

Strength and Durability of Polystyrene Concrete

Ankur Arun Kulkarni



Abstract: Now a day the construction is having rapid pace, and it has increased the requirement of raw material of construction especially coarse aggregate. In order to conserve the natural resources, use of plastic waste as partial replacement of natural aggregate in production of concrete will be a right step. This research paper discusses about the study and experimental work of "Polystyrene Concrete", comprising of polystyrene waste shredded aggregates. Polystyrene concrete is a type of concrete, produced from a mixture of cement, sand and expanded polystyrene aggregate (EPS or UEPS aggregates). Thermoplastic polymeric material which is in the beginning in the solid form (UEPS) and it can be expanded by the use of steam and an expansive agent is called as Polystyrene. The polystyrene waste shredded to size of coarse and fine aggregate is used to replace 40% of natural aggregates. Nine trial mixes with varying proportion of these three types of polystyrene waste shredded aggregates and water-cement ratio are used. The workability of the fresh concrete mix as well as compressive strength of concrete at 28 days was obtained. This study has revealed that the polystyrene waste can be effectively used for production of resilient light weight concrete. The polystyrene concrete is best suited material for non-load bearing resilient concrete structures such as partition walls and facades.

Key words: polystyrene, concrete, light-weight, resilience, recycled plastic, conservation, impact

I. INTRODUCTION:

Due to rapid urbanization, the construction is having highest speed, and concrete comprises major portion of materials used. Thus, the raw material required for manufacturing of concrete, especially coarse and fine aggregate are in a great demand. While considering various options of partial replacement of natural aggregates, plastic is an ideal choice as plastic material have become an inseparable and integral part of our daily life. Due to different characteristics such as low density, strength, user-friendly designs, fabrication capabilities, long life, light weight, and low cost the adaptability of plastic has shown phenomenal growth. Plastics are used in enormous areas starting from packaging, automotive and industrial applications, medical delivery systems, to housing, communication materials, security systems, and other uses. Due to such a wide and varying applications, plastic is contributing to an ever-increasing volume in the solid waste. From point of view of conservation of natural resources, use of aggregate made up of recycled plastic will reduce use of natural aggregates, utilization of solid waste and results in energy saving.

Thus, extensive study is carried out to ascertain the effects of use of aggregate made up of recycled plastic on strength and stiffness of concrete.

In India now a day's solid waste management is a major environmental concern. All over the world every day millions of tons of polystyrene waste are produced, which is a great threat to the environmental balance.

Recycling and safe disposal of polystyrene waste within the framework of national and international environmental regulations is expensive and requires lot of energy and produces hazardous gases. The large quantity of plastic materials, polyethene, plastic bottles are deposited in household waste and in landfill; this is also causing major environmental threat. Thus, using polystyrene waste in manufacturing of concrete not only results in economy but helps in conservation of natural resources and reduces burden of disposal of polystyrene waste. Within last few years' construction industry is looking forward for application of expanded polystyrene (EPS) in various construction activities. Due to light weight, good thermal insulation properties EPS is widely accepted as insulation material. Generally, EPS comprises of tiny polystyrene beads obtained through polymerization process. After completion of the polymerization, expanding agent such as pentane and hexane are used for infusion in EPS. Beads are molded during the expansion process. Then, the beads are stabilized pre-expanded and re-exposed to steam in order to obtain binding between the beads. According to Doroudiani and Omidian[01], the foam in EPS consists of small spherical-shaped particles containing about 98% air in the form of lightweight cellular plastic. Figure 01, shows the three common forms of the EPS.

Manuscript received on January 14, 2021.

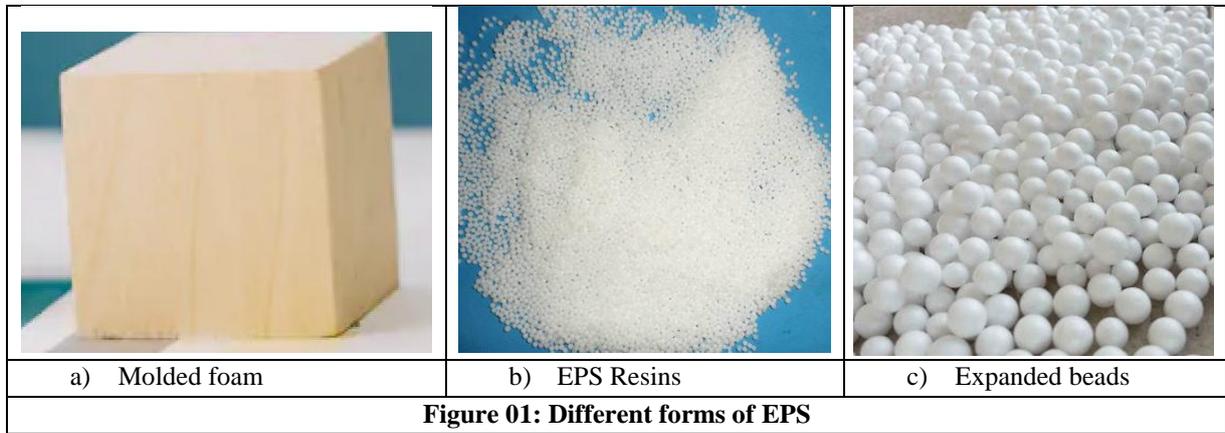
Revised Manuscript received on January 18, 2021.

