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Partial Replacement of Fine Aggregate with Plastic Waste in Cement Concrete

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Abstract

As many developed countries are continuously trying to perform different researches and experiments using recycled and raw polymer fibers in concrete and mortar to enhance the performance of the concrete and had gained many positive results. Even though there exist benefits of using PP fiber unfortunately they have not been widely adopted by construction industries due to limited research and detailed understanding on all of its mechanical properties and overall performance in concrete. In this study, M20 cement concrete is considered in which the Shredded Plastic Particles is used as the replacement of fine aggregate in the concrete. Various tests were carried out for different batches of concrete, the first batch was that of normal concrete which is the control samples batch, and then SPP mixed concrete at 1%, 2%, 3%, 4%, 5%, 10%, 15%, and 20% dosage were prepared and tested for 7 & 28 days of compressive strength of concrete. Specifically, the Compressive Strength test was carried out to meet the objective of this research work on concrete and mortar specimens for different Percentage dosages of replacement of SPP as fine aggregate. A sample of 54 concrete cubes was cast and tested concerning workability, density, and strength tests complying with IS codes. Data were analyzed and the result showed that a 2% replacement of SPP as FA in M20 Concrete is acceptable to provide compressive strength of the required grade. These data also showed that the weight of the samples tends to decrease as the % dosage of the SPP increases due to the low specific weight of the plastic.

Keywords: *Compressive Strength, Concrete, Lightweight concrete, Plastic Waste*

1. Introduction

Today, second only to water, concrete is the most consumed material, with three tons per year used by every person in the world (Gagg, 2014). Concrete being low cost, provides excellent strength, is durable, and is easily available, has been accepted worldwide as the universal construction material. It can be prepared by mixing cement with aggregates of different sizes in the presence of water where cement act as a binding agent and provides strength of various capacities as per their mix design ratio. Concrete builds durable, long-lasting structures that will not rust, rot, or burn. It is widely used for making architectural structures, foundations, walls, bridges, and many other civil engineering works.

Plastic, one of the most significant innovations was first produced in 1907 by Leo Baekeland, marking the beginning of the global plastics industry. The plastics industry has developed considerably since the invention of various routes for the production of polymers from petrochemical sources. Plastics have substantial benefits in terms of their low weight, durability, and lower cost relative to many other material types (Andrady & Neal, 2009). It also provides environmental benefits: it plays a critical role in maintaining food quality, and safety and reducing food waste. Nowadays most of the materials we use for our daily purposes contain plastic to a certain percentage, from the simplest objects such as toothbrushes to the biggest vehicles planes containing plastic, plastic shopping bags are the simplest yet widely used plastic goods, and our cell phones and laptops contain plastic.

Besides having huge beneficial aspects, the plastic waste produced is now a serious environmental threat to modern civilization. Global plastic waste generation more than doubled from 2000 to 2019 to 460 million tons (Ritchie et al., 2023). Nearly two-thirds of plastic waste comes from plastics with lifetimes of under five years, with 40% coming from packaging, 12% from consumer goods, and 11% from clothing and textiles (OECD, Louren Foye, 2022). Plastic is composed of several toxic chemicals, and therefore plastic pollutes soil, air, and water. Since plastic is a non-biodegradable material, landfilling using plastic would mean preserving the harmful material forever.

