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Utilization of shredded waste plastic bags to improve impact and abrasion resistance of concrete

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Abstract

Plastic bags (PB) have become a requisite part of human beings in the present time. Hundreds of varieties of plastic bags are used for packing and protecting general things. The disposal of PB is a prime environmental problem which significantly threatens the environment, as its disposal affects fertility of land due to its non-biodegradable nature; it lowers useful land area and generates toxic gases on incineration. Hence, there is a requirement of useful applications for these increased quantities of wastes. The usage of waste plastic bags (WPB) in concrete not only solve dumping crisis of WPB but also yields cost-effective concrete, which is worthy to both plastic recycling and construction industry. In this study, the influence of shredded WPB as fine aggregate on the properties of concrete was evaluated. The replacement of WPB was maintained at 0, 5, 10, 15 and 20% by weight of fine aggregate. The finding of the tested samples showed that the workability, density, compressive strength, flexural strength, static and dynamic modulus of elasticity of concrete samples decreased with increase in the WPB content, while penetrability to water increased. Microstructural analysis of the plastic waste concrete (PWC) specimens was carried out using scanning electron microscope. The microstructural studies indicated the presence of voids and openings between mortar matrix and WPB which was the main reason for the inferior properties of PWC. However, there has been a significant improvement in abrasion resistance, impact resistance and energy absorption capacity of PWC.

Keywords Plastic bags · Modulus of elasticity · Abrasion resistance · Impact resistance · Energy absorption capacity · Microstructural analysis

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1 Introduction

Concrete is a composite material incorporating binder (mainly cement), aggregate (fine and coarse), water and admixtures and is one of the most largely used construction material (Muthukumar and Mohan 2004). The massive requirement of natural ingredients including cement and aggregate for the production of concrete causes scarcity of natural ingredients and leads to substantial pollution (Gupta et al. 2016). Therefore, there is a need for a new alternate material which can replace natural resources.

In the present time, plastic has turned out to be a requisite part of living beings (Siddique et al. 2008). The consumption of plastic in India was 8.5 million tons in the year 2007, which is estimated to increase to 20 million tons by the year 2020 (CPCB 2015). In India, about 6000 tons are discarded everyday as litter out of more than 15,000 tons of plastic waste (Dave 2016). Sharma and Bansal (2016) also reported that only 60% plastic waste is collected out of 689.5 tons of plastic waste (PW), in Delhi, India. The waste from plastic industry is expanding all over the world at an alarming rate. Globally, by the end of 2050, the plastic waste (PW) will be touched to 12 billion tons (Wallace 2017). The disposal of PW in an open environment produces serious problems such as reduction in fertility of land because of its low biodegradability, lowers useful land area, and generates toxic gases on incineration (Siddique et al. 2008). In rural and urban areas, the biggest problem is dumping and disposal of plastic waste (PW) in the open environment. It has been observed that PW stays untreated and becomes a leading crisis for the environmental cleanliness even after the availability of well-organized recycling plant and waste administration in a lot of cities (Bhogayata et al. 2013). The shortage of area for landfilling and the adverse environmental effect of PW are the prime reasons to find its alternative utilization (Marzouk et al. 2007). The proposal of mixing of PW in concrete could become a very profitable and environmentally effective approach for its disposal.

Significant research work is available on the utilization of PW, especially high-density polyethylene (HDPE) plastic, in concrete. Naik et al. (1996) examined the compressive strength of concrete by adding HDPE plastic and showed that beyond 0.5% PW addition by volume of mix, the compressive strength of plastic waste concrete (PWC) decreased drastically. Marzouk et al. (2007) studied the mechanical and durability properties of mortar samples comprising of waste polyethylene terephthalate (PET) bottle as fine aggregate replacement and reported that compressive strength, flexural strength, modulus of elasticity of plastic waste concrete (PWC) decreased with increasing amount of PW. Ismail and Al-Hashmi (2008) evaluated the properties of concrete incorporating shredded plastic waste (prepared from discarded containers) as replacement of fine aggregate by weight and observed lower values of slump, density, compressive strength and flexural strength for PWC as compared to control concrete. Thorneycroft et al. (2018) used the different types of HDPE plastics in different sizes in concrete as replacement of fine aggregate by volume and concluded that concrete can be produced by using graded HDPE waste as replacement of sand. Other authors also evaluated the effect of HDPE plastic waste in concrete (Albano et al. 2009; Frigione 2010; Borg et al. 2016; Islam et al. 2016; Marthong and Sarma 2015; Islam and Gupta 2016; Ramadevi and Manju 2012) and in mortar (Hannawi and Prince-Agbodjan 2014; Al-Tulaian et al. 2016). Al-Hadithi and Hilal (2016) and Alqahtani et al. (2016) assessed the effect of PET waste in self-compacting concrete and lightweight concrete, respectively, and noticed the reduction in strength due to poor interface bonding. They concluded that PWC could be utilized for the production of low strength construction components, for example, road barriers, pavement blocks, concrete curbs and sidewalks.

Some researchers also carried out the investigation using the waste plastic bag (WPB) in concrete. Ghernouti et al. (2011) examined the effect of recycled plastic aggregate (granular shape) obtained by the heating, cooling and crushing of WPB in the concrete, as a volumetric substitution of fine aggregate up to 40%. They found that the density, compressive strength, flexural strength and ultrasonic pulse velocity of PWC decreased, whereas workability increased due to the smoother surface of the plastic aggregate. Ghernouti et al. (2015) also determined the influence of recycled plastic fiber made by heating, cooling, extraction and cutting of WPB in self-compacting concrete. Bhogayata et al. (2012, 2013) also studied the effect of shredded WPB in the concrete by performing workability, compressive and split tensile strength test. They noticed reduction in workability and strength of PWC because of the partial compaction and incomplete hydration of cement paste, respectively, owing to macrofibers of WPB. Another investigation by Bhogayata and Arora (2017) examined workability and strength properties of concrete incorporating metalized plastic fibers produced by waste food wrapping articles. They reported that the fluidity and strength of PWC decreased substantially with the increase in PW by volume of concrete mix. Bhogayata and Arora (2018) investigated the effect of waste metalized plastic fibers obtained from food packing films on concrete properties. They reported that workability and compressive strength of concrete decreased with the increase in dosage of waste metalized plastic fibers by volume of mix. Mohammadhosseini et al. (2018) added waste metalized plastic fibers obtained from food packing films in concrete and reported that the slump and compressive strength of concrete decreased with the increase in dosage of waste metalized plastic fibers by volume of mix. Foti (2013) prepared concrete mixtures containing 0, 0.5, 0.75 and 1% dosage of PET fiber and reported that to achieve workable concrete mixtures; it required higher dosage (0.8%) of superplasticizer at 1% incorporation of PET fiber as compared to mixtures prepared by using less than 0.75% PET fiber. Borg et al. (2016) incorporated 1% dosage of superplasticizer in concrete mixtures containing PET fiber to achieve desired workability of modified concrete mixtures and proper distribution of PET fibers within concrete. Colangelo et al. (2016) also added higher dosage of superplasticizer in concrete containing polyolefin waste plastic aggregates than the control mixture in order to achieve similar workability. They reported that despite the addition of higher dosage superplasticizer in concrete, there was the slight decrement in the slump of concrete as the increment in the percentage of polyolefin waste plastic aggregates.

