	22
3	Elongation Index	%	12
4	Crushing Strength	%	17.5

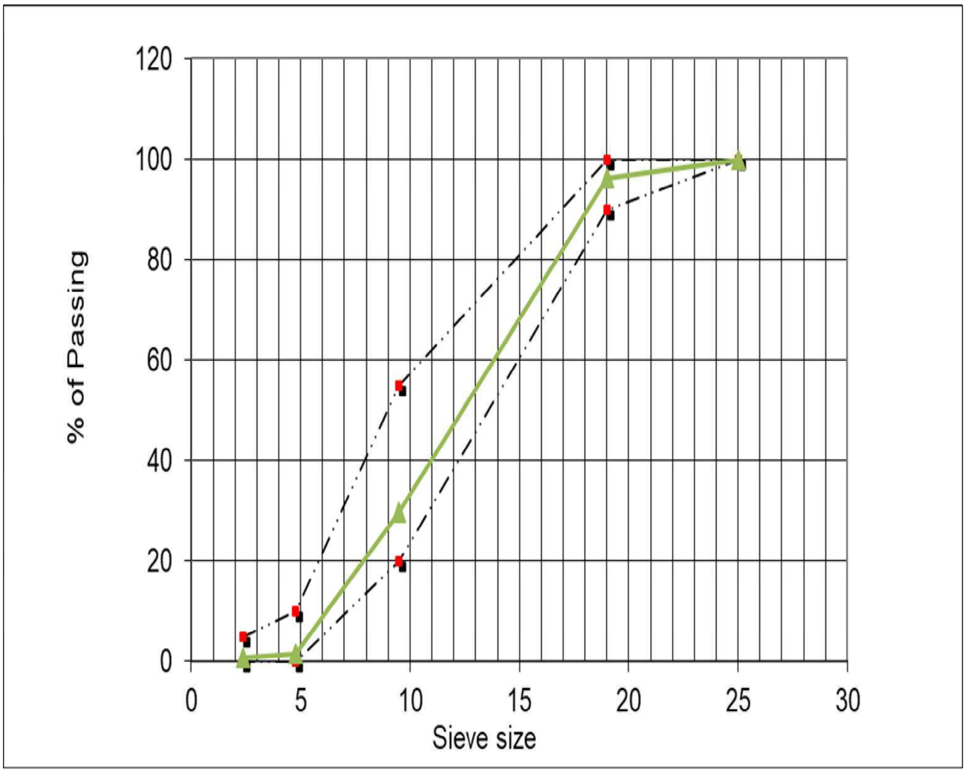

Fig-3: Sieve analysis of 19 mm nominal size combined graded aggregate.

E. Fine Aggregate

Table-V
Physical properties of Fine Aggregate

SL No	Test parameters	Unit	Test Results
1	Sp gravity	-	2.65
2	Fineness Modulus	-	2.51
3	75 micron passing	%	3.4

IV. EXPERIMENTAL DETAILS

In the present research work a reference concrete of C-30/37 grade were used with 440 Kg CEM-I 52.5 N grade cement per cum with w/c ratio 0.45 & superplasticiser dosage 0.6% by weight of cement and subsequently cement and water were reduced gradually by increasing the dosages of superplasticiser in the mix. There are four different types of samples were used with reduced cement content, water content and increased dosages of superplasticiser in addition to the reference mix. The research experiment was conducted on two part like analysis of fresh concrete properties and hardened concrete properties. In fresh concrete properties the test was carried out to know the rheological behaviours of concrete and also workability of fresh concrete by slump test at immediate, 30 minute, 45 minute and 90 minute respectively. But to analyse the mechanical properties of hardened concrete both compressive strength at 3-days, 7-days, 28-days and Flexural strength at 7-days & 28-days was conducted. However to analyse the durability factor of concrete threshold pore size & pore size distribution of concrete paste structure were studied by using MIP test. The sample sizes used for compressive strength of concrete was 150 mm x 150 mm x 150 mm sizes cube & for flexural strength 500 mm x 250 mm x 250 mm concrete beams were used. The number of sample were used for each type of testing at each testing ages were 3 nos. The samples mix proportions used for the present research experimental work is shown in Table-VI below.

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Table-VI
Mix details of various Sample ID

Name of the ingredient / Other concrete parameter	Quantity of different concrete ingredient of different sample ID in Kg/cum						
	Reference Mix (S-0)	Sample ID (S-1)	Sample ID (S-2)	Sample ID (S-3)	Sample ID (S-3R)	Sample ID (S-4)	Sample ID (S-4R)
Cement (CEM-I, 52.5 N)	440	420	400	380	380	360	360
Water (Treated construction water)	198	168	152	136.8	136.8	122.4	122.4
w/c ratio of mix	0.45	0.40	0.38	0.36	0.36	0.34	0.34
Coarse Aggregate (Crushed basalt)19 MM	685	700	712	735	735	750	750
Coarse Aggregate (Crushed basalt) 9.5 MM	457	472	482	500	500	510	510
Fine Aggregate (River sand having FM-2.51	680	690	700	712	712	725	725
Superplasticiser PCE based in %	0.6%	0.80%	1.00%	1.20%	1.60%	1.40%	2.00%
Superplasticiser PCE based by weight in kg	2.64	3.36	4.00	4.56	6.08	5.04	7.20
Total weight of aggregate CA+FA	1822.00	1862.00	1894.00	1947.00	1947.00	1985.00	1985.00
Total unit weight of of mix	2463	2453	2450	2468	2470	2472	2475
Fine aggregate ratio in total aggregate	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Coarse aggregate proportion in total aggregate	0.63	0.63	0.63	0.63	0.63	0.63	0.63

Fig-4: Different ingredient of concrete.

Fig-5: Sample preparation for both compressive strength & Flexural strength of concrete.

. Fig-6: Slump test of concrete at immediate & after 30 minute.

Fig-7: Slump test of concrete at 45 minute & at 90 minute.

Fig-8: Compressive and Flxural test of concrete.

