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THE EFFECTS OF RECYCLED WASTE ON CONCRETE MIXTURE PROPERTIES

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THE EFFECTS OF RECYCLED WASTE ON CONCRETE MIXTURE PROPERTIES

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ABSTRACT

Recent years have seen an exponential increase in plastic product consumption worldwide, Manufacturing, and individuals rely on plastics in almost every aspect, as a result, a negative impact on the environment is detected due to the large quantities and low biodegradability of plastic waste. The massive amount of plastic waste and end-of-life tires produced annually required a vast area of landfills, which became a major concern far and wide. To address these issues, an eco-friendly approach consisting of incorporating plastic and rubber waste into engineering applications, such as plastic concrete, and rubberized concrete was proposed. A primary objective of this study is to summarize recent advancements in the utilization of recycled materials in the concrete mix design. Three types of plastics, High-Density Polyethylene -HDPE, Ultra-High Molecular Weight Polyethylene -UHMWPE, Polyethylene Terephthalate -PET, and a Grind/ Crumb rubber were evaluated to be used in a concrete mixture to determine the physical and mechanical properties. There are numerous differences between the approaches and techniques used by the studies covered in this paper, making comparisons unsuitable. In the author's opinion rubber was superior to other materials. Recommendations were provided based on the findings.

DEDICATION

This thesis is dedicated to my wonderful family, my loving husband Hussein Hadbawi, my beautiful daughters Ayah and Malak, and my caring son Muhammad. The support and help you have provided me cannot be adequately thanked. You have been of incredible support and assistance to me, and I thank you from the bottom of my heart. Thanks for your steadfast belief in me and for your help with this research work.

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Ultimately, I owe God thanks for giving me the strength and patience to complete my master's degree.

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CHAPTER 1

1 INTRODUCTION

1.1 Research background

1.1.1 Concrete:

Concrete is a material used primarily in the construction of buildings, bridges, roads, dams, and several other types of structures in the world. After water, it is the second most commonly used material worldwide by individuals and contractors. It is expected that by the year 2050, the demand for concrete will grow from 10 to 18 billion tons a year, it was reported that the production of natural aggregates in 2008 in the UK and US were approximately 5 and 8 tones per capita respectively, [1, 2, 3,4]. The Construction of concrete uses cement mixed with aggregate; -grained mixtures of stones and sand. A local body of water provides aggregates that are crushed naturally, and the natural process produces almost no carbon emissions. It is cement, however, which has a high carbon footprint. In the process of making cement, limestone, clay, and other materials are fired in a kiln. CO2 emissions are emitted as a result of the energy used to fire the materials and the chemical reaction occurring when they are exposed to heat. Concrete releases 0.93 pounds of carbon dioxide per pound, according to the National Ready Mixed Concrete Association. The amount of CO2 released by the concrete industry is on the rise, due to its widespread use. [5] The cement industry is the third biggest polluter, releasing more than 500,000 tons of sulfur dioxide, nitrogen oxide, and carbon monoxide per year. A variety of health problems are affected especially children and people with lung diseases, and adverse environmental impacts can be attributed to nitrogen oxide (NOx), including ground-level ozone, acid rain, global warming, water quality degradation, and blindness. When sulfur dioxide (SO2) reaches high concentrations, it can cause breathing problems and aggravate respiratory and cardiovascular diseases. SO_2 is also a major contributor to acid rain. And Carbon monoxide, CO, is responsible for the formation of smog (ground-level ozone), which could contribute to respiratory ailments. In 2008, EPA developed a coordinated, integrated strategy for addressing compliance issues at cement manufacturing facilities under the Clean Air Act's New Source Review. [6]

Compared to steel, wood, plastics, and aluminum combined, concrete is used twice as much around the world, due to the ease of casting to the desired shape, low-cost maintenance, freedom from defects and flaws, very high durability, soundproofing, fire-safe due to its non-combustible nature, wind and water resistance, and high compressive strength [7]. On the other hand, concrete is less ductile, has relatively high weight compared to strength, much lower tensile strength, therefore it is usually reinforced with materials that are strong in tension such as steel [7]. These weaknesses motivated researchers worldwide to investigate more materials to reinforce concrete.

1.1.2 Recycled materials:

Plastic has become a fundamental resource for our everyday use in our modern life after the industrial revolution in the 18th century. Industrialization led to countless benefits, but it also generated an enormous amount of waste. In the decades following, recycling innovations have brought us closer to closing the recycling loop, even though there is still much to be done. Recycling plastic was one of the most significant game-changing innovations of the 1960s when people began to realize that plastic could be hazardous to their health [8]. Recycling materials has been a concern in civil engineering since the early

1960s. It is becoming increasingly challenging to control plastic/rubber products waste as plastic/tire waste is produced worldwide at a rate that is unmanageable as accumulated waste. The global plastic and rubber waste stream amounts to approximately 6.5 billion tons per year, and the long degradation periods of plastics cause a significant threat to the environment, land, and aquatic ecosystems [9]. In fact, researchers have found that plastics have the ability to endure for 4500 years without degrading [10]. In an average year, only 20% of household waste is recycled, leaving the remaining 80% buried or dumped into oceans. Photo-degradation and biodegradation are the only processes that can break down 80% of the plastic that is not recycled [11]. An international team of scientists from the University of Georgia, University of California, Santa Barbara, and Sea Education Association carried out the first global analysis of all plastics ever made, their production, use, and fate [12]. According to researchers, 8.3 billion metric tons of plastic were produced by humans by 2015, 6.3 billion tons of which had already become waste. But only nine percent of that waste was recycled, 12 percent was incinerated, and 79 percent could be found in landfills or accumulated in natural settings. The same report predicts that there will be 12 billion metric tons of plastic waste in landfills and the natural environment by 2050. This is 35,000 times as heavy as the Empire State Building [12].

Based on Environmental Protection Agency EPA and information from the American Chemistry Council, the United States generated 35.7 million tons of plastics in 2018, 12.2 percent of municipal solid waste (MSW). According to the American Chemistry Council, the National Association for PET Container Resources, and the Association of Plastic Recyclers to measure the recycling of plastic, recycling rates for PET and HDPE in the U.S. were respectively 29.1% and 29.3 % in 2018, while plastics recycling rates overall in the country were 8.7% [13]. Using plastic/rubber waste in the materials industry minimizes the adverse environmental effects caused by the indiscriminate disposal of solid waste and minimizes the need for landfills used in waste incineration. End-of-life waste management issues spur research worldwide to identify best practices for enhancing waste disposal and (if possible) recycling to achieve environmental and economic sustainability. Rubber/Plastic-containing concrete additionally offers a double benefit to the environment since it reduces both the environmental impact associated with tire/plastic disposal (landfilling and burning) and the excavation process of recovering aggregates from quarries or quarries' riverbeds [14][35].

Abundant studies have been conducted to find the ideal content of plastics/rubber in concrete, which does not impact the engineering properties. The concrete with plastic aggregates (PA) and plastic fibers (PF) had been the subject of over 80 research studies by 2016[15]and much more by now. Numerous researchers around the world have been studying the feasibility of using recycled plastics in concrete. Studies have shown that as the amount of PA substituted for the natural aggregate in the concrete increases, composite concrete loses compressive strength, elastic modulus, splitting tensile strength, and flexural strength [15,16]. PA concrete, however, can become 15% stronger than conventional concrete after being pre-exposed to small amounts of gamma radiation, then pulverized into fine powders before being mixed with cement paste and fly ash, according to MIT researchers (2017) [15,17].