Few studies have been carried out concerning the influence of PW on water permeability, abrasion resistance, and impact resistance of PWC. The resistance to water, resistance to abrasion and higher energy absorption characteristics are necessary for water-retaining structures, hydraulic structures, and structures subjected to dynamic/impact loading, respectively. Islam and Gupta (2016) examined the effect of polypropylene fibers on concrete specimens and found the higher penetration of water through PWC specimens due to the enhanced interfacial transition zone. Saikia and de Brito (2014) observed the improved resistance to abrasion of concrete specimens containing PET waste as volumetric substitution of natural aggregate. Hannawi et al. (2010) studied the toughness behavior of mortar specimens containing PET waste as volumetric substitution of natural fine up to 50% and stated that PWC specimens had higher energy absorbing capacity than specimens without PW. Ismail and Al-Hashmi (2008) noticed fewer cracks in PWC specimens as compared to control concrete specimens due to the crack-arresting mechanism of PW. Mohammadhosseini et al. (2018) evaluated the impact resistance of concrete containing waste metalized plastic fibers by volume of mix and reported that resistance to impact increased with the increase in dosage of waste metalized plastic fibers. Bhogayata and Arora (2017) also observed the significant deformation behavior of PWC specimens.

It is clear from above matters that very limited number of studies is available on the incorporation of WPB, especially shredded plastic bags pieces, in concrete. It is also observed from the above-given literature that the properties of concrete like abrasion resistance, water permeability, static and dynamic modulus of elasticity, impact resistance, energy absorption capacity and microstructure analysis of concrete were not investigated by using WPB.

Given the above discussions, an experimental study has been conducted to illustrate some properties of this modified concrete. In this study, WPB is utilized in the shredded form in an amount of 0–20% by weight as substitution of fine aggregate in the concrete and mechanical, durability, abrasion and impact characteristics of PWC specimens were investigated. Microstructure analysis of PWC specimens was also carried out to observe the bonding between cement paste and WPB.

1.1 Research significance

The usage of waste plastic bags (WPB) in concrete not only solve dumping crisis of WPB but also yields cost-effective concrete, which is worthy to both plastic recycling and construction industries. The abrasion resistance, impact resistance and energy absorption capacity are important for various construction applications, which can be improved by using WPB in concrete. Most of the researchers had investigated the effect of metalized plastic aggregate prepared from food packing particle on concrete properties. Very limited investigations have been carried out on the incorporation of non-metalized WPB in concrete. Therefore, this study was carried out to develop modified concrete by using WPB for sustainable construction.

2 Materials and mix design

To accomplish the objectives of this experimental investigation, the work was undertaken as per following steps.

2.1 Materials

Cement, fine and coarse aggregates, WPB and tap water were utilized to produce concrete mixes with and without WPB. Ordinary Portland cement (OPC) of 43-grade was used. Natural river sand belonging to zone-II was utilized as a fine aggregate according to BIS:383 (2016). Two sizes (10 and 20 mm) of coarse aggregate were utilized for this investigation according to BIS:383 (2016). Based on the laboratory test, the properties of cement and aggregate (fine and coarse aggregate) are presented in Tables 1 and 2, respectively. The sieve analysis of river sand (size < 4.75 mm) and coarse aggregate is shown in Figs. 1 and 2, respectively. The PW used in this study consists of WPB which was collected from the local dumping units. The shredding machine, as shown in Fig. 3, was utilized for shredding the WPB. The WPB was placed into shredding hopper, and shredding machine was then started. The shredded pieces of WPB passed 10 mm opening sieve were collected and utilized for this study as shown in Fig. 4. The shredded pieces of WPB were in the fiber form. The properties and size distribution of WPB are shown in Table 3 and Fig. 1, respectively.

Table 1 Physical properties of cement

Properties	Specifications as per BIS:8112-1989	Results
Consistency	–	32%
Initial setting time	30 min (min)	130 min
Final setting time	600 min (max)	213 min
Specific gravity	–	3.13
7-day compressive strength	33 MPa	34.95 MPa
28-day compressive strength	43 MPa	45.29 MPa

Table 2 Properties of aggregate

Properties	Results
Specific gravity of fine aggregate	2.63
Specific gravity of coarse aggregate	
(i) 10 mm size	2.70
(ii) 20 mm size	2.78
Fineness modulus of fine aggregate	2.83
Fineness modulus of coarse aggregate	
(i) 10 mm size	6.29
(ii) 20 mm size	7.06
Water absorption of fine aggregate	0.4%
Water absorption of coarse aggregate	
(i) 10 mm size	0.5%
(ii) 20 mm size	0.7%

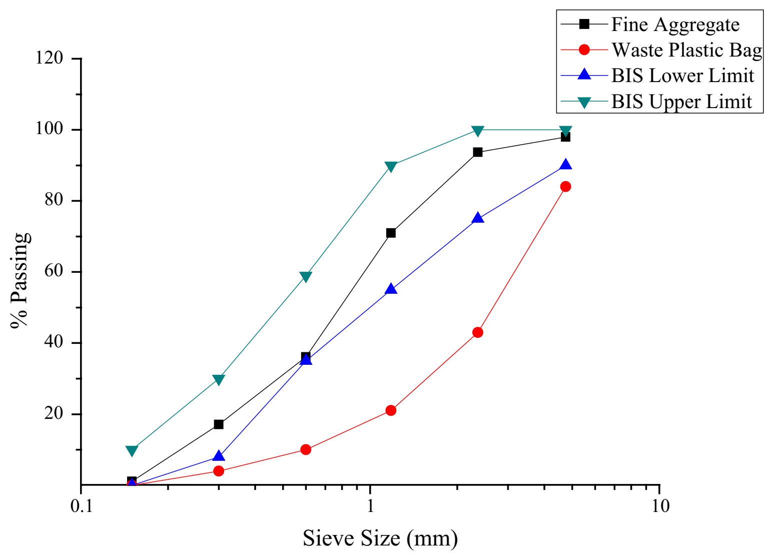


Fig. 1 Sieve analysis of fine aggregate and waste plastic bag along with BIS limits

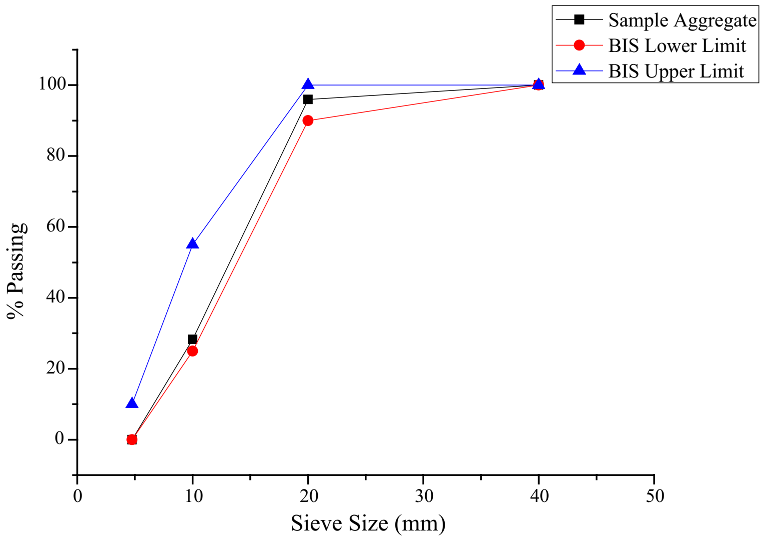


Fig. 2 Sieve analysis of coarse aggregate along with BIS limits

Fig. 3 Shredding machine

2.2 Mix design

The concrete mix design was made as per the guidelines which are given in (BIS:10262 2009). The mix proportion for the control (without PB) and the other mixes containing

