



ACBA 5005

Materials Engineering

Mariah Edwards

2114464

Introduction

According to a recent OECD report, the world is producing twice as much plastic waste as two decades ago with only 9% successfully recycled.

This consumption on plastics has quadrupled over the past 30 years which causes a concern regarding the accumulation of waste and plastic pollution. This highlights the need to improve waste management and increase recycling.

The OECD mentions the need for solutions to the plastic waste problem as global plastic waste is set to almost triple by 2060. (OECD, 2022)

The problem of plastic waste is largely caused by the construction sector. According to statistics from the trade group plastics Europe, construction accounts for around 10 million tonnes of the roughly 51 million tonnes of plastic demand in Europe, making it the second largest market after packaging. A portion of the packaging is used in construction as well, further boosting the sector's impact.

90% of all plastic trash is made up of six distinct varieties, with PVC being the most prevalent and making up nearly half of all waste plastics, followed by polyethylene and polypropylene.

But an increasing industrial emphasis on material reuse and recycling, embodied carbon, and the circular economy has changed the conversation and sped up attempts to reduce plastic waste. (RICS, 2022)

Plastics

Plastics are a class of materials that may be moulded when soft and then hardened to maintain the desired shape. These materials can be synthetic or naturally occurring. Polymers make up plastics and are materials comprised of several repeating unit. Polymers can usually be grouped based on their physical properties as either thermosetting, thermoplastic or elastomeric. (Lyons, 2014)

Plastics in Construction

Thermosetting Plastics

The linking of adjacent macromolecular chains creates the three-dimensional cross-linked structure of thermosetting polymers. Thermosets do not soften when heated; instead, intense heat will cause them to scorch and deteriorate. Thermosets are often made from a powder that has been partially polymerized or by combining two elements, such a resin and a hardener. The hardener crosslinks the liquid resin to create the thermoset plastic, with the resin serving as the main macromolecular component. Epoxy resin adhesives and polyesters used to make glass fibre-reinforced polyester (GRP) cure at room temperature, but phenolic and formaldehyde-based resins need to be heated up and under pressure in order to cure. Due to their three-dimensional structure, thermosets are often more durable and solvent-resistant than thermoplastics. (Lyons 2014)

Thermoplastic

Thermosets soften when heated and reset when cooled. Repetition of the cycle has no impact on the material because the process is reversible and extreme temperatures that may induce polymer breakdown are avoided. While certain thermoplastics swell by absorbing solvents, many thermoplastics are soluble in organic solvents. Thermoplastics are often created initially as tiny grains that may later be broken down into components. (Lyons 2014)

Elastomeric

Long-chain polymers called elastomers have helical or zigzag molecular chains that are naturally free to straighten when the material is stretched and recover when the load is removed. The extensibility of the polymeric chains determines the degree of

elasticity. Because natural rubber has a high degree of extensibility, adding sulfur causes the vulcanization process, which locks together nearby polymer chains, to further restrict mobility. For the majority of applications, cross-linking is necessary to guarantee that an elastomeric material resumes its initial shape when the applied stress has been eliminated. (Lyons 2014)

Characteristics of concrete mix

Concrete mixtures are created to provide desired qualities at the lowest cost. Strength and durability are typically the most crucial qualities, although other factors like fire resistance, acoustic and thermal insulation, and visual appeal can also be quite significant.

The qualities necessary in the hardened concrete are considered while deciding the composition of a concrete mix, as well as the workability or ease of placing and compaction of the fluid mix. (Lyons 2014)

There have been several studies including waste plastic forms as aggregates in concrete. Below is an analysis of two recent studies using various thermoplastics as a replacement for fine aggregates and coarse aggregates.

Polypropylene (PP) is a thermoplastic, its vulnerable to UV radiation yet resistant to chemicals. It is also reasonably priced and moisture resistant. In comparison to unreinforced concrete, fibre-reinforced concrete has greater impact resistance thanks to the usage of fibres. It is often used in drainage systems, cold water plumbing, and pipes and fittings in the construction sector. (Lyons, 2014)

The investigation made use of rounded, 4mm-sized particles. In this study the workability and compressive strength of PET and PP as a partial replacement for fine aggregates were compared with conventional concrete mix.

A slump test was done to determine the workability of the mixes. The (PP) mix showed an increase of workability beyond 5% indicating lack of cohesiveness. A 5% Polypropylene replacement showed a slump of 90mm which indicates medium workability. This is an appropriate range for normal reinforced concrete placed with vibration.

