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Characterization of Polymeric Concrete for Pavement Construction

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Abstract - Polymer assists in improvisation of the mechanical properties of concrete than the conventional concrete as one of the catalytic admixtures. In this project Poly- Ethylene Glycol (PEG), Styrene Butadiene Rubber Latex and Poly-carboxylate Ether (PCE) polymers were used in varying proportions with cement concrete matrix. These three varieties of polymers are used in concrete manufacturing process as an admixture to increase the basic feasible properties of concrete. Polymers induced must impart betterment of slump value, reduction of water cement ratio, lowering shrinkage and well framing mechanical stratification of concrete.

The objective of the present study is to investigate the behavior of polymer impregnated concrete in both fresh and hardened state. For this experimental study the M35 Grade conventional concrete is used. The results obtained from literature studies and conclusions are inspiring for partial addition of polymer with conventional cement concrete which enhances the strength of concrete in both stages.

Key Words: PEG, SBR, PCE, Polymer, Concrete and M35 Grade Concrete.

1. INTRODUCTION

The world has been technologically advanced and regularly globalised, by reducing travel time in proper planned way. The main reason behind this development is connectivity between two locations via any means basically like Roads.

For faster access road have been paved reducing friction and enhancing hurdles passage over it without any contradictions. Only variations are in the materials that had been used in construction of paved roads. Such as Rocks with (granite, basalt, Sandstone, etc.) or Binding slurry made up of mud adding lime, starch and few times blood, along with broken terracotta clay, sand or rock dust, to a desired and required thickness by proper compaction of the laid material.

The figure No. 1 below, shows the construction methodology in the past era by Romans. The need of more suitable and faster roads has revolutionized the technique and science of road constructions from time to time. In this era we are preferably as well as considerably using rigid paved roads more for better transit with lesser defects. This rigid road section or say; rigid pavements are basically constructed by using concrete matrix, as concrete reflects high rigidity after being set or attains hardness. Concrete rigid pavement can be reinforced suitably by using reinforcement materials like steel bar for better stress divergence and load carrying capacity.

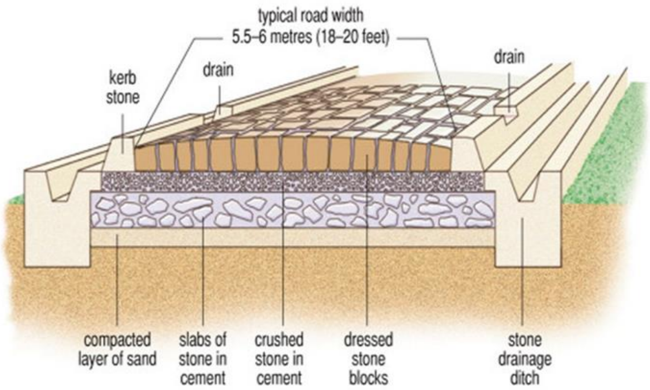

Fig. – 2. Ancient Roman Road Section (source: Google - Reddit.com)

1.1 Pavements with concrete

Basically, pavements built using concrete mass is termed as rigid pavements but it might be divided in two sub groups such as elaborated below,

a. **Rigid Pavements**: These types of pavements possess a high flexural strength and may transfer the masses returning over it to the lower layers with the slab block action of the varied layers. The varied materials like plain cement concrete, strengthened cement concrete or the pre-stressed concrete were the best materials to be used because the rigid pavement materials. The rigid pavements are measured, framed, analysed and designed by exploitation the elastic theory, during which the surface layer is considered because the elastic layer, that is supported by another elastic plate known as the sub grade. The rigid pavement won't deform just like the versatile pavements if the undulating surface is there at the bottom.

b. **Semi Rigid Pavement:** These pavements square measure made with the materials just like the pozzolana concretes, the lime-fly ash-aggregate combine, or lean cement concrete and therefore have adequate flexure strength. They possess the flexural strength in between those of the rigid pavement which of the versatile pavements. They're designed because the versatile pavements however with some correction factors applied thereto, or they're designed by another strategies. These materials don't have the great resistant against the impact and the abrasion hundreds that the surface course is made with the versatile pavement materials.