1.2 Types of Materials:

I. Thermoset – is a polymer that is irreversibly hardened by heat. This type can withstand high temperatures without losing severity due to its ability to remain in an everlasting state when it is hardened. Epoxy, silicone, and melamine are examples of thermoset plastics.[18]

II. Elastomer -any material that is able to resume its original shape when a deforming force is removed. They can be stretched over 100% of their original length with no permanent deformation. This type cannot be melted. Rubber is an excellent example.[18]

III. Thermoplastic plastics -is a type of plastic made up of polymer resins that soften at high temperatures and harden when cooled. Its chemical makeup remains unchanged regardless of how many physical states it changes into. PVC, Polyethylene (UHMWPE, LDPE, HDPE, PET), and Nylon are good examples of thermoplastic plastics.[18]

1.3 Plastics categories:

Recycling is symbolized by the number inside a triangle on many plastic products. Currently, in the United States, only plastics that have polyethylene terephthalate (1) ♳or high-density polyethylene (2)♴ are widely recycled. The rest are typically disposed of in landfills [19].

Table 1 recycling symbols and applications of plastics

Symbol	Plastic	Examples /applications
♳	PET Polyethylene Terephthalate	Water and soft drink bottles, salad domes, cookie trays, salad dressing, and peanut butter containers
♴	HDPE High-Density Polyethylene	Milk and juice bottles, freezer bags, shampoo, and detergent bottles
♵	PVC Poly Vinyl Chloride	Cosmetic containers, commercial cling wrap
♶	LDPE Low Density Poly Ethylene	Squeeze bottles cling wrap, trash bags
♷	PP Poly Propylene	Microwave dishes, ice cream tubs, yogurt containers, detergent bottle caps
♸	PS Polystyrene	CD cases, plastic disposable cups, plastic cutlery, video cases
♸	EPS Expanded polystyrene	Foam polystyrene hot drink cups, food takeaway trays, protective packaging for fragile items
♹	Other	Water cooler bottles, flexible films, multi-material packaging

[19]

1.4 The objective of the study

The paper in hand discusses the advantages and disadvantages of several recycling materials to be considered in the concrete mix as a reinforcement. End-of-life tiers, Polyethylene (High-Density Polyethylene- HDPE, Ultra-High Molecular Weight Polyethylene - UHMWPE, and Polyethylene Terephthalate – PET), were evaluated to find the best recycled material that can be used in concrete mix.

This study will achieve its goal when answering the following questions:

- How will concrete react when incorporate with plastics/rubber particles?
- Does the additive of recycled materials enhance the physical and mechanical properties of raw concrete?
- Can recycled plastic/rubber replace the steel for reinforcement in conventional concrete? Will the final product be in use in structural applications?
- Could we rely on recycled plastics aggregates to save the mineral resources of limestone and natural aggregates?

1.5 Cost-benefit analysis of recycling materials: Does Recycling Worth It?

Most municipalities around the USA agreed that recycling is more expensive than other forms of waste disposal. The costs associated with recycling programs are among the highest waste disposal methods. In addition to the costs of collecting and storing these materials, the country incurred interest payments on the recycling facility. Recycling is much more expensive than landfills or incinerators due to the time, money, and energy involved in the processing and collecting of recycled materials. [20,21] Recent shifts in overseas demand have made recycling of nearly all materials extremely challenging over the past few years. For many years, recycling was relatively cheap up until 2018, when China stopped buying millions of tons of low-quality and contaminated recycled materials from North America and Europe [22]. In addition, large-scale recycling is becoming less profitable, and the level of contamination tolerated by these facilities is decreasing, causing more valuable post-consumer plastic to end up in landfills. Recycling plastic, particularly as of 2021-2022, is <u>not cost-effective</u>. On top of added health and safety concerns, employment shortages, and a general slowdown in manufacturing, the coronavirus pandemic and the existing plastics recycling market turmoil have caused price fluctuation and uncertainty about end users' commitments to sustainability. Coronavirus pandemic impact has coincided with historic drops in oil prices; Consequently, US oil has no value and is a liability, according to oilprice.com [23]. Scrap markets around the world have been restructured terribly. Low oil prices, combined with low scrap values and high recycling costs, make it more expensive than ever to recycle plastic than to manufacture virgin plastic.

The demand for recycled plastic, however, is on the rise as manufacturers move away from virgin materials to reduce their environmental footprints. Recycling plastic will become cost-effective in the future with this new outlet for waste materials [20].

The current prices of different recycled materials in region 6 (south-east), as of April 6, 2022, are listed on recyclingmarket.net [24]. and shown in the table below, Table 2.

Table 2: Up-to-Date Materials Prices – [recyclingmarket.net]

Material	**Current Average Cost $/ton**
Glass flint	30
Glass - amber	27.5
Glass -green	10
Paper mixed	72.5
White goods	42.5
Steel canes	230
Aluminum canes	118.5
Recycled tires	300
colored HDPE	680
natural HDPE	1080
PET	855

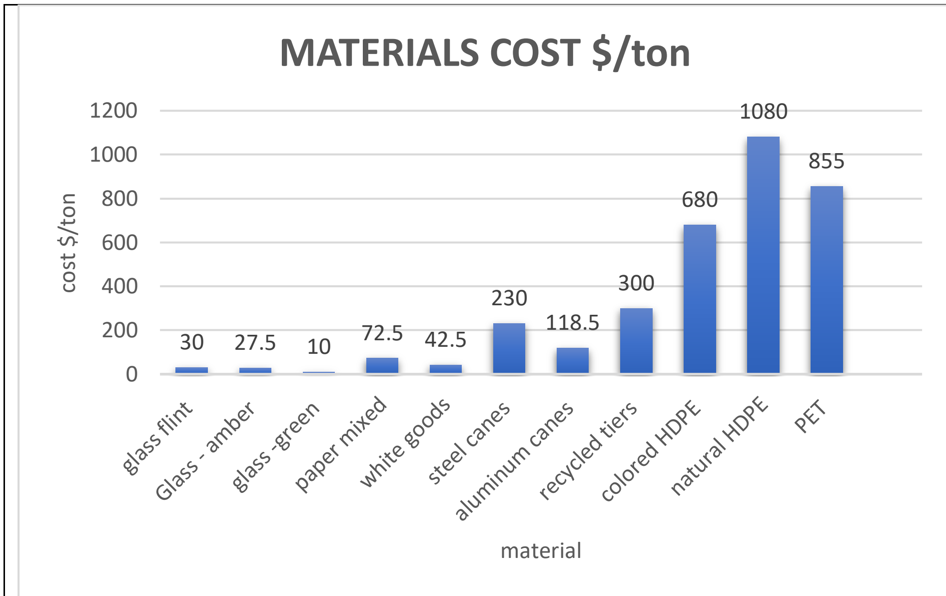

Figure 1: up -to- date material prices

Compared to other materials, recycled plastic is relatively elevated, according to the data the author obtained by communicating with recyclingmarket.net, and Liberty Tire Recycling agents [25]. **Even though recycling is relatively expensive, proponents argue that the benefits to the environment and health outweigh the costs** [21].

CHAPTER 2

2 LITERATURE REVIEW

2.1 Recycled Shredded Tires

In the global economy, rubber waste represents a significant problem because accumulated waste rubber, particularly in the form of tiers, can pose a significant fire risk [26]. Rubber Recycling prevents this problem and generates new materials with desirable properties that virgin rubbers lack. (Kim Jin Kuk, 2018) [26]. Over 300 million scrap tires are produced annually in the U.S. alone [27,28]. Most post-consumer rubber-derived products are still discarded as waste, buried in landfills, or incinerated. Such materials require many years to degrade naturally due to i) their complex cross-linked composition and ii) the additives used during manufacturing to extend the lifespan of rubber (Medina, et al, 2018) [29]. Therefore, rubber tires are preferred for milling to produce granules, chips, powders, and textiles, meaning they can be used in many advanced applications [30]. By the end of 2017 only about 60 million scrap tires remained in the U.S. stockpile[31], which is a huge redemption level. Besides the ecological solution, tire recycling has great economic importance. Using recycled crumb rubber in asphalt paving mixture was a promising solution. The addition of recycled crumb rubber into the asphalt mixture was a success due to increasing the resistance to rutting, fatigue cracking, and low- temperature cracking. (Shu& Huang, 2014) [32]. The same finding was revealed by a group of North Dakota State University scientists who studied the effect of using crumb rubber from old tiers to rubberize aging asphalt; they concluded that it was very sturdy and useful [33]. Tiers as a recycled aggregate have been widely studied and used in concrete products and asphalt at present. According to Lavanaga et al,(2020)[34], When rubber is incorporated into concrete, it can provide many benefits, including improved toughness and thermal/electrical/acoustic insulation properties [34]. The encouraging mechanical properties of rubber concrete, mainly its increased toughness, invited researchers to evaluate its structural performance in areas requiring high dynamic stress resistance, such as earthquake-resistant buildings. Previous research by Dr. Osama Yussf at the material level revealed that Rubber additives had been shown to improve ductility, damping ratios, and energy dissipation properties of concrete, which are the major determinants of earthquake load-bearing concrete structures [Youssf, et al 2016] [35,36].

