

**FRONTIERS IN CIVIL ENGINEERING  
AND CONSTRUCTION MATERIALS**

**ISSN: ( 3065- 4181 )**



✉ editor.fcecm@gmail.com

🌐 <https://multisciajournals.com/journals/index.php/fcecm>

# An Overview of Engineering Materials Formulated Using Recycled Polyethylene Terephthalate (PET)

U. Hgulyman, P. Caponiuk,  
Department of Civil

## Article Info

Received: 28-10-2025    Revised: 23-11-2025    Accepted: 10-12-2025    Published: 22-12-2025

*Abstract*— Over the last several decades, there has been an unprecedented surge in the global use of plastics. Numerous plastic products end up in landfills as a result of manufacturing, service sectors, and MSW. The growing environmental consciousness has greatly heightened worries about how to properly dispose of trash. Solid waste management is supposedly among the world's most pressing environmental issues. The rising cost of plastics and the scarcity of landfill space have made recycling used plastics a promising waste management option. Using road pavement, cements, and concretes as examples, this article summarizes experimental work on the use of poly(ethylene terephthalate) (PET) in civil engineering projects. According to the statistics presented, this strategy is cost-effective since it uses waste PET to modify asphalt, cement, and concretes, improving their specified attributes. In addition, recycling PET bottles into new construction materials cuts down on the need for synthetic polymers, which in turn reduces pollution from things like carbon dioxide emissions and garbage disposal issues.

*Index Terms*—Bitumen, building materials, concrete, PET, recycling.

## INTRODUCTION

The ubiquitous plastics we use every day are integral to almost every part of our lives. Appropriate end-of-life management is necessary due to the massive production of plastics trash. Durables (such as tires, construction materials, furniture, etc.) and disposable products (such as medical equipment) both include plastic, but containers and packaging (such as bottles, packing, cups, etc.) contain the most plastic overall [1]. cheap density, ease of manufacturing, superior mechanical qualities, exceptional chemical resistance, outstanding thermal and electrical insulating capabilities, and cheap cost are some of the special features of plastics that contribute to their diversity of uses. Many different things may be made out of plastics that have been through the manufacturing and consumption processes. Nonetheless, two primary avenues stand out in this domain: First, recycling used polymers into new materials; second, burning plastic waste as a fuel alternative in cement kilns and power plants. About 38%wt of the 200,000,000 tons of MSW produced in the US each year comes from paper products, 8%wt from plastic, and 3% wt from other materials, according to the US Environmental Protection Agency (USEPA 1992).upholstery and rugs [2]. The percentage of plastics in municipal solid waste (MSW) increased to 12%wt in 1996 [3]. From around 204 million tons in 2002 to over 300 million tons in 2013, the yearly global use of plastic materials has risen significantly [4]. The use and manufacturing of polymers and plastics will also continue to rise steadily in the next year. In Table I estimated data about types and quantities of polymers in MSW stream generated annually in United States are presented. Thermoplastic polymers such as poly(ethylene), poly(propylene), poly(styrene), and poly(ethylene terephthalate) make up the bulk of municipal solid waste (MSW).

TABLE I: TYPES AND QUANTITIES OF PLASTICS IN MSW IN THE USA [5], [6]

Type of plastic	Quantity (1000 tons)
Low density polyethylene (LDPE)	5010
High density polyethylene (HDPE)	4120
Polypropylene (PP)	2580
Polystyrene (PS)	1990
Polyethylene Terephthalate, (PET)	1700
Others	3130

In India approximately 40 million tons of the municipal solid waste is generated annually, with evaluated increasing at a rate of 1.5 to 2% every year. Plastics constitute to around 12.3% wt of the total MSW. It is worth to notice, that the most of plastics fraction are drinking bottles which are made mainly of PET [7].

Plastic (polymers) used for applications in bitumen modifications, can be subdivided into two main types depending on their behavior after exposure to heat. First type are thermosetting polymers (e.g. resins, elastomers) which are cured during heating. Three-dimensional structure of cross-linking bonds formed during curing unable softening of polymer matrix and its easy re-processing. Second type are thermoplastic polymers. This type of polymers can be shaped and designed in new shapes using heat. In contrary to thermosetting polymers this process is reversible. Examples of aforementioned materials are shown in the Table II [8]. The plastics used for bitumen modification may be also classified as thermoplastic and thermosets.

TABLE II: EXAMPLES OF THERMOPLASTICS AND THERMOSETTING MATERIALS

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

This paper presents a detailed review about using of waste PET in road pavement asphalt and also building concretes.

