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Experimental investigation on replacement of PET aggregate as fine aggregate and water hyacinth as bio plasticizer in concrete

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ABSTRACT

Usage of single use plastics has been rapidly increasing in the recent past and it is challenging to dispose of these plastics safely, since they are non-biodegradable. Especially, Polyethylene Terephthalate (PET) which is widely used in the form of water bottles cannot be easily recycled or reused. On the other hand, construction projects require sustainable materials having good strength, accordingly various studies have been conducted to reuse plastic wastes in the concrete and positive results have been obtained. In this study, the crushed PET bottles are partially substituted with fine aggregates and water hyacinth is added as a bio plasticizer in concrete. The concrete specimens are cast by substituting PET aggregates with the fine aggregates at 2, 4, 6, 8, 10% and water hyacinth is added at 10 & 20% by weight of water. The specimens are tested and it is noted that with the addition of PET aggregates up to 4% the strength of the concrete increases and beyond 4%, strength of the concrete gradually decreases, and addition of water hyacinth enhances the strength of the concrete.

KEYWORDS

PET aggregates, water hyacinth, SEM, compressive strength

1. INTRODUCTION

In the modern world plastic plays a vital role, although it is harmful to our environment, plastics have become unavoidable in human's routine life. The key reasons for extensive usage of plastics are their cost effectiveness, physical properties and ease of access. Plastics are used in various forms such as plastic bags, plastic toys, plastic pipes, plastic water bottles, plastic pots, plastic boxes, etc., due to its flexibility, durability, lightweight and cost effectiveness [1]. Plastics are classified into seven types, namely Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polystyrene (PS), Low-Density Polyethylene (LDPE), Polyvinyl Chloride (PVC), Polypropylene (PP), and others (BAS) [2]. Among these types, the most commonly used one around the world is PET [3]. PET is made from petroleum hydrocarbons by combining ethylene glycol and terephthalic acid, which is a thermoplastic variety and it can be manufactured either transparent or opaque depending upon the chemical composition. The plastic bottles are manufactured by heating the PET and blowing it up into the mould and allowing it to cool. Once cooled, the PET bottles are ready to use [4]. It is mainly used by potable water manufacturing companies.

It takes millions of years for this plastic to degrade when disposed in the land [5]. The slow degradation nature of plastics causes severe problems to environment affecting vegetation, soil fertility, groundwater percolation, etc. [2]. Organic wastes can be managed by

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composting but plastic waste is non-degradable. In household waste, plastic alone constitutes approximately 10% and ends up to landfills [2]. Normally the plastic waste is disposed either in landfills or it may be used for incineration or recycling [2]. Even though landfilling is the common way to dispose of plastic, scarcity of spaces in land makes major problem in landfilling. Also, the leachate at landfill sites causes environmental and public health issues and also contaminates the soil and groundwater [6–9]. The next possible way to disposing plastics is incineration because of its high energy value. [6, 10, 11]. However, incineration also has certain disadvantages as it produces compounds such as halogenated additives, PVC, dioxins, Poly Chlorinated Biphenyls (PCBS) that are released into the environment and cause air pollution. The ash produced during the incineration of plastic gets settled on the soil and plants which leads to collapse of food chain, further it reacts with water and changes the pH value which paves way for change in the aquatic ecosystem.

Since most of the plastic wastes are non-biodegradable, reuse or recycling is found to be feasible and a suitable way to minimize the disposal rate of plastics into the environment. Nowadays PET bottles are recycled into many new products such as polyester fabric, carpet, clothing, food trays, and petroleum products by reducing fossil fuels, plastic as coal in cement kilns and thermal power plants, floor tiles and construction materials [12–16]. In the construction sector, PET bottles are reused as roofing and flooring tiles by melting the PET bottles chips. PET aggregate is used in road and building construction to reduce the usage of natural resources like sand, and gravels [17–21].

