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Mechanical Propagates of Concrete with Partial Replacements of Sand by Plastic Waste of Vehicles under Impact Load

Mustafa Maher Al-Tayeb*
School College of Applied Engineering and Urban Planning, University of Palestine, PO Box 1075, Gaza, Palestine

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Abstract:

Plastic waste of vehicle causes serious health and environmental problems all over the world. As a possible solution to the problem of plastic waste of vehicle, an experimental study was conducted to examine the potential of using it as sand replacement in the concrete. This paper examines impact strength properties of concrete in which different amounts 2.5%, 5%, 10% and 20 % of plastic waste particles were used as sand replacement. For each amount, six cubes of 100 mm ×100 mm × 100mm were subjected to 4.5 kg hammer from 480mm height. The number of blows of the hammer required to induce the first visible crack of the cubes were recorded. The results are presented in terms of impact energy required for the first visible crack. The concrete mixtures exhibited ability to absorb a large amount of impact energy. The plastic waste of vehicle increased the first crack impact energy of concrete.

Keywords: Plastic waste of vehicle; Cement concrete; Compressive strength; Impact energy.

I. INTRODUCTION

The plastic waste of vehicle is considered as one of the major environmental problems faced by every country due to their health hazards and difficulty for land filling [1]. The reuse of wastes is important from different points of view. It helps to save and sustain natural resources that are not replenished, it decreases the pollution of the environment and it also helps to save and recycle energy production processes. Concrete has been identified to be one of the feasible options. Although concrete is the most commonly used construction material, it has limited properties such as low tensile strength, ductility, toughness and impact resistance [2].

Substantial research was carried out on the application of polymers in concrete [3-18]. Batayeneh et al. [3] showed the deterioration of compressive strength with an increase in the proportion plastic content. For the plastic proportion of 20% of sand, the compressive strength was reduced up to 70% compared to that of normal concrete. Recently, Marzouk et al. [4] studied the use of consumed plastic bottle waste as sand substitution aggregate within composite materials for building applications and showed the effects of polyethylene terephthalate (PET) waste on the density and compressive strength of concrete. It was found that the density and compressive strength decreased when the PET aggregates exceeded 5% by volume of sand.

Rahmani et al. [5], observed that the 5% replacement of fine aggregates with PET particles yields better results in compression. However, with further increase in polyethylene terephthalate particles to 10% and 15% the compressive strength of concrete decreases due to weak cohesion between the texture and the PET particles. Araghi et al. [6] reported that the concrete containing plastic waste has better sulfuric acid attack resistance in industrial structures and sewer pipes. Raj et al. [7] investigated the strength and behavior plain and fiber reinforced polymer concrete beam column joints and the results were compared with plain and steel fiber reinforced conventional concrete beam column joints. The comparison of test results revealed that the strength and behavior of plain and fiber reinforced polymer concrete beam column joints are marginally better than corresponding conventional concrete beam column joints.

Al-Tayeb et al. [8] investigated the effect of partial replacements of sand and cement by waste rubber on the fracture characteristics of concrete. They found that addition of waste tire in concrete enhanced the fracture properties, while both compressive and flexural strengths were decreased. Al-Tayeb et al. [9] conducted tests to examine the performance of rubberized concrete with 5 %, 10 % and 20 % replacements by volume of sand by waste crumb rubber under static and impact load conditions. Their results showed that the addition of rubber improved the impact load behavior of concrete.

However, the mechanical properties of concrete with partial replacements of sand by plastic waste of vehicles under impact load are yet to be explored. In this study, effects of partial replacements of sand by plastic waste of vehicle on the performance of concrete under low velocity impact loading were investigated. Specimens were prepared for 5%, 10% and 15 % replacements by volume for coarse aggregate. For each case, six cubes of 100 mm ×100 mm × 100mm were subjected to 4.5 kg hammer from 457mm height. The number of blows of the hammer required to induce the first visible crack of the cubes were recorded.