#### I. POLYETHYLENE TEREPHTHALATE (PET)

The most popular kind of thermoplastic polyester is poly(ethylene terephthalate, or PET). Despite the fact that polyester resins are thermosetting, the material is often referred to simply as "polyester," leading to some misunderstanding. PET is a see-through polymer that has excellent mechanical characteristics and dimensional stability even when subjected to varying loads. In addition, PET is chemically resistant and has excellent gas barrier qualities [9]. Bottles, thermally stabilized films (such as capacitors, graphics, film bases, recording tapes, etc.), and electrical components are some of PET's many uses due to its aforementioned characteristics. The manufacture of fibers for a vast array of textile sector uses PET as well.

PET is a kind of thermoplastic that has remarkable physical characteristics [10]. Around 18% of all

polymers are made of PET, and of that, more than 60% go into synthetic fibers and bottles, which account for around 30% of PET demand globally [11].

## II. SOURCES OF PET WASTES

Waste PET source can be categorized into three main stream: a) Bottles - small problems with material recycling; problems related with impurities (e.g. glue on labels), different types additives used during production (e.g. stabilizers, pigments), molecular weight of PET, etc., which are affecting on repeatability of obtained products. b) Foils - small problems with material recycling; problems related with additives used during production (e.g. stabilizers, pigments), molecular weight of PET, etc., which are affecting on repeatability of obtained products. c) Cord from tires - huge problem with material recycling. Currently, this fraction of waste PET is used as alternative fuel. Example of waste tire cord is presented in Fig. 1 and its composition in Table III. Waste tire cord can be significant and cheap source of valuable poly(ethylene terephthalate). The main problem during material recycling of waste tire cord are contaminations of ground tire rubber and metals.



Fig. 1. Recycled textile fiber from used tires.

Other methods of overcoming the problems of waste PET through recycling processes may include the incorporation of PET with asphalt binders as a modifier for asphalt used at road constructions [12], [13] and as reinforcement material for concrete and other building materials by partial substitution for the fine aggregates (i.e. sand) [14]. These approaches are usually intended to improve the engineering properties and increase the service life of modified materials. In this way, it appears that it is a viable route contribution to both achieving economical benefits, and to decrease the environmental impact of waste tire cord.

TABLE III: COMPOSITIONS OF WASTE TIRE CORD

Compositions	Weight percent (%)
Poly(ethylene terephthalate) (PET)	77.6
Polyamide (PA)	18.7
Polypropylene (PP)	3.7

## III. UTILIZATION OF PET IN ASPHALT PAVEMENT

Recycling of waste PET plastics can make significant contribution to environment and economy from different aspects. It helps to reduce the exploitation of natural resources to reduce the environmental

pollution level, saving energy and money, and it contributes to modifying the physical and engineering properties of construction materials such as asphalt and building concrete.

Asphalt has been widely used in road pavement construction as the binder of aggregates [15].



However, it is well recognized that asphalt mixture or coating layer shows severe temperature susceptibility such as high temperature rutting, medium temperature fatigue and low temperature cracking damage (Fig. 2). Therefore, asphalt mixture modification is sometimes used to improve its further application. Fig. 2. (A) Rutting; (B) Fatigue cracking [16].

Choosing the right beginning crude oil or regulating the refinery operations to make the asphalt you want may improve its qualities, although these goals are notoriously difficult to realize [17]. To that end, the widely used strategy for enhancing One way to improve asphalt is to change it. Hardening asphalt is achieved by air blowing. To make asphalt more workable, it is sometimes necessary to employ a fluxing agent or diluent oil. The inclusion of polymers is another way that may greatly enhance the quality of asphalt [17]. One typical way to enhance the rheological qualities of asphalt is to modify it using polymers [18]. The capacity of the asphalt mixture to withstand push and rutting during prolonged traffic and repeated traffic loads is a crucial quality. As a result, the stability of the asphalt should be sufficient to support the traffic. Unstable asphalt mixes cause road surfaces to unravel and flow. The capacity of hot mix asphalt (HMA) pavement to adapt to small shifts and settlements in the subgrade without developing cracks is known as flow [19]. The asphalt's viscoelastic qualities are directly impacted by its chemical makeup, which in turn affects the asphalt's performance. Not only can traffic loads contribute to pavement flaws like rutting in hot weather and cracking in cold weather, but the asphalt concrete's capacity to withstand temperature variations is also a factor. Higher tire pressure, traffic volume, and heavier loads all put more strain on road pavements, necessitating improved pavement performance. Asphalt with superior adhesion to stone aggregates and reduced susceptibility to low-temperature cracking and high-temperature rutting is necessary for a pavement with improved performance.