Manuscript published on January 30, 2021.

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II. USE OF POLYSTYRENE IN CONCRETE:

The study conducted by Zoorob and Suparma[01] showed that major consumer of plastic is packaging industry (41%) and construction industry (20%). Other users of plastic are large industries (15%), automobile sector (7%), agriculture (6%)[02]. The properties of concrete comprising of polystyrene (PS) aggregate as partial replacement of natural coarse aggregate was studied by Sabaa and Ravindrarajah[03] and they found that the density, compressive strength and modulus of elasticity decreases as the quantity of polystyrene waste shredded aggregates in concrete increases, while creep and drying shrinkage increases along with increasing quantity of polystyrene waste shredded aggregates in the concrete. Babu and Babu[04] showed that in lightweight expanded polystyrene concrete containing silica fume, along with the increase in quantity of silica fume the strength and absorption capacity of concrete reduces. Use of expanded polystyrene beads in concrete was studied by Babu *et al*[05]. They showed that the failure of concrete is gradual due to presence of polystyrene beads. The research work of Miled *et al*[06] showed that the compressive strength of concrete increases as the size of polystyrene beads reduces. Hafizah *et al*[07] explored resilient behavior and possibility of using

polystyrene concrete as a partition wall or insulating barrier. Recently Kulkarni[08], presented study regarding strength and stiffness of concrete using recycled concrete waste. All this research work highlighted various advantages of using polystyrene in concrete such as;

- Good electrical and thermal insulation properties,
- Durability and longevity,
- Ability to get combined with other materials like adhesives, papers and aluminum foil,
- Good resistance to chemicals, water and impact
- Lighter weight than other similar materials
- Relatively economical in production cost

III. EXPERIMENTAL WORK:

The basic objective of the experimental work carried out; is to compare characteristics of concrete with and without polystyrene as aggregates. The preliminary tests are conducted on ingredient materials and control concrete mix is designed.

3.1 Materials used

Cement of Grade 53 is used for laboratory testing. The basic tests are conducted on cement and following properties are obtained;

Table 01: Properties of cement used

Sr. No.	1	2	3	4	5	6	7
Property	Normal consistency	Initial setting time	Final setting time	Fineness	Cube compressive strength		
					3 days	7 days	28 days
Value	35%	51 min.	230 min.	4.6%	28 N/m ²	43 N/m ²	55 N/m ²

The properties of aggregates used for laboratory experiments are tested as per the procedure laid down in IS 383: 2016. Local sand passing through 4.75 mm IS sieve is cleaned and washed and is used as fine aggregates. The basic tests are conducted on fine aggregates and following properties are obtained;

Table 02: Properties of fine aggregates used

Sr. No.	1	2	3	4	5	6
Property	Type	Maximum size	Specific gravity	Water absorption	Grading zone	Fineness modulus
Value	Natural	4.75 mm	2.67	1.06%	III	2.52

The crushed aggregates from the local quarry is used as coarse aggregates. These aggregates are cleaned and washed before testing. The aggregates of maximum size 40 mm are used and the basic tests are conducted on the natural coarse aggregates and following properties are obtained;



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Table 03: Properties of natural coarse aggregates used

Sr. No.	1	2	3	4	5
Property	Type	Maximum size	Specific gravity	Water absorption	Fineness modulus
Value	Natural	20 mm	2.85	3.72%	7.74

For casting of polystyrene concrete recycled plastic is used as a partial replacement of fine and coarse aggregates. The recycled plastic [Figure 02(a)] flakes are crushed and segregated into fine and coarse plastic aggregates as shown in Figure 02(b) and (c).

