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# Experimental Investigation on Mechanical and Durability Properties of Concrete with Plastic Waste

**[1]V N V Visweswara Sastry Dhara, [2]Sunil kumar. K, [3] Dr. Vimala. A**

*[1]M.Tech student Civil engineering department Anurag Group of Institutions Hyderabad, India*
*[2]Assistant Professor Civil engineering department Anurag Group of Institutions Hyderabad, India*
*[3]Professor, Head Civil engineering department Anurag Group of Institutions Hyderabad, India*
**Email: vjydharad@gmail.com*

**Abstract**—

Industrial activities in India are associated with significant amounts of non – biodegradable solid waste and plastic waste. Plastic waste being prominent which is rarely recycled with as much as 40% left in landfill. Plastic waste is causing environmental pollution which is a major problem in the present era as the usage of plastic is growing day by day and it takes hundreds of years for plastic material to degrade. The plastic if burnt releases many toxic gases, which are very dangerous for health. So, there is an urgent need to recycle plastic waste so as to reduce the environmental impact. One possible way to minimize the plastic waste is to use plastic waste in concrete industry. Environmental concerns arising from the over dredging of sand have led to restriction on its extraction across India, a suitable environmental friendly alternative to sand must be found to match the huge demand in the concrete construction industry. To tackle both the issues plastic waste can be used in the concrete as the replacement of fine aggregate in known proportions. In this research work the fine aggregate has been replaced by two types of plastic waste, one is Low Density Polyethylene (LDPE) and second one is Polypropylene (PP) in varying proportions to find out the optimum content of plastic waste. The optimum content of plastic waste was determined by conducting tests on mechanical and durability properties. The mechanical test results shown that LDPE and PP plastic waste can be used in concrete mixtures up to 5% replacement level with fine aggregate. For this replacement level the durability property – Sulphate attack resistance was determined, results demonstrate the mass loss of specimens and compressive strength.

***Keywords:*** *Plastic waste; Low Density Polyethylene; Polypropylene; Durability; Sulphate attack resistance; Concrete; Compressive strength; Flexural strength; Workability*

## 1. Introduction

Concrete is a very strong and versatile moldable construction material mainly due to its low cost, availability, its long durability, and ability to sustain extreme weather environments. About four tons of concrete are produced per person per year worldwide. Due to rapid industrialization and urbanization in the country lots of infrastructure developments are taking place because of which the consumption of concrete ingredients are being used away in large scale and hence there is a scarcity of concrete ingredients such as fine aggregate, coarse aggregate and cement. On the other hand of the rapid industrialization and urbanization there is a wide usage of plastic and hence this leads to the increased dumping of waste materials produced from plastic. A piece of plastic thrown into the nature or sent to landfill, will deteriorate after several decades or even centuries during which human life, plants, animals and insects are seriously threatened and damaged. It applies to the flow of water and air in different living environments (land, water, air), causing the draining of the water and sinks, smothering of fauna and flora and the emission of toxic air contaminant gas. The Indian central pollution control board (CPCB) reported in 2008 that approximately 15,000 tons of plastic waste is dumped every day in India [ 1]. When different types of plastics are melted together, they tend to phase-separate, like oil and water, and set in layers. The phase boundaries cause structural weakness in the resulting material, meaning that polymer blends are useful in only limited applications. Recent developments in the technology of concrete and demands for delivering more eco-friendly and sustainable construction projects gave rise to the idea of disposing postconsumer waste polymers into structural concrete. The two directions that emerged in practice and research are utilization of the raw plastic granulate as partial substitute for sand aggregate [2–6] whereby concrete is used as a medium for disposal of polymer waste in the amounts that do not significantly affect its strength and the other is the use of processed resins for production of polymer concrete [7,8]. The mechanical behavior of concrete with recycled PET has been studied by Albano et al. [9]. Portland cement, fine aggregate (river sand), coarse aggregate (crushed stone) and light-weight aggregate (recycled PET) were used in their study with varying water/cement ratios (0.50 and 0.60), PET content (10% and 20% by volume) and the particle size along with the influence of the thermal degradation of PET in the concrete when the blends were exposed to different temperatures (200, 400, 600°C). Both w/c ratios presented lower compressive strengths. On the other hand, the flexural strength of concrete-PET when exposed to a heat source was strongly dependent on the temperature, water/cement ratio, as well as on the PET content and particle size. PET waste bottles have been utilized in fiber and plastic forms in concrete. A review on the usage of plastic waste aggregates in cement and concrete mortars demonstrated effects of size and shape of recycled plastic aggregates on workability. It is mentioned that the irrespective of the size and type of the aggregate in the mortars the strength reduces with the increased contents of the aggregates [10].