Asphalt that incorporates virgin polymers to enhance the features of the final asphalt that is treated with polymers have been achieved for a long time [19]. However, recycled polymers, such as shredded PET containers, have lately attracted attention as a potential replacement for commercial virgin material. Another material that has shown promise in pavements is reclaimed rubber, which is derived from used

tires [19]. To increase rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility, asphalt substitution techniques, including hot mix and cold mix using polymers like PET, are used in pavements. When enhanced performance and longevity are priorities, they are used. Their low life cycle costs are a major factor in their selection [17]. Improved adhesion and cohesion capabilities are also seen in binders that have been treated with polymers [20]. The quantity of polymer needed to increase pavement performance should be kept to a minimum due to the high cost of polymers compared to asphalt. Given the closeness in performance between recycled polymers and virgin polymers modified asphalt, it is feasible to envision the potential of disposing of waste plastics like PET bottles inside road asphalts. This might have positive environmental and economic impacts. So, a possible solution to the waste disposal issue and an improvement in road pavement quality might be the use of CR (crumb rubber) from old tires or thermoplastic polymers like PE, PET, or EVA as an asphalt-modifying agent [18]. There is a wide variety of polymers that have found application as asphalt modifiers; these modifiers fall into many categories, each with its own set of pros and cons [17].

The most important justifications for using polymers to alter asphalts are: 1) achieving less cracking and softer blends at low service temperatures, 2) attaining harder blends at high at lower temperatures while decreasing rutting; decreasing viscosity; boosting mixture stability and strength; enhancing blend abrasion, fatigue, oxidation, and aging resistance; decreasing structural thickness and life costs of pavements; and so on [21]. Polymers are known to increase the mixture's resilience to fatigue cracking, thermal cracking, and permanent deformation, which in turn improves asphalt pavement performance throughout a wide temperature range [22]. A. Examples of Real-Life Situations Researchers Vasudevan et al. [23] looked into recycling polymers for use in making flexible pavements. Researchers used melted waste plastic to encapsulate stone aggregates in the research that were presented. Coating aggregates with polymers increased their soundness, decreased porosity, and prevented moisture absorption, they found. One of the most effective ways for simple disposal of waste plastics was determined to be the use of recycled plastics for flexible pavement. Low density polyethylene (LDPE) [24], high density polyethylene (HDPE) [25], polypropylene (PP) [26], ethylene-vinyl acetate (EVA) [27], [28], acrylonitrile-butadiene-styrene (ABS) [26], polyethylene terephthalate (PET) [29], and polyvinyl chloride (PVC) [30] are the most commonly mentioned polymer (plastic) wastes in connection with asphalt modification. In 2007, Awwad and Hbeeb [31] looked at how asphalt that has been changed with polyethylene (PE) may be improved. They have also done research to find out how much PE is ideal for asphalt and what kind of PE to use. To cover the aggregate, two forms of PE were added: HDPE and LDPE. An examination of the data revealed that the engineering qualities were improved by using ground HDPE polyethylene modifier. Twelve percent by weight of asphalt was the suggested percentage of modifier. Researchers also discovered that it made the material more stable, lighter, and with somewhat more air and mineral aggregate spaces. Researchers have discovered that polyethylene (PE), the most widely used plastic, is one of the best polymer additives for asphalt [32]. When it comes to plastics, polyethylene is by far the most common. In addition to being inexpensive, semi-crystalline polyethylene has great fatigue and wear resistance, as well as outstanding chemical resistance.

For this investigation, Fuentes-Audén et al. [33] examined how PE affected the altered asphalt's characteristics. Their research led them to the conclusion that asphalt containing more than 5% PE would produce an unprocessable mixture due to the high viscosity that would arise. Rutting, cracking, and thermal fatigue resistance are all improved with the use of recycled PE. The use of recycled EVA to modify asphalt produced very satisfactory outcomes, as shown by the research of García-Morales et al. [27]. The concentrations that were investigated in their study varied between 0% and 9% by weight. The findings also showed that the binder viscosity rose at higher service temperatures due to the recycled EVA, which improved road performance (e.g., resistance to rutting). Even at 9% concentration, the asphalt's viscosity was low enough for it to be used adequately in pavements, regardless of the temperature of manufacturing or application. When comparing recycled materials for asphalt modification, Casey et al. [26] found that discarded HDPE and LDPE were the most promising, followed by recycled PET, PVC, and ABS. They have expected better results to be obtained with ABS, and

pointed out to a concentration of 4% as the ideal concentration of recycled HDPE and LDPE used as additives in the asphalt binder. Additionally, Costa et al. [34] sought to assess the potential benefits of enhancing the asphalt binder's characteristics by including various plastic wastes, including HDPE, LDPE, EVA, ABS, and CR (crumb rubber). Traditional asphalt and a commercially available modified binder were pitted against modified binders that included recycled polymers in terms of performance. Characterization of the various asphalts changed with 5% of the investigated polymers showed that

