Assessment of Mechanical and Durability Properties of Concrete Containing PET Waste

Rajat Saxena¹, Trilok Gupta²*, Ravi K. Sharma³, Sandeep Chaudhary⁴ and Abhishek Jain⁵

¹Former Research Scholar, Department of Civil Engineering, CTAE, MPUAT, Udaipur, Tel. +91-9950652928, E-mail: rajat.sxn1991@gmail.com
²Assistant Professor, Department of Civil Engineering, CTAE, MPUAT, Udaipur, Tel. +91-9414406223, Fax: +91-294-2471056, E-mail: guptatrilok@rediffmail.com
³Professor, Department of Civil Engineering, CTAE, MPUAT, Udaipur, Tel. +91-9414474968, E-mail: sharmaraviks@gmail.com
⁴Associate Professor, Discipline of Civil Engineering, Indian Institute of Technology Indore, Simrol, Indore 453552, India Tel. +91-9414475375, E-mail: sandeep.nitjaipur@gmail.com
⁵Former Research Scholar, Department of Civil Engineering, CTAE, MPUAT, Udaipur, Tel. +91-8058170872, E-mail: abhishekJn11@gmail.com

Abstract
Plastic waste is a silent threat to the environment, and their disposal is a serious issue. To sort out this issue, many efforts were made to reuse the plastic waste, but no significant results were achieved. On the contrary, concrete being the widely used construction material is facing problem due to unavailability of ingredient material (sand and coarse aggregate). In this study PET (polyethylene terephthalate) aggregates manufactured from the waste un-washed PET bottles in shredded form were used to partially replace fine aggregate and coarse aggregate in concrete in various percentages (0%, 5%, 10%, 15% and 20%). Various tests like workability, compressive strength, flexural strength, water permeability, abrasion resistance, dynamic and static modulus of elasticity were performed. The micro-structural analysis of the specimens was carried out using an optical microscope. It was found that the workability, compressive strength, flexural strength, dynamic and static modulus of elasticity decreased with the increasing amount of PET waste in concrete. Water permeability of concrete was found to increase with increasing amount of PET waste. In both the cases, i.e., when fine and coarse aggregates were replaced with PET waste, an improvement in the abrasion resistance of concrete was found.

Keywords: PET waste, static modulus of elasticity, dynamic modulus of elasticity, abrasion resistance, water permeability, microstructure.

*Corresponding Author:
Dr. Trilok Gupta, Assistant professor, Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur-313001, Tel. +91-9414406223 E-mail: guptatrilok@rediffmail.com
1. Introduction

In modern lifestyle, the advancement of technology has led to an increase in the amount of waste being generated, leading to a waste disposal crisis [1]. Plastic is a polymer of hydrocarbon monomers and is frequently used in everyday life in the form of polythene bags, food packaging material, water bottles etc. [2, 3, 4]. On an average about 10 million of plastic bags are discarded every day in India’s capital [5, 6]. The world’s annual consumption of plastic materials was about 5 million tons in the 1950’s which has now increased to 100 million tons, resulting in more amount of generation of plastic waste [7].

The disposal of plastic waste leads to various harmful effects on the environment [8, 9, 10]. It leads to poor soil fertility, emission of toxic gases, poor drainage due to landfill, pollution of groundwater due to leaching of chemicals from these waste products, etc. This makes the environment polluted and causes blockages of sewer systems [11].

Since plastic waste has low biodegradability and is present in large quantities, disposal of plastic waste in open environment is considered to be a big problem [12]. Out of the total plastic waste that is generated, the majority of plastic wastes are not reused and recycled as it require massive manpower and large processing cost [8].

Recently, many researchers have suggested the utilization of plastic waste in concrete. Utilizing of plastic waste in the construction industry has two advantages namely: (i) resolve the environmental problem due to disposal of the waste and (ii) reduction in construction costs as these wastes are available in large quantity at low costs [8].