In an experiment done by (Azad Khajuria & Puneet Sharma, 2019) It was observed while experiment that the compressive strength of concrete initially increases at 2.5% PCA but further addition of PCA shows the reduction in strength. The optimum compressive strength is obtained at 2.5% PCA. The idea of using plastic bottles in concrete building construction was originated by Andreas Froese in Eco-Tec in 2001 where PET bottles are installed within the walls along with mortars to shape a structure (Froese, 2014). In this process, the plastic bottles were installed horizontally with concrete as the binding agent. This study concluded that the concrete blocks with pet plastic bottles exerted 57% more compressive strength than the concrete hollow blocks available normally in the market (Safinia & Alkalbani, 2016). (Saikia & Brito, 2012) have studied substantial growth in the consumption of related waste. Recycling of plastic waste to produce new materials like concrete or mortar appears as one of the best solutions for disposing of plastic waste, due to its economic and ecological advantages. Several works have been performed or are underway to evaluate the properties of cement composites containing various types of plastic waste as aggregate, filler or fiber. This paper presents a review of the recycling of plastic waste as aggregate in cement mortar and concrete productions. For better presentation, the paper is divided into four different sections along with introduction and conclusion sections. In the first section, types of plastics and types of methods used to prepare plastic aggregate as well as the methods of evaluation of various properties of aggregate and concrete were briefly discussed. In the next two sections, the properties of plastic aggregates and the various fresh and hardened concrete properties of cement mortar and concrete in the presence of plastic aggregate are discussed. The fourth section focus on the practical implications of the use of plastic waste in concrete production and future research needs.

The compressive strength of 28 days of light weight concrete with plastic waste with replacement ratio of 75% decreases by 33% compared to the normal controlled concrete samples however the workability of the concrete improves by 123% for same ration of waste plastic replacement (Choi et al., 2005). It was observed that the presence of fibers will not have a considerable effect on the compressive strength. Results of flexural test shows a drastic increment in strength than the control specimen. It was 11% and 59% flexural strength increment in the 4 kg and 6 kg fiber proportion mixes respectively (Sachindra Premasiri, 2019). The use of plastic fibers in concrete can increase its flexural strength to a great extent.

Recycled polypropylene (PP) fibers have been proven to enhance performance of normal concrete in areas of reducing drying shrinkage cracks and improving post cracking performance of concrete elements. Environmental benefits are also another reason for using recycled PP fibers over virgin PP fibers or meshed steel mesh. Even though there are an existence of benefits of using recycled PP fiber unfortunately they have not been widely adopted by construction industries due to limited research and detailed understanding on all of its mechanical properties and overall performance in concrete (Vilive Tuatoko Anise, 2019). (Kou et al., 2008) their study on replacing aggregates with PVC pipe granules concluded two major findings that the concrete prepared by replacing plastic granules were lighter and have more ductility, however the compressive strength and tensile splitting strength were reduced.

The results presented show that substituting sand at a level below 50% by volume with granulated PET, whose upper granular limit equals 5 mm, affects neither the compressive strength nor the flexural strength of composites. This study demonstrates that plastic bottles shredded into small PET particles may be used successfully as sand-substitution aggregates in cementitious concrete composites. These new composites would appear to offer an attractive low-cost material with consistent properties; moreover, they would help in resolving some of the solid waste problems created by plastics production and in saving energy (Marzouk et al., 2006).

The main purpose of this work is to evaluate the feasibility of the incorporation of ground polyethylene terephthalate (PET) waste in mortars by comparing the values obtained of mechanical resistance (after 28 days), capillarity water absorption coefficients, and thermal conductivity coefficients in an experimental program with the standard values. Mortar prototypes produced at ratios of 1:4 and 1:3 in weight, with partial replacement of the aggregate by PET residuals in different percentages (0, 5 and 10%) were considered (Gracia et al., 2020).

In a country Nepal, most of the construction technologies are still traditional and outdated as compared to the other developed countries. Hence, concrete is the primary construction material available. However, the river quarry available for obtaining aggregates are exploited daily by unmanaged excavation done to extract as much materials as possible. This not only affects the environment and its surroundings but also makes the construction materials cost higher. Also use of plastic due to its various benefits has been popular in Nepal so with increasing amount of use produces an increasing amount of leftover plastic waste which has a negative impact on the environment. So, it is very necessary to formulate some innovative ideas to minimize or manage plastic waste production by converting such waste into other possible outcomes.