comparable or even superior qualities might be achieved compared to commercially available modified asphalt. Specifically, the following was noted: SBS, HDPE, and EVA are the most likely polymers to raise the modified binder's softening point; HDPE and EVA had the most impact on the penetration test results; elastomers, SBS, EVA, and CR demonstrated the best resilience performance; all modified asphalts, with the exception of those containing ABS and CR, only attain the appropriate viscosity to create asphalt mixtures at temperatures near or above 180 °C, including commercial asphalt; HDPE, LDPE, and EVA mix well with asphalt; SBS, ABS, and CR are hard to melt into asphalt. The flowability and dispersibility of the utilized modifiers in the asphalt matrix were affected by their viscosity, which was the cause of this phenomena. One of the most common types of plastic trash is PET, which is used for recycling from the household waste stream as mentioned by Action Program (WRAP) survey [35], may be used as an additive and modifier for asphalt binder. This was investigated by a number of researchers and many reports and scientific studies on this subject were published in the last years.

The application of waste PET; a thermoplastic polymer resin of the polyester family, in the form of granules pellet of 3 mm size was part of a study carried out by Hasean et al. [36]. They blended the waste PET as a partial fine aggregate with an asphalt binder (from 60/70 penetration grade asphalt and 12.5mm aggregate grading) at (140 -180) oC and then compacted it using Marshall hammer with 50 blows on each side. The results obtained in this study proved that the aggregate replacement of 20% fine aggregate (2.36 - 4.75 mm) by volume with PET granulates (5% total weight of the asphalt mixture) was the effective use to get the highest Marshall Quotient with the lowest flow and the highest of stability.

In addition, PET has been found to be the most effective polymer additives due to its low glass transition temperature and semicrystallinity [19]. A number of investigations were focused on the influence of fiber additives on the engineering properties of asphalt binder or asphalt mixture. In SMA, the hot asphalt is coated over hot stone aggregate mixed, laid and rolled. Asphalt acts as a binder. The significant disadvantages of SMA mixes belong to the action of water, which penetrates and causes defective spots on the pavement, when stagnating over the roads. The use of anti stripping agents has a limited use only and the process also increases the cost of road construction [37]-[40]. The use of virgin or waste plastics and plastic coated aggregates to improve the performance of asphalt against this defect has been studied. The improvements of the asphalt mixes were done in a number of attempts by incorporating various types of additives to asphalt such as rubber latex, CR, SBS, SEBS, recycled PP, LDPE [41] PE [42], EVA (5%) [43] and polyolefines [44], [45]. Some of the properties improved are durability, fatigue life [46], [47], resistance to rutting, softening point, viscoelastic property [48]. Other fiber modifiers from the polyester family were among the modifiers of asphalt, and have obtained more and more attention for their excellent improvement effects. Cellulose fibers, and mineral fibers are two types of commonly used fiber modifiers. They have been widely used in different kinds of asphalt mixtures, especially in stone mastic asphalt (SMA); it is a type of HMA with open grade friction concrete (OGFC) [47], [48].

SMA was developed in Germany in 1960s and has been using among European countries for more than 20 years [13], [49], [50]. In 2004, a comparison study carried was carried out by Putman and Amirghanian [51] to investigate the performance of SMA mixtures containing waste CR from used tires, and carpet fibers with commonly used cellulose in one occasion and polyester fibers in the other. The results indicated that the. significantly improved the toughness of the mixtures, but no significant difference in permanent deformation or moisture susceptibility was found. Polyester fibers are usually

used when strong and durable reinforcements of asphalt-fiber mastics are needed at higher temperatures; as it was reported by Shih and Kuei [52]. The influence of polyester and cellulose fiber additives on the engineering properties of asphalt was also investigated by [52]. They have found that good adhesion between the polyester fibers and asphalt enhanced the load-carrying ability of asphalt-fiber mastics.

The type of mixing or the process involved in production of very effective asphalt road pavements is very important factor in determining the final product properties. In 1987, an available report has implied the successful application of BoniFibers™; it is the trade name for polyester fibers of 6mm length

manufactured in the city of Tacoma, United States of America and supplied to blend with asphalt. The report stated that in order to assure uniform distribution of BoniFibers™ throughout the asphalt concrete, BoniFibers™ must be added to the aggregate at the beginning of the dry-mix cycle which lasts at least 15 s and preferably 30 s [21]. The assessments of the engineering properties of SMA mixture and the effect of incorporating scrap from waste PET bottles was the center of the study conducted by Esmail et al. (2012). The mechanical properties of asphalt mixes that include various percentages of PET (0%, 2%, 4%, 6%, 8% and 10%) were calculated and assessed with laboratory tests. The results showed that the appropriate amount of PET was found to be 6% by weight of asphalt. Additionally, the incorporation of PET has also a significant positive effect on the properties of SMA such as increasing viscosity and stiffness of asphalt at normal service temperatures. However, all applied amounts of PET additives did not increase the elasticity of asphalt significantly and on heating, they do not perform satisfactory [53].