From the literature review, it is evident that, not much research work has been taken place in the area of usage of plastic in concrete. Therefore, this research work is an attempt to minimize the environmental effects arising from landfill of plastic waste. In this research work the fine aggregate was replaced by Low Density Polyethylene (LDPE) and Polypropylene (PP) in the proportions of 5, 10, 15, 20% by the weight of fine aggregate.

The objectives for this dissertation work are

1. To determine the mechanical properties – Compressive strength, Flexural strength of concrete with plastic waste as LDPE and PP.
2. To determine the durability property – Sulphate attack resistance of concrete with plastic waste as LDPE and PP.
3. To determine the optimum percentage of plastic waste that can be added to concrete.

# 2. Experimental Programme

## 2.1. Materials

The materials used in casting of different plastic concrete cubes and prisms are the basic concrete ingredients: cement, fine aggregate, coarse aggregate, water. Two different types of plastics namely Low Density Polyethylene (LDPE), Polypropylene (PP) used in the concrete as a partial replacement of fine aggregate in varying proportions. Ordinary Portland cement of 53 grade manufactured by KCP Cements was used and is shown in figure 1. Locally available river sand of zone II was used as fine aggregate and is depicted in figure 2. Crushed granite of 20 mm maximum size was procured from the local crushing plant and was used as coarse aggregate, shown in figure 3. LDPE and PP plastics were manufactured by Reliance polymers and was procured from the local retailer. Fig. 4 shows LDPE plastic, fig. 5 shows PP plastic. These plastics were of size ranging from 2 to 5 mm.

## 2.2. Physical properties of materials used

Ordinary Portland cement of 53 grade confirming to IS: 269 – 2015 [11] was used. It was tested for its physical properties as per IS: 4031 (Part 11, Part 5) – 1988 [12] in the Concrete laboratory. The details of test results are given in Table I. Locally available river sand conforming to IS: 383 – 2015 [13] was used as fine aggregate. The physical properties of fine aggregate were investigated in accordance with IS: 2386 – 1963 [14]. The details of test results are given in Table II. The physical properties of coarse aggregate were investigated in accordance with IS: 2386 – 1963. The details of test results are given in Table II. Fineness modulus of fine aggregate and coarse aggregate were presented in Table III, IV.

Potable water free from any amounts of oil, alkalis, sugar, salts and organic materials conforming to IS: 456 – 2000 [15] was used for mixing and curing of concrete. Sodium sulphate solution of concentration 5% was used to treat the cubes for durability test – Sulphate attack resistance. Two different types of plastics namely LDPE, PP was used in concrete as a partial replacement of fine aggregate. The concrete mix was done using two types of plastics LDPE and PP as partial replacement of fine aggregate at varying proportions of 0%, 5%, 10%, 15% and 20% by weight. The physical properties of plastics used in this dissertation work were given in the Table V.

Slump test was performed according to IS: 1199 - 1959 [16] to determine the workability of conventional concrete, concrete with plastic waste and the results are presented in Table VI. The apparatus used for determining the workability of concrete using slump cone was shown in fig. 6. From the table VI it can be seen that as the dosage of plastic content in concrete was increased, the workability of the concrete decreased. This is due to the angular shape of the plastic used in the mix.

## 2.3. Concrete mix design

Using the properties of cement and aggregates, concrete mix of M40 was designed as per IS: 10262 – 2009 [17]. The same proportion of mix was used throughout the experimental program. Details of various mixes are given in Table VII.

## 2.4. Experimental details

The experimental details of the present research work are presented in the Table VIII. In this, the no. of specimens casted and age of testing for each specimen is mentioned.