2. Materials and Methods

2.1 Materials

2.1.1 Cement

In this investigation, standard OPC cement of 53 grade is used for all types of mixes. The physical properties of the cement used are given in

Table 1: Physical Properties of Cement

Properties	Content	Properties Content Values per IS 12269: 1987
Grade	43	43
Specific gravity	3.13	3.15
Normal consistency	33%	30% - 35%
Initial setting time	48 min	> 30
Final setting time	260 min	< 600

2.1.2 Waste Polymer

Waste plastic used for our study was obtained from waste water jar caps which were shredded further into small particles using a shredding machine. Such jar caps are generally thrown away after opening the water jars. However, for this study, the shredded jar caps were collected from Pokhara Industrial Estate.

Table 2: Physical properties of shredded plastic particles

S.N.	Particulars	Properties
1	Color	White, Blue
2	Shape texture	Irregular
3	Particle size	0mm - 10 mm
4	Odor	Odorless

2.1.3 Coarse aggregate

The coarse aggregate used for this study was collected from Kotre crusher and was retained after passing through the sieve of size 20 mm and retained in a 4.75 mm sieve. The physical properties of coarse aggregate are shown

Table 3: Physical properties of coarse aggregate

Property	Values obtained
Specific gravity	2.63
Fineness modulus	7.14
Water absorption	0.80%

2.1.4 Fine aggregate

The fine aggregate used for our study were collected from Kotre Crusher and were passed through 4.75 mm sieve.

Table 4: Physical properties of fine aggregate

Property	Values obtained
Specific gravity	2.68
Fineness modulus	2.45
Grade zone	II
Water absorption	0.20

2.1.5 Water

Water used for mixing and curing purposes in this study were taken from tap water available at Barahi Technical Solution Lab.

In the study area, most of the concrete in construction works is prepared using coarse and fine aggregate available from a nearby crusher. Mostly fine aggregates of river beds are used for plaster works only. As per the information obtained from different construction personnel the main source of crushed fine and coarse aggregate is from Kotre and Hemja crusher and Arghakhachi (OPC) cement was considered for this research work. The shredded plastic particles were obtained from the Pokhara Industrial Estate as it was easy, convenient, and in abundant amounts to perform this research work. In this study the changes in properties of cement concrete behavior as we mix the different ratios of shredded plastic particles in them can be considered as the main study area as plastic waste can be obtained from any part of the world in abundant amounts. So, this study tends to reveal that waste plastic particles from any place in any form can be utilized as aggregate to a certain extent. The outcome of this study is expected to have a beneficial effect on utilizing waste plastic materials that cannot be disposed of easily but can be dissolved in cement concrete hence mitigating the problem of their storage.

The experimental study covers the following area, and determine the optimum dosage rate of shredded plastic particles where the concrete give ultimate results. Different parameters that influence the characteristics of concrete mixed with SPP are kept constant for experiment work like water-cement ratio, chemical composition of SPP, and type of curing.

As per the literature review and previous studies conducted on this matter, most researchers have conducted their experiments in different manners. Some have used macro poly fibers, some have used whole plastic bodies and some have used fine pellets and the rate of dosages of such replacement are at different ratios, where some researchers have gone for higher percentage replacement while some have considered lower percentage replacement. So, for our study proposal, we have considered that the highest % of SPP replacement will be 20% and the Lowest will be 1%.

2.1.6. Design Mix Concrete and Mortar

Design mix concrete is the type of concrete used in construction, to produce the grade of concrete having the required workability and characteristic strength nominal mix, which will reduce the cement content used in concrete reduce the water-cement ratio also will increase the strength. In this, the general procedure has been given for the concrete of grades vary from this procedure M20 grade of concrete.

Table 5: Mix design of concrete cube.