Fig. 4 Shredded plastic bags

Table 3 Properties of WPB

Properties	Results
Type	Low-density polyethylene
Category	Normal household bags
Color	White
Thickness (mm)	0.025–0.040
Size	
(i) Length (mm)	15–30
(ii) Width (mm)	3–5
Shape	Straight and non-uniform
Specific gravity	0.39
Water absorption (%)	0

Table 4 Mix proportion of concrete

WPB (%)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)		WPB (kg/m^3)
			10 mm	20 mm	
0 (Control mix)	425.73	653.92	470.78	706.16	0
5	425.73	621.22	470.78	706.16	32.70
10	425.73	588.52	470.78	706.16	65.40
15	425.73	555.83	470.78	706.16	98.09
20	425.73	523.14	470.78	706.16	130.78

a different percentage of WPB are shown in Table 4. The WPB fibers were incorporated in an amount of 0, 5, 10, 15 and 20% by weight substitution of sand for the development of concrete mixes, and the water–cement ratio was fixed at 0.45. In this way, total 120 concrete specimens of cubes, cylinders and beams were cast with the inclusion of WPB.

3 Testing procedure

3.1 Workability and density

Slump test and compacting factor test were carried out as per the BS EN:12350-2 (2009) and BS EN:12350-4 (2009) for checking the workability of concrete mix. The density of 150 mm cubic specimens was evaluated after 28 days of curing.

3.2 Compressive strength

Compressive strength was evaluated on 100 mm cubic specimen as per the BS EN:12390-3 (2009). This test was conducted on 7- and 28-day-cured specimens using compression testing machine. The loading rate for the test was maintained at 140 kg/cm^2/min.

3.3 Flexural strength

Flexural strength of concrete mixes was evaluated for beam specimens of 500 mm × 100 mm × 100 mm as per the BS EN:12390-5 (2009). The flexural strength test was conducted on beams after 28 days of curing, and digital flexural testing machine of 200 kN capacity was used for testing specimens. The specimens were placed on the supporting rollers of the machine having a distance of 400 mm between them. Two point loading systems were used on the specimen at a distance of 133.33 mm between them, and the load was then applied without vibration or shock at a rate of 180 kg/cm^2/min until the failure of specimen.

3.4 Static modulus of elasticity

Static modulus of elasticity was performed after 28 days of curing on cylindrical specimens (300 mm height and 150 mm diameter) following the guidelines of ASTM:C469 (2014). The 300 ton capacity of automatic compression testing machine was used in order to measure the modulus of elasticity with the aid of subsequent expression 1:

$$K_s = \frac{(A_2 - A_1)}{(\varepsilon_2 - 0.000050)} \tag{1}$$

where K_s = modulus of elasticity (MPa); A_2, A_1 = stress at 40% of ultimate load (MPa) and longitudinal strain of 50 millionths, respectively, and ε_2 = longitudinal strain corresponding to stress A_2.

3.5 Dynamic modulus of elasticity

For this test, 150-mm cubic specimens were cast to calculate the dynamic modulus of elasticity as per the guidelines are given in the ASTM:C597 (2016). The test was performed on

28-day-cured specimens with the help of portable ultrasonic pulse velocity (UPV) tester. Transducers with the frequency of 54 kHz were used to transmit and receive the pulse through the specimen. The following expression 2 given by Topçu and Bilir (2009) was taken in order to calculate the dynamic modulus of elasticity, E_d.

$$E_d = \frac{\rho V^2}{g \times 100} \tag{2}$$

where E_d = dynamic modulus of elasticity (GPa), ρ = density of concrete specimen (kg/m^3), V = pulse velocity (km/s) and g = acceleration equal to 9.81 m/s^2.

3.6 Water permeability

For measuring water permeability, 150-mm cubic concrete specimens after 28 days of curing were subjected to a water pressure of 5 bar for 3 days as per the guidelines of DIN:1048 (1991). In this process after 3 days, the depth of water penetration was calculated by splitting the specimen into two parts.

3.7 Abrasion resistance

It is the property that allows material and structure to withstand the effect of abrasion, for example, rubbing, scraping and repeated wearing. Abrasion resistance test was performed on the specimen size of 100 mm cubes after 28 days of curing as per the recommended guidelines of (BIS:1237 2012). The loss of thickness was calculated using the subsequent expression 3.

$$t = \frac{(P_1 - P_2) \times V_1}{P_1 \times A} \tag{3}$$

where t = thickness loss (mm), P_1 = initial weight (g), P_2 = weight after abrasion (g) and V_1, A = initial volume (mm^3) and area of the specimen (mm^2), respectively.

3.8 Impact resistance through drop weight

This test was performed on the 28-day-cured cylindrical specimen having a size of 150 mm in diameter and 75 mm in height according to ACI:544 (1999), and employed apparatus is displayed in Fig. 5. Hammer ball of 4.5 kg was dropped on the steel ball of 65 mm diameter, which was put at the center of the cylindrical specimen. The dropping height was maintained at the 450 mm from the top of the steel ball. During the test, a number of blows (B_1) and a number of blows (B_2) were recorded when the first crack and final failure of the specimen were seen, respectively. The impact energy absorbed by specimens for the first crack and final failure of specimens was calculated by using the subsequent Eqs. 4 and 5, respectively.

$$E_{fc} = B_1 \times m \cdot g \cdot h \tag{4}$$

$$E_{ff} = B_2 \times m \cdot g \cdot h \tag{5}$$

where E_{fc} = impact energy at first crack corresponding to B_1, E_{ff} = impact energy at final failure corresponding to B_2, m = mass of the hammer taken as 4.5 kg, g = acceleration taken as 9.81 m/s^2, and h = drop height taken as 450 mm.

Fig. 5 Impact testing machine

3.9 Energy absorption capacity

Falling weight impact test setup was used for measuring the energy absorption capacity of concrete specimen up to failure. Testing setup consisted of falling weight impact frame (shown in Fig. 6), data acquisition system, signal conditioner module, motor controller and computer system. The test was conducted on 28-day-cured concrete specimens of size 500 mm × 100 mm × 100 mm. The falling weight impact frame consisted of a load cell (i.e., falling weight) of 25 kg which was allowed to freely fall on the concrete specimen from 0.5 m height with a velocity of 3.13 m/s. The data acquisition system software attached to the impact frame then recorded the deflection and the load data in the user-specified files. The same data files were used for postprocessing for energy calculations. The energy consumed by specimens was then calculated with the help of impact energy software by selecting the section from the graph of load and deflection. This process is called windowing.

3.10 Microstructural analysis

The microstructure attributes of PWC were evaluated by using the scanning electron microscope (SEM) of "ZEISS" brand at extra-high tension acceleration voltage of 20 kV. The small 10 mm × 10 mm specimens were cut from PWC for performing this test. Before conducting this test, the slight deposition of gold was applied to the surface to make the specimen conductive for proper and clear images.

Fig. 6 Falling weight impact testing machine

4 Results and discussion

The results of each test have been reported in an average of three specimens. The findings for each mix were then compared against control mix.