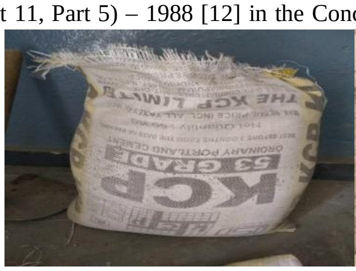
**Fig. 1**: Opc 53 Grade Cement


**Fig. 2**: Fine Aggregate


**Fig. 3**: Coarse Aggregate


**Fig. 4:** Ldpe Plastic


**Fig. 5** :Pp Plastic


**Fig. 6:** Slump Cone

**Table** 1: Physical Properties Of Opc 53 Grade Cement

| S. No | Property | Test Result |
|---|---|---|
| 1 | Specific gravity | 3.1125 |
| 2 | Initial setting time<br>Final setting time | 35 min<br>190 min |

**Table 2:** Physical Properties Of Fine And Coarse Aggregates

| S. No | Aggregate | Specific gravity | Water absorption |
|---|---|---|---|
| 1 | Fine aggregate | 2.66 | 8% |
| 2 | Coarse aggregate | 2.65 | 0.69% |

**Table 3:** Fineness Modulus Of Fine Aggregates

| IS sieve No. | Weight aggregate retained | % weight retained | Cumulative% retained | % Passing |
|---|---|---|---|---|
| 4.75mm | 5 gm | 0.5 | 0.5 | 99.5 |
| 2.36mm | 7 gm | 0.7 | 1.2 | 98.8 |
| 1.18mm | 100 gm | 10 | 11.2 | 88.8 |
| 600 µ | 236 gm | 23.6 | 34.8 | 65.2 |
| 300 µ | 549 gm | 54.9 | 89.7 | 10.3 |
| 150 µ | 99 gm | 9.9 | 99.6 | 0.4 |
| PAN | 4 gm | 0.4 | 100 | 0 |

Total weight = 1000gm
Fineness modulus = 268.42/100 = 2.68

**Table 4:**. Fineness Modulus Of Coarse Aggregates

| IS Sieve No. | Weight of aggregate retained | % weight retained | Cumulative % retained | % Passing |
|---|---|---|---|---|
| 80mm | - | - | - | 100 |
| 40mm | - | - | - | - |
| 20mm | 278gm | 5.56 | 5.56 | 94.4 |
| 10mm | 4722gm | 94.4 | 100 | 0 |
| 4.75mm | - | 0 | 100 | 0 |
| 2.436mm | - | 0 | 100 | 0 |
| 1.18mm | - | 0 | 100 | 0 |
| 600 µ | - | 0 | 100 | 0 |
| 300 µ | - | 0 | 100 | 0 |
| 150 µ | - | 0 | 100 | 0 |

Total weight = 5000gm
Fineness modulus = 705.56/100 = 7.05

**Table 5:** Physical Properties Of Plastic

| S. No | Type of Plastic | Melt Flow Index (gm/10min) | Density (gm/cm$^3$) | Tensile strength at break (MPa) | Elongation at break (%) |
|---|---|---|---|---|---|
| 1 | LDPE | 7.0 | 0.917 | 18 | 250 |
| 2 | PP | 11 | 0.946 | 36 | 100 |

**Table 6:** Workability Of Concrete

| S. No | Mix ID | Slump value (mm) |
|---|---|---|
| 1 | CV | 54 |
| 2 | LDPE5 | 41 |
| 3 | LDPE10 | 33 |
| 4 | LDPE15 | 20 |
| 5 | LDPE20 | 16 |
| 6 | PP5 | 43 |
| 7 | PP10 | 33 |
| 8 | PP15 | 24 |
| 9 | PP20 | 17 |

With reference to Table VI, CV stands for conventional mix. LDPE5, LDPE10, LDPE15, LDPE20 stands for Low Density Polyethylene at 5, 10, 15, 20% replacement level with fine aggregate by weight in the concrete mix. PP5, PP10, PP15, PP20 stands for Polypropylene at 5, 10, 15, 20% replacement level with fine aggregate by weight in the concrete mix.

**Table 7:** Mix Design Details In Kg/M$^3$

| S. No | Mix ID | Cement | FA | CA | W/C ratio | LDPE | PP |
|---|---|---|---|---|---|---|---|
| 1 | CV | 450 | 743 | 1006 | 0.4 | 0 | 0 |
| 2 | LDPE5 | 450 | 743 | 1006 | 0.4 | 37.17 | 0 |
| 3 | LDPE10 | 450 | 743 | 1006 | 0.4 | 74.34 | 0 |
| 4 | LDPE15 | 450 | 743 | 1006 | 0.4 | 111.52 | 0 |
| 5 | LDPE20 | 450 | 743 | 1006 | 0.4 | 148.69 | 0 |
| 6 | PP5 | 450 | 743 | 1006 | 0.4 | 0 | 37.17 |
| 7 | PP10 | 450 | 743 | 1006 | 0.4 | 0 | 74.34 |
| 8 | PP15 | 450 | 743 | 1006 | 0.4 | 0 | 111.52 |
| 9 | PP20 | 450 | 743 | 1006 | 0.4 | 0 | 148.69 |