The compressive strength results indicated a decrease beyond 5% PP replacement. The control mix with 0% added plastic waste replacement showed a compressive strength of 38.7 MPa at 28 days. 5% at 28 days showed a slight decrease in compressive strength at 38.3 MPa. However, at 10% and 15% showing the more significant decrease with a value of 33.3 MPa and 27.9 MPa at 28 days respectively.

Polyethylene Terephthalate (PET), a kind of polyethylene, is a member of the polyester family. It is made of one of the least expensive polymers. Most of it comes from water bottles. It is better at resisting chemicals and absorbs less water. It is very flexible, stiff, and ductile in its current condition. (Lyons, 2014)

Flaky particles with a size of 2 mm were employed in the investigation. Slump values in the PET mix showed a decrease in slump values at 10% and 15% PET replacement. Indicating that when more PET was added to the mix it became less fluid. (Suram et al. 2021)

The compressive strength of the Polyethylene Terephthalate mixes at 28 days showed a 5% increase to 39.6MPa compared to the control mix of 38.7 MPa at the same 28 days. Then a decrease at 10% to 38.2 MPa and a further decrease in value at 27 MPa for 15% PET replacement aggregate. (Suram et al. 2021)

This indicates that the excess plastic content not only decreases compressive strength but also the plastic obstructs the flow of the concrete causing a decrease past 10% PET replacement in mix.

Workability and compressive strength of concrete can be affected by concrete containing plastic. Increased plastic content results in decreased workability and compressive strength. Due to the increase in plastic material, voids grow as the concrete's volume grows. Due to the differing volume occupied by plastics and sand in concrete, the density of concrete falls as PET and PP are substituted for sand as a fine aggregate. The compressive strength and workability of the concrete with 10% PET were superior, whereas the workability and compressive strength of the concrete with 5% PP were good. Therefore, it is determined that 5% of PP and 10% of PET are the best replacements for fine aggregate.

A study was conducted by (Tamil et al. 2021) with HDPE granules as replacement for coarse aggregates. Concrete grade M30 was used to cast all specimens and Ordinary 53 grade Ordinary Portland Cement was used.

HDPE frequently substitutes heavier materials. Less environmental impact might result from materials that are lightweight and durable. HDPE has a density range of 930 to 970 kg/m³. A white, semi-opaque thermoplastic material that is semi-crystalline (usually between 70 and 80 percent), has qualities like those of LDPE but is much stronger, tougher, and even chemically resistant. Although it is substantially greater than that of LDPE, the impact tolerance is almost high and at low temperatures. (Tamil et al. 2021)

In the mix a replacement of coarse aggregates with 1%,2%,3%,4% and 5% HDPE granules were done separately and compared to a control mix. The control mix had a compressive strength of 31 was recorded at 28 days. There was an increase in compressive strength until 4%. At 1% a compressive strength of 31.99 MPa was recorded, 2% at 33.8 MPa, 3% at 38.1 MPa, 4% at 27.2 MPa and 5% at 26.7 MPa. (Tamil et al. 2021)

It was discovered that the strength of concrete grade M30 that had some of the coarse aggregate replaced with high density polyethylene granules was higher than the strength of concrete grade M30 as is. (Tamil et al. 2021)

The values rose at 4% and 5%, with 3% being the ideal replacement It is deemed economically advantageous to partially replace coarse aggregate with HDPE granules, which also results in an increase in concrete strength. (Tamil et al. 2021)

Waste disposal, particularly the burning of plastics, has become a significant issue. Plastics harm the environment, especially our seas, and has detrimental effects on human health. Dr. Rajagopalan Vasudevan of the Thiagarajar College of Engineering developed an innovative technique for reusing plastic waste to build roads. His process involves shredded plastic combined with heated gravel, which is then added to molten asphalt. Because both plastic and bitumen are made of petroleum, they adhere to one another effectively. By including waste plastic into bituminous mixtures, it has been demonstrated that the mixture's qualities are enhanced and that some of the disposal issues are partially resolved. The combination lengthens the road's lifespan and increases its capacity to support weight.

Although, field applications using plastics in actual road construction is quite limited there are several laboratory tests that have shown positive results when a small amount (5-10% by weight) of plastic is incorporated in bituminous mixes (asphalt) that resulted in improved pavement stability, strength, and durability. (Sasidharan et al. 2019)

A few case studies were found of applications of plastic materials application in road construction in countries such as India, Ghana, United Kingdom and the Netherlands. In these examples we discuss the processes used, techniques and design methodologies.