4.1 Workability

The workability of concrete containing WPB as partial substitution of natural river sand was evaluated by conducting slump and compaction factor test. The results of both tests are displayed in Fig. 7, where the error bars show the standard deviation. The workability of concrete observed from different concrete mixes showed that the slump and compaction factor values for the control mix was obtained as 81 mm and 0.91, respectively, while 12 mm slump and 0.68 compaction factor was achieved at the 20% fine aggregate replacement, respectively. The general trend of the slump and compaction factor values showed that swapping of fine aggregate with WPB lowered the workability of the PWC as compared to the control mix. The compaction factor decreased slightly from 0.91 for the control mix to 0.86 at 5% content of WPB, while slump value decreased from 81 mm for the control mix to 69 mm at 5% content of WPB. A further rise in the WPB content resulted in a massive reduction of the slump and compaction factor values. The higher replacement of WPB with fine aggregate influences the consistency and viscosity of the concrete mixtures, which was due to the balling effect of WPB and concrete constituents. Therefore, a higher/appropriate dosage of superplasticizer is required to make workable concrete containing 15

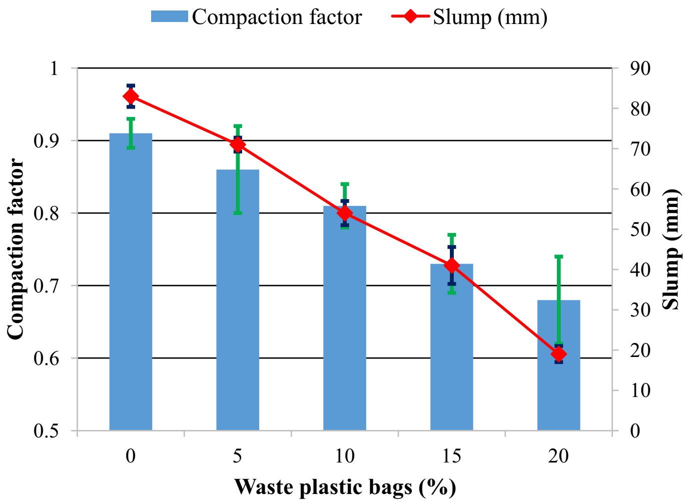


Fig. 7 Influence of waste plastic bags on slump and compaction factor values of PWC mixes

and 20% PW. The workability of PWC mixture can be improved by incorporating superplasticizer, which aids in the reduction of balling effect, segregation, voids and honeycombs in the mixtures related to the better dispersion of WPB fibers.

Slump and compaction factor of concrete containing WPB were reduced by 14.81 and 5.49% at 5% replacement of fine aggregate, respectively, and by 85.19 and 25.3% at 20% replacement of fine aggregate, respectively. In the present investigation, the decreased in workability may be due to the long and non-uniform shape of WPB fibers which may result in less fluidity and high voids and finally reduced the workability. The smooth surface and low density of WPB caused segregation and improper cohesiveness leading to declining in workability. Despite reduction of workability, the PWC mixtures falls into the category of low workability range (for slump: 25–75 mm and for compacting factor: 0.78–0.85) up to 15% WPB content (Shetty 2013). The PWC mixtures can thus be used in lightly reinforced section, pavement, slab and mass concreting work up to 15% WPB content. Bhogayata et al. (2012) also observed a similar reduction in the compaction factor of concrete comprising WPB. Ismail and Al-Hashmi (2008) had obtained the 95.33% reduction in slump of concrete at 20% replacement of waste plastic container (in shredded form) with fine aggregate by weight (Albano et al. 2009) found nearly 60% reduction in the slump of concrete on 20% volumetric replacement of fine aggregate with shredded particles of PET bottle. The reduction in workability of concrete containing HDPE plastic was also observed by many authors (Al-Hadithi and Hilal 2016; Frigione 2010; Kan and Demirboğa 2009; Marthong and Sarma 2015; Naik et al. 1996; Rahmani et al. 2013).

4.2 Density

The density of PWC after 28 days curing of 150 mm cubic specimen is displayed in Fig. 8, where the error bars show the standard deviation. The density of PWC was observed as 2408.82, 2279.41, 1900, 1691.18 and 1455.88 kg/m^3 at 0, 5, 10, 15 and 20% replacing of fine aggregate with WPB, respectively. The general trend of density decreased on the inclusion of WPB. If the density of concrete is varied from 1400 to 1800 kg/m^3, then it can be

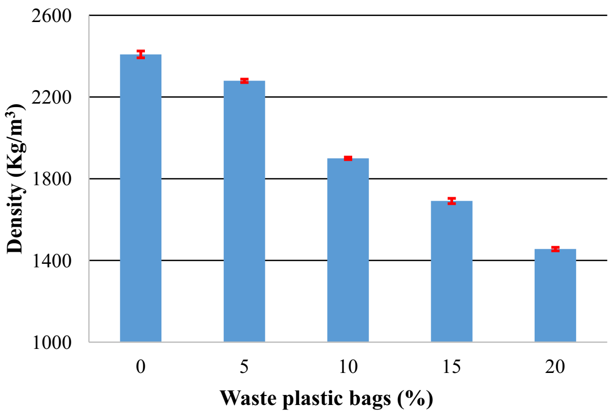


Fig. 8 Influence of waste plastic bags on density of PWC mixes

termed as lightweight concrete (Neville and Brooks 1987). The density of concrete specimens, in this work, was obtained more than 1400 kg/m^3. Therefore, the WPB can be used for the production of lightweight concrete. The density of PWC specimens was reduced by 5.37 at 5% WPB content; however, it was reduced by 39.56 at 20% WPB content.

The decrease in density of PWC is mainly due to the low specific gravity of WPB (0.39) as compared to that of river sand (2.63). The low slump and compaction factor values as reported in Sect. 4.1 can also be the reason for this reduction. The lower density of PWC was also reported by many authors (Ghernouti et al. 2011; Ismail and Al-Hashmi 2008; Ruiz-Herrero et al. 2016).

4.3 Compressive strength

The compressive strength of concrete specimens containing WPB as partial substitution of natural sand at 7 and 28 days curing are presented in Fig. 9, where the error bars show the standard deviation. Though the compressive strength of the PWC specimens increased with the increase in curing age irrespective of WPB, the general trend of the compressive strength is decreasing with the incorporation of WPB.

The compressive strength of concrete without WPB after 7 days of curing was observed as 17.8 MPa, while it was reduced to 1.6 MPa at 20% replacement of fine aggregate by

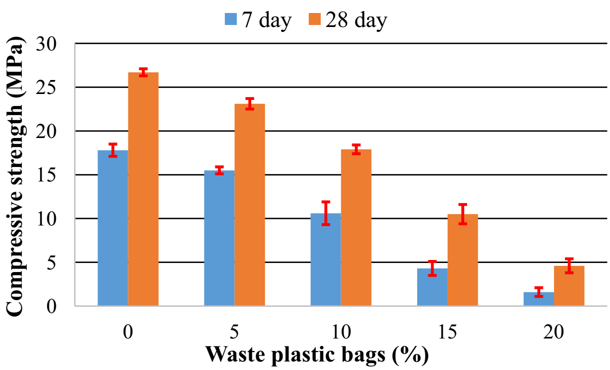


Fig. 9 Influence of waste plastic bags on compressive strength of PWC mixes

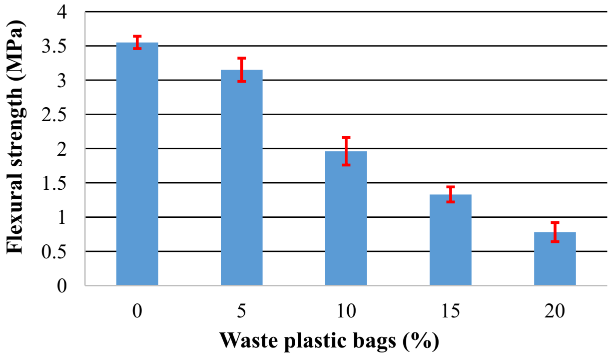
WPB. For 28 days of curing, the compressive strength of concrete specimens was observed as 26.7 and 4.6 MPa for an amount of 0 and 20% WPB content, respectively. The compressive strength of PWC was reduced by 13.48% for an amount of 5% WPB, whereas the significant decline was observed by 82.77% for an amount of 20% WPB content. However, the concrete can be used for structural work if it has minimum strength 17.5 MPa according to ACI 318 (2015). At replacement of 10% of WPB content with fine aggregate in concrete, 17.9 MPa strength of PWC was achieved in this study. PWC can thus be used for structural concrete work up to 10% of WPB content.