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V. RESULTS & DISCUSSIONS

From the experimental results it has been observed that the fresh concrete properties like workability of concrete is getting reduced on decreasing the cement content of the mix due to increase in friction between the aggregate particles [7]. It is also noticed that mix with cement content less than 400 kg like 380 kg and 360 kg cement, the workability of concrete is significantly reduced & even not workable mix with lesser dosages of Superplasticiser even up to 1.4% by weight of cement. However with increased dosages of superplasticiser beyond 1.5% like 1.6% and 2% dosages for 380 kg and 360 kg cement shows improved workability up to 45 minute. Thus with reduced paste volume of cement in concrete the admixture dosages requirement is more to have better dispersion effect of fresh concrete. The research work also shows that the mechanical properties of concrete with reduced cement & w/c ratio with higher dosages of superplasticiser shows better compressive strength and Flexural strength of concrete. As per the pore size distribution analysis through MIP test the critical pore size diameter and porosity of concrete got reduced in concrete having low w/c ratio and also optimum cement content as a results both mechanical properties and durability performance of concrete is found better. From the experimental results it shows that cement with higher cement content shows lesser strength than concrete with lower cement content mix. So the experimental results conclude that even the mix is having higher cement content, all the cement particles are not hydrated due to early shielding formation by hydration of smaller cement particles over larger size cement particles. Moreover excessive cement in the mix has always having detrimental effect on concrete microstructure due to more heat of hydration in concrete core leading to development of thermal cracks in concrete core leading to formation of weak ITZ between aggregate and hydrated cement product [8]. Thus by increasing the dosages of superplasticiser in the concrete helps to reduce water demand in concrete and subsequently reduce the cement requirement of concrete mix along with carbon foot print of the atmosphere. According to the National Ready Mixed Concrete Association each Kg of cement reduction helps to reduce 0.875 kg of CO_2 in the atmosphere.

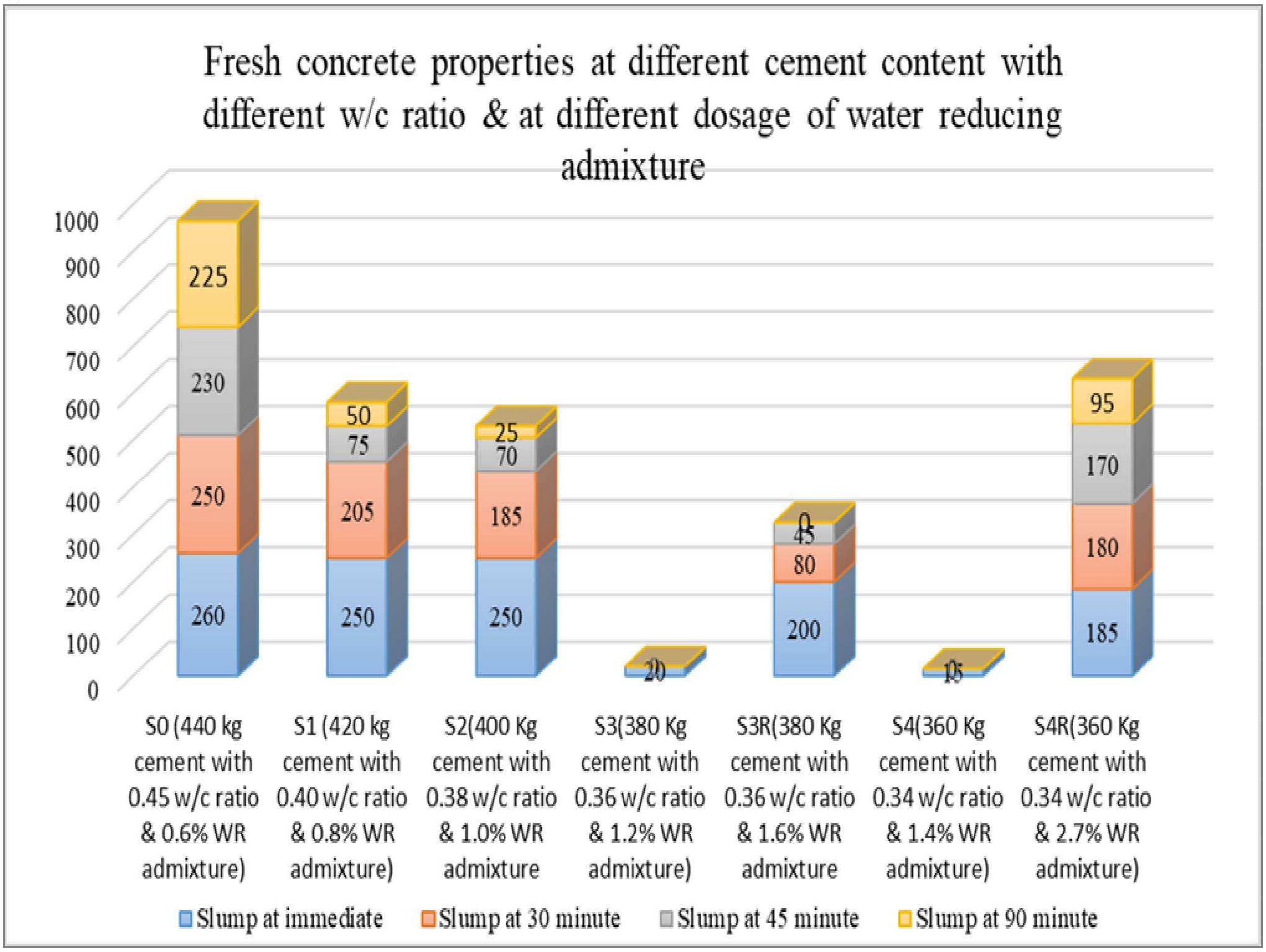

Fig-9: Fresh Concrete properties of concrete by slump test at immideate, 30 minute, 45 minute and 90 minute respectively.