The most current case on reinforced concrete with crumb rubber. *practical Application of Crumb Rubber Concrete in Residential Slabs*, was reported by *Youssf et al, 2022*, [37,38]. in *the science direct journal, Elsevier Ltd.* To replicate a real-world situation, the paper demonstrates how crumb rubber concrete CRC research has transformed from the lab to the slab. To assess the characteristics of a large-scale residential application, there were two large reinforced concrete residence footing slabs, each measuring four meters by eight meters. crumb rubber concrete (CRC) was used in one and conventional concrete (CC) in the other. both with nominal 20 MPa strength. Abrasion tests were also performed on two reinforced concrete residential ground slabs constructed with CRC and CC mixes, with nominal 32 MPa strength. Concrete ground slabs were poured at the entrances of a civil engineering laboratory where they received high traffic. In attendance there has been extensive investigation and comparison of a variety of factors, including the impact of rubber used on concrete mixing, delivery, workability, pumpability, ease of surface finishing, and curing. For footing slabs, contractors have reported that screeding is easier and takes less physical effort, with no difference reported when using a concrete power trowel to finish the concrete surface. In their opinion, CRC shouldn't have more than 100 mm of slump after manual finishing. Other properties besides toughness were investigated. The following factors were also considered: fresh and hardened density, compressive strength, modulus of elasticity, shrinkage, carbonation, chloride ingress, abrasion resistance, rising dampness, and corrosion. In the residential concrete market, CRC appears to be a viable and promising alternative to conventional concrete. Dr. Youssf and a group of researchers at RMIT and the University of South Australia found that grinding old tires into fine particles has been useful in the manufacturing of concrete, in lieu of using sand aggregate. By replacing up to 20% of the fine aggregate /sand with crumb rubber, both in the lab and at the site, the reinforced slabs were superior to the conventional concrete, in impact resistance, toughness and ductility, thermal and acoustic insulation, and lighter weight.

The concern of *Purcell, A. et al (2021),* in the study *Optimising the Performance of Crumb Rubber Modified Concrete,* that was published in the Journal *of Solid Waste Technology & Management*,[39] was to fill a knowledge gap needed to develop a rubberized Trinidad Portland type IP concrete. Due to the fact that the properties of concrete and the impact of additives are dependent on the chemical composition and source of the parent cement, research and scientific studies on Trinidad Portland cement are needed, but not conducted. Several scientific studies have been examined in Trinidad and Tobago to study the reuse of waste materials, particularly in road paving applications. Tires at the end of their life cycle (EOLT) are a large volume of chemical product waste that can be recycled, reused (material recovery), or transformed into energy. It is estimated that more than 1.5 million tires are imported each year to Trinidad and Tobago. The non-biodegradable used tires are disposed of through unsustainable methods such as stockpiling, illegally dumping, or landfilling. As well as being an eyesore, waste tires contribute to the spread of vector-borne diseases and increase the incidence of flooding by blocking waterways. Additionally, they release poisonous fumes during accidental fires. To reduce the effects of EOLTs in some localities, a different approach must be found. There is already a widespread acceptance of the use of EOLT material in asphalt road mixes as well as in concrete. It was found that while there is an 'optimal' weight percentage of crumb rubber that can be added to concrete without adversely impacting its properties, mainly compressive strength and tensile splitting strength, the results vary considerably depending on the crumb rubber concentration. The paper evaluates the effects of EOLT rubber crumb on locally produced Portland Type IP cement, (considering it is one of the most commonly used types of cement in the local general construction industry and exported across the region, and any findings can be applied to non-specialized and high-volume applications), in order to create rubberized concrete using EOLT instead of natural sand. As a replacement for fine aggregate (sand), varying amounts of rubber scrap, from a tire re-threading facility,(0-10%) were added to concrete in the study. Preparation of the concrete was done with a water-to-cement ratio of 0.5, with the intention of achieving concrete with a compressive strength of approximately 30 - 35 MPa of the control case (0% crumb rubber added), as stated by ACI Recommendation Practice 211.1-9, and the cure time was 3-28 days. The samples were subjected to standard testing for compressive strength, split tensile strength, slump tests, and scan electron micrography (SEM-EDS) was done on samples after failure compression tests. As an environmentally friendly solution, the reuse of crumb rubber from EOLT tires for concrete additives can only be achieved if the final material (crumb rubber concrete) performs similarly to standard concrete without rubber. The concrete was tested both for compression strength and splitting tensile strength, both of which are key parameters for measuring concrete quality. There is an overall trend of increasing compressive strength with curing time, in line with all that is known about concrete curing in the literature, with the exception of the samples that included 4% crumb rubber. Moreover, as the weight percent of crumb rubber in the concrete increased, the compressive strength of the concrete decreased. In the 28-day cured sample with 2 wt.% added crumb rubber, the compressive strength was slightly higher (24.414 ± 3.018MPa) than the reference sample with 0 wt.% added crumb rubber (22.705 ± 3.132MPa). In this study, crumb rubber 2-4 wt.% (as sieved according to the specifications) is not found to affect the compressive strength and splitting tensile strength of concrete made from local Portland Type IP cement. According to the results, the compressive strength of crumb rubber cement in thie study was within the acceptable range of 20 MPa for concrete cured for 28 days, indicating that the results should apply to other concretes manufactured under similar conditions.[39]

In the study *Investigating the mechanical properties and durability of concrete containing recycled rubber ash and fibers* by *Gupta et al (2021)*, published in the *Journal of Material Cycles and Waste Management* [40] the authors assess the suitability of employing recycled rubber tires particles as fine aggregates in concrete by developing two types of rubber ash concrete (Series I) and hybrid concrete (Series II) mixes using rubber ash and rubber fibers. The urban lifestyle has led to various environmental and health concerns due to the accumulation of rubber tires in open fields and scrapyards. There are various processing techniques that can be used to reduce the accumulation of rubber tires on open land, including shredding, pyrolysis, and cutting. A challenge remains, however, in upcycling this processed rubber tire waste. As reported by Gupta et al. in a series of studies, rubber fibers decrease concrete's mechanical properties but increase its ductility. Crumb rubber inclusion decreased compressive strength and improved resistance to freezing and thawing cycles, according to Gonen (2018), while Feng et al. (2018) found that rubber concrete with between 40% and 50% rubber particles had much lower static strength properties, and rubber concrete had a higher energy absorption capacity than normal concrete. From literature, it has been seen that using bigger crumb rubber enhances the ductility of concrete. However, the downside is that using bigger crumb rubber is associated with a larger smooth surface, which has a negative effect on concrete's adhesion properties. The aim of the Gupta et.al [40] study is to create rubberized concrete that would mitigate the problem issued when using bigger crumb rubber particles by using rubber ash and rubber fibers. Two series of concrete mixes were formed, alternating series 1 with rubber ash as a replacement for sand and series 2 with a hybrid form of rubber aggregate, consisting of a fixed percentage (10%) of rubber ash and varying percentages of rubber fibers. A rubberized concrete mix with a water/cement ratio of 0.35 was prepared at the gupta study [40]: one mix contained cement, sand, gravel, and rubber ash (at 0%, 5%, 10%, 15%, and 20% replacement by volume of sand), while the other mix had rubber ash fixed at 10% and rubber fibers varied from 0%, 5%, 10%, 15%, 20% and 25% replacement by volume of sand, the samples were cured for 28 days after casting and then tested for compressive strength, flexural strength, impact resistance: i)under drop weigh ii) under rebound iii) under flexural load, fatigue resistance, resistance to water penetration and shrinkage value. As a result of adding rubber waste, the mechanical performance of concrete decreases. The compressive and flexural strength decreased by 28.77% and 32.87%, respectively, when 20 % of natural fine aggregate was replaced with rubber ash. The addition of 25% rubber fibers to the concrete mix enhanced the flexural strength, delaying the occurrence of flexural failure due to the fibers' bridging action. The loss of mechanical properties associated with the presence of rubber aggregates is usually due to the difference in stiffness between rubber particles and natural sand. Rubber fibers and ash also create voids in concrete due to the poor packing of lightweight rubber particles. Moreover, the hydrophobic nature of rubber causes a small muddle in the water-cement ratio in pockets of concrete matrix, leading to voids and poor cement hydration products formation. Also, the hydrophobicity of rubber results in excessive water repellence, which decreases the modulus of elasticity and compromises the interfacial bonds. As a consequence of water-repelling, voids form, which leads to weak interfacial zones contributing to poor mechanical properties [40].