1.2 Advancement in Pavement Engineering

Concrete paving technology can be defined as "Laying of concrete matrix, effectively and efficiently, over a horizontal pre-flatten surface in order to make it smooth and convenient to use for transportation or transit movement of vehicles".

Due to ease of the technology, cheaper cost, high durability, and high environmental friendliness of the product, super-plasticized high volume fly ash or slag concrete is expected to have a high impact on the concrete industry. Significant study and growth is expected in the area of ternary blends containing portland cement, silica fume or rice-husk ash, and large volumes of fly ash or slag. Concrete within the standard manner however with a better slump so the workability is nice and concrete running and spreading is finished quickly. The top cover is placed on the filter pad and extended till it covers the strips of the exposed concrete on all sides. The top cover is then connected with the pump through a suction hose and pump is started. Vacuum is instantly created between filter pads and top cover. Atmospheric pressure compresses the concrete and the surplus water is squeezed out. This method lowers the water content within the concrete by 15-25%. The dewatering operation takes approx. 5-2 minutes per centimeter thickness of the ground.

This approach, however, diode to serious issues with sturdiness of structures, particularly those subjected to severe environmental exposures. Among the recent advancements, most noteworthy is that the development of super plasticized concrete mixtures (polymer or monomer based) that offer terribly high fluidness at comparatively tide contents. The hardened concrete because of its higher stiffness is usually characterized by high strength and high sturdiness. Micro - Macro level superior quality cements and with chemicals bonding as in polymers, approaches to lower porosity, higher strength and durable product. For the precise purpose of improvement of service lifetime of concrete structures exposed to corrosive environments, the utilization of corrosion-inhibiting admixtures, epoxy-coated bolstered steel, and electrode protection area unit among the higher proverbial technological advancements.

1.3. Types of Polymers used in Research.

A. Polyethylene Glycol (PEG)

Polyethylene glycol is a condensation polymers of ethylene-oxide and water molecules with the chemical composition H (OCH2CH2)nOH, where; n is the average number of repeating oxy-ethylene groups typically from 4 to about 180. The low molecular weight compounds upto 700 are colourless, odourless viscous liquids with a freezing point from 10C (diethylene gycol), while polymerized compounds with higher molecular weight than 1,000 are wax like solids with melting point up to 67 C for n 180.

The abbreviation (PEG) is termed in combination with a numeric suffix which indicates the average molecular weights. One common feature of PEG appears to be water-soluble. The specifications of PEG600& PEG6000 are shown in table 4.6. It is soluble also in many organic solvents including aromatic hydrocarbons (not aliphatic).

i. Alkyd and polyester resin preparation to enhance water dispersibility and water-based coatings. Coupling agent, humectants, solvent and lubricant in cosmetics and personal care bases.
ii. Low volatile, water soluble and noncorrosive lubricant without staining residue in food and package process. Paper coating for anti-sticking, colour stabilizing, good gloss.
iii. Plasticizer to increase lubricity and to impart a humectants property in ceramic mass, adhesives and binders. Softener and antistatic agent for textiles and Soldering fluxes with good spreading property.

Polyethylene glycol is non-toxic, odourless, neutral, lubricating, non-volatile and no irritating and is used in a variety of pharmaceuticals and in medications as a solvent, dispensing agent, ointment and suppository bases, vehicle, and tablet excipient. Chemical structure of PEG shown below.

Fig. – 2. Chemical structure of Polyethylene Glycol (400) (courtesy: Kowa American Corporation)

B. Styrene Butadiene Rubber (SBR) Latex Polymer

Locally available polymer 'Cemseal Cementone' was investigated in this study. It is a type of Styrene Butadiene Rubber (SBR) latex having 25% of styrene and rest butadiene. Cemseal Cementonex SBR is based on Styrene Butadiene Rubber, special adhesive and bonding chemicals along with hydrophilic agents. Cemseal Cementonex SBR gives a versatile performance in many civil engineering applications. The product is a milky white liquid.