Concrete is one of the most commonly used construction material in India because of its high compressive strength, long service life, and low cost [13, 14]. Concrete requires 3 essential ingredients - cement (the binder), aggregates (ranging in size from fine to coarse) and water [15,
Concrete's constituent materials are available naturally in all parts of the world [17]. With the increasing requirement of concrete, these materials are getting deficient. It is thus a matter of serious concern for the civil engineers and they are searching for suitable materials which can fully or partially replace these materials [8]. Keeping in view the disposal issues of plastic waste, and increasing demand for concrete, its utility in concrete has been studied and investigated by various researchers [18].

Properties of concrete are affected by inclusion of plastic waste. Workability of concrete with plastic waste decreases gradually with increasing plastic waste percentage [6]. Similar observations of decrease in workability have been reported by Kumar et al. [17] who used plastic bags in fibre form to replace cement concrete. However, Ghernouti et al. [19] reported slight improvement in workability with recycled plastic bag waste as replacement of sand in concrete.

Systematic reduction in compressive strength has been observed with the increase in plastic waste content in concrete by some researchers [6, 11, 19, 20, 21]. Borg et al. [22] used PET fibres in concrete and reported that the PET fibres lead to a reduction in compressive strength with increasing fibre volume fractions. However, Al-Hadithi and Hilal [23] carried out an experimental study using waste plastic fibres in self compacting concrete and reported the increase in compressive strength with increasing amount of waste plastic.

Flexural strength of plastic concrete is also influenced by the inclusion of plastic waste. It has been reported in the literature that flexural strength decreases with the increase of plastic waste content [11, 19, 24]. However, Ramadevi and Manju [21] reported that flexural strength of the specimens containing PET waste increased gradually with increase in the replacement percentage.
Detailed studies have also been carried out for finding the effect of addition of plastic waste on modulus of elasticity of concrete and it was shown that modulus of elasticity decreased with the increase in plastic waste content [24, 25, 26]. Yang et al. [27] used recycled polypropylene waste in self-compacting concrete to replace sand and reported the decrease in elastic modulus with an increase in plastic content. However, Pesic et al. 2016 [28] reported slight increase in elastic modulus on using recycled high-density polyethylene plastic fibres in structural concrete.

It is evident from the work reported that though a number of studies are available on utilization of plastic waste in concrete, most of studies are limited to mechanical properties of concrete containing plastic waste. Effects on properties of concrete like abrasion resistance, water permeability and dynamic modulus of elasticity has not been reported comprehensively.

In this study, the feasibility of PET waste (plastic waste) in concrete as partial replacement of fine aggregate and coarse aggregate was evaluated. Fine aggregates were replaced by waste plastic from 0% to 20% in increment of 5% by weight. Similarly, coarse aggregates were also replaced by waste plastic from 0% to 20% in increment of 5% by weight. Various properties of waste plastic concrete such as compressive strength, flexural strength, water permeability, abrasion resistant, static and dynamic modulus of elasticity were evaluated in the laboratory. Micro-structural study was also carried out on these specimens.

2. Experimental Investigation

2.1. Materials

Commonly used ordinary Portland cement (OPC) of 43 grade was used for the investigation. Cement used was free from lumps and care was taken to avoid the possible content of moisture while storing. Physical properties of cement used are shown in Table 1.
The locally available river fine aggregate passing 4.75 mm sieve as per IS: 383-1970 [30] was used as fine aggregate in this study. Sieve analysis and specific gravity test were performed using the standard testing procedure. Sieve analysis results are shown in Fig. 1. As per the guidelines of IS: 383-1970 [30], the sand belonged to zone II gradation. Specific gravity was observed to be 2.63.

The coarse aggregate used in this study was procured from the supplier as per IS: 383-1970 [30]. Sieve analysis results of coarse aggregates are shown in Fig. 2. Specific gravity of coarse aggregate was observed to be 2.74.

Waste PET bottles were collected from the local waste supplier in shredded form. PET waste was shredded in two sizes, i.e., between 0-4.75 mm for fine aggregate (FA) replacement and between 4.75-20 mm for coarse aggregate (CA) replacement as shown in Fig. 3 and Fig. 4. It was bought from the same source throughout the study. The waste was not given any special treatment except sun drying.