Note: CV – Conventional mix. LDPE5, LDPE10, LDPE15, LDPE20 – LDPE at 5, 10, 15, 20% replacement with fine aggregate by weight respectively. PP5, PP10, PP15, PP20 – PP at 5, 10, 15, 20% replacement with fine aggregate by weight respectively.

**Table 8:** Experimental Details

| S. No | Mix ID | No. of Cube Specimens | | No. of Prism Specimens | |
|---|---|---|---|---|---|
| | | 7 Days | 28 Days | 7 Days | 28 Days |
| 1 | CV | 3 | 6 | 3 | 3 |
| 2 | LDPE5 | 3 | 6 | 3 | 3 |
| 3 | LDPE10 | 3 | 3 | 3 | 3 |
| 4 | LDPE15 | 3 | 3 | 3 | 3 |
| 5 | LDPE20 | 3 | 3 | 3 | 3 |
| 6 | PP5 | 3 | 6 | 3 | 3 |
| 7 | PP10 | 3 | 3 | 3 | 3 |
| 8 | PP15 | 3 | 3 | 3 | 3 |
| 9 | PP20 | 3 | 3 | 3 | 3 |

# 3. Results and Discussion

Casting and Curing of concrete cube specimens were performed according to IS: 516 - 1959 [18]. Generally, the compressive strength of concrete differs according to the age (i.e. 7, 14, 21 & 28 days). For this dissertation work 7 and 28 days of curing was considered. A total of 54 cube specimens and 54 prism specimens were casted in this work. Flexural strength, Compressive strength for prisms and cubes were performed according to IS: 516 – 1959. In this experimentation program 18 cubes were casted to determine the durability property – Sulphate attack of hardened conventional concrete and also hardened plastic concrete.

## 3.1. Compressive strength

The compressive strength tests were carried out at two different ages 7 and 28 days. The compressive strength of plastic waste concrete was compared to that of conventional mix. The results of compressive strength was shown in table IX. Figure 7 shows a graphical representation of the results. It was observed that for PP and LDPE the compressive strength was less than the conventional mix at all percentage variations, but at 5% replacement it was close to the conventional concrete varying by 5 and 8% for PP and LDPE respectively. Beyond 5% replacement level the strength is reducing for both PP and LDPE as the dosage of plastic content increased, the density of the concrete reduced there by reducing the strength. Also Comparing PP and LDPE concrete, PP concrete has shown better results than LDPE concrete as the physical properties of PP plastics state that its density is higher than the LDPE plastic. The Interstitial Transition Zone (ITZ) between cement paste and the aggregates is better in the PP plastic than LDPE, this is due to the rough nature of PP plastic aggregates. This ITZ also might be a reason for the higher compressive strength of PP when compared to LDPE. Fig 8 shows the cubes that were tested for compressive strength at 28 days.

**Table 9:** Compressive Strength Results

| S. No | Mix ID | Compressive strength (N/mm$^2$) at 7 days | Compressive strength (N/mm$^2$) at 28 Days | % Variation with conventional concrete for 28 days |
|---|---|---|---|---|
| 1 | CV | 33.15 | 50.66 | - |
| 2 | PP5 | 32.88 | 48.24 | 5 |
| 3 | PP10 | 31.32 | 43.40 | 14 |
| 4 | PP15 | 29.98 | 37.47 | 26 |
| 5 | PP20 | 27.84 | 34.51 | 32 |
| 6 | LDPE5 | 31.73 | 46.40 | 8 |
| 7 | LDPE10 | 28.12 | 32.29 | 36 |
| 8 | LDPE15 | 20.02 | 27.10 | 46.5 |
| 9 | LDPE20 | 16.58 | 18.51 | 63 |