However, regardless of concrete's solid nature, concrete is vulnerable to fire-induced explosions spalling, which are caused when fire temperatures reach higher than concrete's melting point. The rise in temperature causes pressure to build behind the exposed concrete surface, weakening structural elements within the material and triggering its failure, says *Dr. Shan-Shan Huang* from *Sheffield University*, who investigated with her team the benefits of the use of waste tires to enhance the spalling issue of conventional and high-performance concrete. (Huang S et al 2019) [41].

Hossein Ataeia 2015 [42] stated that rubber tire concrete has many applications currently being explored and can be used because of its nonprimary structural load-bearing capacity, which is medium to low in strength. The vast majority of active research in this area examines rubberized concrete's other properties and features [43]. The lightweight rubber concrete (RC) can be used as environmental-friendly and cost-effective partition walls, road barriers, and pavements, according to *Batayneh et al*[44]. Further, Ataei and Khaloo [45] and Khaloo et al. [46] report that rubberized concrete exhibits a more ductile behavior under compression without sudden failure; crack sizes in rubberized concrete are smaller than those of plain concrete, and crack propagation is more gradual and uniform in rubberized concrete despite having larger deformations than plain concrete. Observing an increase in toughness of rubber tire concrete over plain concrete, *Tontanji* [47] recommended using it as a highway crash barrier, as sound barriers and vibration absorbents, as well as fences and poles in agriculture. The rubber tire concrete not only provides a sustainable solution for recycling rubber tire waste, but RC is also a recommended alternative in the study based on *Hossein Ataeia's 2015* [42]observations and results, their recommendations were: 1) Applications requiring low strength yet high resilience, such as sidewalks, driveways, runways for light aircraft, and selected base fills for road construction; (2) crash barriers around bridges and in roadblock guards as RC specimens are extremely tough and high plastic energy-absorbing; 3) applications such as nailing concrete, stone backing and interior construction due to the lightweight of rubber tire concrete; (4) to fill highway retaining walls and surround airport fields and terminals due to rubber tire concrete's high sound and vibration absorption.[42]

On the other hand, the disadvantages of using end-of-life tires are detected. Rubberizing concrete reduces the final composite's mechanical strength significantly. An important reduction in both mechanical resistance and specific mass has been observed. The actual compressive strength and flexural strength of concrete will be reduced by using particles [42,43,44]. As a result of these side effects, not only do rubber components differ mechanically from mineral aggregates, but they are also characterized by poor interfacial adhesion between rubber and cement pastes, which significantly reduces the volume of rubber that can be loaded into concrete [34].

2.2 HDPE - High-density polyethylene HDPE

High-density polyethylene -HDPE is a thermoplastic polymer made from petroleum. A multipurpose plastic material, HDPE plastic is commonly used in a wide range of applications, such as toys, milk jugs, shampoo bottles, bleach bottles, cutting boards, Chemical Containers, recycling bins, pipe insulation, and grocery bag.[48] Despite its popularity and cost-effectiveness, HDPE has some advantages and disadvantages that should be considered before using it. The molecular structure of this polymer makes it most effective in applications that require moisture and chemical resistance. Additionally, it is a perfect fit for an application that requires UV resistance, stiffness, heat resistance (Can withstand temperatures from -148 to 176 degrees Fahrenheit), and leaching resistance. On the other hand, HDPE has poor weathering resistance, is flammable, sensitive to stress cracking, and difficult to bond [48]. HDPE is the most common recyclable plastic known as No. 2 and finds its way into civil engineering structural and nonstructural applications. All findings in Pešić et al. (2016)[49] *Mechanical properties of concrete reinforced with recycled HDPE plastic fibers* study propose that recycled HDPE fibers are useful for creating a new value chain in the construction industry and helping it perform better in terms of environmental protection. Pešić et al study investigated the mechanical and serviceability properties of concrete reinforced with HDPE; While the compressive strength and the elastic modulus of concrete were unaffected, the tensile strength and flexural (rupture) modulus were marginally increased over the plain concrete, between 3% and 14% in the presence of HDPE fibers. No signs of chemical deterioration were found on SEM imaging when assessing the durability of HDPE [49]. In a case study of Kigali city, Rwanda, with a particular goal of maximizing post-consumer plastic waste utilization, and in addition to determining the optimal mixing ratio of HDPE for maximum compressive strength, *Ingabire et al (2018*)[50], investigated the impact of temperature on the melting point and subsequent effects on HDPE . The team designed a study to assess the performance of a paving material constructed from sand and plastic waste. Similar studies concluded that sand could enhance the mechanical properties of recycled plastics used for making construction materials, such as rigidity and strength. Compared to conventional materials, paving materials made from HDPE waste and sand composite performed significantly better, it is not prone to spalling. By creating a smooth and even surface, the edges create a barrier that allows very little, if at all, moisture to reach the road foundation.[50]. In the same context, the physical and mechanical properties were examined by *Lopez et al (2019)*[51] to use HDPE to replace coarse aggregate in acrylic polymer pervious concrete (AcPPC). Pervious concrete is an eco-friendly option that prevents flooding by allowing rainwater to drain efficiently. A variety of sizes and ratios were evaluated. AcPPC was found to have increased porosity and permeability due to the partial replacement of recycled HDPE. In contrast, the AcPPC's compressive and flexural strength decreased. Among the pervious concrete materials tested, only the 1 /2" pervious concrete with a 10% HDPE modification with a 15% acrylic additive (PCHA) achieved compressive strengths within the acceptable range for pervious concrete. Similarly, the pervious concrete with a 10% PCHA thickness of 1/2" and a 10% PCHA thickness of 3/4" met the standard specification for flexural strength Accordingly, the 1/2’’ 10% PCHA mix was the best fit in this study.[51]