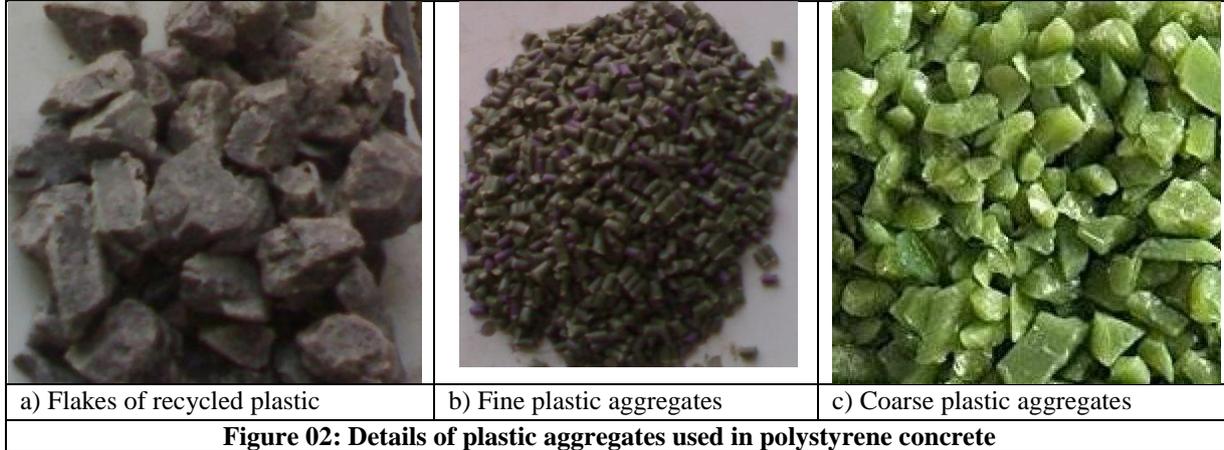


Figure 02: Details of plastic aggregates used in polystyrene concrete

The fine plastic aggregates of maximum size 4.75 mm and coarse plastic aggregates of maximum size 40 mm are used and the basic tests, like sieve analysis as per IS 383:2016, specific gravity, packing density, fineness modulus are conducted and following properties are obtained;

Table 04: Properties of plastic aggregates used

Sr. No.	1	2	3	4	5
Property	Type	Maximum size	Specific gravity	Combination for optimum packing density	Fineness modulus
Value	Fine plastic aggregates	4.75 mm	0.97	40%	7.43
Value	Coarse plastic aggregates	20 mm		60%	9.14

Packing density of aggregates is worked out using following relation;

$$\text{Packing density} = \frac{\text{Volume of plastic aggregates}}{\text{Volume of equivalent water}} \quad \dots \text{eq. (01)}$$

Various combinations of fine and coarse plastic aggregates are tried to obtain optimum packing density and it was observed that 40% - 60% combination has given highest value of packing density (i.e. 0.568). In order to obtain the highest value of the packing density, the coarse and fine plastic aggregates are mixed in different proportions. Using eq. (01) corresponding packing density is obtained. It is observed that up to certain level, as the quantity of coarse aggregate decreases and fine aggregate increases the value of packing density increases and after reaching to optimum value further reduction of quantity of coarse aggregate results in reduction of packing density. Corresponding to variation of coarse and fine aggregates % the variation of packing density is shown in Figure 03, below. Normal potable tap water is used for casting of the concrete cubes.

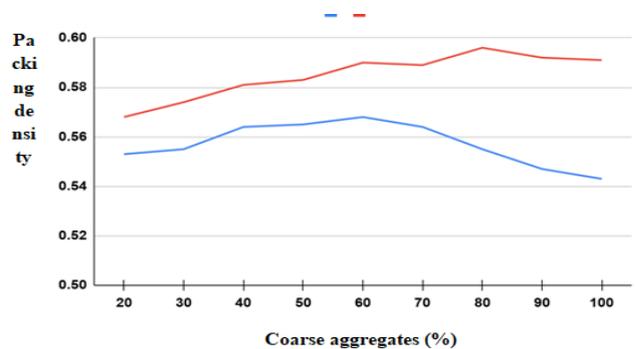


Figure 03: Variation of packing density along with coarse & fine plastic aggregates

3.2 Concrete mixing proportions:

Control concrete mix is used as per the guidelines stipulated in IS 10262:2009. Using the value of specific gravity of plastic aggregates, the quantity of plastic aggregates is worked out. The water cement ratio is varied between the range of 0.45 to 0.52.



