ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE June 2021. Vol. 17(1):173-184
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

WASTE TO WEALTH IN BUILDING MATERIALS DEVELOPMENT: A REVIEW OF PLASTIC WASTE IN CONCRETE

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ARTICLE INFORMATION

Submitted 2 Nov., 2020
Revised 24 Januray 2021
Accepted 27 Januray 2021

Keywords:
Building Materials
Concrete
Waste
Wealth
Post-Consumer Plastics

ABSTRACT

Recently, there has been a growing interest in the use of post-consumer plastics in the production of concrete. Consequently, a large number of studies reporting the behaviour of concrete containing waste and recycled plastics have been published. These studies have great potential for improving the inherent weakness of concrete, reduction of pressure induced on the environment and creation of employment opportunities for economic development. This paper presents a review of journal publications on the effects of waste and recycled plastic materials on some fresh and hardened properties of concrete. The effects of waste plastic materials on slump, density, compressive strength, tensile/flexural strength and permeability are discussed. It was concluded that Post-consumer plastics can be successfully and effectively utilized to replace conventional concrete. This presents a strong potential for the production of sustainable concrete as well as meeting the goals of sustainable development requiring a waste to resource approach. The study suggests public education and awareness on the prospects of using waste plastic in concrete for economic empowerment among the population

1.0 Introduction

The United Nations Statistics Division (UNSD) *Glossary of Environment Statistics* (2012) describes waste as materials that are not prime products (products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. Federation of European Publisher FEP (2018) also affirms that waste is a natural byproduct of the phenomenon of life and growth of societies generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Waste excludes residuals directly recycled or reused at the place of generation. Examples of waste includes Municipal solid waste (MSW), hazardous waste, electronic waste, construction and demolition waste among others (UNSD, 2012).

According to United Nations Economic and Social Commission for Asia and the pacific UNESCAP (2020), meeting the goals of sustainable development is an outstanding global challenge requiring waste to resource approach. Waste is a valuable resource that could be managed to produce some sustainable benefits for a range of actors. Hence it is important to look at "waste" as valuable resource that can be converted into a variety of useful products (FEP, 2018). The process of conversion of waste to products that can be primarily used is wealth generation process, thus "waste to wealth." The potential waste to wealth enterprise is very high with promising advantages that may lead to reduction of pressure induced on the environment, creation of opportunities for income and employment and impact the quality of life (FEP, 2018).

Interestingly, the global plastic production exceeded 311 million metric tons from 2.5 billion metric ton of solid waste generated in 192 countries, about 275 million tons were plastic waste (UNEP, 2016 in Bokani 2019). For instance, in Nigeria, the per capital consumption of plastics has grown by about 5% annually over the past ten years, from 4.0 kg in 2007 to 6.5 kg in 2017 and is estimated to be 7.5 kg in 2020 (Bokani, 2019). This fast growth could be attributed to the boost in industrialization and the rapid improvement in standards of living (Rahim, et al, 2013). Therefore, plastic materials are typical waste materials of interest and are arguably the most common forms of waste in African cities (Iwuoha, 2013). For instance, a recent study by Aderoju and Guerner (2020) showed that plastic constitutes a higher average percentage of municipal solid waste within Abuja Municipal Area Council (AMAC), Nigeria as in Table 1. The United Nations Environment Report (2018) estimated that only 9% of plastic waste ever produced has been recycled, 12% is incinerated and the remaining 79% is accumulated in landfills, dumps or the natural environment. The generation of non-decaying plastic wastes materials, combined with a growing consumer population, has resulted in a waste disposal crisis requiring urgent solution. The obvious implication is that one of the solutions to this crisis lies in the conversion of the waste plastic materials into useful products for economic empowerment (Parasivamurthy, 2007).