Using plastic waste materials in road pavement can be either in form of aggregate replacement, binder modifier or mixture reinforcement. The last option was selected by Moghaddam and Karim in their study [13] when they investigated the effects of adding waste PET particles into the asphalt mixture. The results of the study showed that PET reinforced asphalt mixtures had higher stability value in comparison with the virgin mixture. In terms of the convenient quantity of the PET to be added, it was noted that the optimum value in case of stability was 0.4% PET. Moreover, adding higher amounts of PET into the mixture increased the flow values. In contrast, stiffness of the mixture was decreased, yet fatigue life was increased by adding higher amount of PET. Kalantar et al. (2010) [20], have investigated the possibility of using polyethylene terephthalate as polymer additives in Bituminous Mix. The binders were prepared by mixing the PET in amount of 2%, 4%, 6%, 8%, and 10% by the weight of optimum bitumen at 150°C. Results showed better resistance against permanent deformations and rutting when compared to conventional binders. The result also showed that the addition of PET to bitumen increases the softening point value, and as the higher PET content increases the softening point temperature increases. This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Low Density Polyethylene (LDPE) was also used in asphalt mixtures as an aggregate replacement. It was reported that Marshall Stability was increased by 250%, and mix density was reduced by 15% with the replacement of 30% LDPE in form of aggregates particles with the size of 2.36-5mm [13].

#### IV. UTILIZATION OF WASTE PET IN CONCRETE

Concrete is a heterogeneous composite material made up of cement, sand, coarse aggregate and water mixed in a desired proportion based on the strength requirements. Concrete is the most frequently used construction material worldwide. However, it is characterized with a number of defects such as low tensile strength, low ductility, heavy weights, and low energy absorption [54]. These main disadvantages have triggered civil engineers to make use of conventional reinforcement to increase the tensile strength and ductility of concrete.

The addition of fibers to concrete would act as crack inhibitors and substantially improve the tensile strength, cracking resistance, impact strength, wear and tear, fatigue resistance and ductility of the

modified concrete. The concept of using fibers in concrete as reinforcement is not new one. For last three decades numerous studies were performed on Fiber Reinforced Concrete (FRC). In the early 1960's only straight steel fibers were used and the major improvement occurred in the areas of ductility and fracture toughness, the flexural strength increases were also reported. In the beginning fiber reinforced concrete was primarily used for pavements and industrial floors. Currently, the fiber reinforced cement composite is being used for wide variety of applications including bridges, tunnels, canal linings, hydraulic structures, pipes, explosion resistance structures, safety valves, cladding and rolled compacted concrete [55].

#### *A. Case Studies*

A number of scientific reports [56]–[60] concluded that an effective way to improve the toughness of concrete is adding a added the concrete mixture while it is still in the mixing process; typically, this is 0.5 to 2% by volume. As a result of being dragged out or pressured to rupture, the fibers in fiber reinforced concrete (FRC) encourage the bridging of matrix fractures, which prevents cracks from propagating and opening. The tensile qualities of concrete may be greatly enhanced using this kind of fiber reinforcement, according to several research. atigue strength, wear resistance, and durability are some of the other advantages of FRC. Reduced section thickness and well controlled cracking are two benefits of using FRC instead of traditional concrete, which leads to lighter constructions with longer life expectancy. These days, you may find FRC in a wide variety of places, from buildings and highway overlays to bridges and airport runways [57]–[59]. In load bearing applications it is generally used along with traditional steel reinforcement [61]. It is now standard practice to strengthen floor slabs with tiny amounts of synthetic fibers while constructing buildings. Reinforcing concrete has long made use of a variety of fibers, some of which are now commercially accessible. Materials such as carbon, glass, nylon, polypropylene, and steel are among them. Research has shown that a wide variety of fibers extracted from MSW streams may be used as reinforcement in concrete. The processing cost of recycled fibers is often cheaper than that of virgin fibers, which is one of the many benefits of employing them.