Rishinath et al. [20] substituted 2, 4, and 6% of PET for fine aggregate and observed that the compressive strength of the concrete increased up to 2% upon replacement of PET and beyond that point increment of PET decreases compressive strength. Srinivasan et al. [22], on substitution of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, and 55% of fine aggregate, noted that the optimum substitution percentage of PET is 40%. Dawood A. O. et al. [23], upon substitution of 5, 7.5, 10, 12.5, 15, and 20% of PET with fine aggregate, observed that the compressive strength increases when PET is augmented up to 12.5%. However, the workability of concrete decreases while adding PET in concrete. Maria Enrica Frigione [24], on substitution of 5% of PET with natural sand, noted that the compressive strength of PET concrete is 0.4% lower compared to conventional concrete but there is no change in workability.

Chemical based commercial superplasticizers are used to enhance the workability and compressive strength in PET mixed concrete but it is expensive. Baboo Rai et al. [25], by adding CONPLAST SP 320 as a plasticizer increased the workability and also the compressive strength was increased by 5% in PET concrete. Rafiq Ahmad Pirzada et al. [21] used polycarboxylate ether as a super plasticizer in their study and observed that workability increases with an incremental addition of super plasticizer.

Water Hyacinth (Agayathamarai) is a rapidly growing invasive plant and doubles the quantity within two weeks due to presence of nutrients in wastewater [26]. It obstructs the waterways, degrading the water quality and causing eutrophication thereby the whole aquatic ecosystem is affected [27].

There are studies in which PET is used in various replacement percentages for fine aggregate in various applications, but those studies revealed that an increase in the proportion of PET in the concrete, impacts its compressive strength. Various admixtures are available in the market to enhance the compressive strength and workability of the concrete. But in this study, water hyacinth, a plant from waterways that needs its removal is being extracted and processed as an admixture and used in the concrete with PET aggregate replaced at varying percentages. So, this paper emphases on the utilization of PET as fine aggregate and water hyacinth as a bio-plasticizer in the manufacturing of concrete. PET aggregates are substituted at 2, 4, 6, 8 and 10% for fine aggregate, and the liquid form of water hyacinth extract is replaced at 10 and 20% for water and the physical properties of raw materials were analysed. PET concrete with and without water hyacinth is casted and tested for its strength properties. The workability of the concrete is verified with a slump cone test and the compressive strength of the concrete is tested after the specimens attained the age of 28 days. The PET concrete without and with water hyacinth extraction in the concrete is compared with conventional concrete and the optimum concrete mix with PET and water hyacinth is obtained.

2. MATERIALS AND METHODS

2.1. Materials used for the study

The Ordinary Portland Cement (OPC) of 53 grade is bought and used in this experimental work. As per IS: 4031 (part-1) – 1996 and IS: 2720 (part-3) the raw material characteristics are studied. Manufactured sand (M – Sand) is used as fine aggregate and the natural crushed stones of 10 mm size are taken as coarse aggregate for this study. The damaged PET bottles are collected from the PET bottles manufacturing industry in Karaikudi. The collected bottles were cleaned and shredded using the blender. Then the shredded PET particles having the size equal to the M-sand are replaced for fine aggregate at 2, 4, 6, 8, and 10%. The specific gravity, water absorption, and sieve analysis of fine aggregate, coarse aggregate, and PET aggregates are done according to IS: 2386 (part-3) – 1963 and IS: 460-1962. The water hyacinth plants are collected from the local pond in Rajapalayam, stems and leaves of the plants were cleaned to get rid of impurities and then finely chopped into small pieces. The chopped pieces were ground into a paste which was filtered using a fine screen. The filtered extraction is used as a bio-plasticizer. The water hyacinth and PET aggregates used in the study are shown in Figs 1 and 2 respectively.