Table 1: Mean Household Composition of MSW in AMAC and Bwari Area Council Districts, Abuja

Districts	Plastic Ave (%)	Paper Ave (%)	Food / Organic Ave (%)	Metal Ave (%)	Other waste Ave (%)
Asokoro	17.839	14.485	35.761	12.111	19.804
Maitama	16.474	15.066	36.424	10.513	21.523
Wuse	16.216	14.479	38.765	12.509	17.761
Garki	17.551	13.855	40.094	12.09	16.381
Kubwa	13.067	7.559	44.276	12.419	22.678
Dutse	13.477	7.547	48.787	9.704	20.678
Gwarinpa	14.592	10.086	41.202	13.747	20.386
Durumi	13.269	9.6	43.582	14.025	19.525
Bwari	14.035	7.309	51.169	8.041	19.444
Kado / Life Camp	16.27	8.761	41.802	12.516	20.651
Karu / Nyanya	14.317	11.013	45.154	8.811	20.704
Utako / Jabi	15.781	13.75	38.906	11.719	19.844
Wuye	15.512	11.08	45.706	9.695	18.006
Mpape	14.081	8.831	49.165	7.159	20.764
Airport Road	12.645	9.484	46.681	10.221	20.969
Mabushi / Jahi	13.224	8.438	44.332	8.06	25.945

(Aderoju and Guerner, 2020)

Globally, the construction industry consumes an estimated 11.5 billion tons of concrete every year and might reach 18 billion tones by the year 2050 (Mamman and Abdulsalam, 2011). According to Rai et al. (2012), concrete has proven to be an excellent disposal means for fly ash, silica fume, ground granulated blast furnace slag, marble powder which has the capacity not only to trap the hazardous materials but also enhance the properties of concrete.

Consequently, research and development efforts aimed at improving concrete performance have triggered researchers to consider the use of polymeric materials such as waste tires and plastics for the purpose of improving concrete deficiencies (Parasivamurthy, 2007). Therefore, a comprehensive review of these research efforts utilizing waste plastic materials for concrete purposes is necessary. This would provide a better understanding of the subject as well as the prospects for the creation of income and employment opportunities. This paper aims to provide a review of existing reports on the use of various waste plastic materials in their different forms.

2.0 Plastics and their General Properties

Plastics are organic materials made from resins, plasticizers and pigments. They have the quality of being easily shaped or moulded in soft state when subjected to heat and pressure in the presence of a catalyst and used in solid state (Duggal, 2008; Ahmed and Raju, 2015). According to Averill and Eldredge (2015), plastics are material choices for engineering application over other building materials due to their low cost, availability, light weight, improved heat resistance and good chemical resistance among others.

According to Duggal (2008) and Tasie (2010) plastic materials vary enormously in their properties; they however agreed that it is possible to make a few generalizations. According to the authors, plastics possess high strength to weight ratio with most plastics having average range of 10 -100 MNm^{-2} and the values for Young Modulus in the range of 0.25 to $5Nm^{-2.}$ Plastics generally have lower densities than metals. The Specific Gravities (SG) for unfilled plastics are tactically within the range of 0.83 – 2.2. Plastic materials also vary in their tenacity and toughness. Some materials are glassy and brittle, others are glassy but tough, and others are leather-like while some are more or less rubbery.

Plastics show a very wide range of chemical resistance and solubility. However, the heat resistance of plastic materials is very limited. Nevertheless, a few very specialized materials can withstand temperatures in excess of 200°C. Plastic materials are well reputed for their good electrical insulating properties, corrosion resistance, high coefficient of thermal expansion (about ten times of steel), high refractive index, available in desired colours and texture, high resistant to aggressive conditions and a unique ability to combine other materials like aluminum foil, paper and adhesives (Tasie, 2010).

2.1 *Classification of Plastics*

Plastics can be broadly classified into two types according to their behavior with temperature as thermosetting and thermoplastics (Tasie, 2010). Thermosetting plastics are those plastics that are cured or hardened into permanent shapes and cannot be re processed. Their curing normally occurs rapidly under ultra violet light or heat and leads to irreversible cross-linking of the polymer in which no after –treatment can cause the molecules to flow again (Kurtz, 2002). Thermoplastics, on the other hand, are formed by additional polymerization and have long chain molecular structure. The basic difference between these two groups lies with the fact that thermoplastics can be used severally; implying that after moulding an article, it can be ground and reprocessed without loss in physical and chemical properties (Tasie, 2010). Table 2 shows some examples of thermosetting and thermoplastics plastics. The principal uses of thermoplastics are that they are used for consumer goods, machine parts as well as packaging and storage materials while thermosetting plastics are used in electrical equipment (Tasie, 2010).