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The specific gravity of the plastic is worked out and is used to obtain the quantity of plastic. After numerous trials a mixing method similar to “sand coating” method is adopted for mixing of the polystyrene concrete. As the EPS particles needs to be coated properly for homogeneity of the concrete mix, first one minute they are mixed with cement slurry. After that natural sand and aggregates are added and the whole mix is mixed thoroughly for 03 minutes in mixer.

This staged mixing method ensures good workability and homogeneousness of polystyrene concrete. Corresponding to each combination of ingredients, set of 06 cubes are casted and each set of three cubes is tested after 7 and 28 days respectively. The trial mix proportions of each set of three cubes i.e. total 54 cubes are casted and tested in laboratory. The details of casting of cubes and testing are shown in Figure 04.



3.3 Various test conducted

To obtain various important properties following various tests are conducted on fresh as well as cured concrete;

a) *Workability*: Initially using compaction factor method, workability of fresh concrete with and without polystyrene aggregate is carried out. The variation of compact factor along with water cement ratio for both ordinary concrete and polystyrene concrete is shown in Figure 05. It is observed from the graph that compaction factor increases along with water cement ratio up to 0.49, and then further increase in water cement ratio causes reduction in compaction factor. Thus, it is decided to adopt 0.49 as water cement ratio for laboratory testing of concrete.

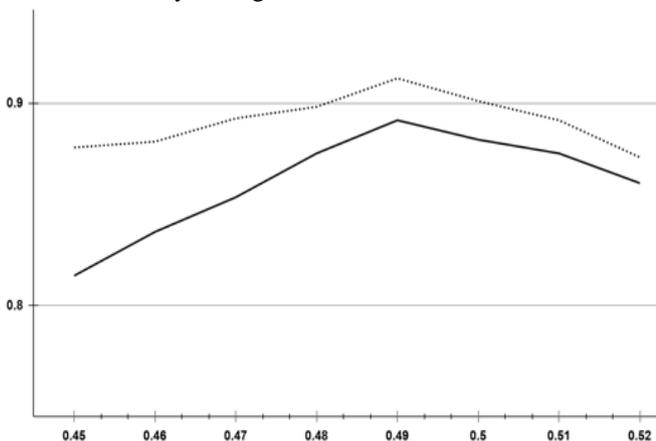


Figure 05: Variation of compaction factor along with water cement ratio

b) *Compressive strength*: Cubes of polystyrene concrete of 150 mm size are casted for studying the compressive strength of concrete. Post curing for 28 days the cubes are tested. Water cement ratio is one of the decisive factors which governs the compressive strength of the concrete. The compressive strength reduces with higher value of water cement ratio, thus the optimum value of water cement ratio 0.49 is adopted for casting of concrete.

c) *Impact resistance*: For testing the durability, cubes of polystyrene concrete cyclic loading are applied using a standard hammer. Bayasi and Zeng[09], showed that the use of polypropylene plastic fibres improves considerably impact resistance of concrete. Suroshian *et al*[10], studied durability of concrete comprising recycled plastic using standard hammer and observed increase in impact resistance in concrete as compared to ordinary concrete.

In the experimental work described in this paper a standard hammer of weight 13.60 kg (30 pounds) is dropped from a height of 380 mm (15 inches). The number of blows required for formation of first visible crack and corresponding to failure are noted as in Table 05. Due to presence of EPS in the form of aggregates, the impact resistance of polystyrene concrete improves significantly.

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Table 05: Drop weight test results (number of blows required)

Specimen ID	CP-00	CP-05	CP-10	CP-15	CP-20	CP-25	CP-30	CP-35	CP-40
First Crack	77	80	88	94	101	107	111	118	126
Failure	82	85	92	100	114	132	141	145	151

Table 06: Details of ingredients of concrete mix, proportion and laboratory results, using water cement ratio 0.49

Mix ID of set of 6 cubes	Cement kg/m^3	Fine aggregates kg/m^3	Coarse aggregates kg/m^3	Polystyrene quantity (kg/m^3)	Polystyrene Volume (m^3)	Ave 28 days Comp. strength (MPa)	Mass Density kg/m^3
CP-00	400	820	980	--	0.00	43.25	2390
CP-05	400	830	928	22.0	0.18	40.85	2175
CP-10	400	802	923	44.0	0.36	34.12	2079
CP-15	400	786	908	66.0	0.54	30.95	2001
CP-20	400	780	898	88.0	0.72	26.80	1895
CP-25	400	767	881	110.0	0.90	21.26	1791
CP-30	400	750	879	132.0	1.08	16.84	1683
CP-35	400	748	876	154.0	1.26	13.09	1602
CP-40	400	700	870	176.0	1.44	09.46	1558