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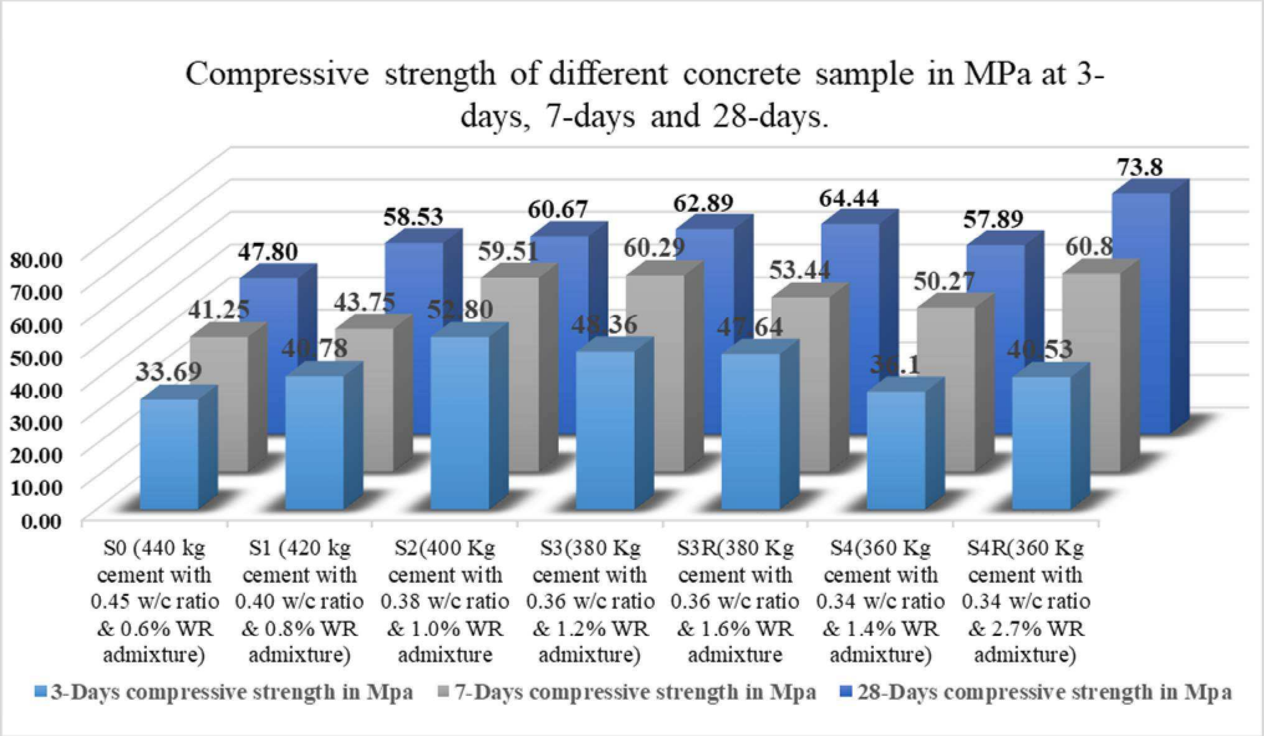

Fig-10: Compressive Strength of concrete at 3-days, 7-days and 28-days respectively.

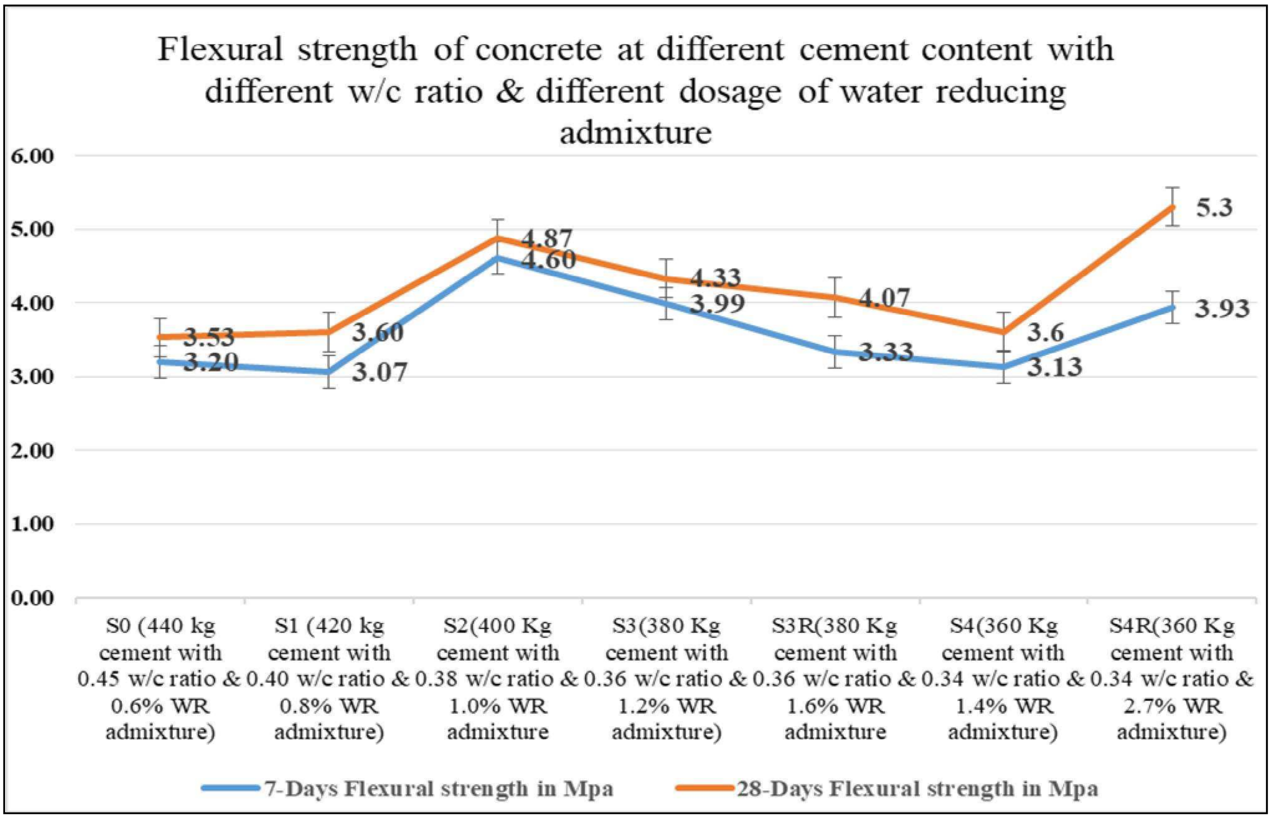

Fig-11: Flexural Strength of concrete at 7-days and 28-days respectively.