Table 2: Examples of Thermoplastics and Thermosetting Plastics

Thermoplastics	Thermosetting
Polyethylene Terephthalate (PET)	Bakelite
Polypropylene (PP)	Epoxy resins
Polyvinyl Acetate (PVA)	Melamine resins
Polyvinyl Chloride (PVC)	Polyesters
Polystyrene (PS)	Polyurethane
Low Density Polyethelene (LDPE)	Urea-Formaldehyde
High Density Polyethylene (HDPE)	Alkyd resins

Source: Sulyman et al. (2016).

3.0 Preparation of Concrete Containing Plastic Aggregates and Fibres

Plastic cement concrete is basically a special concrete composite consisting of Ordinary Portland Cement based matrix with polymer materials as additives. These additives are either plastic based fibres or plastics in other processed forms (Naik, et al., 1996). According to Gu and Ozbakkaloglu (2016), plastic aggregate concrete is typically manufactured by replacing natural coarse aggregates or fine aggregates with plastic coarse or fine aggregates of the same volume, which is called direct volume replacement. In general, plastic aggregates and plastic fibres concrete are quite similar to the conventional concrete in terms of preparing, casting and curing of the concrete.

According to Hopewell et al. (2009) and Siddique et al. (2007) plastic aggregates and fibres are basically extracted from different types of plastic waste and processed as melted, shredded or pulverised forms. The melted form being a process where concrete is produced incorporating molten plastic materials as aggregates. The plastic aggregates according to Hopewell et al. (2009) consist of long strands, which are cut to an estimated length of 28mm in a slender fibre form. Shredded/crushed/flakes waste plastic are however produced by shredding waste plastics obtained from a mixed plastic stream; the process yields plastic flakes with a maximum planner dimension of approximately 25mm in size. Pulverization on the other hand being the process of mechanically reducing larger waste plastic materials into fine particles depending on the type and configuration of the machine used, resulting in the formation of new surfaces (Hopewell et al., 2009). According to Plastic Waste Management Institute (2009), the pulverization process involves the collection, segregation and grinding or crushing of the waste plastic materials in which compressive strain and shear are employed.

4.0 Research Findings on the use of Plastic Waste in Concrete

In this section, research findings related to the uses of plastic aggregates and plastic fibres on the properties of concrete are presented. The properties of concrete covered are slump, density, compressive strength, flexural strength, behaviour at elevated temperatures, and permeability of concrete. Table 3 gives a summary of some previous studies using different forms of waste plastic in concrete production.

Table 3: Summary of Selected Previous Studies Using Waste Plastic as Reported in Literature

S/N	Reference	Form of Plastic Used	Method	Summary of Findings
1	Naik et al. (1996)	Shredded plastic	Admixtures	Improved compressive strength
2	Rai et al. (2012)	Pulverised Plastic pellets	Replacement of fine aggregates	Decreased density, compressive strength and slump Increased flexural strength
3	Prahallada and Prakash (2009)	Shredded plastic buckets	Admixtures	Decreased compressive strength
4	Corodoba et al. (2013)	Flakes of PET bottles	Admixtures	Increased compressive strength and modulus of elasticity and same values of young Modulus.
5	Anum and Job (2011)	Shredded polyethylene	Admixture	Decreased density and water absorption Increased compressive and flexural strength and ductility.
6	Anum, Job and Dakas (2019)	Pulverized High Density Polyethylene	Admixture	Decreased density and slump and increased flexural strength.
7	Anum, Job and Dakas (2019)	Pulverized High Density Polyethylene	Admixture	Decreased density and improved performance at elevated temperatures. Reduced spalling effect
8	Patil et al. (2014)	Heating/melting plastic	Replacement of coarse aggregates	Reduced Density and compressive strength
9	Raghatate (2012)	Shredded waste plastic bags	Admixtures	Decreased compressive strength but increased Tensile strength up to a point before decrease.
10	Ahmed and Raju (2015)	Shredded plastic pieces	Replacement of coarse aggregates	Decreased compressive and Tensile strength
11	Gowri and Rajkumar (2011)	Shredded polyethylene sheet, straw, raw plastic and road waste	Admixtures	Decreased compressive strength
12	Al-Manaseer and Dalal (1997)	Crushed plastic pieces	Replacement of coarse aggregate	Decreased compressive strength