2.2. Mix proportions
Concrete mix of M 25 grade was designed as per IS:10262 [31] and IS:456 [32]. All materials were mixed with the help of pan type mixer and the PET waste was used in different proportions to partially replace the fine aggregate (FA) and coarse aggregate (CA). Details of mix proportion are shown in Table 2.

2.3. Preparation of specimens
Total 180 samples of cubes, 60 samples of beams and 60 samples of cylinder were cast in this study for various tests (compressive strength, flexural strength, water permeability, abrasion resistance, static and dynamic modulus of elasticity). During casting, all the specimens were compacted properly using the vibrating table. The specimens were stored in a place, free from
vibration for 24 hours ± ½ hour from the time of addition of water to the dry ingredients. After this period, the specimens were marked and removed from the moulds and, immediately submerged in clean and fresh curing water.

3. Results and discussion

3.1. Fresh concrete

Workability of fresh concrete mixes was determined by compacting factor test as per guidelines of IS: 1199-1959 [33]. The variation of compaction factor of concrete is shown in Fig. 5. Compaction factor of concrete for 0.45 w/c ratio without PET waste was found to be 0.91. The compaction factor was found to decrease with the increase of PET waste in concrete. Similar decrease in workability was reported by Kumar et al. [17]. Compaction factor of fresh concrete containing PET waste was observed as 0.91, 0.83, 0.73, 0.66 and 0.61 at 0%, 5%, 10%, 15% and 20% replacement of fine aggregate respectively and as 0.91, 0.81, 0.70, 0.63 and 0.56 at 0%, 5%, 10%, 15% and 20% replacement of coarse aggregate respectively. The decrement can be attributed to the fact that particles of PET waste have angular and non-uniform shapes resulting in less fluidity [34]. Decrement in workability can also be due to the high specific surface area of PET particle compared to the sand which results in more friction between the elements resulting in low workability [35].

3.2. Compressive strength

This test was performed as per guidelines of IS 516:1959 [36]. Compressive strength of concrete containing PET waste is shown in Figs. 6. 28 days compressive strength of concrete without PET waste was observed as 26.7 N/mm² which reduced to 6.9 N/mm² at 20% replacement of fine aggregate by PET waste and it reduced to 5.4 N/mm² at 20% replacement of coarse aggregate by PET waste. Reduction in compressive strength due to incorporation of PET waste in concrete
was also reported by Borg et al. [22]. The decrease in strength can be attributed to the fact that PET-aggregate cannot interact with cement paste and therefore the interfacial transition zone (ITZ) in concrete containing PET aggregate is weaker than that in the reference concrete, which results in lower compressive strength [24]. After 10% inclusion of PET waste in concrete, sudden decrease in compressive strength can be attributed to the fact that PET-aggregate has very low water absorption capacity which causes more accumulation of water in the transition zone and makes it weaker [37].

3.3. Flexural strength

Flexural strength of PET concrete was determined as per guidelines of IS 516:1959 [36] and the test results are shown in Fig. 7. Flexure strength of concrete for 0.45 w/c ratio without PET waste after 28 days of curing was observed to be 3.55 N/mm². The flexure strength was decreased with the increasing amount of PET waste in concrete. Similar observation was reported by Saikia and Brito [24]. Flexural strength of concrete containing PET waste was reduced by 49.6 % at 20% replacement of fine aggregate and it reduced by 49% at 20% replacement of coarse aggregate. This decrease in strength may be due to decrease in adhesive strength between the surface of waste PET particles and the cement paste, as well as the hydrophobic nature of PET waste which sometimes limit the hydration of cement [34].