Based on its increased strength, hardness, and high-temperature resistance, HDPE was selected by *Tamrin and Nurdiana (2021)*[52] over other plastics. Their study titled *The Effect of Recycled HDPE Plastic Additions on Concrete Performance* determines if HDPE can be used as an additive in concrete to increase its tensile strength and compressive strength for nonstructural applications. Starting with presenting a rich intro of the plastic origin and uses, the authors pronounce that the manmade material of plastic has long been considered to have many advantages and disadvantages, and due to plastics' inability to decompose, many plastics create a lot of waste and can pollute the environment for hundreds to thousands of years. Groundwater quality can be impacted, as can animal and human health, food chain contamination, and soil fertility. Additionally, plastics emit carbon monoxide (a greenhouse gas) when burnt in an open area. It is also dangerous to dispose of plastics in waterways because they can cause siltation and impede water flow, thereby leading to flooding. Recycling is on the rise in developed countries, offering a partial solution since 2006. Identifying any opportunities within the value chains is necessary to solve the problems of plastic waste and divert it from landfills. As a possible option for increasing circularity of plastics, especially macro-plastics, a nexus between construction and waste management becomes apparent. The advantages of using plastic in concrete are their lightweight qualities, improved weather resistance, superior waterproofing, and thermal insulation properties. The purpose of this study was to examine the potential use of HDPE addition on different types of concrete. The researchers evaluated the effect of different lamellar particle sizes and percentages as lightweight admixtures for nonstructural concrete mixes, but not as a substitute for cement or other materials. As examined in *Tamrin and Nurdiana* study, the final use for plastic additions to concrete will be for nonstructural projects, such as wall panels, parking lots, or pathways. Different sizes and percentages of HDPE were mixed with low, medium, and strength concrete. The low concrete strength corresponds to concrete with a cylindrical strength of f'c = 7 MPa, the medium and high concrete strength corresponds to cylindrical strengths of f'c of 10 MPa and 25 MPa, respectively. To examine how different sizes of HDPE lamellar –(From the Latin, lamella means a small plate or flake, but it may also refer to an arrangement of fine sheets of material held adjacent to one another in a gill-shaped enclosure) affect concrete properties, three different sizes of HDPE lamellar, (10 * 10 mm, 5 * 20 mm, and 2.5 * 40 mm) were added to the mixtures with the same thickness of 0.5 mm. following ACI (American Concrete Institute) and ASTM (American Society for Testing and Materials) testing standards and requirements in order to calculate specific gravity, slump value, unit weight, tensile and compressive strength. In the experiments, concrete of the medium class (with a compressive strength of 10 MPa) responded well to HDPE. The optimal mix for all concrete types was 5% HDPE, while the most suitable size was 5 x 20 mm. [52].

The purpose of the research *The Study on Using HDPE and Crumb Rubber on Concrete Mixture by Harsojo, et al. (2022),*[53] published in *Earth & Environmental Science* is to evaluate how waste utilization affects concrete mixtures in terms of compressive strength, porosity, electrical conductivity (EC), total dissolved solids (TDS), and PH, mainly in road pavement usage. whereas the purpose of a road is to distribute stress from vehicles above it to the ground beneath. There are two types of road pavement: rigid pavements, which consist of concrete coatings, and flexible pavements, with a bitumen surface coating. conventional /Surface-layer concrete for rigid pavement is commonly between 20 MPa and 35 MPa in strength, depending on the application. with many advantages, such as being well permeability, which can be useful for recharging groundwater, absorbing sound and reducing noise, and reducing water pollution, another type of rigid pavement known as the porous concrete was considered in this study as well. Porous concrete is formed by reducing or omitting the fine aggregates in concrete mixes. due to the application of this concrete on sidewalks or roads with lower traffic volume, it requires a lower compressive strength ranging from 8 MPa to 12 MPa. Due to the increasing need for construction materials and the accumulation of waste, there have been a number of attempts to explore natural resources for concrete mixtures. One solution had already been implemented: using rubber and plastic waste in the concrete mixture. Usually, in Indonesia, plastic and rubber waste are burned or dumped into the sewers, which causes flooding and air pollution because of the chemicals released in the combustion process. So far, waste has been used as a replacement for aggregates in conventional concrete in rigid pavement and in tall buildings.

Harsojo, et al study aims to evaluate both conventional and porous concrete mixtures that are mixed with crumb rubber and HDPE plastic. The patching consisted of natural aggregate obtained from a quarry, and preliminary tests, including specific gravity and absorption tests, were conducted in accordance with Standard Nasional Indonesia (SNI), and a Portland cement type I was used for the concrete mixture. This experiment included recycled waste materials, including HDPE and crumb rubber, which were used as a substitution for natural aggregates. Both percentages of HDPE and crumb rubber added varied between 5 %, 7,5 %, 15%, and 17 %. The concrete mixtures were tested for compressive strength at 7 and 28 days, and the concrete specimens were tested for porosity and permeability with a falling head permeameter, as the water passes through the pipe, it will create pressure, which in turn will cause water to flow through the concrete specimen on the right side of the apparatus. The falling head permeameter is made by connecting PVC pipes into a U configuration and installing a valve in the middle to control the flow of water. Afterward, the pH, TDS, and electrical conductivity (EC) of the water filtered through conventional and porous concrete specimens were measured. Compared to porous concrete, conventional concrete had a higher compressive strength value at 28 days. In part, this was because conventional concrete presses were already designed to have a higher compressive strength than porous concrete and porous concrete for rigid pavement. Concrete with HDPE and crumb rubber mixtures experience a steady decline with increased waste volume, whereas porous concrete barely changes. The permeability coefficient of porous concrete is higher than that of conventional concrete for the reason that structures with high strength are constructed out of conventional concrete, and to achieve that strength, the porosity and permeability of the concrete must be low. Testing the permeability of porous concrete is not as time-consuming as conventional concrete tests because water penetrates concrete in just seconds. The reason for this is that fine aggregates haven't been used in large quantities in designing porous concrete. Tests of concrete with HDPE waste showed nearly identical porosity results to standard concrete; when conventional concrete was mixed with crumb rubber, there was a 75%-100% increase in porosity compared with control concrete. Only 0.4 pH units separate the smallest and largest values, and the concrete penetration water passes the criteria set by the World Health Organization for drinking water and irrigation, which is 6.5 - 8.5.

If a combination of conventional concrete and crumb rubber is used, the TDS value of the concrete will be higher than for porous concrete alone. As per the standards of the World Health Organization, water results in the penetration of the porous concrete, so conventional concrete samples can be safely used for irrigation and drinking water. In all conventional concrete samples with HDPE and crumb rubber mixtures except those with 5% and 7.5% crumb rubber mixtures, the EC value was lower than in the control concrete samples.[53]

2.3 UHMWPE - Ultra-High Molecular Weight Polyethylene

Ultra-High Molecular Weight Polyethylene (UHMWPE) is an astonishing and promising material in the plastic market. besides having unique and amazing mechanical, physical, and tribological properties, UHMWPE also boasts many other advantages, such as excellent chemical resistance, resistance to UV radiation, and micro-organisms, outstanding abrasion resistance, fabricability, a very low coefficient of friction, and it is nonpolar [54]. It is an extremely tough plastic because of its exclusive physical properties with high impact resistance, high incision/ cut and abrasion tolerance, high strength, excellent vibration damping capability, low dielectric constant, low moisture absorption, and self-lubricating properties[55-59], we need to keep in mind that its melting point is around 130 to 136 °C, UHMWPE will deform continuously at temperatures above 80 to 100°C for prolonged periods, an effect known as creep. For this reason, UHMWPE may not be suitable for high-load applications. UHMWPE, which is composed only of carbon and hydrogen, is a structurally complex polymer, despite its simple chemical composition [54,60]. It is a type of polyolefin whose strength derives primarily from the length of each molecule (chain). It is made up of long and straight chains, all aligned in the same direction. UHMWPE is a linear polyethylene with an extremely high molecular weight. It is the highest quality polyethylene (PE) available, engineered for tough jobs and a wide range of applications that require durability, low friction, and chemical resistance; polyethylene is a versatile plastic that is commonly used in aerospace, biopharmaceuticals, industrial equipment, transportation, and engineering.[54]

UHMWPE has the lowest density among the high modulus soft fibers in the world [59]. It has a very low density (0.93–0.95 g/cm3), which makes it the best material in the film form in terms of the strength to weight ratio [54]. Due to its strength, toughening and cracking resistance, and additional properties, researchers in civil engineering start testing the material for reinforcement and aggregate replacement. Fiber cement-based materials have been widely used in construction projects [61]. Relevant research [62-63] indicates that mixing UHMWPE into concrete can improve the impact toughness and tensile strength, which will lead to better penetration resistance.