II. MATERIALS AND METHODS

2.1. Materials

For the development of the present research, conventional concrete compounds were prepared with type I ordinary Portland cement. The cement chemical compositions are presented in Table 1.

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Table 1: Chemical compositions of cement

Item	Percentage in Cement (%)
Oxide compositions	
SiO3	19.98
Al2O3	5.17
Fe2O3	3.27
CaO	64.17
MgO	0.79
SO3	2.38
Total alkalis	0.90
Insoluble Residue	0.20
Loss on Ignition	2.50
Mineral compositions	
C3S	63.13
C2S	9.61
C3A	8.18
C3AF	9.94

The maximum coarse aggregate size was 20 mm, and the fine aggregate was graded natural silica sand. The specific gravities of fine and coarse aggregates were 2.67and 2.65 respectively. The composition of this concrete is presented in Table 2. Concrete mixes were prepared with replacements of sand volume by 5, 10, and 15% with plastic waste of particle size 0.1–10 mm (Figure1). The compositions of the plastic waste concrete are presented in Table 3. Figure 2 shows the images of plastic waste sample (relative density, 0.8) used in the present study.

For the compression test, cubic specimens of 100mm side were prepared for each type. For split-tensile test, three cylinders of 160mm height and 100 mm diameter were prepared with the aforementioned proportions of plastic waste. In the case of impact test, 6 cubic specimens of 100mm side were prepared for each type. All specimens were cured in water for 28 days in accordance with ASTM C 192/C192M-98 [19].

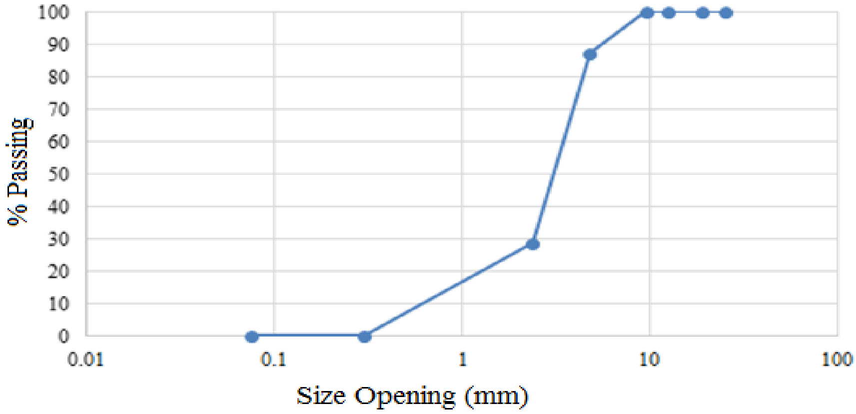

Fig. 1: Particle size distribution of plastic waste.


Figure 2: Images of the plastic waste.

Table 2: Mixture properties of normal concrete

Unit	Cement	Water	Fine aggregate	Coarse aggregate
Weight (kg)	454	195	670	1072
Volume(m^3)	144	195	251	405

Table 3: Mixture properties of powder plastic concrete

Unit	Plastic percent	Cement	Water	Fine aggregate	Coarse aggregate	Plastic waste
Weight (kg)	-	454	195	638	1072	10.0
Volume(m^3)	5%	144	195	239	405	12.5
Weight (kg)	-	454	195	603	1072	20.1
Volume(m^3)	10%	144	195	226	405	25.1
Weight (kg)	-	454	195	569	1072	30.2
Volume(m^3)	15%	144	195	213	405	37.7

2.3. Experimental set-up and procedure

Figure 4 shows the hammer of modified proctor which was used as drop weight machine to investigate the impact resistance of plastic concrete.

Fig. 4: Hammer of modified proctor.