4.1 Slump of Concrete containing plastic aggregates

The slump of plastic concrete is affected by a number of factors such as water-cement ratio (w/c), substitution level of plastics or fillers, and the shape of the waste plastic. A general tendency for decreased slump was reported with the substitution of plastic fillers or aggregates

(Rai et al., 2012). Prahallada and Prakash (2009) showed that the slump of waste plastic fibre reinforced concrete was maximum when 1% fibres were used. Addition of more than 1% of waste plastic fibres was found to decrease the workability. This according to the authors, is due to the fact that addition of waste plastic fibres may obstruct the flow of concrete creating many interlocks with aggregates. Similarly, the inclusion of 0.5% polypropylene fibres, air content of concrete was increased whereas slump was reduced (Siddique et al., 2007). However, Choi et al. (2005) reported an increase in workability with increased substitution level of two types of filler aggregates. According to the authors, this increase may be attributed to the spherical shape and smooth surface of the aggregates with almost a zero absorption capacity of the waste plastics.

4.2 Density of Concrete Containing Plastic Aggregates

Al-Manaseer and Dalal (1997) investigated the effects of plastic aggregates on the bulk density of concrete. Concrete was produced using different water – cement ratios containing varying percentages (0%, 10%, 30% and 50%) of plastic aggregates. Angular post-consumer plastics aggregates having a maximum size of 13mm were used. They concluded that (i) bulk density of concrete decreased with the increase in plastic aggregate content. (ii) Reduction of bulk density was directly proportional to the plastic aggregates content. (iii) Density of concrete was reduced by 2.5%, 6% and 13% for concrete containing 10%, 30% and 50% plastic aggregates respectively. Choi et al. (2005) studied the effects of polyethylene terephthalate (PET) bottles light weight aggregate (WPLA) on the density of concrete designed with water-cement ratios of 45%, 49% and 53% and the replacement ratios of WPLA of 0%, 25%., 50% and 75% by volume of aggregates. Density of concrete decreased with the increase in WPLA Furthermore, a study by Anum et al. (2019) on the characteristics of concrete modified with pulverised high density polyethylene (HDPE) observed that the densities increased with the curing age and decreased with an increase in the HDPE content. The above findings were consistent with the findings of Silva et al. (2013) and Anum and Job (2011) that the density of concrete incorporating plastic materials decreased with increased substitution level of the plastic materials. This phenomenon could be attributed to the lower density of the HDPE compared to that of the aggregates leading to reduction in overall density of the concrete.

4.3 Compressive Strength of Plastic Concrete

Compressive strength of plastic concretes depend on many parameters such as the w/c ratio,constitution level of the plastic materials (mostly aggregates) , and the type and shape of the waste plastic (Akcaozoglu et al., 2010; Albano et al., 2009; Asokan et al., 2009). The mechanical properties of concrete containing recycled PET were identified by Corodoba et al. (2013) to depend on the particle size with the highest compressive strength obtained with the smallest sizes of PET (0.5mm). The study also established the fact that mechanical properties of plastic concrete such as compressive strength increases with reduced particle size of plastics and with lower concentrations of the plastic content. The lower sizes and concentrations of plastic particles create less spaces in the concrete, consequently strength is increased (Corodoba et al., 2013). Compressive strength of plastic shreds in concrete was studied by Naik et al. (1996). The study reported a compressive strength decrease with increase in the amount of the plastic in concrete, particularly above 0.5% plastic addition.