In this analysis, the significant decrease in compressive strength was because of (i) the reduction in interface bonding between the surfaces of WPB and cement paste and (ii) the large particle size of the WPB, which increased the pores and cavities in the concrete (Bhogayata et al. 2013; Ghernouti et al. 2011). The decrement in compressive strength of PWC in this study is due to the presence of pores and voids in concrete. Other authors also mentioned the decrement in strength of concrete containing PW (Albano et al. 2009; Ghernouti et al. 2011; Ismail and Al-Hashmi 2008; Bhogayata et al. 2012, 2013; Bhogayata and Arora, 2017; Choi et al. 2005). Ferreira et al. (2012) and Hannawi et al. (2010) have also noticed up to 50 and 47.1% decrement in compressive strength of cement based composite on 15 and 20% replacement of natural aggregates by PW, respectively. A reduction in compressive strength of SCC has been observed by Hama and Hilal (2017), when sand was replaced with PW due to its soft nature as compared to the sand.

4.4 Flexural strength

The flexural strength of concrete specimens comprising of WPB as partial substitution of natural sand at 28 days curing is presented in Fig. 10, where the error bars show the standard deviation. The flexural strength of PWC was observed as 3.55 and 0.78 MPa for an amount of 0 and 20% WPB content, respectively. The flexural strength of PWC was reduced by 11.27 at 5% replacement of fine aggregate and it reduced by 78.02 at 20% swapping of river sand by WPB. It diminished significantly at the higher percentage of WPB content. The significant decrease in flexural strength is because of the weak interfacial transition phase between WPB and cement paste. The soft nature and low strength of WPB can also be an influencing factor in the reduction of flexural strength. The hydrophobic nature of WPB which confines the hydration of cement lowers the strength carrying capacity of flexural. The decline in the strength of PWC has also been observed by many researchers (Al-Hadithi and Hilal 2016; Alqahtani et al. 2016; Ghernouti et al. 2011; Ismail and

Fig. 10 Influence of waste plastic bags on flexural strength of PWC mixes



Al-Hashmi 2008; Bhogayata and Arora 2017; Bouziani et al. 2014; Frigione 2010). The former study was done by Albano et al. (2009) also realized up to 70% reduction in flexural strength on 20% swapping of sand by shredded particles of PET bottle.

The trend of decline in flexural strength is alike to compressive strength. However, on comparing both strengths with control mix at a same amount of WPB, for instance at 5%, the lesser reduction in flexural strength (by 11.27%) was found with respect to the compressive strength (by 13.27%). This behavior showed the slight ductile nature of PWC due to a relatively long particle of WPB, which prevent the onset of cracking. The same result was also observed by Bhogayata and Arora (2017) who utilized fiber of waste food wrappers article in their study.

4.5 Static modulus of elasticity

The static modulus of elasticity of the 28 days cured concrete specimen comprising of WPB as partial exchanging of natural river sand for 0.45 w/c is displayed in Fig. 11, where the error bars show the standard deviation. The trend of decrement of the modulus of elasticity with the increment in WPB content is alike to compressive strength. The static modulus of elasticity was observed as 26100 MPa for an amount of 0% WPB, while it was obtained as 7862 MPa for 20% of WPB content. The decrement in static modulus of elasticity with respect to control mix was seen as 6.32 and 69.88% at 5 and 20% substitution of sand, respectively.

Previous authors (Albano et al. 2009; Ghaly and Gill 2004; Hannawi et al. 2010; Kim et al. 2010; Marzouk et al. 2007; Yang et al. 2015) also observed the reduction in modulus of elasticity of concrete incorporating HDPE plastic. Liu et al. (2013) reported up to 40% decrement in static modulus of elasticity on 20% volumetric replacement of sand by polycarbonate plastic particle. The decrement in static modulus of elasticity probably can be because of the low modulus of elasticity and low rigidity of PW compared to natural aggregate (Rahmani et al. 2013). The substantial decline in static modulus of elasticity was obtained with the increment in WPB content due to the reduction in paste amount which was related to the quantity and size of WPB. The reduction in modulus of elasticity of PWC may also be due to the weak bond between WPB and cement. Due to the alike aforementioned reason, (Hannawi et al. 2010) detected up to 69% reduction in modulus of elasticity of concrete on 50% volumetric substitution of sand by the waste PET. This above-discussed behavior indicates the higher flexibility as well as better deformation characteristics

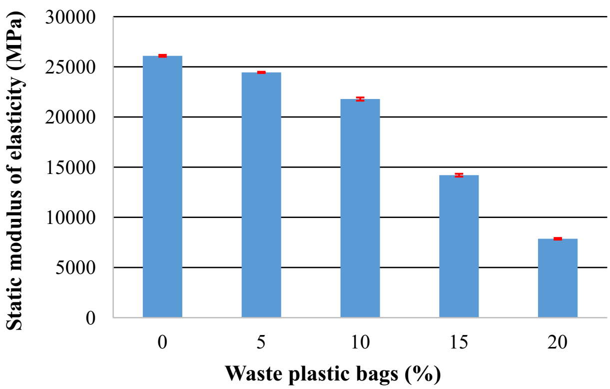


Fig. 11 Influence of waste plastic bags on static modulus of elasticity of PWC mixes

of concrete samples incorporating the WPB. The improvement in flexibility characteristics can be viewed as positive gain for the PWC mixtures which can be used in construction application where flexibility is prime concern rather than strength.

4.6 Dynamic modulus of elasticity

The dynamic modulus of elasticity of the 28-day-cured concrete specimen comprising of WPB as substitution of fine aggregate is displayed in Fig. 12, where the error bars show the standard deviation. This test is performed by measuring pulse velocity without any application of stress. For an amount of 0% of WPB, the dynamic modulus of elasticity was obtained as 52.89 GPa, while it was obtained as 4.18 GPa for 20% of WPB content. The decrement in dynamic modulus of elasticity with respect to control mix was seen as 20.49 and 92.09% at 5 and 20% substitution of sand, respectively.

The drop in dynamic modulus of elasticity is mainly because of the low modulus of elasticity of WPB. The weak attachment between cement paste and WPB is also a probable reason for the aforesaid reduction. The other reason for the decrement in dynamic modulus of elasticity may be due to absorption of ultrasonic waves in the voids of concrete matrix. The reduced modulus of elasticity of mortar composite incorporating waste PET as substitution of sand was also noticed by Marzouk et al. (2007), because of lower composite bulk density. The investigation relating to concrete incorporating the waste rubber fiber was carried out by Gupta et al. (2016) who observed the lower dynamic modulus of elasticity due to the lower density as well as the poor structure of rubberized concrete. A reduction in density was also found, in this work, which can also be the reason for the decline in dynamic modulus of elasticity of PWC.