For impact test, 6 cubic specimens of 100mm side were prepared for each type. A 4.5 kg hammer 51 mm in diameter with a circular flat face was raised to 457 mm above the specimen, and then released by following the procedure Mohammadi et al. [20]. The hammer was dropped repeatedly and the number of blows required to produce the first visible crack in the specimens were recorded. The impact energy (U) imparted by the hammer for 'n' number of bows with mass of hammer (m) and a hammer velocity 'v' was calculated as follows:

$$\mathrm{U} = n * 1/2(\mathrm{m}v^2) \tag{1}$$

where,

$$v = \sqrt{2 * (0.9g) * h} \tag{2}$$

g = gravitational acceleration and = drop height of hammer. The factor, 0.9 accounts for effect of the air resistance and friction between the hammer and the guide rails [21].

III. RESULTS AND DISCUSSION

3.1 Slump test

One of the problems when adding plastic waste into the concrete is the reduction of workability of the concrete. Therefore, Superplasticizer with 1% was added to solve this problem. The procedure of slump test was according to ASTM C143 [22]. As shown in Figure 5 the slump of the concrete decreases with increase in plastic content. As 15% of sand volume is replaced by plastic waste, the slump reduces to 30mm only where it still within the designed slump for this concrete (30-60mm). The reduction of the slump with increase in the amount of plastic particles in the concrete might be attributed to the increase in the interior voids and the rough surface of the plastic particles which might result in increasing friction between the fresh concrete ingredients. Generally, superplasticizer produced the same electrostatic charges on the cement particles surface. This resulted in the repulsion among the cement particles, prevented the coagulation and minimized the interior voids and the friction between the fresh concrete ingredients.

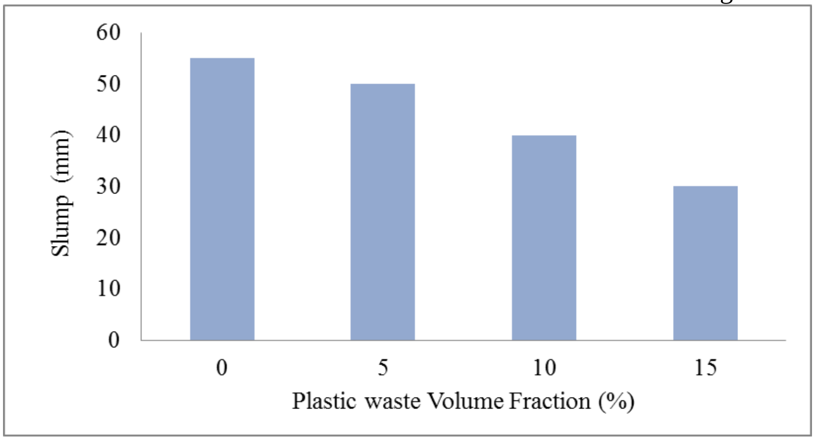

Fig. 5: Effect of sand replacement ratio on slump of plastic concrete

3.2 Compressive stress and modulus of elasticity

The compressive strength and modulus of elasticity were tested according to ASTM C 39 [23] and ASTM C 469 [24]. The results presented in Table 4 show a systematic reduction in concrete compressive strength with the increase of plastic content. The initial 28-day compressive strength of almost 43 MPa decreased to about 26 MPa when 15% replacement of sand by plastic waste was made. The compressive stress are reduced by 21, 33 and 40% with the sand replacement by plastic by 5, 10, and 15% of volumes, respectively. Similar is the case of elastic modulus which reduces by 7, 15 and 20%.

Although strength reduction is certainly a negative property that may hinder the use of plastic waste, elastic modulus results appear the positive effect in the form of the failure mode. The results sustained a much higher deformation than the control mix. With plastic content 15%, the samples exhibited significant elastic deformation, which was retained on unloading. Thus, flexibility and ability to deform elastically is increased significantly.