Prahallada and Prakash (2009) have reported that the maximum compressive strength of waste plastic fibre reinforced concrete can be obtained with 1% addition of waste plastic

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fibre, beyond which strength decreased. Similarly, Patil et al. (2014) reported that the modified concrete mix, with addition of plastic aggregate replacing conventional aggregate up to certain 20% gives strength within permissible limit but decreased compressive strength when plastic was replaced with coarse aggregate. Besides, Raghatate (2012) reported that there is about 20% reduction in compressive strength at 28 days of curing using the plastic pieces in concrete. In each case reported, compressive strength reduction was as a result of improper bonding between organic plastic materials and inorganic cementitious materials.

In a previous study by Gu and Ozbakkaloglu (2016) reduction in compressive strength was attributted to one or a combination of the following: the elastic modulus of the plastic aggregates/filler aggregates being lower than the natural concrete aggregate, the low bond strength between the surface of the plastic aggregate/filler and the cement paste, the restrained cement hydration reaction near the surface of the plastic resulting from the hydrophilic nature of the plastics or the high air content and porosity of the plastic concrete. The use of recycled plastic fibres with a high ultimate tensile strength and smaller fibre content results in more significant improvement in compressive strength than fibres with low compressive strength (Fraternali et al., 2014; Song et al., 2005). Additionally, compressive strength of plastic concrete was increased with the injection of plasticizer (Rai et al., 2012).

The aspect ratio and geometry of fibres also affect the compressive strength of plastic concrete (Khadakbhavi et al., 2010). The authors reported that the aspect ratio(defined as the ratio of the fibre length to diameter) of HDPE fibres on the compressive strength of concrete contains 0.6% fibres by volume. The authors also observed that the fibres with the aspect ratio of 20, 40, 60 and 80 percents respectively increased the compressive strength by 5, 8, 14 and 3 percents respectively. This increase in compressive strength could be as a result of water reduction action of the plasticizer in reducing bleeeding and segregation in concrete. Fraternali et al. (2011) also found that straight fibres increased compressive strength more than those with embosed geometry

4.4 Behaviour of Plastic Concrete at Elevated Temperatures

Neville (2000) defined elevated temperatures in concrete as the increase in temperatures above 250°C which occur when there is fire disaster. Studies by Poon et al. (2004) on high performance modified concrete subjected to high temperatures of 600°C revealed that the concrete retained 45% of its strength. Nwankwo and Achuenu (2014), however, recorded a 24% reduction in the compressive strength of fibre reinforced ternary concrete at elavated temperature of 600°C. This reduction was attributed to the chemical decomposition of the depleted calcium silicate hydrate (C-H-S) in the blend. The concrete was however reported to be stable and was recommended for structural elements requiring thermal stability. Han et al. (2005) reported results of residual compressive strenghth of concrete containing polypropylene fibres after heating the specimen to 850^0C for 40 minutes. The results showed that conventional concrete underwent severe spalling failure with no residual compressive strength whereas, plastic concrete containing 0.05 – 0.1% of polypropylene fibres experienced no spalling and retained 75% of its residual compressive strength. Anum et al. (2019) studied the compressive behaviour of concrete modified with pulverised high density polyethylene at elevated temperature. The study concluded that concrete with high density polyethylene (HDPE) admixtures exposed to elevated temperature of up to 600°C behaved differently from normal concrete, retaining a maximum of 11.16% strength above the normal concretes (control samples) with 0.75% dosage of HDPE. The authors also reported that the high-density polyethylene admixture reduced explosive spalling of concrete as a result of fibre bridging in the matrix and prevents spalling failure caused by high vapour pressure generated at high temperatures.

4.5 Flexural Strength of Plastic Concrete

The flexural strength of concretes made with plastic replacing coarse aggregate recorded 5 % increase in flexural strength over the nornal concrete according to Patil et al., (2014). Similarly, the highest value of 6N/mm^2 was recorded at 0.8% inclusion of plastic pieces over 4N/mm^2 of normal concrete at 28 days of curing in water (Raghatate, 2012). A separate study by Anum and Job (2011) recorded a 16 % increase in flexural strength over control specimens with the additon of 0.5% fractions by weight of polyethylene shreds to concrete. These results are in agreement with the findings of Neville and Brooks (1997) that Polymer Portland Cement concrete has improved tensile strength compared with conventional concrete.