3.4. Water permeability

Guidelines of DIN 1048 [38] were followed for determining the depth of water penetration. Fig. 8 shows the water permeability test results. Water penetration depth for 0.45 w/c ratio without PET waste after 28 days of curing was observed to be 24 mm. The water penetration depth increased with increasing amount of PET waste in concrete and was observed as 24 mm, 28 mm, 42 mm, 71 mm and 105 mm at 0%, 5%, 10%, 15% and 20% replacement of fine aggregate
respectively. The water penetration depth was observed as 24 mm, 35 mm, 62 mm, 121 mm and 150 mm at 0%, 5%, 10%, 15% and 20% replacement of coarse aggregate respectively. This increase in depth of penetration of water can be attributed to the fact that PET waste increases in the interfacial transition zone which can act as a bridge between pores, which leads to increase in the number of voids in the structure of concrete. PET waste, due to the irregular shape and less adhesion with cement paste further increases the number of voids in concrete resulting in increased water permeability [39].

3.5. Abrasion resistance

The abrasion resistance test was performed as per recommended guidelines of IS 1237 [40] and the test results are shown in Fig. 9. Abrasion resistance has been determined in terms of the depth of surface wear. The depth of wear of control concrete was observed as 0.42 mm for 0.45 w/c ratio. With the increase in PET waste as replacement of fine aggregate (FA) and coarse aggregate (CA), the depth of wear decreased at all replacement level. Depth of wear was observed as 0.42 mm, 0.38 mm, 0.33 mm, 0.32 mm and 0.27 mm at 0%, 5%, 10%, 15% and 20% replacement of fine aggregate respectively. Depth of wear was observed as 0.42 mm, 0.31 mm, 0.26 mm, 0.25 mm and 0.23 mm at 0%, 5%, 10%, 15% and 20% replacement of coarse aggregate respectively. This indicates that resistance to wear increases with an increase in the replacement of fine aggregate and coarse aggregate by PET waste. This increase in abrasion resistance can be because PET waste has good abrasion resistance and high toughness [24].

3.6. Static modulus of elasticity

Guidelines of ASTM C469-1994 [41] code were followed for determining the static modulus of elasticity. Test results of static modulus of elasticity for 0.45 w/c ratio are shown in Fig. 10. Static modulus of elasticity without PET waste after 28 days of curing was observed to be 26100
MPa. The modulus of elasticity decreased with the increase in the amount of PET waste. Yang et al. [27] also reported decrease in modulus of elasticity with the increase in the amount of PET waste. Static modulus of elasticity after 28 days curing of cylinders containing PET waste was decreased to 13775 MPa at 20% replacement of fine aggregate by PET waste. Static modulus of elasticity was decreased to 13121 MPa at 20% replacement of coarse aggregate by PET waste. The modulus of elasticity of PET is considerably lower than that of natural aggregates, hence, higher PET-aggregate contents lower the resulting concrete’s modulus of elasticity [25]. Moreover, the modulus gradually decreases since PET waste is less resistant than natural sand and deforms less when an equivalent stress is applied [42].

3.7. **Dynamic modulus of elasticity**

The dynamic modulus of elasticity test was performed as per the guidelines given in the ASTM C597-2009 [43] and the test results are shown in Fig. 11. Dynamic modulus of elasticity was determined with the help of UPV (ultrasonic pulse velocity) test. Dynamic modulus of elasticity for 0.45 w/c ratio without PET waste after 28 days of curing was observed to be 52.88 GPa. The dynamic modulus of elasticity decreased as the amount of PET waste increased in concrete. Dynamic modulus of elasticity after 28 days curing of cubes containing PET waste was reduced to 17.68 GPa at 20% replacement of fine aggregate by PET waste and it was reduced to 16.04 GPa at 20% replacement of coarse aggregate by PET waste. Reduction in modulus of elasticity can be attributed to the reduction of composite bulk densities and to plastic aggregates, which decrease the celerity of wave by disturbing the ultrasonic wave propagation [26].

3.8. **Micro-structural analysis**

The micro-structural analysis of the concrete specimens was carried out using an optical microscope (OM) at 90x magnification. Microscopic images of the plastic concrete specimens
(for 0.45 w/c ratio) containing PET waste as replacement of FA are shown in Fig. 12(a)-(d), which shows that the PET particles have an irregular shape. Gaps in the interface of PET waste and cement matrix are shown in Fig. 12(a) and (b). These gaps reflect weak bond of PET waste with cement mortar. In Fig. 12(c) and (d), cracks can be observed in the interface of PET waste and cement matrix which reduce the strength of concrete.