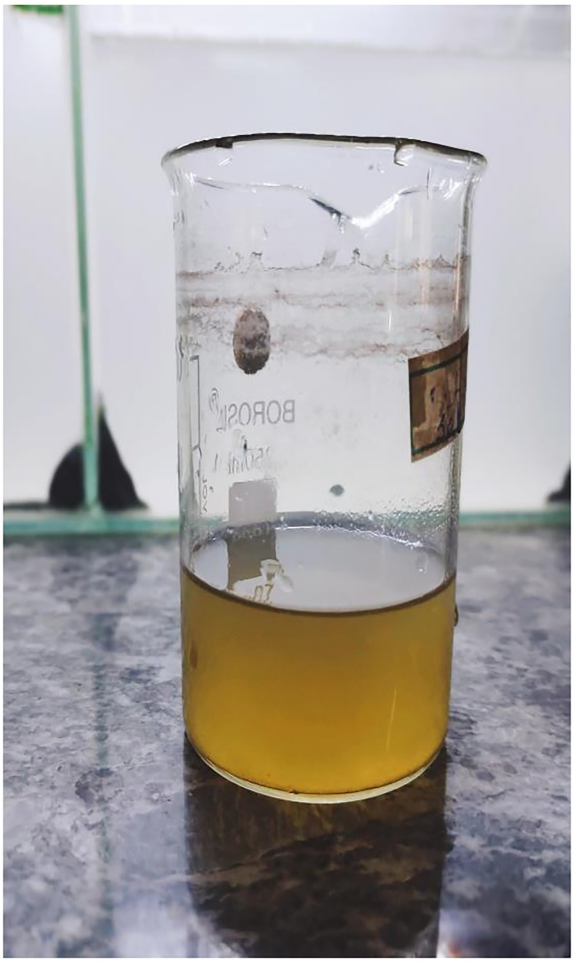

Fig. 1. Water hyacinth

Fig. 2. PET aggregates

Table 1. Physical properties of raw materials

Physical properties	Cement	Fine aggregate	PET aggregate	Coarse aggregate
Specific gravity	2.85	2.63	1.35	2.67
Water absorption	-	0.8%	0.02%	1.5%
Fineness modulus	-	2.79	3.21	2.89

2.2. Physical properties of the materials

The properties of the raw materials are tested and it is shown in Table 1.

The specific gravity of cement, fine aggregate, coarse aggregate, and PET are 2.85, 2.63, 2.67 and 1.35 respectively. The water absorption of fine aggregate, coarse aggregate, and PET is 0.8%, 1.5%, and 0.02% respectively.

2.3. Concrete mix proportion

The grade of concrete adopted is M25 and the mix design for the concrete is followed as per IS 10262-2019. The required quantity for casting the concrete specimen is specified in Table 2.

The specimens required for the test are cast under the normal environmental condition as per the mix design which is then subjected to water curing for the period of 28 days. The cured samples are used for testing.

2.4. Testing

2.4.1. Testing of raw materials. Specific gravity, sieve analysis, and water absorption are examined to calculate the physical properties of the raw materials. The microstructure of the raw material and the hardened concrete specimens are analysed by means of an EVO18 (CARL ZEISS) scanning electron microscope.

2.4.2. Testing of fresh and hardened concrete. The workability of the fresh concrete is undertaken by slump cone method. In order to know the workability of the concrete, a mould having the shape of the frustum of a cone with a height of 30 cm, a bottom diameter of 20 cm, and a top diameter of 10 cm is placed on a non-porous flat surface. The concrete is filled in 3 layers into the mould and each layer is stamped with a tamping rod, then the frustum is slowly lifted and the height of the concrete that falls into the ground is noted as the workability. The slump cone test is performed on all the percentage replacements of the concrete mix.

