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UTILIZATION OF WASTE PLASTICS AGGREGATE IN CONCRETE: A REVIEW

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Abstract- Plastic a material of thousand uses is enormously produced worldwide, this production has significantly increased the generation rate of plastic waste which is causing a serious threat to life on earth and environment. Recycling and reuse of plastic waste incorporated in concrete as aggregate is an eco-friendly solution, as it decreases the incineration and safeguarding the valuable land from landfilling. It has drawn attention many researchers and in the last decades extensive studies have been done and published on the replacement of plastic waste aggregate in concrete. This paper aims at the review of the latest research on concrete made with plastic aggregate. Discussions are made on the making of aggregate from plastic waste, followed by physical properties, mechanical properties and durability performance of plastic waste concrete. Due to lesser specific gravity of plastic, decrease in dry density is concluded. The Reduction in Compressive is attributed to the weaker bond of plastic waste aggregate with mix. Lessons learned for the practical applications and recommendations for future study are provided.

Keywords- Aggregate, concrete, mechanical properties, plastic waste.

1 INTRODUCTION

Plastic can be referred as a material of thousand uses, it meets demand in almost everything from automotive to food industries, electronics, clothing, packaging and medical equipment's. associated with its usage, worldwide, plastic is enormously produced. Materials that are produced in access in the production units than its elimination on earth, result in the environmental issues [1]. The excessive production of polymeric materials, and their globally accepted and versatile use, associated with the acceptance they have gained, make these materials devastatingly hazardous to our lives on Earth and all the habitants of it [2]. As delineated by United Nations Environment Program (UNEP), the worldwide generation was more than almost 400 Million tons of plastics annually. Figure 1 presents the plastic wastes production and generation from 1950s to 2015, throughout the world [3]. After the usage, the unwanted plastic is now categorized as waste and a huge amount of landfill is needed for the disposal as that much plastic cannot be recycled in plant a single day [4]. Each year, plastics waste of nearly 30 million metric tons (Mt) of the overall municipal solid waste (MSW) generation of United States only, and less than 9% is taken to recycling. Although recycling practices are performing well but the defective tractability of municipal consumer is causing the low figure of Recycling. Some of scientific limitations are the stupendous hinderance to plastics recycling [5]. It has been estimated that globally around 8000 Mt as of freshly produced plastics to date. Up till 2015, approximately 6200 Mt of waste polymeric materials had generated, around 9%of which had been put for recycling, 12% was incinerated or used for energy production, and 79% disposed in environment which is finally disturbing the aquatic as well. If current production, higher generation rate continue, by 2050 approximately 12,500 Mt of plastics will overburden the natural environment [6]. Traditionally, plastics are very tough and not readily biodegradable in the surroundings exposed to environmental effects. Thus, plastics waste can remain on land for longer durations or may be many decades. Due to its high non bio degradability factors and chemically un reactive nature, Polymeric waste needs many of years for elimination in normal environmental conditions [7]. Currently plastics are derived from energy resources, about 4% of the resources are used for production of plastic and similar amount is provided as a raw materials [8].
Inequalities in existing plastic control methods and regulations are particularly pronounced in developing countries with high plastic waste generation [9]. The presence of large quantities of wasted plastic and the low biodegradability due to polymeric chains, adversely affect the environment. All types of plastic used in everyday life eventually become waste and cannot be recycled quickly, and tons of plastic waste requires large areas of land to be disposed of [4]. Waste recycling is important in different sectors; it helps to recycle, reduces energy production and pollution and services in the production

and use of renewable natural resources [10]. The generation and recovery rate of plastic waste in Municipality solid waste (MSW) of USA, from 1960 to 2012 are shown in Table 1 [11]. The amount of plastics waste generated in USA MSW increased from around 0.4 million tons to 31.70 million tons in the last 50 years. The generation of plastic waste increased approximately 80 times that in 1960s. ironically, the efficient recovery and recycling was not started until 1980, when started, its rate was 0.3% that year. Apart from this technological development and awareness in the span of three and half decades, the recycling rate jumped to around 9% in 2012 [12].