It is a high-quality emulsion which enhances the performance of cement mortar and concrete. Some examples from its innumerable uses are as follows:

ii. An excellent product in concrete repairs as in combination with cement (1:1) it produces a very strong primer and as an additive in the mortar to make strong waterproof plaster. An indispensable product in floor repairs, Cemseal Cementonex SBR is used in mortar as an additive to make screeds which can be feather edged and can be used successfully in restoring the nosing's of floor ducts and stairs.

iii. Cemseal Cementonex SBR modified mortars are used in joining prefabricated members and as bedding mortar in precast block work to secure water tight joints. With fine sand cement mortar Cemseal Cementonex SBR is admixed to get an excellent adhesive for fixing wall paneling, stones, tiles including granite and marble tiles.

iv. Cemseal Cementonex SBR is used in making waterproof slurries for repairs of old waterproofing works and waterproof mortars for new waterproofing works. SBR is used in arresting leakages from overhead as well as underground potable water tanks.

C. Polycarboxylate Ether (PCE)

Polycarboxylate ether (PCE) comb-copolymers are widely used as water reducing agents in the concrete industry while maintaining a high fluidity via the polymer adsorption to the cement particles. Polycarboxylates are linear polymers with a high molecular mass (Mr ≤ 100 000) and with many carboxylate groups. They are polymers of acrylic acid or copolymers of acrylic acid and maleic acid. PCE copolymers with a broad range of structures are well established by Free radical polymerization, however, understanding the structure-property relationship is still complex due to the high polydispersity of PCE copolymers prepared by conventional polymerization. The influence of different structural parameters using well-defined polymeric structures is yet to be explored.

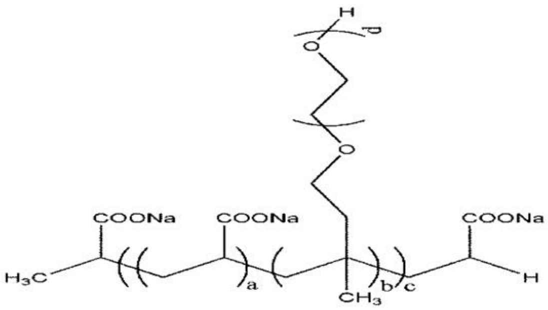

Fig. – 3. Chemical structure of Polycarboxylate Ether (PCE) (courtesy: Kowa American Corporation)

2. LITERATURE SURVEY

The performance of modified polymer concrete easily be enhanced because of the synergy of polymer emulsion with silica fume, water reducing agent, antifoaming agent and stabilizing agent. The action mechanisms are as follows. Specific bridged bond can be formed between polymer chain, when the chemical reaction, between large mixing amount of ester group (COO^-) in acrylic ester, SiO_2 and cement on surface of aggregate, $Ca(OH)_2$ generated by hydration reaction and Ca^{2+} born from hydroxylation, is happened. That will make the whole system a net structure, enhance the compactness and increase the density of cement paste [1]. The capacity resistance to chloride penetration can be enhanced with adding silica fume.

The main reason that can be concluded that one is the compact effect, filling effect and pozzolanic effect of the ultrafine powder; another is reducing the porosity, improving porosity character and extending the capillary channel. Their recombination can make the microstructure of cement paste more homogeneous and compact and improve the pore structure. In addition, polymer emulsion can wrap around the silica fume and cement particle sufficiently, which will make net structure easier even in a lower mixing amount to restrain cracks forming and developing [2].

On macroscopic level, it means the mechanical strength increased. Various polymers and aggregates had used in fabrication of PCs such as unsaturated polyesters, epoxies, acrylics [3]. Unsaturated polyester resin (UP) is a category of thermos setting polymers which is widely used in various industrial applications such as composites, automotive paints, protective coatings, storage tanks, piping and construction [4]. When the SBR latex dosages increased from 0% to 20%, the anti-freezing ability of PCSA increased, and the air voids decreased, as well as the permeability. The rate of increase of anti-freezing ability became low when the SBR latex dosages exceed 10%. [5].