Table 2. Quantity of materials for PET concrete without and with water hyacinth

Specimen	Cement (kg m^{-3})	Fine aggregate (kg m^{-3})	PET aggregate (kg m^{-3})	Coarse aggregate (kg m^{-3})	Water (kg m^{-3})	Water hyacinth (kg m^{-3})
C-P0-F100 (control)	428.48	816.615	0	829.035	232.973	0
C-P2-F98	428.48	800.28	16.33	829.035	232.842	0
C-P4-F96	428.48	783.95	32.66	829.035	232.712	0
C-P6-F94	428.48	767.625	48.99	829.035	232.597	0
C-P8-F92	428.48	751.285	65.33	829.035	232.467	0
C-P10-F90	428.48	734.955	81.66	829.035	232.347	0
C-P0-F100-W10	428.48	816.615	0	829.035	209.676	23.297
C-P0-F100-W20	428.48	816.615	0	829.035	186.378	46.595
C-P2-F98-W10	428.48	800.28	16.33	829.035	209.558	23.284
C-P2-F98-W20	428.48	800.28	16.33	829.035	186.274	46.568
C-P4-F96-W10	428.48	783.95	32.66	829.035	209.441	23.271
C-P4-F96-W20	428.48	783.95	32.66	829.035	186.17	46.542
C-P6-F94-W10	428.48	767.625	48.99	829.035	209.34	23.26
C-P6-F94-W20	428.48	767.625	48.99	829.035	186.08	46.519
C-P8-F92-W10	428.48	751.285	65.33	829.035	209.22	23.247
C-P8-F92-W20	428.48	751.285	65.33	829.035	185.98	46.49
C-P10-F90-W10	428.48	734.955	81.66	829.035	209.112	23.235
C-P10-F90-W20	428.48	734.955	81.66	829.035	185.877	46.47

Compressive strength test for the concrete was carried out as per IS 516-1959. 150 mm × 150 mm × 150 mm size of specimens were cast. The specimens are demoulded the next day after casting and allowed to cure in water at room temperature for a period of 28 days. After 28 days, the cured concrete specimens are loaded in a compression testing machine to know the load at which the specimens attain failure. For every experimental mix, three specimens are tested and the average of the three values is recorded as the compressive strength of the concrete.

3. RESULT AND DISCUSSION

3.1. Particle size distribution

Figure 3 shows the particle size distribution curve of fine, coarse, and PET aggregate. From the curve, it is noted that the fine aggregate and the PET aggregate are similar. The Coefficient of Curvature (C_c) and Coefficient of Uniformity (C_u) of M sand are 1.21 and 0.64 respectively whereas the C_c and C_u values of PET aggregates are found to be 1.58 and 2.38 respectively. From this, it is found that both the M sand and PET aggregate fall between 0.1 and 5 mm in size and it comes under the category of poorly graded soil as per IS 1498-1970.

3.2. Workability

The workability of the concrete for all the combinations is experimented and Figs 4 and 5 show the graphical representation of the workability obtained for the concrete specimens without water hyacinth and with water hyacinth.

From Fig. 4, it is observed that the slump value of the control specimen (C-P0-F100) is found to be 80.5 mm. Whereas when PET is replaced at 2–10% at 2% incremental, the slump value is noted to be 74, 69, 64, 60.5, and 56.5 mm respectively. The workability decreases with an increase in the percentage of PET aggregates in concrete. The possible reason could be the plastic does not have the capacity to