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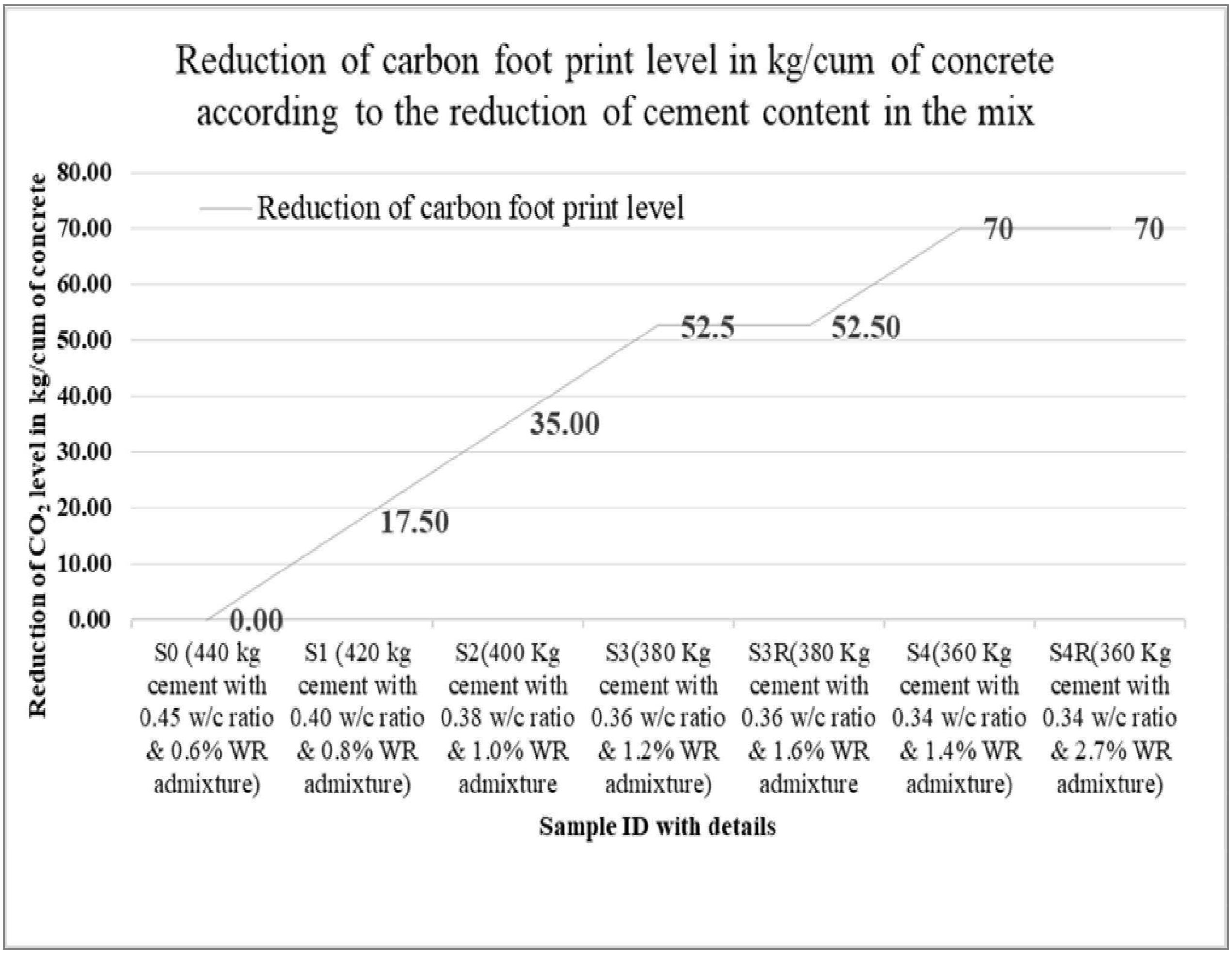

Fig-12: Reduction of carbon foot print level kg/cum of concrete on reduction of cement content in the mix.