Batayeneh et al. [3] found that the compression stress was decreased by approximately 70% when plastic waste was added to concrete as a substitute for sand, with 15% by volume. The reduction in compressive stress and modulus of elasticity with the addition of plastic to the concrete as sand replacement is also consistent with the earlier investigation Marzouk et al. [4]. The reduction of compressive stress of concrete is attributed to the weak compressive stress of the plastic particles compared to the compressive stress of the natural sand. In addition to that the weak bond between plastic particles and the cement paste and the deformability of the plastic particles, which result in the initiation of cracks around the plastic particles in a fashion similar to that, occur in normal concrete due to air voids, cause reduction in stress. This reduction may also be due to grading, as the particle size of sand used in this research was smaller than the particle size of the plastic waste which increased the voids between the aggregate.

Table 4: Compressive strength and modulus of elasticity

Plastic Percent %	Average compressive stress (Mpa)	Average elastic modulus (kN/mm^2)
0%	43	29.4
5%	34	27.3
10%	29	25.1
15%	26	23.5

For split-tensile test, three cylinders of 160 mm height and 100 mm diameter were used for each concrete mixture. The test was carried out in accordance with the procedures stated in the ASTM C 496 standard [25]. Fig .6 shows the result of splitting-tensile test, which indicates that the plain concrete is yielded at 4.1 MPa, while with the sand replacement (5, 10, and 15 % of volumes) by plastic waste it is reduced by 10, 24 and 32% respectively. This is also consistent with the result of compression stress. Further, the reduction in tensile strength is lower than that in compression strength.

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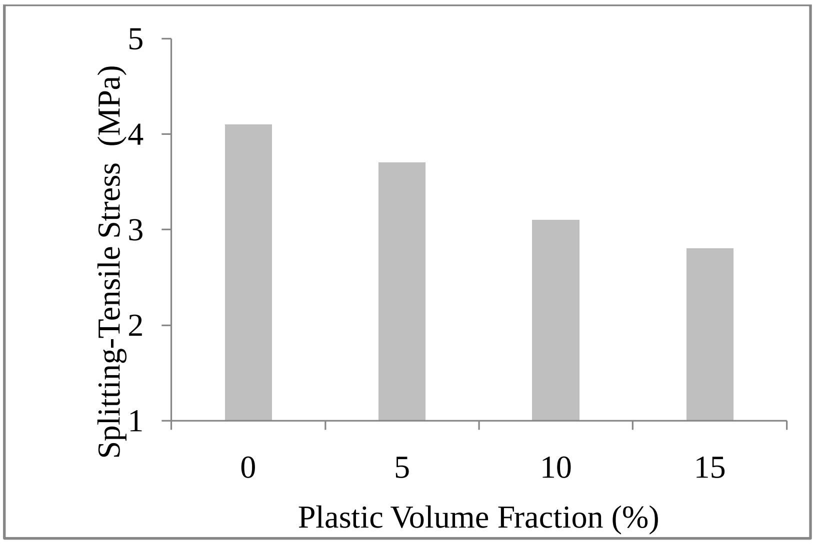

Fig. 6: Splitting tensile stress against volume fraction of plastic waste.

3.1 Impact test

Six concrete cubes of each type of mixtures were prepared for this test. The tested cubes were 100×100 mm. The numbers of impact blows required for producing the first visible crack, for each type of concrete specimen were recorded in Table 5, and the corresponding plot is shown in Figs. 7.

Figs. 8 presents the results in terms of first crack impact energy. The results show that the first crack resistance increases by 21, 52 and 81% with 5, 10, and 15 % of plastic replacements respectively. The enhanced first crack impact resistance is due to the enhanced flexibility of the composite mix by the addition of plastic. The increases in flexibility are attributed to the high ductility of plastic which when added to the concrete, improves the mix ductility [7] and the ability to absorb the impact load.

Table 5: Impact test results for plain and plastic concrete.