4.7 Water permeability

The permeability of water in PWC was evaluated in terms of depth of water penetration and results of this test are presented in Fig. 13, where the error bars show the standard deviation. The ingress of water into the 150 mm concrete cubes containing WPB was observed as 24 mm and 150 mm at an amount of 0 and 20% altering of natural sand aggregate with WPB, respectively. At 20% quantity of WPB, the water completely transported through the concrete specimens. The general trend of water permeability increased with the inclusion

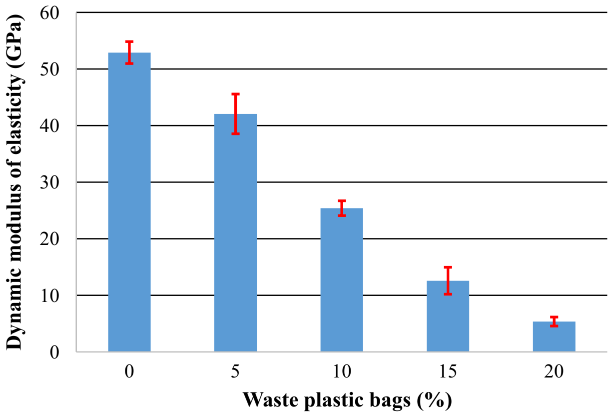


Fig. 12 Influence of waste plastic bags on dynamic modulus of elasticity of PWC mixes

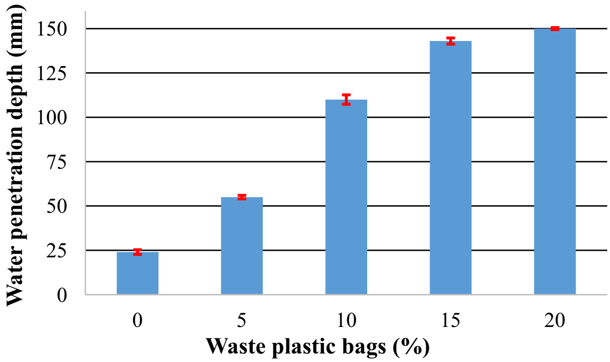


Fig. 13 Influence of waste plastic bags on water penetration depth of PWC mixes

of WPB and also exhibited high variation in water penetration. The depth of water penetration of concrete specimens containing WPB was increased up to 55 mm at 5% replacement of sand, while it increased up to 150 mm at 20% switching of sand with a comparison to control mix.

The prime cause for the significant ingress of water may be because of the higher number of voids in the structure of PWC resulting from the long size of PB and weak bonding between the cement paste and WPB particles. The significant permeability of PWC specimens may be due to the higher porosity which was related to the twisting of long WPB fibers within the concrete matrix. An earlier study done by Islam and Gupta (2016) has also observed the higher penetration of water into concrete by using polypropylene fiber because of the poor microstructure. According to the DIN:1048 (1991), the penetration depth of water has been divided into three groups as low (lower than 30 mm), medium (between 30 and 60 mm) and high (higher than 60 mm) permeability. The PWC in this study had been found in the category of medium permeability up to 5% replacing of sand; however, beyond 5% WPB content, the PWC was classified into the category of high permeability.

4.8 Abrasion resistance

The resistance to wear/abrasion of 100-cured concrete cube containing WPB as partial changing of natural aggregates is displayed in Fig. 14, where the error bars show the standard deviation. The resistance to wear of concrete was measured in the context of loss of thickness of the specimen. The depth of wear of concrete cubes was achieved as 0.42 mm for the control mix, whereas it was achieved as 0.21 mm at an amount of 20% WPB content. The depth of wear of concrete containing WPB was decreased by 14.29% at 5% replacement of natural fine, while it decreased by 50% at 20% replacing of natural fine. As far as the abrasion resistance is concerned, the results indicated that it enhanced with the increase in WPB. The decline in the depth of wear demonstrated the superior resistant to wear of PWC, which put the PWC into the category of heavy-duty purpose floor tiles (limit of depth of wear <2 mm) as per recommended guidelines of (BIS:1237 2012). The WPB can be used for the production of concrete paver blocks, which can be used in the construction of ramps, residential roads and rural road with low volume traffic, etc. The improvement in resistance to wear of PWC is mainly due to the less abrasion of WPB fibers, which can be seen by the surfaces of PWC specimens before abrasion (Fig. 15a) and

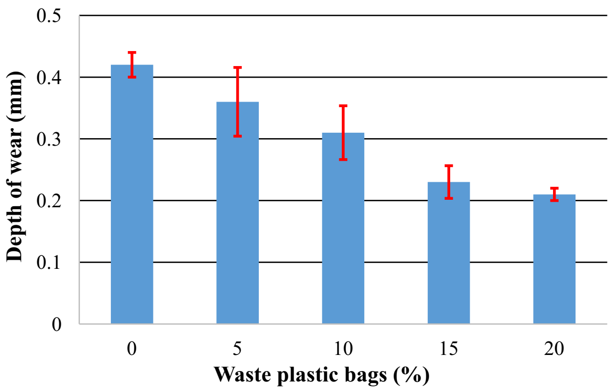


Fig. 14 Influence of waste plastic bags on abrasion resistance of PWC mixes

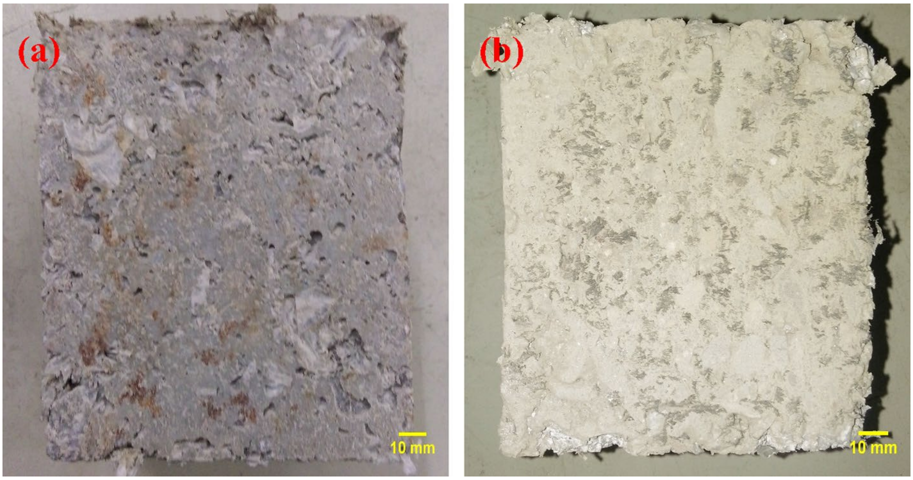


Fig. 15 Surface of PWC specimens, **a** before abrasion, **b** after abrasion

after abrasion (Fig. 15b). On the application of abrasion to the surface of specimens, there was higher pull out of sand particle compared to the plastic fibers due to the entanglement of WPB fibers within the concrete matrix, which eventually enhance the wear resistance of PWC specimens. The increase in abrasion resistance of concrete incorporating PW may also be due to the high toughness and good abrasion behavior of PW compared to the sand (Saikia and de Brito 2014).