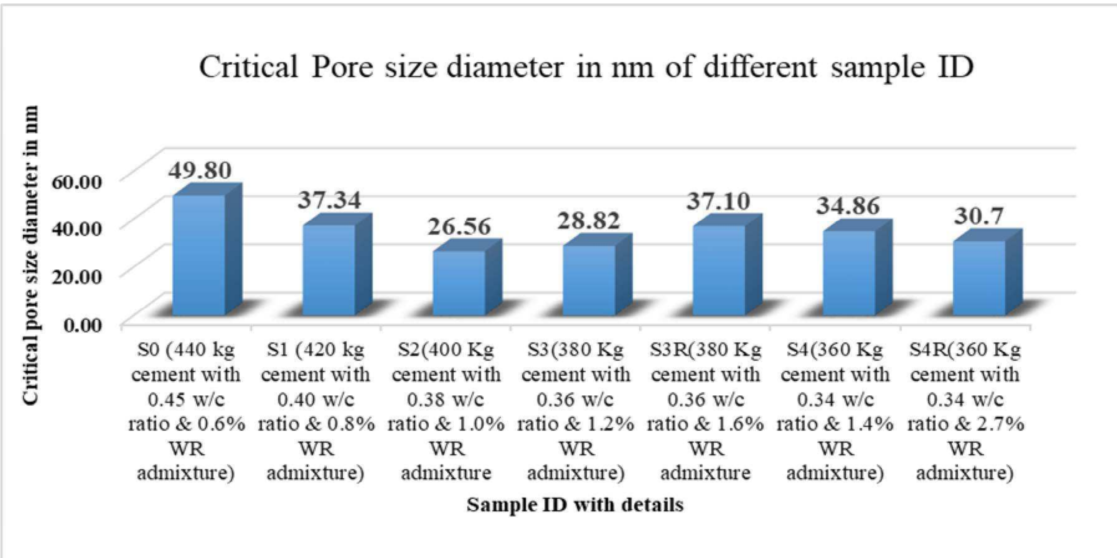

Fig-13: Critical pore size diameter of different concrete sample in nm

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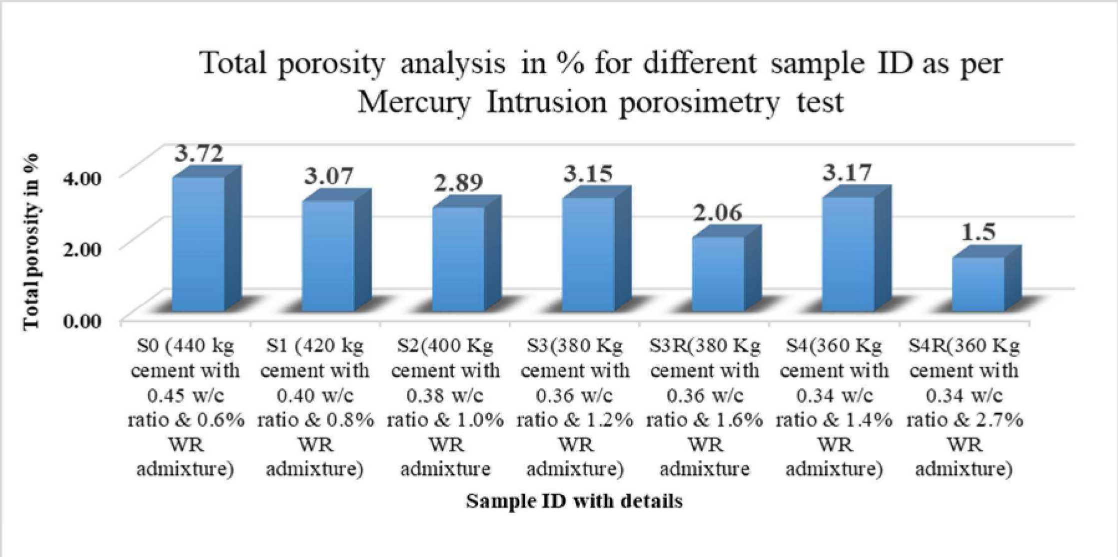

Fig-14: Total porosity of different concrete sample in %.

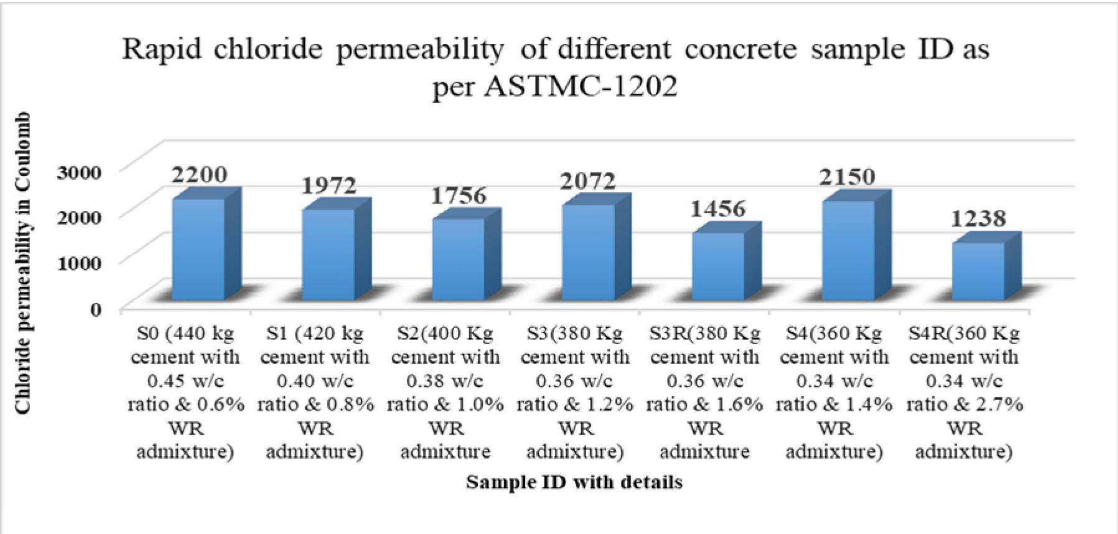

Fig-15: Rapid chloride permeability of different concrete in Coulomb.

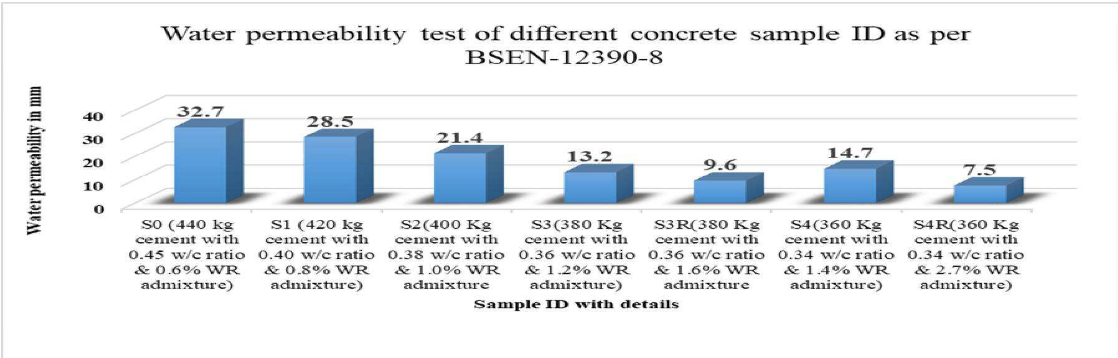

Fig-15: Water permeability of different concrete in mm.

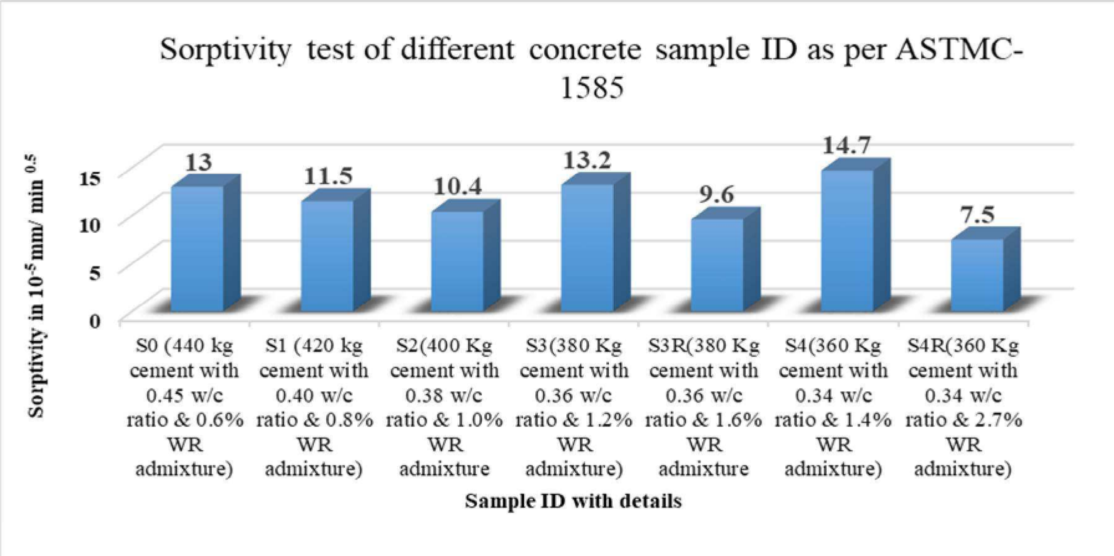

Fig-16: Sorptivity of different concrete in 10^{-5} mm/min $^{0.5}$.