IV. RESULT AND DISCUSSION:

The research work presented in this paper is carried out with the objective of verifying the feasibility of using recycled plastic waste in the form of EPS. Ordinary Portland cement of grade 53, local natural sand and aggregates and potable water is used for concreting. After studying variation in packing density, the coarse and fine particles of plastic waste in the form of EPS in proportion of 40:60 is used. Using analysis of variation in packing density and workability using compaction factor test, along with particle size water cement ratio 0.49 is adopted for laboratory work. Total 54 cubes using different proportion of natural aggregates and polystyrene particles for same water cement ratio are casted. The cubes are tested for 7 and 28 days. The quantity of ingredients used for each set of 06 cubes is tabulated in Table 06. Three cubes are tested after 7 days curing and remaining three cubes are tested after 28 days curing. The variation of compressive strength of concrete along with variation in volume of polystyrene is observed and represented graphically in Figure 06. From this graph it is clearly indicated that as the quantity of polystyrene increases in concrete, the strength reduces. Similarly, it is also observed that as the quantity of polystyrene increases in concrete, the mass density of concrete reduces as detailed in Figure 07. For testing impact resistance of polystyrene concrete, the 28 days cubes are tested for drop load test. The results shown in Table 05 clearly indicates that due to presence of polystyrene in concrete, the impact resistance gets enhanced considerably.

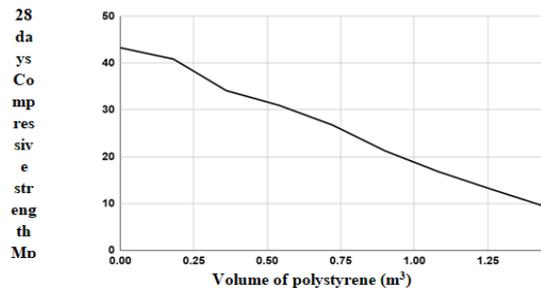


Figure 06: Variation in compressive strength of concrete along with volume of polystyrene

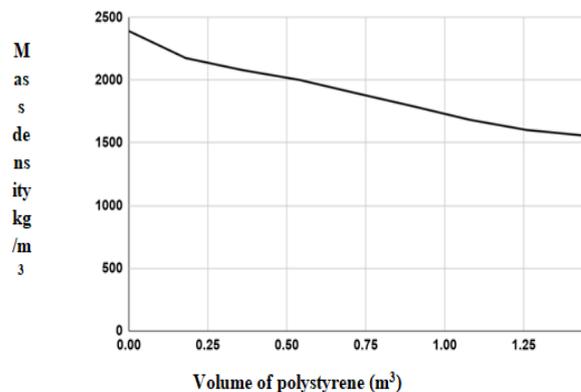


Figure 07: Variation in mass density of concrete along with volume of polystyrene

V. CONCLUSION:

The research work presented in this paper intends to find out the effective way of using recycled plastic waste particles as a partial replacement to natural aggregates. This study highlights the effective utilization of plastic waste as a partial replacement of natural aggregates. This leads to conservation of natural resources as well as constructive utilization of environmental hazardous waste i.e. plastic. But due to introduction of plastic waste in concrete the strength and mass density of concrete reduces thus limited use of plastic in polystyrene concrete is advisable. Within the range of 5 to 20 % the replacement of natural aggregate by polystyrene the reduction of strength does not affect fitness. But beyond 20 % replacement of natural aggregate by polystyrene results in high reduction in strength and affects usability of concrete.

Following conclusions can be drawn from the study presented in this research paper;

1. Polystyrene can be used to replace partially the natural aggregates. The reduction of mass density of polystyrene concrete makes it suitable for applications as non-load bearing light weight concrete such as partitions, panels, exterior facades etc.
2. Polystyrene concrete is having high resistance to impact and high value of ductility, resulting higher deformation before failure. This property makes polystyrene concrete suitable for use where there is a large variation of temperature.
3. Polystyrene concrete can be used with partial replacement of natural aggregate up to 20%
4. As the failure of polystyrene concrete occurs mainly due to debonding of cement paste and plastic particles; thus, water cement ratio plays secondary role in imparting strength to polystyrene concrete.
5. For the same water cement ratio, the addition of more plastic in polystyrene concrete results in reduction of mass density, compressive strength and increase in impact resistance.

CONFLICT OF INTEREST

The author declares no conflicts of interest.

ACKNOWLEDGEMENT:

The experimental work described here was supported by Savitribai Phule Pune University, Pune

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