Existing studies by Begherzadeh et al. (2011); de Oliveira and Castro-Gomes (2011) on the effect of plastic fibre on the flexural strength of plastic-mortar also indicated that the flexural strenghth increased upon the addition of plastic fillers to the matrix. Iftekhar and Prakash (2010) also studied the mechanical properties of fly ash filled High Density Polyethylene, and it was discovered that tensile strength could also be increased by up to 22% by using 14μm ash particles. The authors further pointed out that better strength might be expected with the use of further reduced sizes of fly ash particles. This tensile strength increase recorded in each case according to Song et al. (2005) is attributed to stress transfer that occurs when the fibres bridge across the split portions of the matrix and thus gradually support the entire load. On the contrary, results obtained by Naik et al. (1996) recorded a decrease in tensile strength beyond 0.5% which was contrary to the expected trend. This according to the researchers was attributed to lack bonding between the plastic and the cementitious materials. The researchers suggested either physical processing or by chemical treatment of the plastic materials prior to mixing with concrete.

4.6 Permeability of Plastic Concrete

Previous studies by Anum and Job (2011); Albano et al. (2009) established that increasing the content of plastic fillers/shreds in concrete increases water absorption of the concrete as a result of the porous nature of the concrete created by improper mixing of the natural aggregates to plastics. Again, studies by Saika and Brito (2013) have revealed increased water absorption of concrete containing coarse flaky aggregates of PET than those of fine and pellet aggregates. On the other hand, water porosity and absorption capacity of concrete containing 0.05%, 0.10% and 0.20% polypropylene fibre increased by approximately 6%, 18%, and 28% respectively, as compared to the corresponding values of the control specimen (Karahan and Atis, 2011). The effect of recycled plastic on the permeability of concrete was also studied by Bayasi and Zeng (1993) and the results of permeability showed that 19-mm polypropylene fibres significantly increased the permeability of concrete with an inconsistent effect on the volume fraction of permeable voids; 12.7 mm long fibres somewhat increased the permeability of concrete and tended to decrease the volume of permeable voids.

Bagherzadeh et al. (2011) reported that there was no significance increase in air permeability with increasing dosage of different types of polypropylene. However, Kakooei et al. (2012) have demonstrated that concrete containing polypropylene fibres had lower gas permeability than the conventional concrete. This decrease in gas permeability was attributed to the fact that fibres prevent crack growth in concrete by forming bridges across cracks. Their findings are consistent with other researchers such as Raghatate (2012), Rai et al. (2012), Gowri and Rajkumar (2011) and Naik et al. (1996) which revealed that the introduction of plastics in concrete considerably increased tensile strength, crack resistance, and decreased permeability at low densities, offering great potentials for it to be used in sound barrier, retaining structures and pavements.

5.0 Conclusion

Based on the review of some published works presented, the study concluded that post-consumer plastics can be successfully utilized in concrete as an environmentally friendly means of discarding this category of wastes. The findings further support the fact this practice substantially enhanced some properties of concrete. This approach is expected to lead to reduction of pressure induced on the environment as well as the creation of employment opportunities and increased income, especially in Nigeria and other developing countries where cost of building materials is ever increasing. This is in line with sustainability target for the construction industry, which is aimed at replacement of natural materials with secondary or recycled alternatives while reducing waste disposal.

6.0 Recommendations

On the basis of the focus of this paper, the following were suggested;

1. The construction industry is encouraged to adopt this emerging innovation of the use of plastic waste in concrete as a result of its established superior performance over conventional concrete and its promise towards creation of wealth and economic development.
2. Stake holders (Ministries, Institutions and Professional bodies) should endeavor to develop platforms (Conferences and workshops) and also champion the campaign for the utilization of waste plastic materials in concrete. This may lead to reduction in waste and construction cost, as well as create job opportunities and boost the nation's economy.

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