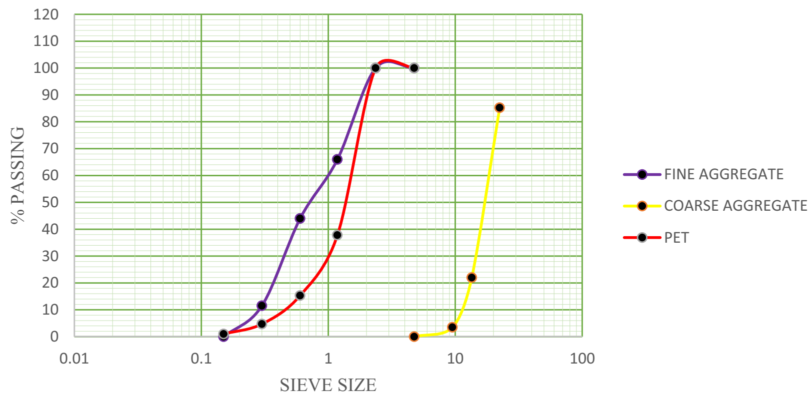

Fig. 3. Particle size distribution

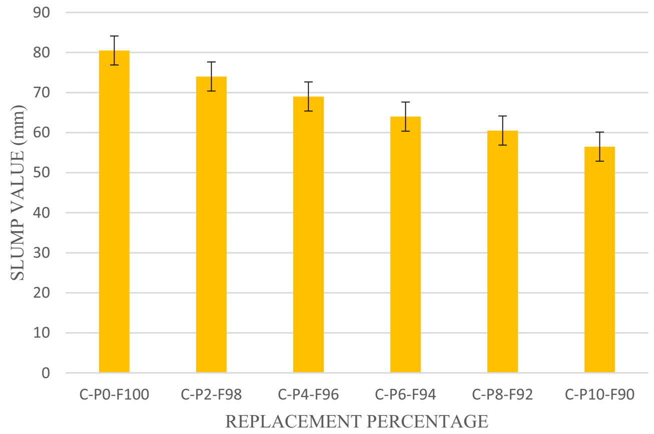

Fig. 4. Slump value of PET concrete without water hyacinth

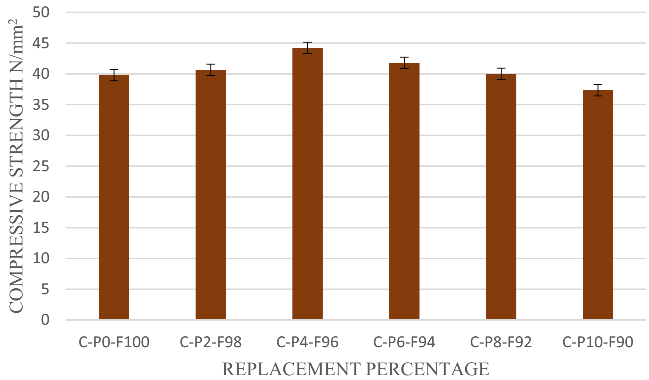

Fig. 6. Compressive strength of PET concrete without water hyacinth

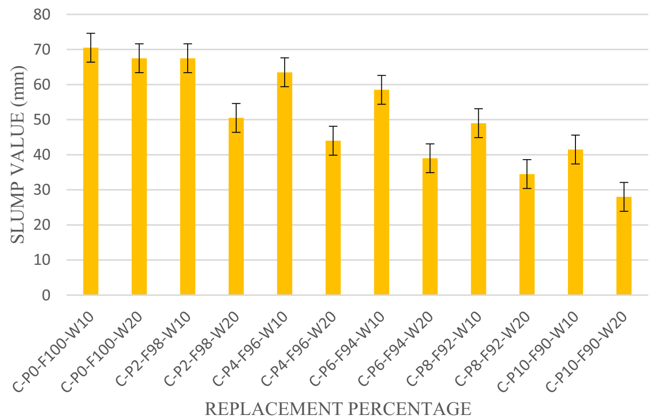

Fig. 5. Slump value of PET concrete with water hyacinth

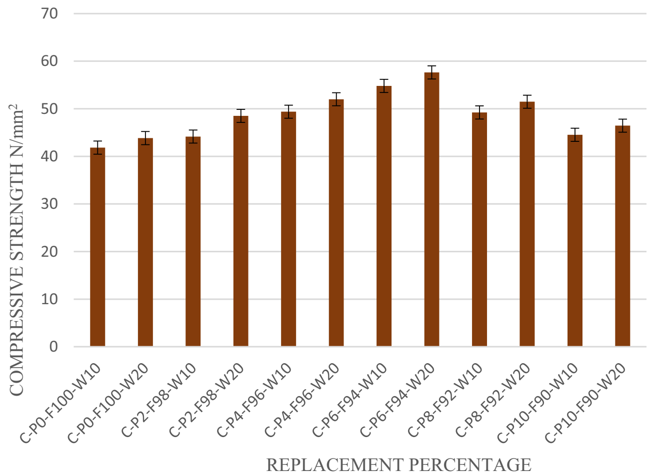

Fig. 7. Compressive strength of PET concrete with water hyacinth

absorb water causing the workability of the concrete mix to decrease [28]. Also, the decrease in workability is observed by [23, 29]. From Fig. 5, it is noted that when water hyacinth is added at 10% to the concrete specimens containing PET at 0, 2, 4, 6, 8, and 10% the workability is 70.5, 67.5, 63.5, 58.5, 49, and 41.5 mm respectively. On the other hand, workability of the concrete specimens when water hyacinth is added at 20%, is found to be 67.5, 50.5, 44, 39, 34.5, and 28 mm respectively. The addition of water hyacinth along with PET aggregates further reduces the workability. The percentage increase of water hyacinth decreases the workability [30, 27]. From this, it can be concluded that the water hyacinth when added as a plasticizer in concrete, it has the tendency to reduce the overall water requirement of the concrete.

3.3. Compressive strength of PET concrete

The compressive strength test results for the concrete specimens are shown in Figs 6 and 7 which indicate concrete without water hyacinth and with water hyacinth.

From Fig. 6, the compressive strength of the concrete with PET aggregate replaced at 0, 2, 4, 6, 8, and 10% are found to be 39.8, 40.65, 44.22, 41.78, 40, and 37.34 N mm^{-2} respectively. From the results, it is apparent that the maximum compressive strength of the concrete while substituting PET percentage of 4 is almost 5 N mm^{-2} more than conventional concrete. The possible reason could be the materials are compatible and heterogeneous mixture of PET and M sand may fill the pores in the concrete better than when only M sand alone is used as filler in concrete. The other percentage replacement also gives good compressive strength values.