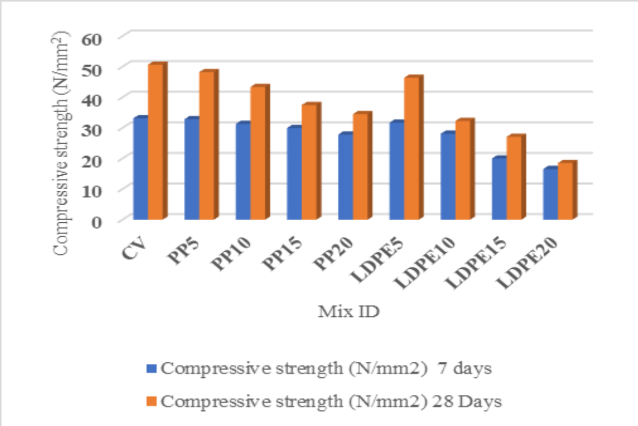


**Fig. 7:** Compressive Strength Results

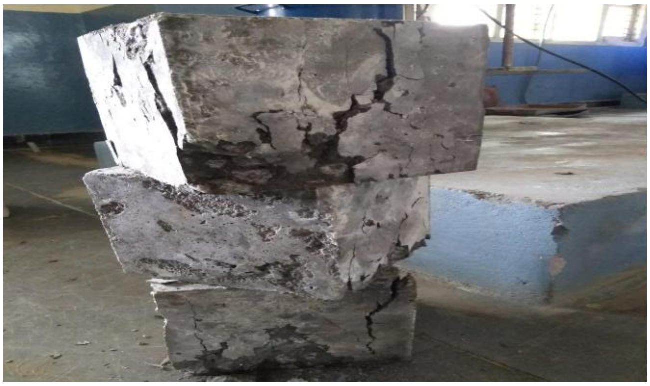

**Fig. 8:** Cubes Tested After 28 Days

### 3.2. Flexural strength

The flexural strength tests were done for two different ages 7 and 28 days. The flexural strength of conventional concrete was compared to that of concrete with plastic waste. The results are shown in Table X. Figure 9 shows the graphical representation of the flexural strength results. It was observed that for PP and LDPE the flexural strength for all the replacement levels was decreasing but for 5% replacement level the percentage variation of plastic waste concrete with conventional mix was close. PP plastic at 5% replacement level has shown 18% variation in strength and LDPE plastic at 5% has shown 41% variation in strength. Beyond 5% replacement level the flexural strength was reducing for all replacement levels as the content of plastic waste increased and fine aggregate content reduced. The PP plastic has shown lesser variation because the PP plastic aggregates have tensile strength better than LDPE plastic aggregates. Figure 10 shows the prism specimen tested for flexural strength with LDPE plastic aggregate.

**Table 10:** Flexural Strength Results

| S. No | Mix ID | Flexural strength ($N/mm^2$) at 7 days | Flexural strength ($N/mm^2$) at 28 days | % variation with conventional concrete for 28 days |
|---|---|---|---|---|
| 1 | (CV) | 4.44 | 6.02 | - |
| 2 | PP5 | 3.60 | 5.06 | 18 |
| 3 | PP10 | 2.79 | 4.35 | 38 |
| 4 | PP15 | 1.99 | 3.55 | 69.5 |
| 5 | PP20 | 1.25 | 2.59 | 132 |
| 6 | LDPE5 | 3.10 | 4.25 | 41 |
| 7 | LDPE10 | 2.17 | 3.5 | 72 |
| 8 | LDPE15 | 1.37 | 2.76 | 118 |
| 9 | LDPE20 | 0.61 | 1.96 | 207 |