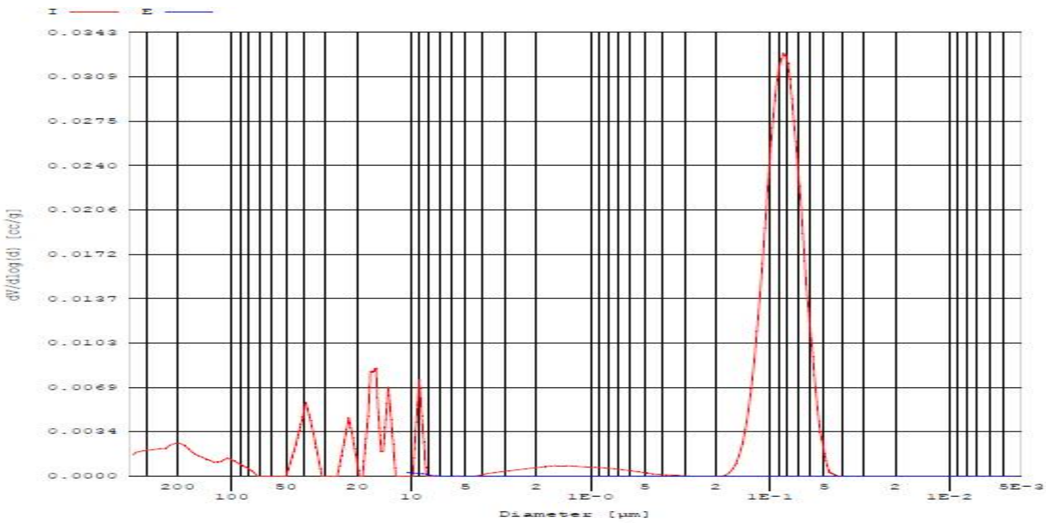

Fig-17: Pore size distribution of concrete sample ID-S_0

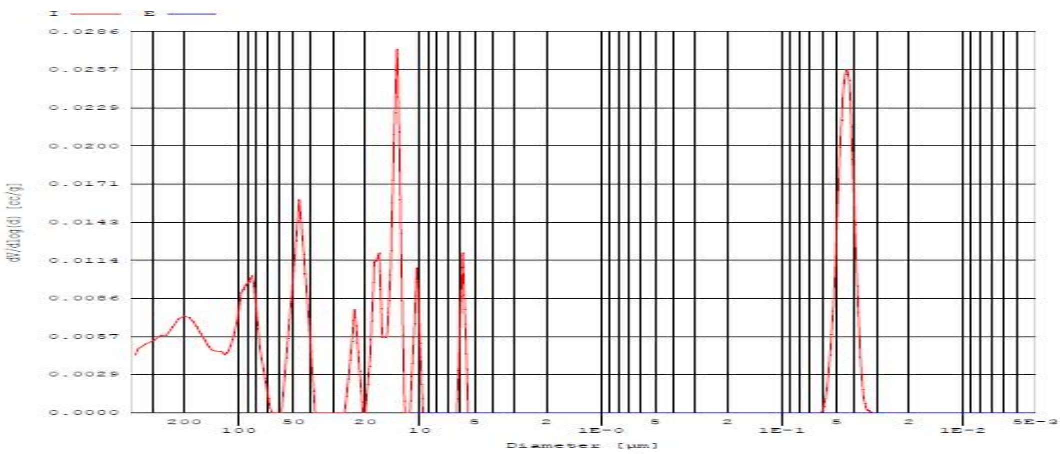

Fig-18: Pore size distribution of concrete sample ID-S_1

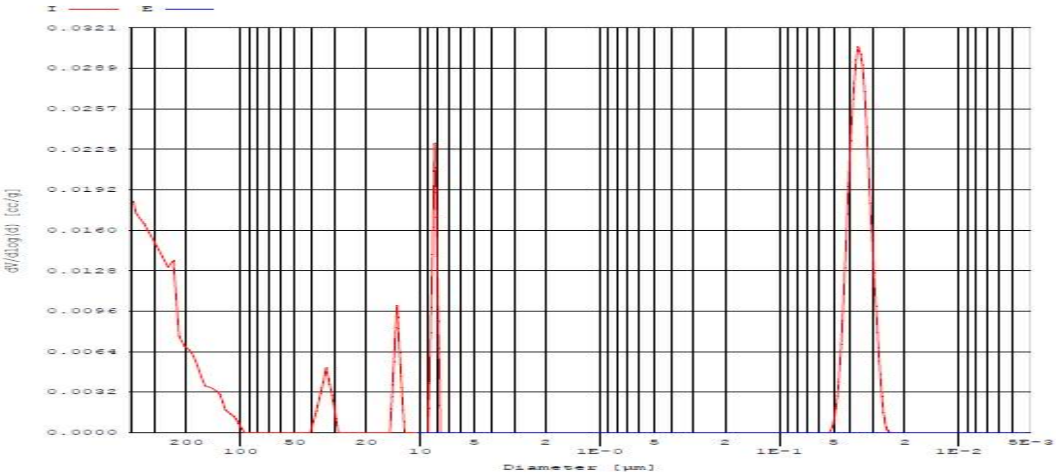

Fig-19: Pore size distribution of concrete sample ID-S_2