Figure 7 shows the compressive strength results of the concrete specimens with addition of 10% and 20% water hyacinth along with PET aggregates. At 10% water hyacinth replaced for PET at 0, 2, 4, 6, 8, and 10%, the compressive strength is found to be 41.84, 44.16, 49.38, 54.8, 49.22, 44.53 N mm^{-2} respectively. Whereas when water hyacinth is substituted at 20% for the same PET concentrations, the compressive strength is noted to be 43.84, 48.5, 52, 57.64, 51.48, and 46.45 respectively. It is found that the addition of water hyacinth increases the compressive strength drastically. From the results, it is evident that the compressive strength of the specimens with 20% water hyacinth showed higher compressive strength than the specimens with 10% water hyacinth. With the increase in the percentage of water hyacinth, the compressive strength of the concrete also increased [30, 31]. This corroborates our study. This higher strength may be due to the presence of the lignocelluloses present in the water hyacinth, which increases the binding property when it is added to the concrete [32]. This nature of water hyacinth accelerates the hydration reaction in the concrete which improves the strength. The compressive strength of the PET concrete with water hyacinth C-P6-F94-W20 attained higher compressive strength (57.64 N mm^{-2}) and the higher compressive strength attained in the concrete specimens is due to the higher addition of water hyacinth. However, the addition of water hyacinth decreases the workability. Hence is recommended to add the optimum content of water hyacinth in order to meet strength requirements as well as to solve the workability issues.

3.4. Scanning electron microscopy (SEM) analysis

SEM analysis is carried out for the control specimen and the specimen with higher compressive strength with PET aggregate which is 4%. Figures 8 and 9 show the SEM image of the concrete specimens without PET aggregate and with 4% PET respectively. From Fig. 8, the black colour spot as seen on the image is known to be voids present in the concrete [33]. It is clear that in the control specimen more voids are visible, whereas in Fig. 9, the addition of PET in the concrete decreases the voids in the concrete matrix. It is a known fact that water hyacinth is an excellent bio plasticizer which may increase the binding of PET in the concrete effectively [30]. However, SEM analysis of concrete specimens with water hyacinth and PET needs to be carried out in future.