Macrebur: Denbighshire, Wales

The company Macrebur has conducted many plastic roads projects in the United Kingdom and abroad. In Denbighshire, Wales 1800 kg of plastic was recycled saving 2790 kg of Co2e because of resurfacing works carried out by the collaborative efforts of MacRebur, Lewis & Hunter Contracting, Robert Hunter & Son, ClwydAlyn Housing Limited, Welsh Government and Williams Homes (Bala) Ltd. The project

A 10mm Stone Mastic Asphalt was poured, with 6% of the binder weight made up of MacRebur MR8. Robert Hunter & Son were able to maximise the amount of bitumen in the asphalt mix on this project by using MR8 as a partial binder substitute. This gave the customer the chance to boost environmental sustainability while still completing the job to the needed standard and on schedule.

The polymer mixture known as MR8 comes in a shredded form and was created to extend the life of the bituminous binder for asphalt used in road surfaces. Chosen to prolong unmodified bitumen to maximise economic and environmental advantages without impairing asphalt performance. Suitable for use with all types of asphalt in all road construction layers. Ideal for paving parking lots, driveways, and neighbourhood roads when economies and sustainability are the main considerations. (MacRebur, 2018)

Macrebur: South Africa

The existing binder course and asphalt surface were removed to a depth of 100 mm, and they were replaced with 60 mm of 20 mm heavy duty binder course and 40 mm of 10 mm stone mastic asphalt surface course, both of which contained MacRebur's MR6 product, which offers comparable performance to conventional asphalts. The installation on-site required no alterations. The initiative saved the customer money and allowed waste plastics that would have otherwise needed to be disposed of to be reused.

A 270-meter trial section for testing and monitoring. For this part, 230 tonnes of asphalt had to be applied, together with 690 kg of MR6, on-site, at a 30mm thickness.

MR6 is available as pellets and is designed to be integrated right in the asphalt manufacturing plant. It is entirely made of recycled waste plastic. The waste plastics easily melt into the binder to lengthen and modify it since their melting points are lower than those used to produce asphalt and other binders. (MacRebur, 2018)

Macrebur: Green Dragon Lane

Enfield Council was keen to explore cutting-edge sustainable engineering solutions in 2018 as part of a planned local authority repair and enhancement programme to the local road system. This project project prevented the incineration or landfilling of 600 kg of waste plastic, preventing the release of 1416 kg of carbon emissions.

A place for resurfacing was found along a major commuter and bus route. It included a bus stop and a single-lane roundabout that sees a lot of daily traffic. The old asphalt was taken out, and a portion of 35/14 hot rolled asphalt containing Macrebur products was put in its place.

The site was divided into four parts, each of which featured a unique polymer product. Three sections for each MacRebur mix and another containing standard approved Polymer Modified Binder (PMB).

Phase 1 of the study involved examining the impacts of MacRebur waste plastic additives to see if they may be used to asphalt mixtures to prolong the service life of bus stops in this borough and perhaps elsewhere, while also giving environmental advantages from recycling waste plastic.

To reduce variables during resurfacing, all four asphalt mixes were poured on the same day by the same contractor and were provided by the same asphalt manufacturer.

In phase two 150mm cores from each section of the road were removed and tested at a private, UKAS-accredited testing laboratory in September 2019, a year after the resurfacing was completed. The core samples were put through indirect tensile strength modulus (ITSM), wheel tracking, and fatigue testing to acquire performance data and make direct performance comparisons across different road sections.

According to studies done on core samples, samples containing MacRebur MR6, MR8, and MR10 exhibited less rutting than samples containing commercial PMB, with MR10 exhibiting the most reduction in rutting depth, indicating an increase in performance. (MacRebur, 2018)

Conclusion

There have been various studies on the mechanical properties of plastic waste materials as replacement for coarse and fine aggregates in concrete and with the application of waste plastics in road construction. The results from these studies have found to be in acceptable ranges. Thus, being a valid option for the replacement of natural aggregates such as sand. These applications not only offer economical benefits but also environmental by solving the issues of plastic waste pollution. Although there are many benefits there are 'major concerns' According to a recent assessment from the leading transport organisation in Australasia, there are "serious concerns" over the possible health and safety risks employees may be exposed to while handling modified recycled plastic binders during road construction. (Highways