In previous studies, different methods performed to form polymer concrete. Reis [5] used seven solutions with various pH from 1.2to 12.8. Pavlik et al. [6] hanged the specimens with exposed surface facing downwards in chemical solutions to evaluate the corrosion depth. Mehta [7] selected different acid solutions to perform the degradation tests. Hashemi et al. [8] and Jamshidi et al. [8–10] immersed UP-PC specimens in different chemicals (i.e. sulphuric acidic, sodium hydroxide, Gas oil, demi realized water, water etc.). They evaluated compressive strength and flexural strength of the samples after a long term (i.e. continuous [8] and cyclic [9]) exposure to the chemicals. The decrease in mechanical properties of Polymer Concrete after exposing to chemical solution related to several constraints such as resin content, pores in the structure, pH of the solution.

The alkaline solution had severe effect on the mechanical properties than the acidic solution did. In addition to this distilled water reported as an aggressive solution, which had severe effect on the mechanical properties of Poly Concrete.

3. METHODOLOGY

Materials Used: Investigational efforts have been conceded by mixing natural and synthetic polymers in different proportions to the M30 grade concrete. The M30 grade concrete is prepared by using mix designing procedural guidelines as per IS: 10262 - 2009. The detailed concrete mix designing process erstwhile explained afterward. The various proportions of polymers like SBR-Latex, PEG and PCA are used within the proportioning of M30 grade concrete in following percentage range 0% to 10%. These matrix mix masses were used to prepare specimens of cube and prism which are earlier examined for workability and further placed to testing for the determination of their mechanical strength via; water retention property, compressive strength, split tensile strength and flexural strength. For workability tests is performed by slump cone test.

Aggregates: The maximum nominal size of aggregate is taken as 20 mm. Aggregate of size 10 to 12 is desirable for structure having congested reinforcement arrangement. The moisture content or absorption characteristics must be closely monitored as quality of concrete is very sensitive to such changes. The use of matrix aggregates with unnecessary cement water ratio & content ought to be avoided because the necessary polymer-cement ratio will not be achieved. Locally available natural sand with 4.75 mm maximum size was used as fine aggregates, having specific gravity, fineness modulus and bulk density as given in the table no. 1.

The coarse aggregate with 20mm maximum size having specific gravity, fineness modulus and bulk density as below (also shown in table no. 3.3) was used as coarse aggregates. Both fine aggregate and coarse aggregate conformed to Indian Standard Specifications IS: 383-1970. Details of aggregate properties are given in table no. 1.

Table 1 - Properties of Aggregates used in the study conforming to IS: 383 -1970 and IS: 2386 - 1963.

Physical Properties of Coarse and Fine Aggregates Physical tests	Coarse Aggregates	Fine Aggregates
Specific gravity	2.74	2.65
Fineness modulus	6.86	2.64
Bulk density (kg/m^3)	1540	1780

3.1. Mix Design and Proportioning

There are various methods of mix design. In the present work, Indian Standard specified method (IS: 10262 - 2009) is applied for concrete mix design of standard concrete M30 grade. Environmental exposure conditions assumed to be Severe, having concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation (Clause 8.2.2.1 and 35.3.2) from table no. 3 IS: 456 -2000. Assuming concrete to be reinforcement works compatible; minimum cement content 320 Kg/m^3, maximum water-cement ratio 0.45 and minimum grade of concrete i.e. M30; for severe exposures with normal weight aggregates of 20 mm nominal maximum size is taken from Table no. 5, of IS: 456 -2000.

The concrete mix shall be with sufficient degree of workability for medium range work of slump 50 - 100 mm and the workability of concrete to placing conditions and are in accordance with IS: 1199 - 1987. Admixture polymers shall comply with IS: 9103, the workability, compressive strength and the slump loss of concrete with or without making use of admixtures is established during the assessment mixes before use of admixtures.