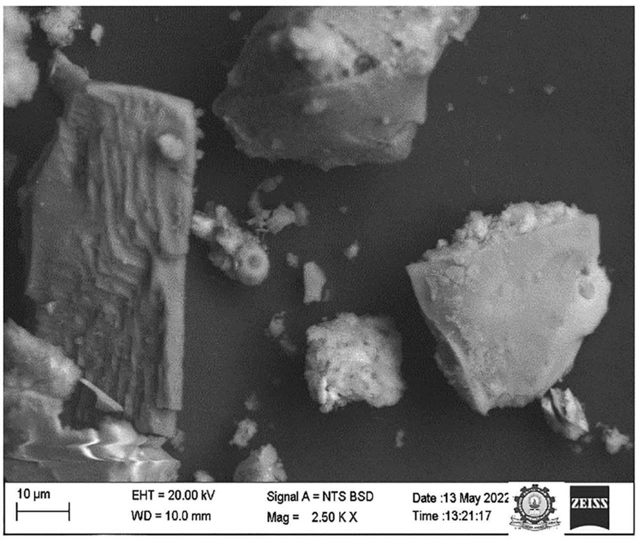

Fig. 8. SEM image of control specimen

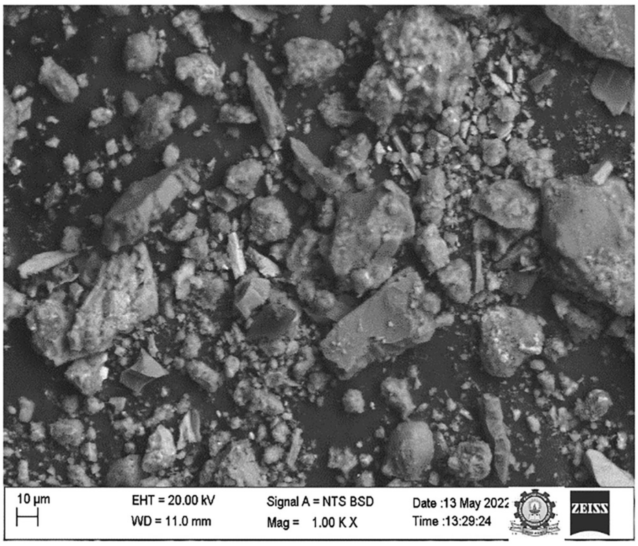

Fig. 9. SEM image of concrete with 4% PET

4. CONCLUSION

Based on the experimental results, the following conclusions are made:

- The particle size distribution curve shows both the M sand and PET come under poorly graded soil.
- The compressive strength of the concrete with 4% PET aggregate was higher than in the specimen without any replacement. The reason could be partial replacement of PET with M sand may fill the micropores which might increase the compressive strength. The PET aggregate with 10% replacement for fine aggregate showed lesser compressive strength than control specimen. The workability of the concrete decreases with increase in PET proportion in concrete.
- The maximum compressive strength is found in the concrete specimen with 6% PET aggregate and 20% water hyacinth. The compressive strength of the concrete is almost increased to 45% when water hyacinth is added in the concrete.
- The increase in the compressive strength of the concrete is due to its better binding in the concrete due to the presence of lignocellulose in the water hyacinth plant. However, the addition of more percentage of water hyacinth extract for water may decrease the workability.
- It is concluded that the addition of water hyacinth up to 20% is found suitable and viable for obtaining strength in PET based concrete. However, more investigation is necessary to find the optimum content of water hyacinth to be added in the concrete.
- It is recommended that further testing is necessary to assess the long-term performance of the concrete with PET aggregate and water hyacinth.

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