doing away with garbage dumps as a disposal option. In addition to the advantages of recycling MSW such as plastics, the incorporation of plastics such as PET wastes in concretes is sometimes essential for the creation of construction building materials with a number of characteristics. Researchers want to address the issue of lightweight aggregate as they create new building construction materials. The reduction of the unit weight of concrete is one of goals at production of earthquake resistant structures since the earthquake forces are linearly dependant on the mass of the structure [62]. Nowadays, there are many lightweight concrete applications made with natural or artificial lightweight aggregates in the literature [63]–[66]. However, the cost of artificial lightweight aggregate production is high due to requirement of high incineration temperature or thermal treatment [67]. s an alternative way of creating lightweight concrete, different from the common materials, using waste plastic granules as lightweight aggregate in the production of lightweight concrete was studied. A lot of people in the scientific community are interested in this. This approach provides benefits of both recycling of the plastic waste and production of a cost-effective lightweight concrete [68]. Some of the plastic wastes used in lightweight concrete were PP, PE, PET and PS. Due to their rapidly expanding consumption rate, PET bottles surpassed the trash. In few years ago, a lot of experimental studies were conducted on using waste PET bottles in concrete reinforcement [69]–[71]. Nowadays, construction engineers intend to utilize polymer concrete which is produced by partially replacing of cement binder with polymer resins. The high cost of virgin resins means that polymer concrete resins are still more expensive than cement-based products. However, waste PET bottles recycling combined with production of polyester resin decreases the cost of resin manufacture when compared to conventional normal resin production [70]. Unsaturated polyester resin based on recycled PET can be used to produce a good-quality polymer

concrete [72]. However, the cost of producing polymer concrete from waste plastics is still high. The other alternative method reported by Silva et al. in 2005 and Ochi et al. in 2007 propose the use of waste PET bottles in the form of PET fibers to produce a lower-in-cost fiber reinforced concrete [56], [73]. The disadvantage of such method is the small volumetric amount of fiber content in the fiber reinforced concrete which is between (0.3 - 1.5)%. In this way, only small of such waste may be utilized. Using of shredded waste PET bottles directly as aggregate in the concrete or mortar production is considered the most economical use of waste PET bottles in concrete, thus, provide benefits in waste disposal and reduce pollution of environment since natural mineral aggregates resources remain unused. Limited research has been carried out on using waste PET granules as aggregate in concrete or mortar. In these studies, PET and the other plastic wastes (PE and PP) were used together by partially replacing of mineral aggregates [74]–[76]. Marzouk et al. (2007) used waste PET granules as aggregate in lightweight concrete. Authors concluded that, plastic bottles shredded into small PET particles may be used successfully as substitution of aggregates in cementitious concrete composites [76]. Reuse of PET and other plastics as well as of CR wastes in building industry is an effective approach in both preventing environmental pollution and designing economical buildings. The increase in acknowledging and utilizing environmentally friendly, low cost and lightweight construction materials in building industry call for the need for searching more novel, flexible and versatile composites; as it was proposed in the work [77]. Some researchers found that the most important aspects of novelty might be the development of integrated insulation products such as waste polymer added mortars, concretes and bricks [77]–[79]. As a part of this interest, establishment of an appropriate thermal test technique is also a challenge for developing and manufacturing of such products [80]. One of the popular applications concerning the concrete reinforcement particularly for the Portland cement concrete in the last few decades is the incorporation of crumb rubber from used tires (CR). Works [81], [82] presented excellent overviews of such studies. Waste PET bottles have earlier been used in making lightweight aggregates to improve concrete mechanical properties [74]. PET recycling for forming thermal-insulating materials for the building industry has been another feasible application [83]. A work related to enhancement of concrete's thermal insulation performance was carried out using waste shredded PET bottle and pieces of CR. They are added into ordinary concrete-mix. Five different concrete samples (one neat concrete, one concrete with scrap rubber pieces and three concretes with waste PET bottle pieces) were considered. Thermal insulation performances of these samples were examined by the adiabatic hot-box technique, recently proposed by the authors [84]. The results revealed that proper addition of selected waste materials into concrete can significantly reduce heat loss or improve thermal insulation performance. The degree of improvement in thermal insulation is found to vary with the added waste material and geometry of shredded-pieces. Flexural strength of concrete is another property of concrete which was an aim of a study by Venu and Rao [55], They have conducted an experimental investigation on flexural strength of fiber reinforced concrete slabs and compared to plain concrete slabs. They involved the examination of five different slabs two contained steel fibers, two with synthetic macro fibers, namely waste PET and waste HDPP and one plain concrete slab. They were (2.2 x 2.2)m in size and nominal thickness of 127 mm after being casted. The authors found that ultimate load carrying capacity of concrete increased by 4.62% with 1% HDPP fiber and by 9.11% with 1% PET fiber; the compressive strength of concrete increased by 4.2% with 1% HDPP fiber and 5.63% with 1% PET fiber, and load carrying capacity of concrete in flexure was increased by using both fibers when compared to plain concrete slabs. In a similar issue, flexural behavior of small steel fiber reinforced concrete slabs studied by Ali and Majid . They found that the addition of steel fibers in the concrete improves the energy absorption capacity of slabs [85]. In addition to the aforementioned, Shaikh Faiz Uddin Ahmed et al. [86] investigated strain hardening and multiple cracking behavior of hybrid fiber reinforced cement composites containing different hybrid combinations of steel and polyethylene (PE) fibers under four point bending. Consequently, hybrid