Types of materials used:

Types of cement	PPC Cement confining to IS: 8112-1989.
Types of fine aggregates	River sand of Zone II as per IS: 383-1970. It should not contain particles coarser than 2.5 mm.
Types of coarse aggregate	20 mm graded crushed aggregate as per IS: 383-1970. (both the aggregates being saturated and surface dry)
SBR Latex Polymer	SikaCem bond liquid polymer containing anti-foamers
Polycarboxylate Ether (PCE)	Gujplast liquid polymer having monomer ether with Polycarboxylate
Poly Ethylene Glycol (PEG)	Poly Ethylene Glycol(400) crystal form

Mix Proportioning:

(i) Stipulation for Proportioning Concrete ingredients having characteristic compressive strength "f_{ck}" required after 28 days with grade designation as M40

(a) Type of Cement : PPC Grade confirming to IS: 8112

(b) Maximum Nominal size of aggregate: 20 mm

(c) Shape of CA : Crushed Angular Aggregates

(d) Workability required at site : 80 mm (slump)

(e) Type of exposure the structure will be subjected to (as defined in IS: 456) : Severe

(ii) Test data of material

The following materials are to be tested in the laboratory and results are to be ascertained for the design mix

(a) Cement Used : PPC Cement

(b) Specific Gravity of Cement : 3.06

(c) Specific gravity

Fine Aggregate (sand) : 2.74

Coarse Aggregate : 2.65

(d) Water Absorption

Coarse Aggregate : 0.8%

Fine Aggregate : 1.0%

(e) Free (surface) moisture Coarse & Fine Aggregate : Nil

(f) Sieve Analysis of fine aggregates: Confirming to Zone II of Table No. 4 in IS – 383

4. RESULT ANAYSIS

The behavior of all the batches is taken as a basic study on the modelled sample batching. The tests were conducted on concrete batches mix to evaluate the performance of all the batches and to present a comparative study. Results has been summarized in a tabulated form in Table 2. – (a) and (b) Here the results observed are tabulated in above tables, so that; the values can be transformed into graphical images for investigating probable outcome visually and compare their results observed comparatively. Hence; the graphs have been plotted on both specimen-based results and Average results so obtained.

Table 2– *(a)* **Various** *Test Results obtained via various laboratory test conducted on concrete.*

Sample Specimen	Sample Specimen Name	Slump (mm)	Average Slump (mm)	Compaction	Average Compaction	Compressive Strength (N/mm^2)		Average Compressive Strength (N/mm^2)		Split Tensile Strength (N/mm^2)	Average Split Tensile Strength (N/mm^2)
						7 Days	28 Days	7 Days	28 Days	28 Days	28 Days
Conventional Concrete	S1	82	81.67	0.86	0.88	26.95	38.7	28.08	39	33.19	33.21
	S2	82		0.89		27.78	38.9			33.22	
	S3	81		0.88		29.5	39.4			33.21	
SBR Latex Concrete	S4	78	77.67	0.94	0.93	26.9	44.65	27.07	44.64	34.49	34.5
	S5	77		0.93		27.2	44.62			34.48	
	S6	78		0.93		27.1	44.65			34.52	
PCE Concrete	S7	88	87	0.91	0.91	30.3	42.45	30.3	42.48	32.25	32.25
	S8	86		0.91		30.1	42.6			32.24	
	S9	87		0.92		30.5	42.4			32.27	
PEG Concrete	S10	83	83	0.86	0.86	28.7	39.5	28.87	39.7	33.23	33.24
	S11	83		0.86		29.2	39.82			33.24	
	S12	83		0.87		28.7	39.78			33.26	

Table 3– (b) Various Test Results obtained via various laboratory test conducted on concrete.