Under close-in blast loads, experiments and numerical simulations were conducted *by Zhao Z. et al.(2020)*[63] to study the blast resistance of concrete beams reinforced with Ultra High Molecular Weight polyethylene; according to the results, UHMWPE fibers increased the blast resistance of concrete beams by reducing the extent of damage, preventing crack formation and development, and preventing spalling on the back surface, indicating that concrete beams reinforced with UHMWPE fibers are more resistant to blast than normal reinforced concrete beams.[63]

The experimental study *Dynamic Compressive and Tensile Characteristics of a New Type of Ultra-High-Molecular Weight Polyethylene (UHMWPE) and Polyvinyl Alcohol (PVA) Fibers Reinforced Concrete* by *Bashir et al. (2019*)[64] was published in *Hindawi* / *Shock and Vibration* Journal, Applied experimental and theoretical methods to the investigation of dynamic compression and tensile properties of different proportions of new-type fiber concrete. A common building material, concrete, may often be subjected to dynamic loads in service. Concrete compression and tensile performances are important parameters for evaluating construction safety and stability. Compared with the compression resistance, the tensile properties of concrete are significantly lower, which leads to the structure being easily damaged by tensile forces, and assessing the dynamic tensile properties from physical testing is difficult. A fiber-reinforced concrete increases its strength, toughness, and anti-impact properties by preventing cracks from propagating and rising. Polyvinyl alcohol (PVA) fiber cement composite material and its dynamic mechanical properties have yet to yield any credible conclusions. The use of ultrahigh-molecular weight polyethylene (UHMWPE) on the mechanical properties of fiber-reinforced concrete under impact is practically nonexistent yet. In order to investigate the dynamic tensile effects of fiber concrete, the study employed a Split Hopkinson pressure bar (SHPB) impact device to test UHMWPE and PVA fiber concrete at different strain rates. Further, the compression and tensile characteristics of UHMWPE and PVA fiber reinforced concrete under dynamic compression is discussed in terms of their failure modes, the anti-sliding properties of the fiber reinforced concrete, as well as the effect of strain rate on tensile strength, dynamic increase factor DIF , and dissipative energy measurement, as well as the uniformity between the dynamic and static strain and strain rate models.Test materials were prepared at the lab with ratios of 230, 440, 620, and 1100 for water, cement, sand, and coarse aggregate respectively. In accordance with ASTM C192, loading and static compression tests were conducted, An SHPB device is composed of a launcher, striker, incident bar, transmission bar, shock absorber, and data acquisition system. In the SHPB test, two assumptions are made: (1) based on a one-dimensional stress wave propagation; and (2) axial stress wave propagation within the specimen and even stress distribution within the specimen. sample preparation of the tensile test is the same as that of the compression test, using a universal testing machine, in accordance with ASTM specifications a static

Brazilian disc test was conducted. A nonlinear relationship exists between dynamic tensile strength, dielectric constant, and dissipative energy of each group as strain rate and fiber content are increased, but strain rate has a stronger effect than fiber content. The experimental results were in agreement with the equations available. Concrete reinforced with UHMWPE fiber can increase compressive strength by up to 23% and ultimate strain by about 17.5%, which is considerably better than concrete reinforced with PVA. UHMWPE exhibits at least a 10% increase in tensile strength compared to plain concrete [64].

Among the many investigations conducted by *Ting et al.(2020)* [65] they examined the behavior of high-strength, strain-hardening cement-based composites (HS-SHCC), reinforced with a continuous, two-dimensional textile made of UHMWPE, which was developed exclusively for this study by the research team. As a result of the UHMWPE textile, the average crack width was reduced when compared to HS-SHCC composites reinforced with carbon fabric. However, the crack width was slightly larger compared to similar composites reinforced with carbon fabric. According to the study conducted by *Yan et al.(2014)*, [66] UHMWPE fibers do not appear to boost concrete compressive strength. However, UHMWPE enhances concrete strength, toughness, and crack resistance by significantly improving splitting strength, tensile strength, and bending strength. With a fiber content of 0.3% or 0.5%, the splitting tensile strength increases by more than 25%; with a fiber content of 0.5%, the bending strength increases by more than 23%. [66].

A study made by *Chen. Z et.al. 2022*,[67] Testing the mixture of UHMWPE for compressive strength and splitting tensile strength reveals the following: at 28 days the maximum increase was about 41.1% and 55.9% compared to the benchmark group respectively. Results demonstrate enhancement of the properties of the mixture. As concrete is reinforced with fibers, its compressive strength and tensile strength are increased at first and then decreased here is why, by scanning electron microscope (SEM), the fibers in concrete exhibit even distribution and a tight bond to the matrix when UHMWPE fiber content is small. Agglomeration and entanglement of the fibers will occur as fiber content increases.[67]

The study *Effect of fiber content on mechanical performance and cracking characteristics of ultra-high-performance seawater sea-sand concrete (UHP-SSC)* published by *Huang et al. (2021)* [68] in the *Advances in Structural Engineering* journal, aims to Utilize polyethylene fibers of ultra-high molecular weight, to perform ultra-high-performance seawater sea-sand concrete (UHP-SSC). Structures made from reinforced concrete are used in marine and coastal infrastructures, such as bridges, ports, and offshore platforms. Marine environments pose a corrosion risk to steel reinforcements, and a lack of fresh water and river/manmade sand often limits concrete production on-site in marine and coastal applications. In its simplest form, ultra-high-performance concrete (UHPC) is a special kind of fiber-reinforced cementitious composites (HPFRCCs) with high compressive strength (* 120 MPa as per Chinese standard (T/CBMF37, 2018) or * 150 MPa as per ACI report (ACI, 2018).Essentially, ultra-high-performance concrete (UHPC) is a specialized form of high-performance fiber-reinforced cementitious composites (HPFRCC) with high compressive strength (120 MPa as per the Chinese standard (T/CBMF37, 2018) or 150 MPa as per the ACI standard (ACI, 2018), high tensile strength, and superior durability. UHPC is much less permeable to water and more resistant to chloride penetration than ordinary concrete. The corrosion of steel fibers in conventional UHPC makes it unsuitable for marine environments. To combat the corrosion problem of steel fibers, ultra-high-performance seawater seas and concrete (UHP-SSC) have been developed without steel fibers. Nevertheless, given that high-strength concrete is more brittle than normal-strength concrete, FRP-reinforced UHP-SSC (without threads) can experience brittle failures as opposed to FRP-reinforced normal-strength SSC. a new type of ductile concrete (UHP-SSC) was needed to resolve this problem, the widely use of ultra-high-molecular-weight polyethylene (PE) fibers in high-tensile-strength ductile concrete Inspire the author/ researchers to develop ductile UHP-SSCs reinforced with PE fibers. Unlike most articles/studies in this paper, this study has been carried out to develop ductile UHP-SSCs incorporating PE fiber, and the effect of fiber content (0-1.5 vol.%) on mechanical characteristics and cracking characteristics was thoroughly investigated. The authors studied and modeled stochastic crack widths at different strain levels of UHP-SSC using a probabilistic technique. The components of the composite were Portland cement, micro silica, seawater, sea sand, superplasticizers, and ultra-high molecular weight polyethylene (PE) fibers, in accordance with ASTM C1437 (ASTM, 2007) the mini-slump flow for all mixed cases was within the normal range. The fibers did not aggregate or separate during the mixing and casting process. specimen of 50mmx500mmx500mm was formed and tested to determine the compressive strength per ASTM C109 (ASTM, 2013), the results show compressive strength over 130 MPa at 28-days. As a whole, polymer fibers can influence concrete's compressive strength in a subtle way: they have the potential to lower matrix compactness (negative effect) as well as bridge microcracks (positive effect). A dumbbell sample was prepared for the direct tension test according to a recommendation by the Japan Society of Civil Engineers (JSCE, 2008). Based on the calculated equation, Fiber content is correlated with tensile strength, which supports the observation in this study. UHP-SSC tensile strength increases from approximately 4 MPa for PE0.5% to approximately 8 MPa for PE1.5%, also the tensile strain capacity increases significantly when it goes from 0.5 vol.% to 1.5 vol.% as the fiber content increases. Photographs were taken within the gauge length of UHP-SSC during the tension test using a Canon EOS 6D Mark ii camera with a 24.2-megapixel sensor. The crack number and crack width for all the tensile samples can be obtained from the recorded digital photos at different strain levels. At all strain levels, the cumulative distributions of crack widths were fitted using Weibull distributions. and the evolution of the crack width distribution of UHP-SSC at different strain levels was modeled with a probabilistic model.[68]