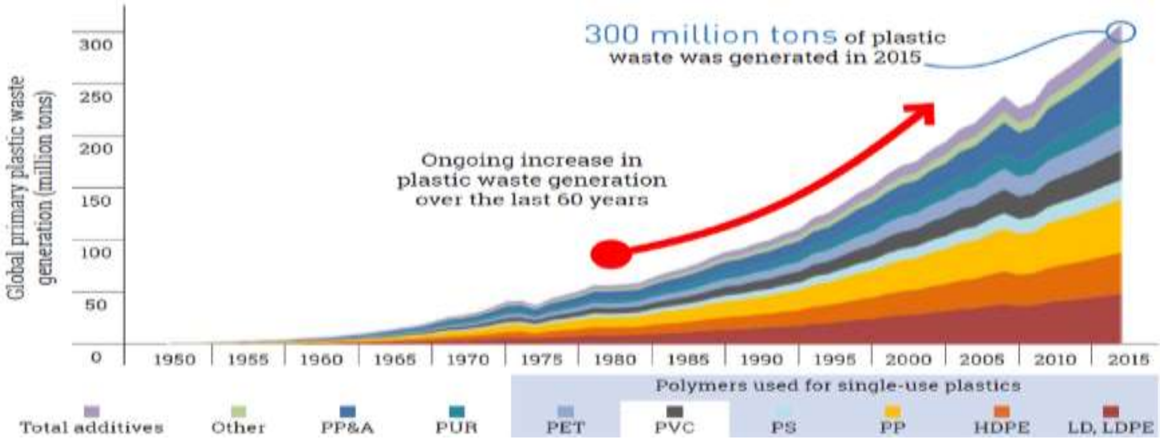

Figure 1: Global primary plastic waste generation in million tons according to UNEP report[3]

Waste reuse is significant in from various applications of plastic recycling, minimize energy production and environmental hazards and provide help in safeguarding natural resources which can last for a longer time[13]. Landfilling is now considered the last resort in dealing with plastic waste because it requires a huge amount of space and causes long-term pollution problems. By this method, recycled plastics can be reused without degradation in quality during the service cycle, and more importantly, the recycled plastics substitute the use of virgin construction materials [14]. Plastic waste aggregate replacement has been extensively investigated by researcher especially in last decades. The aim of this paper is to review the latest research on plastic aggregate replacement in concrete. In this study physical and mechanical properties and durability performance of concrete with plastic aggregate are discussed. Furthermore, recommendations for future studies in this field are provided.

Table 1: Generation, recovery and recovery rate of plastic waste in United States MSW from 1960 to 2012 [11].

Year	1960	1970	1980	1990	2000	2005	2008	2010	2012
Generated(1000t)	391	2900	6830	17130	25550	29380	30260	31290	31750
Recovery (1000t)	Neg	Neg	20	370	1480	1780	2140	2500	2800
Recovery rate	Neg	Neg	0.30%	2.20%	5.80%	6.10%	7.10%	8.00%	8.80%

2 MAKING OF AGGREGATE FROM PLASTIC WASTE

Various types of plastic wastes are being used in concrete as aggregate replacement, but the main types are polypropylene (PP), PVC and PET [15]. These plastic could be processed and transformed in three set ups before they can be further utilized as plastic aggregate in concrete [8]. At first stage, various impurities like label of the product and adhesives should be cleaned and disinfected by washing with detergent. This is significant for making sure that finished product has consistent. The next stage is the shredding, where the plastic is teared up into small pieces or flakes. At last stage, the shredded pieces are melted and then pellet are made. This type of extrusion is simple and the oldest way of transformation process, usually adopted for PET. The latest development in processes of extrusions are molding and converting into extrusion foam[16]. Plastic aggregate has low specific gravity and bulk density than conventional aggregate, some related properties of different types plastic waste are shown in Table 2. The particles of plastic aggregates prepared, have impermeable and smooth surface compared to river sand, resultantly, a weaker bond is formed between waste aggregate and cement mix. therefore, to compensate the loss in mechanical properties caused by this weaker bond, usually pozzolan and plasticizer are used [17]. In addition, modern foaming technology and surface granulation technology which modify the exposed layer of plastic waste aggregate, can significantly enhance the overall mechanical behavior. Kou et all used superplasticizer and granulation of the waste aggregates for achieving improved mechanical properties [18].