Microscopic images of the plastic concrete specimens (for 0.45 w/c ratio) containing PET waste as replacement of CA are shown in Fig. 13 which shows that the PET particles have an irregular shape. Large gaps or voids in the interface of plastic/ cement matrix can be clearly noticed in Fig. 13(a)-(d). Fig. 13(c) and (d) shows that there is an increase in number of cracks and the size of voids as the amount of PET waste is increased. It indicates that the interfacial bonding between the PET waste and cement paste is very poor which resulted in the formation of cracks and reduction in the strength of plastic concrete.

4. Conclusions

Based on the experimental results, the following conclusions can be drawn:

- The workability of concrete decreased with increase in the percentage of PET waste in concrete. Compaction factor of fresh concrete containing PET waste was decreased from 0.91 to 0.56.

- The compressive strength and flexural strength of concrete containing PET waste decreased with the increase of PET waste as replacement of coarse aggregate or fine aggregate. Compressive strength of concrete containing PET waste decreased from 26.7 N/mm² to 5.4 N/mm² and flexural strength from 3.55 N/mm² to 1.79 N/mm².
Water permeability increased when the amount of PET waste was increased in concrete as replacement of coarse or fine aggregate. The water penetration depth increased from 24 mm to 150 mm.

Abrasion resistance of concrete increased as the amount of PET waste was increased as replacement of coarse aggregate or fine aggregate. Depth of wear was decreased from 0.42 mm to 0.23 mm.

Static and dynamic modulus of elasticity of the concrete decreased with increase in the percentage of PET waste in the concrete as replacement of coarse aggregate or fine aggregate. The modulus of elasticity decreased from 26100 N/mm² to 13121 N/mm² and dynamic modulus of elastic 52.88 GPa to 16.04 GPa.

Micro-structural analysis shows the weak interfacial bonding between the PET waste and cement paste which lead to voids at the interface and thus reduces the strength of plastic concrete.

Based on the various test results it can be concluded that concrete made with PET waste can be used in areas where there is need of more abrasion resistance like road pavement and in areas where the strength parameters are not the most important ones. Fine aggregates or coarse aggregates by weight can be partially replaced up to 5% by PET waste as at this replacement level, most of the properties are within permissible limits.

Acknowledgment

The authors would like to acknowledge the Department of Science and Technology, New Delhi for financial support of this study (No. DST/SSTP/Rajasthan/331).
References


CAPTIONS OF FIGURES AND TABLES

LIST OF FIGURES:

Fig. 1. Sieve analysis of fine aggregate

Fig. 2. Sieve analysis of coarse aggregate

Fig. 3. PET waste for fine aggregate replacement

Fig. 4. PET waste for coarse aggregate replacement

Fig. 5. Compaction factor of concrete containing PET waste

Fig. 6. Compressive strength of concrete containing PET waste as fine aggregate and coarse aggregate replacement

Fig. 7. Flexural strength of concrete containing PET waste

Fig. 8. Water penetration depth of concrete containing PET waste

Fig. 9. Depth of wear of concrete containing PET waste

Fig. 10. Static modulus of elasticity of concrete containing PET waste

Fig. 11. Dynamic modulus of elasticity of concrete containing PET waste

Fig. 12. Microstructure of concrete containing PET waste as fine aggregate replacement

Fig. 13. Microstructure of concrete containing PET waste as coarse aggregate replacement

LIST OF TABLES:

Table 1. Physical properties of cement

Table 2. Concrete mix proportion with PET waste
Fig. 5

Fig. 6
Fig. 7

Fig. 8
Fig. 9

Fig. 10
Fig. 11

Dynamic modulus of elasticity (GPa)