Material	1 cube(Kg)	6 cube(kg)
Cement	1.03	6.18
Sand	2.68	16.08
Coarse aggregate	4.03	24.18
Water	0.47	2.82

Table 6: Replacement ratio of SPP in m20 grade concrete

Replacement ratio	Mass of FA (gm)	Mass of SPP for 1 cube (gm)	Mass of SPP for 6 cubes (gm)
0%	2680.00	-	-
1%	2653.20	26.80	160.80
2%	2626.40	53.60	321.60
3%	2599.60	80.40	482.40
4%	2572.80	107.20	643.20
5%	2546.00	134.00	804.00
10%	2412.00	268.00	1608.00
15%	2278.00	402.00	2412.00
20%	2144.00	536.00	3216.00

3. Results and Discussion

The compressive strength of concrete with partial replacement of fine aggregate with SPP is given below. Acceptance Criteria for compressive strength of concrete and mortar can be determined by the mean of the group of non-overlapping consecutive test results in N/mm²

Compressive strength = fck+0.825 x s or fck+4 N/mm², whichever is greater

Table 7: At 7 and 28 days compressive strength of concrete with partial replacement of FA with SPP

S.N.	Replacement of Aggregate with Polymer, % by Weight	W/C Ratio	7 Days Average Compressive Strength (N mm²)	28 Days Average Compressive Strength (N/mm²)
1	0%	0.5	16.08	25.91
2	1%	0.5	12.96	24.64
3	2%	0.5	11.85	24.11
4	3%	0.5	11.98	22.34
5	4%	0.5	11.87	18.47
6	5 %	0.5	11.27	15.68
7	10%	0.5	9.92	15.21
8	15%	0.5	9.49	14.48
9	20%	0.5	8.22	14.11

The specific weight of the plastic is lower than that of the aggregate. Hence, it tends to decrease the weight of the concrete and mortar with the increase in their dosages. It may seem to be in negligible amount in our study but, on a large scale, it can have a significant role in the development of lightweight structure.

Table 8: Deduction in weight of concrete after replacement of FA by SPP

S.N.	Replacement of FA by SPP,% by Weight	Average Weight of Cubes (gm)	Difference in Wt. (gm)
1	0%	8330	-
2	1%	8243	87
3	2%	8191	52
4	3%	8155	36
5	4%	8073	82
6	5 %	7946	127
7	10%	7515	431
8	15%	7042	225
9	20%	6583	211

The compressive strength of concrete at different periods is categorized as the percentage of its ultimate strength. As per this at the age of 3 days, strength gained should be 40%, at 7 days 65%, at 14 days 90%, and at 28 days 99% of the strength. The 28-day compressive strength results of the concrete cube is 25.91 Mpa which is M20 which is without any replacement of aggregate by SPP, but after replacement of aggregate by SPP in concrete it is seen that there is a decrease in the strength of concrete.

The maximum decrease in strength of concrete is at 20% percent of replacement, where the strength is decreased to 14.11 Mpa from design control concrete of M20. At 2% replacement of FA by SPP on M20 grade concrete it is seen that avg. The compressive strength of the cube is 23.45 Mpa which is the ultimate result that can be obtained by replacing the maximum of FA with SPP. This study shows that 2% of FA replacement in M20 concrete is feasible as the compressive strength of the cubes was within the permissible limits. 2% of FA in $1m^3$ of concrete is equal to 2% of 798.61 kg i.e. 15.97 kg. As measured in the lab, we know that 1 bag of SPP on average is equal to 11.28 kg, hence we can conclude that in $1m^3$ of concrete of grade M20, 1.5 bags of SPP can be replaced for the equivalent weight of FA.

4. Conclusions

This study searches for the possibility of replacing fine aggregates using shredded plastic particles without hampering the quality of cement concrete and mortar for construction works. Hence, it is found that till 2% replacement of FA with SPP in concrete of grade M20 and 3% replacement of FA with SPP in cement mortar of 1:4 is seen to have no decrement in their compressive strength compared to the Concrete and mortar without replacement. The compressive strength of concrete and mortar cubes with SPP reduces as the ratio of percentage dosages of SPP increases as compared to the controlled sample. This study shows that the concrete and mortar samples prepared by replacing the FA with SPP tend to reduce the weight of the cubes as the ratio of SPP dosages increases. Since our study was done on a small scale the deduction may seem to be negligible, however, if the same procedure is done on a large scale significant reduction in the weight of the structure can be observed.

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Declaration of Competing Interest

The authors assert that they have no known competing financial attention or personal relationships that could have appeared to compel the work reported in this paper.

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