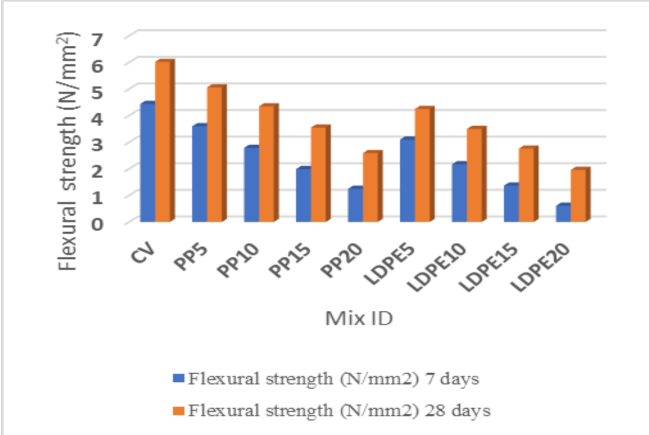


**Fig. 9**: Flexural Strength Results

**Fig. 10:** Flexural Failure Of Specimen At 28 Days

### 3.3. Durability test – Sulphate Attack Resistance

Durability property – Sodium sulphate attack on concrete was determined on three different mixes in this experimental work. LDPE5, PP5 and CV mixes were selected to determine the durability property. LDPE5 and PP5 has shown better compressive strength values and hence these two mixes were considered, CV was taken as the reference mix. The mass loss, compressive strength of the specimens placed in the sodium sulphate solution for 28 days was calculated. The test results are presented in the Table XI, XII. Figure 11 shows the specimens placed in the tank containing sodium sulphate solution and tested for 28 days. In the figure 12, the compressive strength for specimens tested under distilled water and sodium sulphate solution for 28 days was displayed. The percentage variation of distilled water and sodium sulphate solution for PP specimen showed a value of 1.6% which is less than LDPE and CV, this might be due to the formation of ettringite in the concrete samples treated under sodium sulphate solution and might be due to the mass loss.

**Table 11 :**Mass Loss Of Samples In Durability Test

| S. No | Mix ID | Mass before immersion (Kg) | Mass after immersion (Kg) | Mass loss |
|---|---|---|---|---|
| 1 | CV | 0.816 | 0.813 | 0.003 |
| 2 | PP | 0.760 | 0.760 | 0 |
| 3 | LDPE | 0.740 | 0.734 | 0.006 |

**Table 12:** Compressive Strength Of Durability Samples

| S. No | Mix ID | Compressive strength water curing ($N/mm^2$) | Compressive strength Acid Curing ($N/mm^2$) | Percentage variation with water curing |
|---|---|---|---|---|
| 1 | CV | 48.62 | 47.7 | 1.9 |
| 2 | PP | 47.2 | 46.45 | 1.6 |
| 3 | LDPE | 45.17 | 44.17 | 2.3 |

**Fig. 11:** Durability Test Of Specimens

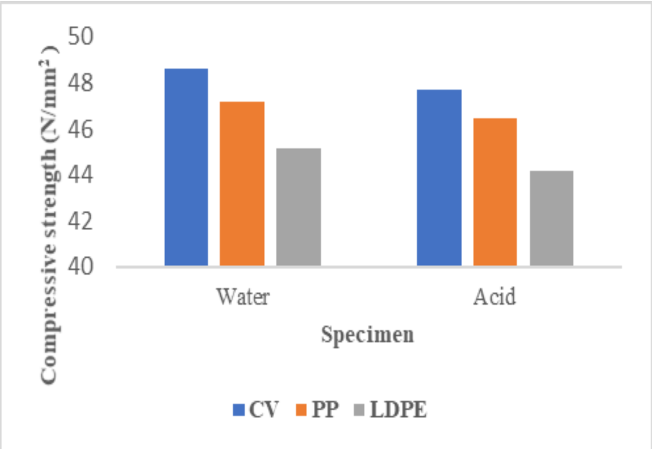


**Fig. 12**: Compressive Strength For Durability Samples

## 4. Conclusions

The present experimental work deals with the possibility of using the PP and LDPE as a replacement of conventionally used fine aggregate with the intention of identifying a better approach for waste plastic recycling and also to reduce the dredging of river sand there by finding an alternative. Various experiments have been performed and results have been analyzed to justify the possibility. The experimental results lead to the following conclusions:

1. The decrease in workability has been observed as the plastic waste content in concrete increased.
2. The compressive strength and flexural strength of PP5 mix are showing better results when compared to other level of replacements.
3. PP5 mix is showing a variation of 5% in compressive strength and 18% in flexural strength with the conventional mix.
4. When compared to PP and LDPE plastic waste, PP plastic waste aggregates can be used in concrete as the replacement of fine aggregates up to 5%
5. The durability property Sulphate Attack Resistance for PP5 mix has shown no mass loss when tested for 28days.
6. The compressive strength of PP5 for water and acid curing has shown a variation of 1.6% which is less than LDPE and CV.

## 5. Future Scope

In this dissertation work water to cement ratio of 0.40 and M40 grade of concrete was used, the research work in future can be carried out for different water to cement ratios and for different grades of concrete. The work can also be carried out for different aspect ratios of plastic aggregates, plastic aggregates in the form of fibers.

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