2.4 PET - Poly-Ethylene Terephthalate

Plastic resin Polyethylene Terephthalate PET is a thermoplastic polymer resin from the polyester family, biodegradable and semicrystalline. The use of PET, a chemically stable polyester, has skyrocketed in the last few decades due to its wide range of applications, from food and beverage containers to electronic components.[69]

Jibrael and Peter,2016 [70] discussed the addition of recycled waste plastic(polyethylene) to concrete in their article, *Strength, and Behavior of Concrete Contains Waste Plastic*, published in the journal of Ecosystem and Echography. Samples were prepared and sorted into three categories,42 cubs to test the compressive strength, 42 cylinders to test the indirect tensile strength, and 42 prisms for defining flexural strength (modulus of rupture);7 groups with different ratios of recycled /non-recycled plastic were arranged, 6 of each type, the first group was the reference case, no plastic was added, the second case was with 1% recycled plastic bottle as a partial sand replacement, group three and four consists of 3% and 5% recycled plastic bottle as a partial sand replacement, respectively, groups five, six, and seven consists of 1%,3%, and 5% of non-recycled plastic bags as partial sand replacement. Out of testing their 126 samples, they conclude that the compressive strength, and indirect tensile strength, were decreased by 12.81% and 10.71%, respectively, for plastic bottles replacement from 0% to 5%, and flexural strength increased by 4.1% at 7 days of testing. whereas all strengths decreased at 28 days by 7.93% for compressive strength, 28.6 for tensile strength, and 23.6% for flexural strength, when waste plastic bottles increased from 0% to 5%. Similarly, the compressive strength, indirect tensile strength, and flexural strength of hardened concrete decreased with increasing the percentage of waste plastic bags from 0% to 5%, by 27.5%, 29.54%, and 7.98% respectively at 7 days and decreased by 16.41%,27.4, and 30.52% at the age of 28 days. The usage of waste plastic changes the modes of failure of the final product, from brittle to more ductile failure. they claimed that concrete with waste plastic bottles and bags could be used in nonstructural concrete applications. [70]

Sangal Gopal Swarup,2018,[71] find in his research, *Study the effect of plastic waste on strength of concrete,2018,* published in the *international journal of advance research and development*, that adding plastic to the concrete mix could increase its strength. Four different types of plastics, named, polythene sheets, raw plastics, road wastes, and plastic strews, were selected to study their behavior in aggregation with concrete, using the definite methodology for each type. The optimum mix of the plastics was found based on the compressive strength, split tensile strength, and flexural strength tests. from the examination, Compressed loads were found to be more resilient to road waste mix. Raw plastic, as well as plastic strews mix concrete, was found sturdier compared to the reference *RC* column. [71]

In *Fakhruddin, et al,2021* [72]study, *Flexural behavior of reinforced concrete beams using PET plastic as partial replacement of coarse aggregate* published in *Earth and Environmental Science*, the purpose is to investigate the flexural behavior of reinforced concrete beams with PET plastic as partial replacement of coarse aggregate. Literatures found that ASTM C1116 / C1116M - 10a (2015) was used in the study to develop the mixing method. In order to measure the compressive strength of concrete, three 100 x 200 mm cylinders were cast for each batch of concrete mix. Static load was applied to four beams consisting of two control beams (CB) and two PET plastic beams (PB). PET plastic was substituted for 10% of the coarse aggregate in the mixture, in addition, 3D steel fiber was added to the cement to increase the tensile strength of the reference and PET concrete. A flexure failure was designed for these beams. a 13 mm and 8 mm rebars were used as tensile reinforcement and shear reinforcement (stirrup), respectively, both types of rebars have average yield strength of 406 mm and 397.2 mm and average ultimate strength of 579 mm and 552.1 mm. respectively. In the study, it was found that PB's flexural strength was reduced by 18.77% compared to CB because PET concrete has a lower compressive strength. The compressive strength of PET concrete was reduced by 38.7% compared to normal concrete. Furthermore, the concrete crushing at the beam's compression zone caused all the beams to fail in flexure.[72]

The study *Comparing the Properties of Polyethylene Terephthalate (PET) Plastic Bricks to Conventional Concrete Masonry Units,* conducted by *Marsiglio et al, 2020* [73]and published at the *Global Humanitarian Technology Conference (GHTC),* analyzes the possibility of using recycled polyethylene terephthalate (PET) bricks to replace concrete masonry units in building construction. Specifically, it introduces the possibility of producing bricks composed entirely of PET, relying on data for pure PET with the intention of further testing to understand the properties of recycled PET. Research in this area has been focused on identifying the potential for creating PET bricks as a way of reducing plastic waste. Recycled PET is likely to behave quite differently than pure PET and impurities are more likely, so lab testing will be necessary in order to pursue this goal further. In order to make bricks, an appropriate plastic had to be chosen for use as an end-product. Due to their availability in waste streams and widespread recycling, PET and HDPE were identified as leading contenders. For brick manufacturing, PET was selected because of its higher creep resistance than HDPE. The purpose of *Marsiglio et al* paper is to examine the possibility of bricks made entirely of plastic that eliminate the shortcomings of plastic-concrete composite. The article compares PET and concrete in the application of building materials. This is a knowledge gap, addressed in the paper. The article begins with a discussion of material properties, particularly mechanical and thermal properties supported by finite element analysis of the materials. In terms of societal impact, both materials are assessed in terms of their environmental impact and risks associated with their use for structural applications. The lack of published information suggests that more research needs to be conducted. A comparison of pure PET and concrete from several angles concluded that PET bricks could act as an adequate substitute for conventional concrete masonry units. PET not only offers superior strength and insulation capability but is also safer for the laborers producing the materials and has lower associated greenhouse gas emissions. Overall, the initial findings indicated that PET bricks will be a superior, safer, and more sustainable alternative to concrete masonry units.[73]

Ibrahim Almeshal et al 2020[74] in their study *Eco-Friendly Concrete Containing Recycled Plastic as Partial Replacement for Sand* published by *Elsevier journal* investigated the effect on the physical and mechanical properties of the concrete mix when PET is substituted with sand at different levels of replacement, 10%,20%, 30%, 40%, and 50%. Samples were prepared in order to determine the workability, unit weight, compressive strength, flexural strength, tensile strength, pulse velocity, and fire-resistant. the experimental results showed a reduction of 31.6% for the PET50 mix in unit weight compared to the reference case, the workability, the compressive strength, the splitting tensile and flexural strengths, and pulse velocity, reduced with the increase of the PET ratio in the concrete mix. They recommended that by replacing sand with specific ratios, plastic concrete can be used in industrial applications. [74]

Chapter 3

3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

The main conclusions were as following:

Crumb rubber

- In *the practical Application of Crumb Rubber Concrete in Residential Slabs* study [37,38], a broad range of tests conducted on a large-scale residential footing slab provide evidence that crumb rubber concrete is a viable substitute for conventional concrete for residential construction applications without significant drawbacks, and 20% was the best ratio to replace fine aggregates with crumb rubber in this study.
- Based on the *Optimising the Performance of Crumb Rubber Modified Concrete* study [39], it suggests that recycling tire waste into modified crumb rubber concrete as a sustainable waste management option may have significant future value.
- From the *Investigating mechanical properties and durability of concrete containing recycled rubber ash and fibers* study[40], it was observed that incorporating rubber ash into concrete increased impact resistance, the results also indicated that rubber fibers and rubber ash up to 10% can be utilized as fine aggregate to create durable rubberized concrete pavements, crash barriers, and paver blocks.