Sample Specimen	Sample Specimen Name	Water-Cement Ratio	L - BOX Test (mm)	L - BOX Test Avg. (mm)	Weight of sample (Kg)	Water Retentivity (Kg)		Average Retentivity (Kg)		Flexural Strength (N/mm2)	Average Flexural Strength (N/mm2)
					1st Day	7 Days	28 Days	7 Days	28 Days	28 Days	28 Days
Conventional Concrete	S1	0.45	1829	1836.67	7.546	7.241	7.195	7.24	7.2	2.65	2.68
	S2		1845		7.548	7.24	7.194			2.71	
	S3		1836		7.562	7.239	7.198			2.67	
SBR Latex Concrete	S4	0.42	1789	1786.67	8.446	8.256	8.129	8.26	8.13	2.95	2.97
	S5		1785		8.436	8.262	8.126			2.98	
	S6		1786		8.441	8.253	8.124			2.99	
PCE Concrete	S7	0.42	1988	1991.67	8.446	8.202	8.115	8.2	8.11	3.08	3.04
	S8		1995		8.436	8.198	8.112			2.99	
	S9		1992		8.441	8.199	8.109			3.05	
PEG Concrete	S10	0.42	1999	1998.33	8.446	8.236	8.116	8.24	8.12	2.7	2.72
	S11		1998		8.436	8.226	8.114			2.71	
	S12		1998		8.441	8.259	8.118			2.74	

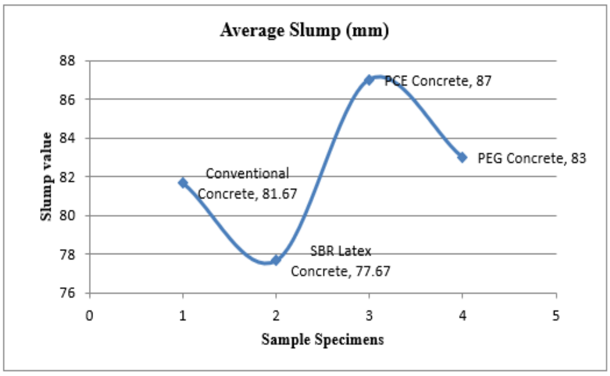

Chart - 1: Results of Average Slump values as observed in test results

It could be easily concluded that the observed values are best for PCE i.e. Poly-Carboxylate Ether than that of others which are in descending order as PCE > PEG > CC > SBR. It is also observed that Sample specimen No. 9 shows best results. From the Graph No. 1, It could be easily concluded that the observed Average slump values are best for PCE polymer, it has best workability attainment i.e. greater than 80mm as compared to others.

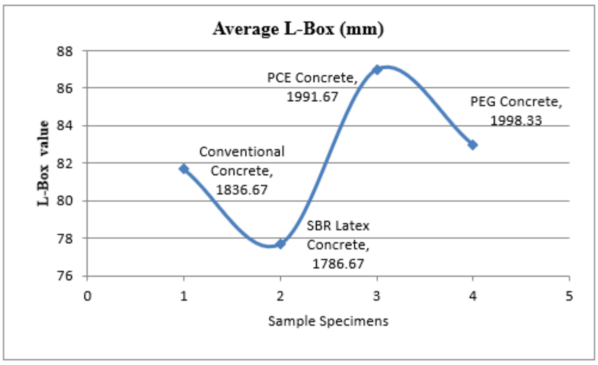

Chart - 2: Results of Average L-Box values as observed in test results

It could be easily concluded that the observed values are best for PCE i.e. Poly-Carboxylate Ether than that of others which are in descending order as PCE > PEG > CC > SBR. From the Graph No. 2, It could be easily concluded that the observed Average slump values are best for PCE polymer, it has best workability attainment i.e. greater than 80mm as compared to others.

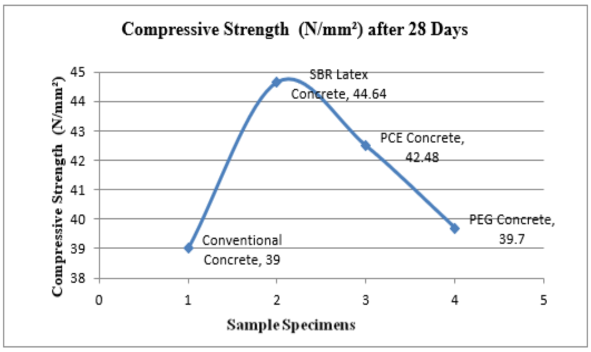

Chart - 3: Results of Average Compressive strength after 28 Days test values as observed in test results.