Magazine,2019) Javadabadi investigated how utilising recycled PET as a fine aggregate in concrete will affect the environment. It was discovered that the concrete mixture with 47% aggregate reduces environmental consequences by 58%. Yin et al. compared steel reinforced mesh to recycled PP fibres for concrete footpath applications and analysed the environmental effects of each. The main findings shown that PP fibres cut CO2 emissions, oil use, and water use by over 90%. (Tahir et al. 2022)

(Russell, 2022) in the New Civil Engineering Journal highlighted demonstration projects have been seen across the UK, as some councils start to explore innovations that promise to divert waste from landfill and reduce the amount of virgin material needed to build new roads. While examples have been plentiful, in most cases they achieve little more than confirming that it is possible to mix granulated waste with asphalt and create a material that can be laid to form a road pavement. Winter and Coopland's knowledge of waste regulation legislation enabled them to take a critical look at this rapidly developing sector. Winter is a specialist in geomaterials and in the reuse of materials in the highway sector, while Coopland was previously on the secretariat of Mineral Products Association Scotland's asphalt, concrete and technical division. They stated no attempt has been made to test or record the technical performance, longevity, or stability of the material and its essential to test a projects operational life to make accurate decisions. It is suggested a framework for an assessment protocol which could be used by highway authorities to assess the benefits and drawbacks of a new material should be done before any agreement to use it.

Reference

GOV UK (2019) *Technological trials to help future proof roads*. Available at: <https://www.gov.uk/government/news/technological-trials-to-help-future-proof-roads> (Accessed: January 12, 2023)

Highways Magazine (2019) *Major report investigates plastic roads*. Available at: <https://www.highwaysmagazine.co.uk/Major-report-investigates-plastic-in-roads/5301> (Accessed: January 13, 2023)

Lyons, A, (2014) *Materials for Architects and Builders*. 5th edn. New York: Routledge.

MacRebur (2018) *Green Dragon Lane*. Available at: <https://macrebur.com/case-studies/pdfs/green-dragon-lane.pdf> (Accessed:10 January 2023).

MacRebur (2018) *Jeffreys Bay South Africa*. Available at: <https://macrebur.com/case-studies/pdfs/jeffreys-bay-south-africa.pdf> (Accessed:10 January 2023).

MacRebur (2021) *Denbighshire, Wales*. Available at: <https://macrebur.com/case-studies/pdfs/william-homes.pdf> (Accessed: 13 January 2023)

OECD (2022) *Plastic pollution is growing relentlessly as waste management and recycling fall short*. Available at: <https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm> (Accessed: December 17 2022).

RICS (2022) *How can construction overcome its dependence on plastic?* Available at: <https://ww3.rics.org/uk/en/modus/natural-environment/renewables/how-can-construction-overcome-its-dependence-on-plastic-.html> (Accessed: December 17 2022) .

Russell, H. (2022), 'Do waste derived asphalts cause more harm than good?' *New Civil Engineer*. Available at: <https://www.newcivilengineer.com/innovative-thinking/how-can-the-benefits-claimed-for-waste-derived-asphalt-be-verified-29-07-2022/> (Accessed: January 13 2023)

Sasidharan, M., Mehran, E., Torbaghan, M. And Burrow, 2019. *Using Waste Plastics in Road Construction*. Jaypee Brothers Medical Publishers (P) Ltd. Available at: https://assets.publishing.service.gov.uk/media/5d41b34040f0b60a86a5e5dc/595_Use_of_Waste_Plastics_in_Road_Construction.pdf (Accessed: January 13 2023)

Suram, R., Srinivas, T. And Naresh Kumar Varma, V. (2021). Plastic as substituent material for fine aggregate in concrete. *E3S Web of Conferences*, 309, pp. 1132. Available at: https://www.e3s-conferences.org/articles/e3sconf/abs/2021/85/e3sconf_icmed2021_01132/e3sconf_icmed2021_01132.html (Accessed: January 13 2023)

Tahir Furqan, Sbahieh Sami, Al-Ghamdi G. Sami, (2022). Environmental impacts of using recycled plastics in concrete. *Materials Today: Proceedings*, (62), pp. 4013-4017. Available at: https://www.researchgate.net/publication/360427359_Environmental_impacts_of_using_recycled_plastics_in_concrete (Accessed: January 13, 2023)

Tamil Selvi, M., Dasarathy, A.K. And Ponkumar Ilango, S. (2021) Mechanical properties on light weight aggregate concrete using high density polyethylene granules. *Materials today: proceedings*, pp1-5. Available at: <https://www.sciencedirect.com/science/article/pii/S2214785321032223> (Accessed: January 13, 2023)