combination of 1.5% steel and 1.0% polyvinyl alcohol (PVA) exhibited best performance in terms of highest flexural strength, 0.5% steel and 2.0% PE exhibited highest deflection and highest energy absorption capacities. The behavior of glass fiber reinforced concrete slabs was studied by Ombres et al. [87]. As a result, they found that the ultimate capacity of slabs increases with the amount of GFRP

rebars while Andrea and Kanrod [88] found that the compressive strength and ductility are increased by using fibers, when conducting experiments on concrete using different fibers like steel, glass, carbon and hemp. Ms K. Ramadevi and Ms R. Manju [89] have investigated the possibility of using the waste PET bottles as the partial replacement of aggregate in Portland cement. In their investigation, 0.5%, 1%, 2%, 4% and 6% volume of sand was replaced by PET bottle fibers. Based upon the experimental results of this study, the following conclusion were drawn: 1) the compressive strength and split tensile strength were increased up to 2% replacement of the fine aggregate with PET bottle fibers and it gradually decreased for 4% and 6% replacements, 2) the flexural strength increased up to 2% replacement of the fine aggregate with PET and it gradually decreased for 4% and remains the same for 6% replacements, 3) the replacement of the fine aggregate with 2% of PET bottle fibers was reasonable than other replacement percentages like 4% and 6% as the compression and split tensile strength reduces gradually. Karim et al. [90] studied the structural behavior of polymer concrete (PC) beams using PET in the concrete. Their results showed that the beams exhibited higher strength and more ductility than base concrete beams, also recycling of PET in PC helps in saving energy and in partially solving a solid waste problem posed by plastics. Nibudey et al. [91] studied the waste plastic fiber reinforced concrete (WPFRC) by using several design concrete mixes with different percentages (0% to 3%) of waste plastic fibers. The major conclusions based on the results obtained in this study as follows: 1) the workability property of concrete was affected in WPFRC, 2) the maximum percentage increase in compressive strength, split tensile strength and flexure strength at 1% of fiber content compared to control concrete, 3) the dry density was reduced and made concrete light weight, 4) the behavior of WPFRC was found ductile due inclusion of fibers, 5) the optimum strength was observed at 1% of fiber content for all types of strengths.

### FINAL REMARKS

The following are the main points drawn from the scientific literatures: Research, experiments, and scholarly articles have shown that plastic trash, and recycled PET in particular, may be used to improve asphalt road pavement and concrete. Research has shown that a variety of polymer binders, when used in small quantities, may enhance the performance and reinforcing capabilities of both road paving asphalt and construction concretes.

### REFERENCES

- [1] Source: [1] US EPA's Plastic Common Wastes & Materials (2013). The Internet. Visit: [www.epa.gov/osw/conservation/material/plastic.htm](http://www.epa.gov/osw/conservation/material/plastic.htm) for more information. "Characterization of unicipal solid trash in the United States," EPA/530-S-92-019 Rep., Washington, D.C. 1992, is cited as [2] in the same document. "Characterization of municipal solid waste" (Franklin Associates Ltd., 2003). Present day (Conducted in preparation for the US Environmental Protection Agency) Prairie Village, Kansas, USA, 1998. (Europe Plastics—the Facts 2014/2015), published in 2013 by Plastics Europe in Brussels, Belgium, is an examination of the most recent statistics on plastics production, consumption, and waste in Europe. [5] In their 2008 article "Use of recycled plastic in concrete: A review," R. Siddique, J. B. Khatib, and K. Inderpreet discuss the topic in Waste Management,

volume 28, pages 1835–1852. Paper published in 2000 by P. M. Subramanian in Resource, Conservation and Recycling, titled "Plastics recycling and waste management in the US," with pages 253-263.

International Journal of Emerging Technology and Advanced Engineering, vol. 2, no. 6, p. 42, 2012, "Experimental investigation on the properties of concrete with plastic PET (bottle) fibres as fine aggregates," K. Ramadevi and R. Manju, 6. [8] "An overview on waste plastic utilization in Asphaltting of roads," by A. Gawande, G. Zamare, V. C. Renge, S. Tayde, and G. Bharsakale

[2]