Type of concrete	Plastic (%)	No. of blows of ultimate failure	Average no. of blows	Impact energy (kN mm) ultimate failure	Average impact energy (kN mm)
Plain	0	78	86	1653	1441
	0	71		1504	
	0	63		1335	
	0	61		1293	
	0	62		1314	
	0	73		1547	
Coarse aggregate replaced with plastic waste	5%	77	82	1632	1738
	5%	81		1716	
	5%	89		1886	
	5%	72		1526	
	5%	86		1822	
	5%	89		1886	
	10%	103	103	2183	2183
	10%	107		2267	
	10%	102		2161	
	10%	97		2055	
	10%	112		2373	
	10%	96		2034	
	15%	115	123	2437	2606
	15%	121		2564	
	15%	133		2818	
	15%	108		2289	
	15%	129		2734	
	15%	133		2818	

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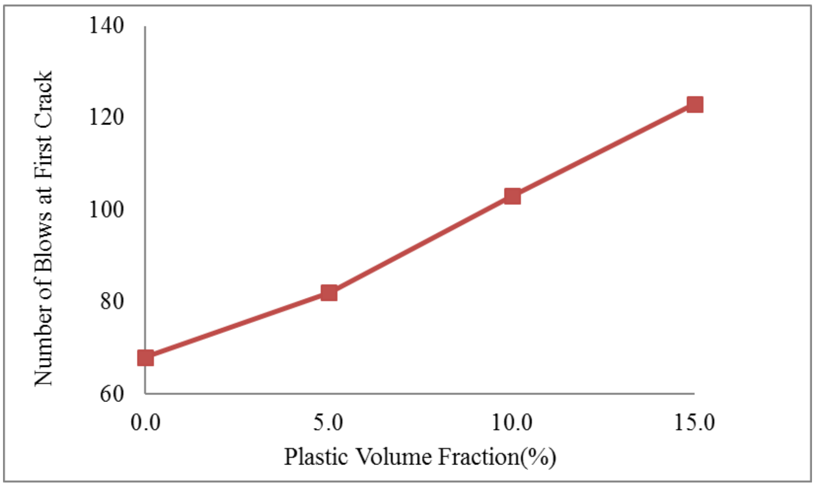

Fig. 7: First crack impact resistance against volume fraction of plastic.

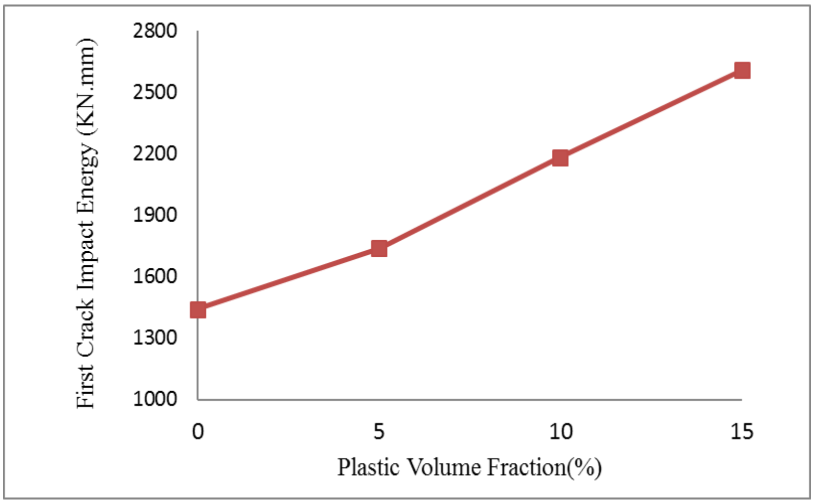

Fig. 8: First crack impact energy against volume fraction of plastic.

IV. CONCLUSION

This study examined how different volume fractions of plastic waste affect the mechanical properties of concrete under static and impact load. The following conclusions were found:

- The slump of the plastic concrete decreases with increase in plastic content. Superplasticizer with 1% will solve this problem.
- The results show that the compressive stress and modulus of elasticity decrease with increase in plastic content.
- The results show that the splitting-tensile stress decreases with increase in plastic content.
- Further, the reduction in tensile strength is lower than that in compression strength.
- The first crack resistance increases by 21, 52 and 81% with 5, 10, and 15 % of plastic replacements respectively. The enhanced first crack impact resistance is due to the enhanced flexibility of the composite mix by the addition of plastic.

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