Table 2: Bulk density and specific gravity of plastic waste aggregate

Plastic waste type	Bulk density(kg/m^3)	Specific gravity	Reference
PVC	641	1.3	[19]
PET	438	1.34	[20]
EPS	30	0.34	[21]
LDPE	179 ±12	0.92	[22]
PP	515	0.90	[21]

3 PROPERTIES OF CONCRETE MADE WITH PLASTIC WASTE AGGREGATE

3.1 Physical properties

3.1.1 Slump

A number of parameters such as water-binder ratio, shape and percentage replacement of the plastic waste results in different values of slump of plastic waste concrete [12]. The replacement of plastic waste influenced the amount free water in concrete and hence alter the workability.[4]. Rehmani et all postulated that that the workability of concrete made with PET waste of flaky shape was decreased due to the effect on free water of concrete. It was also noted that increase in plastic waste content effected workability more pronounced. The decrease in workability was more than 40% when plastic waste replacement was increased at different increment from 0 to 15%. [23]. Silva et all reported that workability decreases with increase in plastic size and roughness causing greater porosity that hindered workability [20]. Saikia and Brito concluded that shape of plastic waste effected the slump. Three different shapes of shredded fractions i.e. fine range, course range and heat-treated cylindrical pellets were used. A slight increase in slump was noted with incorporation of heat-treated cylindrical pellets. Replacement of fine range and course range shredded fraction resulted in sharply decreased values of slump [24]. Researchers have concluded that increase in percentage replacement of plastic waste, decreases the slump values as shown in Table 3.

Table 3: Slump value of different types of plastic waste aggregate concrete

SNO	Plastic waste type	Percentage level (%)	Slump value (mm)	Reference
1	Polypropylene	0	135	[20]
		7.5	131	
		15	130	
2	Polyethylene terephthalate	0	80	[23]
		5	65	
		10	49	
		15	33	
3	MSW Plastic waste	0	53	[39]
		5	49	
		10	37	
		15	29	

3.1.2 Density/ unit weight

It is postulated that fresh density and unit weight of concrete reduces with addition of plastic waste in concrete. Lima et al [25] concluded that replacement of waste ethylene acetate up to 50% in concrete reduced fresh wet, oven dried and dry densities by approximately 26% compared to control concrete. Colangelo et al [26] replaced polyolefins waste in concrete and compared the dry densities with control concrete. 35% plastic aggregate replacement resulted in 23% reduction in density. Similar results of reduction in density was presented by Islam et al [27].

3.2 Mechanical properties

3.2.1 Compressive strength

The non-hydrating and hydrophobic effect, shape size and replacement level of plastic waste played significant part in controlling the behaviour related to compressive strength. Increase in PET waste replacement, reduced compressive strength generally. This compressive strength reduction was attributed to honey-com formation and failure [28]. Coppola et al [29] concluded that smaller and granulated plastic waste aggregate can reduce the loss in compressive strength. Similarly yang et al [15] presented that self-consolidated concrete with replacement of short column plastic waste lesser that 20 % replacement can increase compressive strength due to smaller fraction of plastic waste which can fill up the concrete voids. To prevent large reduction in compression strength the amount of plastic aggregate replacement should be less than 20%. Apart from this, larger plastic aggregate badly effects the compressive strength as it increases smooth surface layer and hence a week bond. Plastic waste of lamellar shape which increase the surface area and demand of water lead to further weakened aggregate mix bond [20].

3.2.2 Tensile strength

Similar performance like compressive strength, split tensile strength reduction was reported by many researchers. Frigione concluded that tensile strength reduced in concrete containing plastic aggregates of shredded PET bottles [30]. Punitha et al investigated different content of plastic with 10% metakaolin in concrete and split tensile strength reduction was up to 40% and 36% at 7 and 28 days respectively [31]. Comparatively tensile strength was less affected by plastic size , however percent replacement and size of plastic waste effect was significant [24]. The Anova results postulated that temperature significantly affected the tensile strength, it was then followed by w/c ratio and type of plastic waste. at normal temperature, the addition of plastic waste particles decreased the tensile strength, while the Polypropylene fibres tend to maintain or enhance tensile strength. The results of the plastic waste in concretes exposed to temperature 600°C showed a positive effect on the tensile strength due to polymeric addition , with no difference for different w/c ratios [32].