It could be easily concluded that the observed values are best for PCE in early days test, From the Graph No. 3, It could be easily concluded that the observed average values are best for SBR polymer after 28 days. This is purely due to hardening of latex after 14 days whereas; PCE, PEG are lacking such bonding mass.

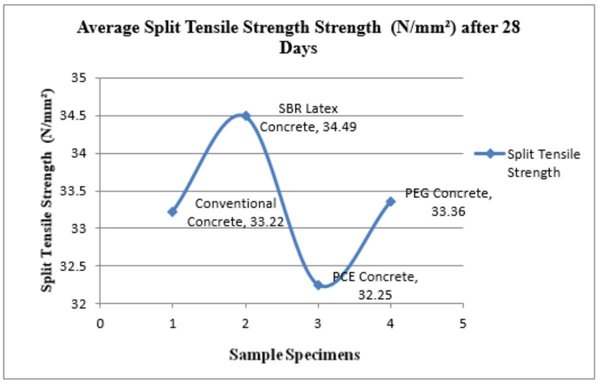

Chart - 4: Results of Average Split strength after 28 Days test values as observed in test results.

It could be easily concluded that the observed values are best for PCE in early days test, From the Graph No. 4, It could be easily concluded that the observed average values are best for SBR polymer after 28 days. This is purely due to hardening of latex after 14 days whereas; PCE, PEG are lacking such bonding mass. This is purely due to hardening and adhesive nature of latex after 28 days whereas; PCE, PEG are lacking such bonding mass.

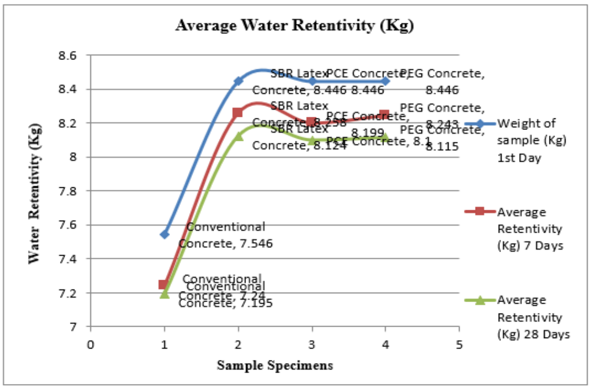

Chart - 5: Results of Average water retentivity test values as observed in test results.

It could be easily concluded that the observed values are best for PCE in early days test, From the Graph No. 5, It could be easily concluded that the observed average values are best for PEG polymer after 28 days. This is purely due to PCG, PCE and SBR are lacking such bonding mass molecular structure.

5. CONCLUSIONS

i. Polymers impart better workability and hence; induce greater usability of concrete due to increase in plasticity.
ii. Water Cement Ratio reduces considerably with the impregnation of polymers. It is observed that introduction of polymer upto 5% reduces water upto 14 -18%. of matrix mass.
iii. Higher compaction is also achieved by use of polymer; however conventional concrete compaction is higher in case of PCE & PEG.
iv. Compressive strength at 7 day is higher for conventional concrete then polymer based concretes, such as SBR but less than PCE and PEG. Whereas after 28 days it is higher for polymer based concretes.
v. The series for compressive strength at later age is SBR > PCE > PEG > Conventional Concrete, which shows that polymer impregnation increases compressive strength of concrete considerably.
vi. Flexural strength at 7 day is higher for conventional concrete then polymer based concretes, whereas after 28 days it is higher for polymer based concretes.
vii. The series for flexural strength at later age is PCE>SBR> PEG > Conventional Concrete.
viii. Split Tensile strength at 28 days is higher for SBR & PEG than PCE polymer concrete along with conventional concrete, which shows that polymer impregnation increases tensile strength of concrete actively.
ix. Modulus of elasticity is also increased after introduction of polymer concrete but it is higher for SBR concrete as compared to other polymer concrete.
x. Water Retentively is best for polymer induced concrete as compared to conventional concrete as polymer forms voids which is filled by water as pore water and used afterwards as internal curing support.

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