- [3] Issue 2, page 1–5, Engineering Research and Studies Journal, 2012, volume 3, issue 2. In The Polymeric Materials Encyclopedia, published by CRC Press Inc. in 1996, A. S. Jabarin discusses the chemistry and manufacture of polyethylene terephthalate. [10] Manual of Fiber Chemistry, Second Edition, L. Menachem and E. Pearce, Marcel Dekker Inc., 1998. Referenced in [11] L. Bottenbruch's Engineering Thermoplastics: Polycarbonates, Polyacetals, Polyesters, and Cellulose Esters published by Hanser/Grander. In their 2001 article "Polymer modified asphalt," published in Vision Technologica, B. Yvonne and M. P. M. R. Yajaira discuss this topic. [13] In their 2012 publication "Properties of SMA mixtures containing waste polyethylene terephthalate," T. B. Moghaddam and M. R. Karim discuss this topic in the World Academy of Science, Engineering and Technology, volume 6, pages 612-622. The article "Polyethylene terephthalate (PET) waste as building solution" was published in the International Journal of Chemical, Environmental & Biological Science in 2013. It was written by C. Swaptik, T. A. Maniar, and O. Suganya. The article "Application of asphalt-containing materials" was published in 1999 in the Polym News magazine and was written by N. Akmal and A. M. Usmani. [16] "New study on improved performance paving asphalt by crumb rubber and polyethylene modification," published in the Journal of Material Science and Engineering, volume 2, issue 4, 2013, by M. Sulyman, M. Sienkiewicz, and J. Haponiuk. In their 2001 article "Polymer modified asphalt," published in Vision Technologica, B. Yvonne and M. P. M. R. Yajaira discuss this topic. 18 O. G. Uranga, "Rheological property of bitumen modified with polyethylene and polyethylene based blends," 2008. The article "Effect of astragalus on characteristics of asphalt concrete" was published in the Journal of Materials in Civil Engineering in 1999 and can be found in volume 11, issue 4, pages 283-286. Twenty-one December 2010, Universiti Tenaga Nasional, Malaysia, Z. N. Kalantar, "Properties of bituminous binder modified with waste polyethylene terephthalate," a presentation at the Malaysia Universities Transportation Research Forum and Conferences. Referenced in [21] "Polymer modification of paving asphalt binders" by L. H. Lewandowski in Rubber Chemistry and Technology (pp. 447-480, 1994). In 2008, S. Aflaki and N. Tabatabaee published an article in the Journal of Construction and Building Materials titled "Proposals for modification of Iranian bitumen to meet the climatic requirements of Iran." The article has 10 pages. [23] "Utilization of waste polymers for flexible pavement and easy disposal of waste polymers," in Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India, pp. 105-111, written by R. Vasudevan, S. K. Nigam, R. Velkennedy, A. R. C. Sekar, and B. Sundarakannan. In their 2006 publication titled "Effect of waste polymer addition on the rheology of modified bitumen," M. García-Morales, P. Partal, F. J. Navarro, and C. Gallegos discuss the topic in Fuel, volume 85, issues 7-8, pages 936-943. The article "Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix" was published in 2004 in the Materials Letters journal and was written by E. Hınıslioğlu and E. Açar. The authors of the 2008 article "Development of a recycled polymer modified binder for use in stone mastic asphalt" (D. Casey, C. McNally, A. Gibney, and M. D. Gilchrist) were published in Resources Conservation and Recycling. The authors of the 2004 article "Viscous properties and microstructure of cycled EVA modified bitumen" were M. García-Morales, P. Partal, F. J. Navarro, F. Martinez-Boza, C. Gallegos, O. González, and M. E. Munoz. The article was published in Fuel, volume 83, issue 1, pages 31-38. The article "Characterization of bitumens modified with SEBS, EVA and EBA polymers" was published in the Journal of Materials Science in 1999 and can be found on pages 3737–3745. [29] E. Ahmadi et al., "Performance evaluation of

- utilization of waste polyethylene terephthalate (PET) in stone mastic asphalt,” *Construction and Building Materials*, vol. 36, pp. 984–989, 2012. [30] "A review of using waste and virgin polymer in pavement," published in 2012 by Z. N. Kalantar, M. R. Karim, and A. Mahrez in *Construction and Building Materials*, vol. 33, pp. 55-62. [31] "The use of polyethylene in hot asphalt mixtures," published in 2007 by M. T. Awwad and L. Shbeeb in the *American Journal of Applied Sciences*, volume 4, issue 6, pages 390-396. [32] S. Hınıslıglu and E. Agar, “Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix,” *Journal of Materials letters*, vol. 58, pp. 267–271, 2004. [33] C. Fuentes-Audén, J. A Sandoval, A. Jerez, F. J Navarro, F. J. Martínez-Boza, P. Partal, and C. Gallegos, “Evaluation of thermal and mechanical properties of recycled polyethylene modified bitumen,” *Polymer Testing*, vol. 27, no. 8, pp. 1005–1012, 2008. [34] L. M. B. Costa, H. M. R. D. Silva, J. R. M. Oliveira, and S. R. M. Fernandes, “Incorporation of waste plastic in asphalt binders to