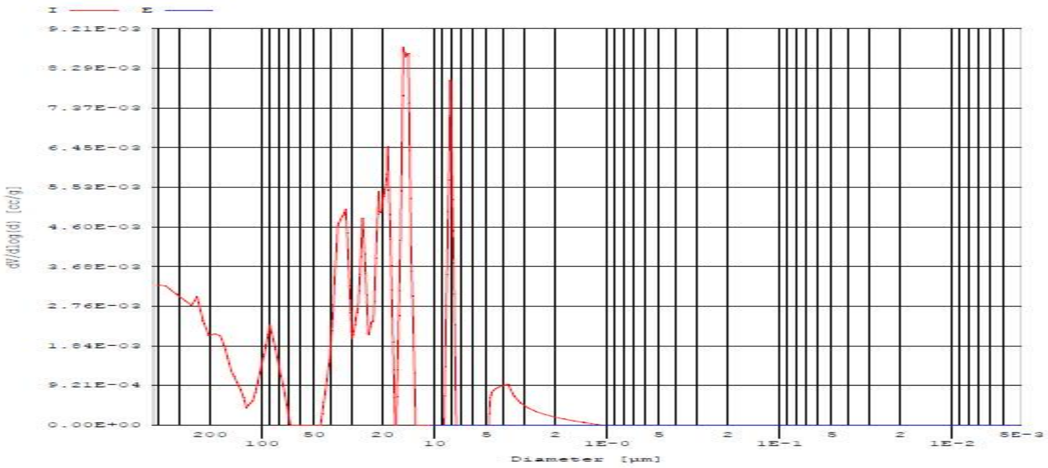

Fig-20: Pore size distribution of concrete sample ID-S_3

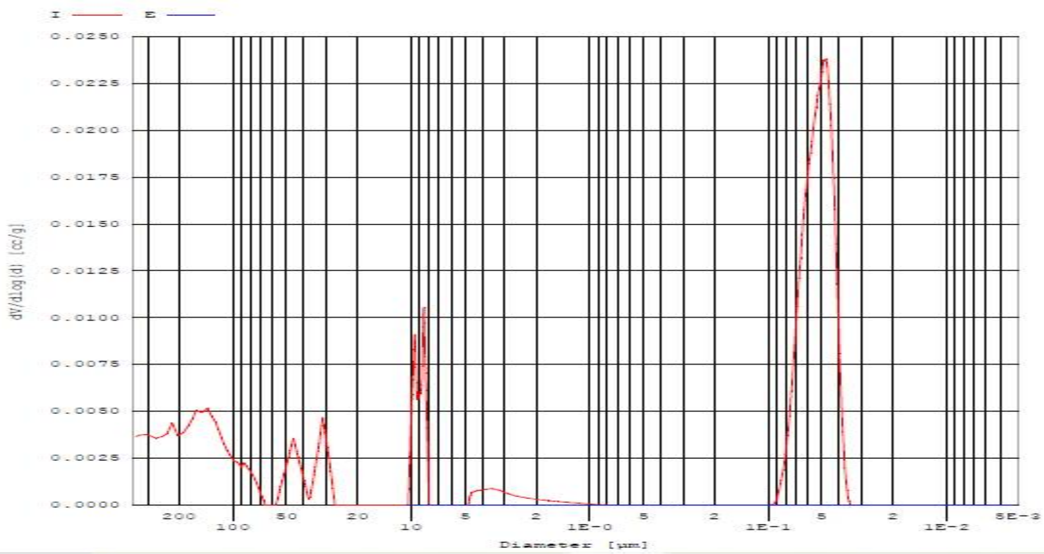

Fig-21: Pore size distribution of concrete sample ID-S3R

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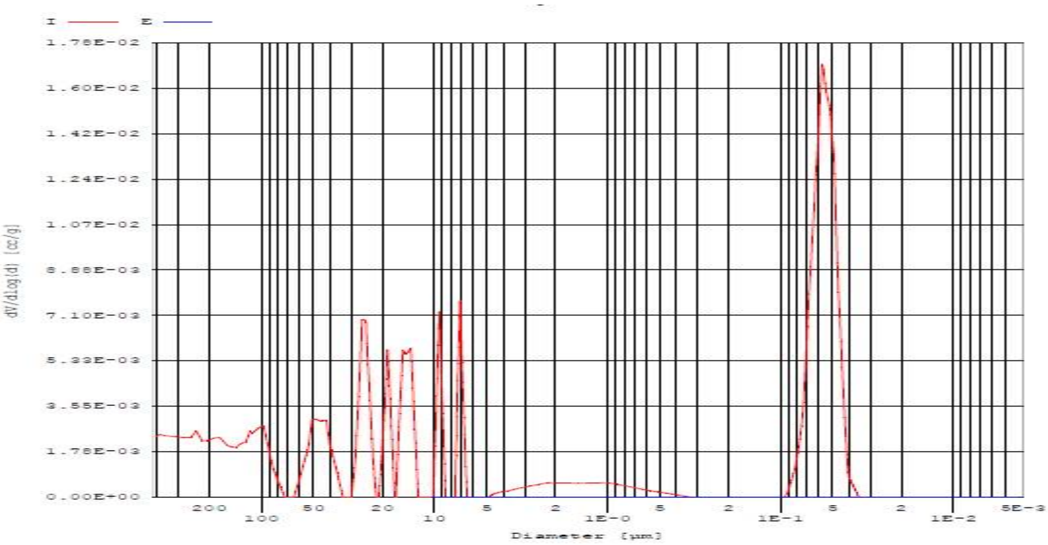