3.2.3 Flexural strength

Sadrimozi et all reported that increasing replacement level of plastic waste, the concrete exhibited improved plasticity and flexibility making it less brittle in failure as the nature of plastic is more flexible compared to conventional concrete [33]. Ruiz-herrero reported the materials had low mechanical properties in term of flexural strength, though the plastic waste was not intended to be part of structural element. It is pertinent to mention that improved mechanical properties could e achieved easily with higher content of cement or admixtures [34]. Similarly, Muhammad et al investigated flexure strength variation in concrete made with partial replacement of poly vinyl chloride (PVC) aggregate. Experimental analysis showed that 15% PVC resulted an increase of 8% in flexural strength. In case of fine aggregate replacement, the flexure strength unaffected in the range of 30% to 65% replacement. However, reduction of 42% in flexure strength was found with 65% replacement of PVC as course aggregate [19].

3.3 Durability performance

3.3.1 Water absorption

Most researchers have reported that replacement level of plastic waste also caused an increment in porosity and hence higher water absorption of concrete. F. Colangelo investigated that substitution of 10%, 20% and 30% plastic waste increased open porosity by 19%, 31% and 40% while water absorption was increased was found to be approximately 9% to 15% accordingly [26]. whereas Iucolano et al [35] proposed that the increased porosity is attributed to difference in particle sizes and shape of plastic waste, and Brito et al [20] related this phenomenon to the weaker interfacial transition zone due smooth and impermeable surface of plastic waste aggregate. Apart from this the angulated plastic aggregate caused higher water absorption than corresponding regular and sphere-shaped aggregate. However finding obtained by Safi et al [36] were opposite to this.

3.3.2 Resistance to freeze and thaw

Wang and Meyer investigated the effect of freeze and thaw on impact polystyrene aggregate and expanded polystyrene foam in concrete. It was concluded that there was no effect of freeze and thaw resistance with replacement of high impact polystyrene in composites. However plastic aggregate in the form of expanded polystyrene foam improved the freeze and thaw resistance [37]. Ferrándiz and Alcocel concluded in their study that enhanced resistance was due to the performance of EPS to release the crystallization pressure of freezing water content which substantially reduces damage to composites. However more strength reduction was examined when the substitution of EPS aggregate was higher than 50%, supposedly due poor workability [38].

4 LESSONS LEARNED FOR PRACTICAL APPLICATIONS OF PLASTIC WASTE

Concrete incorporated with plastic waste produce light weight concrete, studies shows that concrete of different plastic waste aggregate meet various criteria of various national parameters of lightweight concrete. Plastic waste concrete made with polypropylene increases the tensile strength and decreases the weight of the structure so it can be used for earthquake resistance structures. Increase in freeze and thaw resistance at higher percentage replacement make it suitable for use in extreme climatic conditions. Studies shows that many properties are improved with plastic waste incorporation, so a part associated with plastic waste disposal can be minimized.

5 CONCLUSION

Following conclusions can be drawn from the conducted study:

- Fresh and dry densities of concrete produced with plastic aggregate tend to decrease due to low specific gravity of polymeric materials.
- Reduction in Compressive strength was concluded by many researchers and it was attributed to the weaker bond of paste with plastic waste aggregate.
- At partial replacement of sand there was no effect on the freeze and thaw resistance however higher percentage replacement improved freeze and thaw resistance.
- Water absorption and porosity of plastic aggregate concrete is higher than conventional concrete however this flaw can be eliminated by incorporating rich cementitious paste.

Though an extensive research is available on plastic waste aggregate but a detailed study need to be done on leeching of toxic chemicals from plastic waste concrete and similarly a comprehensive research on the long term performance and recycling of plastic waste concrete is suggested to understand and verify its life cycle assessment.

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