HDPE –

- *The Effect of Recycled HDPE Plastic Additions on Concrete Performance* study [52]concluded that, in the addition of lamellar particles, the f’c10 MPa concrete performed best. HDPE at 5% was the optimal content, while 5 * 20 mm was the ideal size. HDPE lamellar particles of all types can be used with f’c10 Mpa concrete. However, only 5 * 20 mm HDPE sheets are recommended for B0 concrete and f’c25 Mpa concrete.
- *The Study on Using HDPE and Crumb Rubber on Concrete* [53]determined that the compressive strength of HDPE mixed concrete was higher than that of crumb rubber mixed concrete, and the trend of decreasing in terms of compressive strength as the rate of crumb rubber and HDPE in conventional concrete increased was obvious, while in porous concrete it was consistent with control concrete. As a result of mixing crumb rubber into conventional concrete, the permeability and porosity will increase by 75%-100% compared to the control concrete, while when HDPE added to conventional concrete, permeability and porosity are similar to the control concrete. It was found that porous concrete with mixtures of crumb rubber and HDPE followed the same pattern, where both concrete types resembled the control concrete. with increasing the amount of the waste used in the concrete mixture, the EC decrease, whereas the TDS and PH value were within the standards levels of the WHO.

UHMW-PE

- The study *Effect of fiber content on mechanical performance and cracking characteristics of ultra-high-performance seawater sea-sand concrete (UHP-SSC*)[68] concluded that Fiber content significantly increases tensile strength and strain capacity, while compressive strength slightly decreases. It was developed that a ductile UHP-SSC would exhibit strain-hardening behavior in tensile configuration and possess a 28-day compressive strength exceeding 130 MPa. Several studies showed the Weibull distribution to be an appropriate way to describe the crack width distribution, UHP-SSC crack width distributions can be described by the Weibull distribution when the fiber percentage is between 0.5 and 1.5 vol.%. The researcher's model involved a probabilistic approach to estimating the crack width distribution of UHP-SSC at different strain levels. For a given crack width limit and cumulative probability, the model results showed good agreement with experimental results. The model can thus be used to estimate UHP-SSC critical tensile strain in practical applications.
- Using 74 mm variable cross section SHPB pressure bar devices, the experiments and theoretical studies on dynamic compression and tensile mechanical properties of new-type fiber concrete (UHMWPE and PVA) were undertaken in the study *Dynamic Compressive and Tensile Characteristics of a New Type of Ultra-High-Molecular Weight Polyethylene (UHMWPE) and Polyvinyl Alcohol (PVA) Fibers Reinforced Concrete*[64] , and it was concluded that : UHMWPE fiber concrete provides better reinforcing, toughening, and crack-resisting properties than PVA fiber concrete. The

dynamic tensile strength, the dissipative energy, DIF - Dynamic Increase Factor, and the strain rate of each group tended to increase nonlinearly as the strain rate and fiber content increased. There was an attenuation of the increase, but strain rate had a stronger effect than fiber content. Compared with plain concrete, UHMWPE fiber concrete boasts the strongest tensile strength, which increased by at least 10%, and it is possible to simulate the relationship between DIF and strain rate by using the logarithmic function expression.

PET:

- *Flexural behavior of reinforced concrete beams using PET plastic as partial replacement of coarse aggregate* [72]concluded that the PET plastic material did not exert much of an effect on compressive strength loss when added to concrete at a rate of 10%. When PET concrete was compared to normal concrete, it showed a 38.7% reduction in strength. And it does not change the failure mode when 10% PET content is used when all beams fail under flexure. The response of the concrete to load deflection changed slightly after PET was added to it.

3.2 Discussion:

Waste materials find their way into civil engineering projects with remarkable success and using recycled materials in structural and non-structural applications proves its efficiency. The strength and stiffness of the concrete mixture are directly related to the original properties of the soil and the cement, they are mainly influenced by the water-cement ratio used in the mix. So, the author suggests that the concrete mixing process can be designed from the outset based on the application of the concrete mix. Due to the low tensile properties of concrete, the structure is vulnerable to tensile failure, which calls for reinforcements. To meet these challenges, end-of-life tires and plastic waste present a good solution. Composites based on fiber cement and rubberized cement provide excellent support and toughening properties, even though, the trend of decreasing compressive strength was pronounced, as the rate of crumb rubber and plastic waste in conventional concrete increased. Aligned with the general consensus waste plastic /rubber content contributed to a decrease in concrete's: compressive strength, flexural strength, split tensile strength, and modulus of elasticity, as the amount of waste was increased. Regarding compressive and flexural strength, two key measurements of concrete quality, the most efficient combination would utilize more of the largest aggregates and less of the smaller ones at the corresponding concrete age. The optimal rate/quantity varies depending on the concrete mixture structure. Most optimal percentage ratios were within the low range of less than 40%. Studies using waste materials/ rubber to replace more than 40% of natural aggregates were few and far between. However, due to the good physical properties of plastics and rubber and their hydrophobic surface, especially when using big particles, it is difficult to bond to a matrix satisfactorily, limiting the uses of rubber/plastic fiber-reinforced composites. Various solutions have been proposed to deal with this issue and enhance the interaction between the fibers and the matrix. For plastics, acid etching, Plasma deposition, UV initiated graft copolymerization were investigated, and pre-treated rubber aggregates with polyvinyl alcohol, water soak method, or sodium hydroxide. In the author's opinion, the water soak method is cost-efficient, and epoxy glue will enhance the adhesion between rubber/plastic and concrete as well. Rubber fibers/ Plastic Aggregates decrease concrete's mechanical properties but increase its ductility, and it is known that ductile behavior prevents cracks from forming in concrete structures. The failure mode changed from brittle to more ductile, indicating that higher ductility can be achieved with higher ratios of rubber/plastics.

3.3 The following impression is the author's own:

UHMWPE plastic attracts the author's attention with so many advantages. While keeping in mind that the UHMW melting point is around 130 to 136 °C, UHMWPE will deform continuously at temperatures above 80 to 100°C for prolonged periods, an effect known as creep. The creep of UHMWPE fibers is influenced by the ambient temperature and the applied load: very high loads or a high temperature will accelerate the creep process. Over the majority of the time, the creep rate is constant, and ultimately the fiber will fail. For this reason, UHMWPE may not be suitable for high-load applications. The author suggests combining PET and UHMWPE and using the mixture as a substitute for coarse aggregate to enhance the creep issue. PET was selected because of its higher creep resistance than UHMWPE since the PET melting point is 260 °C.

3.4 Recommendations

- Concrete reinforced with recycled plastic could be used in structural and nonstructural applications.
- Combining two or more types of materials will be suggested for upcoming research.
- Thermal testing needs to be made to evaluate the use of plastic/rubber concrete in internal buildings.
- The effects of different plastic shapes need to be examined further.
- The replacement of coarse aggregate with plastic/rubber waste will be highly recommended.
- In order to enhance the bonding issues originated from the hydrophobic surface of big particles of rubber/plastic we can simply use epoxy glue.
- Since concrete samples with recycled materials seem to have better tensile and ductility properties, it may be worthwhile to conduct a study to examine if concrete with recycled material have better shrinkage properties than plain concrete.
- A comparative study looking at the behavior of concrete members under low intensity cyclic loading would give insights if this type of application can be used for seismic or pavement applications.

Chapter 4

4 REFERENCES

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