% of PET waste

FA replacement
CA replacement

0 5 10 15 20

0 10 20 30 40 50 60
a) 5% FA replacement  

b) 10% FA replacement

c) 15% FA replacement  

d) 20% FA replacement

**Fig. 12**
a) 5% CA replacement

b) 10% CA replacement

c) 15% CA replacement

d) 20% CA replacement

Fig. 13
Table 1

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Physical properties</th>
<th>Requirement as per IS 8112: 2013[29]</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Consistency</td>
<td>-</td>
<td>32%</td>
</tr>
<tr>
<td>2</td>
<td>Initial setting time</td>
<td>30 minutes (min.)</td>
<td>130 min</td>
</tr>
<tr>
<td></td>
<td>Final setting time</td>
<td>10 hours (max.)</td>
<td>213 min</td>
</tr>
<tr>
<td>3</td>
<td>Specific gravity</td>
<td>-</td>
<td>3.13</td>
</tr>
<tr>
<td>4</td>
<td>7 day compressive strength</td>
<td>33 MPa</td>
<td>34.95 MPa</td>
</tr>
<tr>
<td></td>
<td>28 day compressive strength</td>
<td>43 MPa</td>
<td>45.29 MPa</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cement</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
<th>PET waste (%)</th>
<th>w/c ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>1</td>
<td>1.54</td>
<td>2.76</td>
<td>0</td>
<td>0.45</td>
</tr>
<tr>
<td>F5</td>
<td>1</td>
<td>1.46</td>
<td>2.76</td>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td>F10</td>
<td>1</td>
<td>1.39</td>
<td>2.76</td>
<td>10</td>
<td>0.45</td>
</tr>
<tr>
<td>F15</td>
<td>1</td>
<td>1.31</td>
<td>2.76</td>
<td>15</td>
<td>0.45</td>
</tr>
<tr>
<td>F20</td>
<td>1</td>
<td>1.23</td>
<td>2.76</td>
<td>20</td>
<td>0.45</td>
</tr>
<tr>
<td>C5</td>
<td>1</td>
<td>1.54</td>
<td>2.62</td>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td>C10</td>
<td>1</td>
<td>1.54</td>
<td>2.48</td>
<td>10</td>
<td>0.45</td>
</tr>
<tr>
<td>C15</td>
<td>1</td>
<td>1.54</td>
<td>2.35</td>
<td>15</td>
<td>0.45</td>
</tr>
<tr>
<td>C20</td>
<td>1</td>
<td>1.54</td>
<td>2.21</td>
<td>20</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Technical Biography:

**Rajat Saxena** has been completed his M. Tech. program from Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, India. He received his Bachelor’s degree in 2014 from Pacific Institute of Technology (RTU) College, Udaipur. His research interests include durability of concrete and utilization of waste materials in concrete.

**Trilok Gupta** is an Assistant Professor in the Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, India. He received his Bachelor’s degree in 2001 from Pune University, Master’s degree in 2003 from MNIT Jaipur and Doctorate in 2016 from Malaviya National Institute of
Technology, Jaipur, India. His research interests include durability assessment of engineered concrete mixtures incorporating industrial by-products.

**Ravi K. Sharma** is Professor in the Department of Civil Engineering at College of Technology and Engineering, MPUAT, Udaipur, India. He received his Bachelor’s degree from MNIT, Jaipur; Master’s from M.B.M. Engineering College, Jodhpur; and Doctorate from Indian Institute of Technology, Delhi, India. His research interests include creep and shrinkage of composite structures and durability of concrete structures.

**Sandeep Chaudhary** is an Associate Professor in the Discipline of Civil Engineering at IIT Indore, India. Prior to joining IIT Indore, he was faculty MNIT Jaipur, India for 20 years. He received his Bachelor’s degree from M.B.M. Engineering College, Jodhpur; Master’s from Malaviya Regional Engineering College, Jaipur; and Doctorate from Indian Institute of Technology, Delhi, India. He carried out Post-Doctoral Research at Kunsan National University, Kunsan, South Korea. His research interests include prediction of service load behavior of structures and durability of concrete structures.

**Abhishek Jain** is pursuing his Ph.D. program from MNIT Jaipur. He received his M. Tech. degree from College of Technology and Engineering, MPUAT, Udaipur, India in 2016 and Bachelor’s degree in 2014 from Sir Padampat Singhania University, Udaipur. His research interests include durability of concrete and utilization of waste materials in concrete.