Fig-22: Pore size distribution of concrete sample ID-S_4

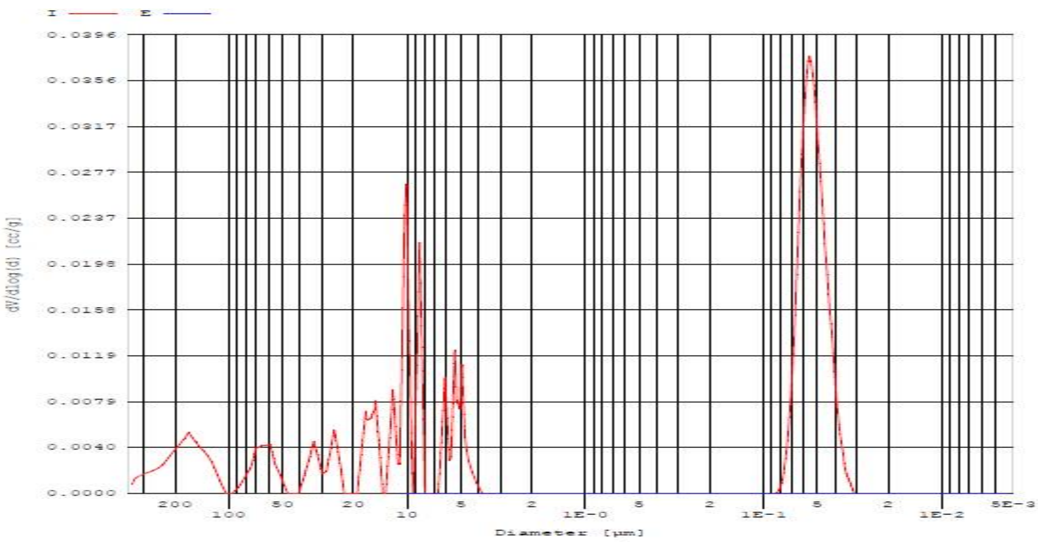

Fig-23: Pore size distribution of concrete sample ID-S_{4R}

VI. CONCLUSIONS

Based on the present research work & interpretation of results based on the various facts. The following are the key outcome of the present research works.

1) The reduction of water demand in concrete more than 35% is possible by introducing long side chain polymer associated with polycarboxylate ester backbone.
2) The workability of fresh concrete get significantly reduced when OPC cement content in the mix is less than 400 kg due to increased level of friction between the aggregate particles.
3) By reducing w/c ratio even up to 0.34 by using higher dosage (> 2%) of superplasticizer and 360 kg cement of grade CEM-I ,52.5N can produce high strength concrete even more than 70 Mpa.
4) On reduction of w/c ratio & cement content in the mix the porosity % and critical pore sizes diameter are also getting reduced leading to higher strength and better durability performance of concrete like RCPT, Sorptivity, Water permeability of concrete as the critical pore size and porosity of concrete governs the durability performance of concrete [8]. Thus lesser the permeability of concrete higher is the durability of concrete [9].

5) Using of high grade PCE based superplasticizer even the dosage up to 2% don't have any ill effect in the hardened concrete properties.
6) By using high grade of PCE based superplasticizer of higher dosage in concrete can significantly reduce the cement requirement in the concrete by reducing the water demand in the concrete.
7) By introducing high dosage of high grade of PCE based superplasticizer having water reduction capability more than 35% can significantly reduce the carbon foot print generated from cement industries.
8) The cost reduction due to depletion of cement consumption in concrete by using additional dosage of superplasticizer beyond its optimum dosage is still cost effective & economical approach.

VII. ACKNOWLEDGMENT

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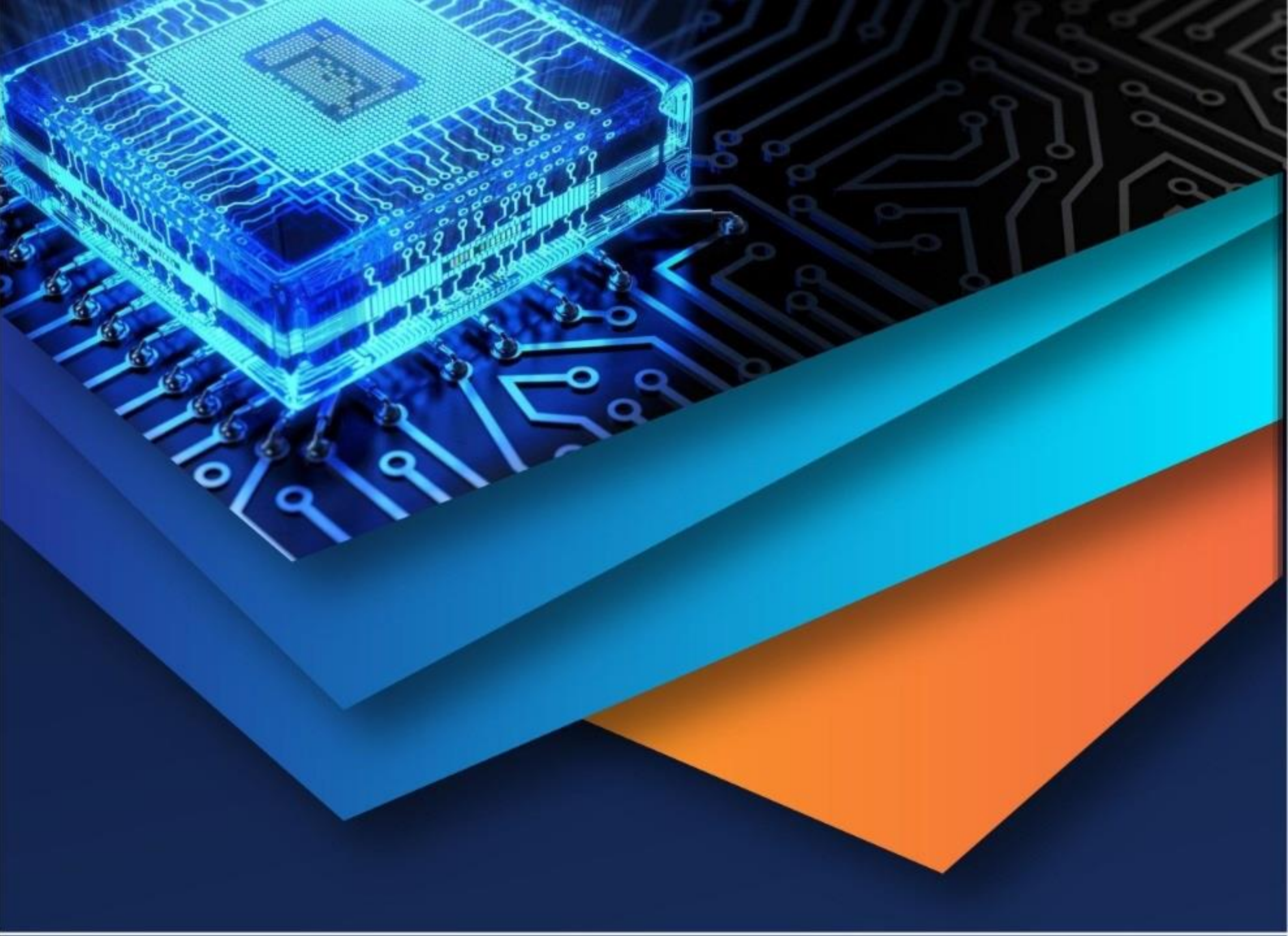

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