4.9 Impact resistance through drop weight

The findings of this test concerning PWC are presented in Fig. 16, where the error bars show the standard deviation. The impact resistance was evaluated in terms of the number of blows. As shown in Fig. 16 that the usual trend of the number of blows for the first crack (B_1) and final failure (B_2) was increased with the increase in WPB as the substitution of natural fine. The number of blows for the first crack and final failure was achieved as 19 and 25 for the control mix, respectively, while it was obtained as 102 and 123 for an amount of 20% WPB content, respectively. The number of blows for the first crack and

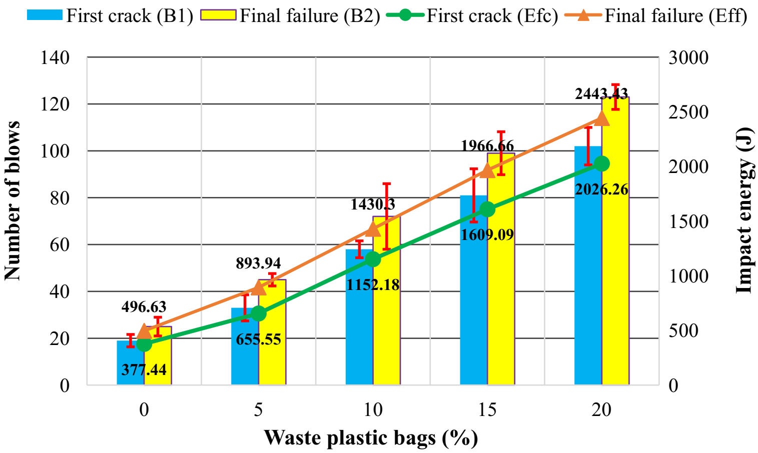


Fig. 16 Influence of waste plastic bags on impact resistance of PWC mixes

final failure was enhanced by 73.68 and 80% at an amount of 5% WPB, respectively, while it was enhanced by 436.84 and 392% at an amount of 20% WPB content, respectively.

The impact energy for the first crack (E_{fc}) and final failure (E_{ff}) was also enhanced along with the rose in the number of blows which can also be viewed in Fig. 16. Failure patterns for the concrete specimen comprising 0 and 20% WPB are shown in Fig. 17a, b, respectively. The better resistance to impact loading of PWC was obtained, in this work, may be because of the substantial energy absorbing capability and better flexibility nature of WPB as compared to the natural fine. During the impact load actions, the stresses were successfully transferred within the concrete constituents due to the crack-arresting effect of fibers. The WPB fibers had a length of approximately 15–30 mm which were stretching or elongating between two crack portions of specimens during the impact load action, ultimately the elongated WPB fiber averted the significant separation of specimens. The improved stresses distribution can also be recognized from the failure patterns of concrete specimens. The specimen comprising WPB (Fig. 17a) showed more number of cracks on the surface of PWC specimens as compared to the specimen prepared without WPB (Fig. 17b). The obtained outcomes of this study are in agreement with (Mohammadhosseini et al. 2018), who observed the improvement in impact resistance of concrete comprising post-consumer metalized plastic fibers by volume of concrete mix. The improvement in impact resistance was also mentioned by many authors (Liu et al. 2013; Marthong and Sarma 2015; Soroushian et al. 2003; Bayasi and Zeng 1993), who did the investigation on concrete incorporating the HDPE waste. The better resistance to impact properties of PWC mixtures can be utilized in several construction applications like crush barriers and road pavements. However the significant decline in strength limits the utilization of PWC mixtures, these mixtures can thus be produced by replacing 5% of sand with WPB.

4.10 Energy absorption capacity

Load and displacement relationship for PWC is shown in Fig. 18. The measured energy absorption capacity of concrete specimens containing WPB as partial substitution of fine aggregate for 28 days curing is shown in Fig. 19, where the error bars show the

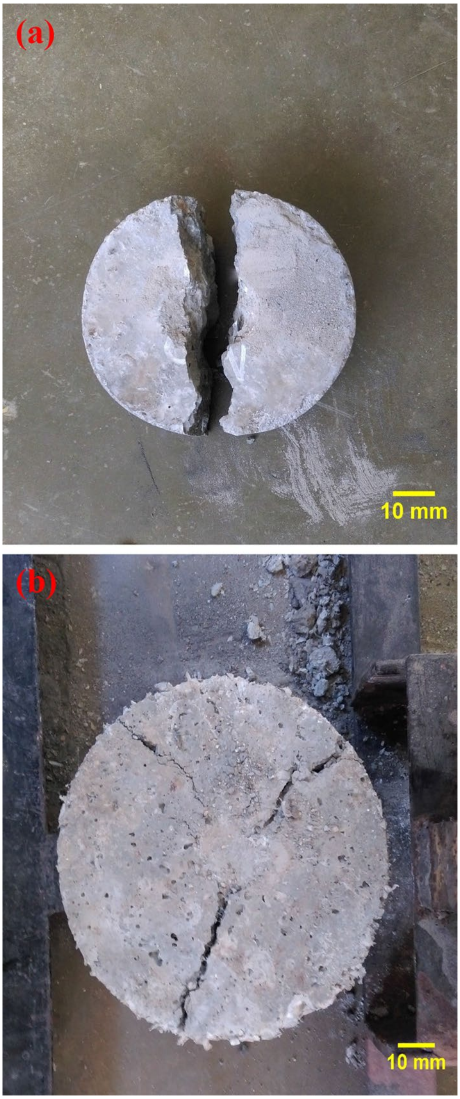


Fig. 17 Failure pattern. **a** Without WPB, **b** with 20% WPB

standard deviation. The general trend of the energy absorption capacity increased as the percentage replacement of fine aggregate with WPB increased. The energy absorption capacity was found as 0.33 J for the control mix, while it was obtained as 1.72 J for 20% WPB content. The increment in energy absorption capacity of PWC with respect to control mix was 127.27 and 421.21% for 5 and 20% WPB content, respectively. The increment in energy absorption capacity is better for PWC mixtures than control mixtures, but more than 5% of WPB in concrete results in significant decline of strength. Moreover, the concrete specimens comprising 5% of WPB coupled with enhanced energy absorption capacity and appropriate strength can be utilized in shock absorbers, crash barriers, and concrete road pavements, etc.

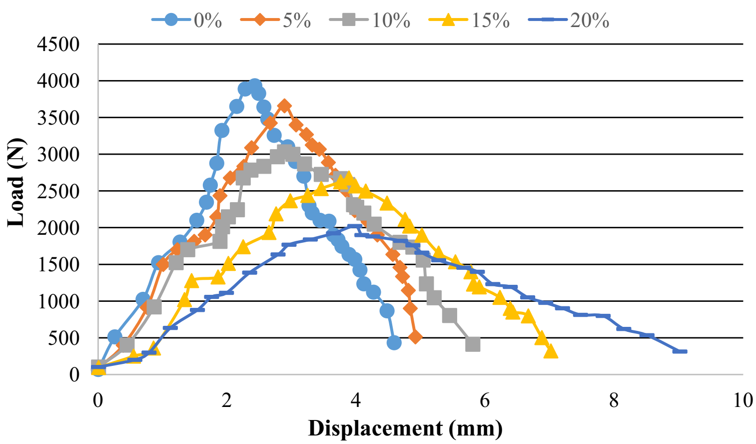
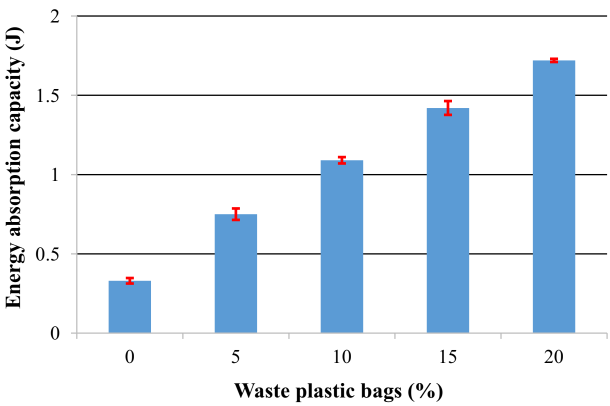


Fig. 18 Load and displacement relationship for PWC mixes

Fig. 19 Influence of waste plastic bags on energy absorption capacity of PWC mixes



The increase in the energy absorption capacity may be due to the high energy absorption capacity and low modulus of elasticity of WPB compared to the sand. The improvement in energy capacity may also be due to crack stitching effect of WPB fibers which slowed the failure process. The non-uniform shape of WPB fibers and their flexibility restrict the complete failure of PWC specimens because WPB fibers were intertwined between the two cracked surfaces. This slowdown of crack propagation with improved deformation capacity for PWC could be clearly seen in Fig. 18. The improvement in energy absorption capacity enhances the dynamic behavior of PWC. The effect of WPB on this characteristic has not been yet evaluated. However, both Liu et al. (2013) and Gupta et al. (2017) noticed the aforementioned behavior in their study concerning energy absorption capacity of concrete specimens containing HDPE fiber and rubber fiber as fine aggregate substitution, respectively.

4.11 Microstructural analysis

The interfacial properties of the 28-day-cured concrete samples containing WPB were analyzed using SEM. SEM images of PWC are displayed in Fig. 20a–c for the 10 and 20%

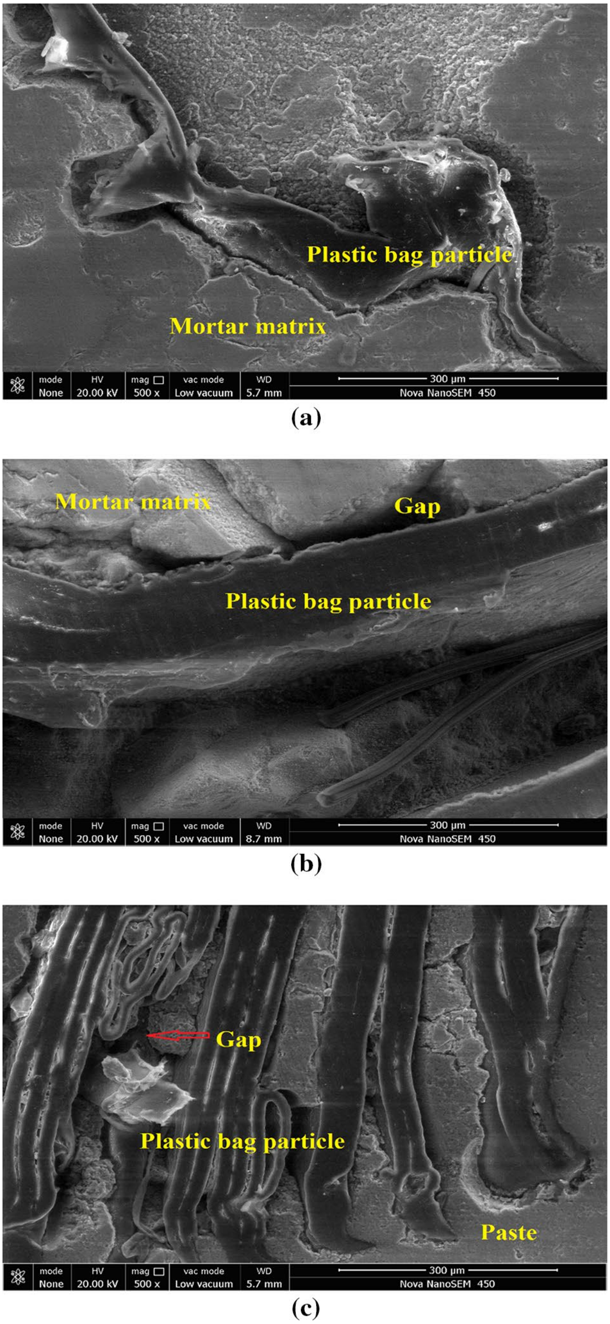


Fig. 20 SEM images of PWC mixes **a**, **b** 10% PB **c** 20% PB

substitution of natural fine with WPB, respectively, which were taken at 500× magnification. The interstices and voids between WPB and mortar composite were identified, which indicates the weak interface bonding between WPB and paste composite. The smooth surface of WPB particle is clearly seen in Fig. 20b, which ultimately leads the poor interfaces between WPB and mortar composites. Several gaps/voids had mainly accumulated along the WPB particle which can be clearly seen in Fig. 20c. These interstices, voids and smooth surface of WPB particle within the concrete matrix are the prime reason for the drop in compressive strength, flexural strength, and modulus of elasticity of PWC. The twisting of long WPB fiber in concrete affects the workability of the concrete matrix, and could also be the reason for the reduction of strength as the presence of twisted fiber can create voids. Moreover, the significant penetration of water in PWC specimens was also due to these gaps. Some authors (Hannawi et al. 2010; Marzouk et al. 2007), had also noticed the poor microstructure of plastic-cement composites.

5 Conclusion

The main intention of this study was to investigate the suitability of waste plastic bag (WPB) as a concrete ingredient and the following outcomes were drawn:

1. The workability and density of concrete specimens containing WPB decreased with increase in the percentage of WPB. The smooth surface and low density of WPB cause segregation and improper cohesiveness leading to declining in workability and density of concrete. However, workability can be enhanced by using suitable superplasticizer.
2. For mechanical strength properties, the weaker interface between WPB and cement paste results in substantially lower values as related to control concrete. The compressive strength values are still in the reasonable range for the 5% replacement of WPB. Moreover, strength of plastic waste concrete (PWC) could be enhanced by using suitable mineral admixtures.
3. The modulus of elasticity of concrete specimens containing WPB decreased with increase in the percentage of WPB; however, specimens containing WPB indicates the higher deformation capacity of PWC.
4. The formation of large gaps and voids on utilizing WPB as fine aggregate results in increased water permeability of concrete specimens. However, the water permeability of PWC was found in medium permeability range up to 5% WPB content, but it requires careful decision while applying to a water-retaining structure.
5. The strong polymeric behavior of WPB and brush like action of polythene provide better abrasion resistance of concrete specimens as related to control concrete. The enhanced resistance to wear of PWC specimens may be due to the entanglement of WPB fibers within the concrete matrix. The WPB can be used for the production of concrete paver blocks, which can be used in the construction of ramps, residential roads and rural road with low volume traffic, etc.
6. The use of WPB increased the impact resistance and energy absorption capacity of PWC as related to concrete mix without WPB. This improvement in impact and energy capacity was due to crack stitching effect of WPB fibers which slows down the failure process. The PWC mixtures can be used in construction application where resistance to impact and higher toughness is prime concern rather than strength.

7. The microstructural analysis reflects the weak adhesion between WPB paste composites which led to gaps/voids at the interface and consequently decreased the strength of PWC.
8. Based on the results, it can be concluded that WPB can be used as partial substitution of sand up to 5% by weight. The PWC can be used in a situation which requires lightweight and low strength construction such as concrete curb, concrete paver block, temporary structures, driveways, walkways and concrete barriers. Moreover, this modified concrete can also be employed to resist higher impact loading as well as resist wear and tear.
9. Durability studies can be carried out in future for carbonation, corrosion, shrinkage, chloride resistance and freeze–thaw action of PWC.

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