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Semi-Rigid Road Pavements from Resin-Stabilized Plastic Waste

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ABSTRACT

Despite some undeniable progress in the field of plastic recycling worldwide, a rate of only 30% of the waste material is currently led to reutilization in the European Union, whereas lower rates of recycling are recorded elsewhere, especially, in low-income countries. Recycling plastic waste in engineering construction projects may be a convincing response to the challenge of plastics disposal, combining, at the same time, the advantages of an environment-friendly technique with the benefits of resistant engineering structures.

Road infrastructure is a field of engineering apt to receive and absorb large quantities of plastic waste, while it can also benefit from some characteristics of the recycled material. Moreover, recycling plastics in road infrastructure can save natural resources and considerably reduce the need for raw materials.

Some types of plastics, especially PET and PVC plastics, exhibit high strength properties and significant durability under adverse external conditions. By contrast to cement and concrete, but also, to bitumen at low temperatures, plastics develop high resistance to cracking. These characteristics may turn the waste material into a useful component of the road infrastructure matrix.

In the Aristotle University (AUTH), an innovative method of recycling plastic waste in pavements has been developed. The method was based on several key requisites: be simple in material processing and mix preparation, absorb significant quantities of waste material and require conventional equipment for construction. In brief, the method consists of designing a mixture of Plastic Waste (PET) aggregates, coarse and fine, bound by epoxy resins, which serve as a special binder in this specific case. The mixture is intended for use in stabilized base of semi-rigid pavements bearing an asphalt overlay. Reasonably, the mix can exhibit significant resistance to cracking and rutting, at low and high temperatures respectively, provided that the fundamental strength characteristics, in short-term, are satisfactory. A theoretical approach and an experimental study with test results delineate the method, which seems to be applicable and beneficial to pavements, subject to high temperature variations.

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Plastic Waste and the Need for Recycling

Increasing rates of production and use of plastics, during the last decades, constitute a puzzling challenge to municipal and regional authorities worldwide, struggling to face the disposal issue. Indicatively, in 1950, production of different forms of plastics attained 1.5 million tons, while, in 2023, 413 million tons of plastics were produced, out of which, 25 million tons in the European Union [1]. This trend in production of plastics, the increasing dependency on oil and the negative impact on the environment by plastics disposal over landfills, create a persistent need for alternative solutions to the plastic waste dumping issue.

It is estimated that, from the total amount of plastic produced worldwide during the last 70 years, only a percentage of 10% has been recycled. Despite some undeniable progress in this field worldwide, a rate of only 30% is currently directed to recycling in the European Union, whereas lower rates of recycling are recorded in low-income countries. Insufficient rates of plastic waste recycling in the European Union have a negative environmental and economic impact. Estimates raise at 95% the economic loss due to the current practice of plastic disposal, instead of the recycling process, while the problem of limited landfill capacity remains unsolved. Recently, the European Union revised the recycling policy for the Member-States, which encompasses nowadays more decisive steps and investments for the protection of the environment through recycling of plastics [2,3]. By adoption of the concept of circular economy, a dual goal is achieved, consisting of both, protecting the environment and fostering innovation. Through this strategy, innovative production methods, new jobs and new products, are emerging that add value to the European industry. More specifically, by this revised policy and the respective directive, the European Union set clear goals regarding the recycling of plastic waste. Member States should meet specific objectives with regard to plastic waste: recycling

rate should be at least 50% by 2030 [3].

Recycling in the construction industry may be a convincing response to the pollution generated by plastic disposal, combining, at the same time, the advantages of an environment- friendly technique with the benefits of resistant engineering structures.

But how and under what conditions can plastic waste be recycled? Plastic is a material that proved to exhibit durability over a long period after its recovery and can withstand several life cycles until it becomes really useless. In fact, this property of plastic waste, which is a serious problem to the environment, by landfill disposal practice, may turn out to be a considerable advantage in engineering. It is precisely the effect of some of the inherent characteristics of the material, such as, the low specific weight, its high strength and durability and the significant resistance to cracking that generated the idea of road pavements from recycled plastic.

Experiences and Prospects of Plastic Roads Worldwide

Road pavements and infrastructure is a field of engineering apt to receive and absorb large quantities of plastic waste, while, at the same time, can benefit from some characteristics of the waste material. Moreover, use of recycled plastic in road pavements can save natural resources and considerably reduce the need for raw materials.

Urban and peri-urban road networks are most adequate to engage in applications of recycled plastic waste for roadways. Reducing project budget by minimizing transport cost is always a requisite in road construction and, in this regard, plastic waste may be an option for street construction, since, most plastic waste processing plants are located in peri-urban areas. Therefore, streets and peri-urban road networks are the best engineering fields to accommodate environment-friendly construction materials from plastic waste.

The basic concept of recycling plastic waste in road construction is originated from India [4]. The development of the original idea led to the most popular, to date, technique in recycling plastic waste (LDPE) in pavements. The technique consists of replacing a part of the asphalt binder by liquid plastic in the asphalt mix. This practice tends to modify the asphalt by a plasticizer, usually LDPE, and make it more resistant at low and high temperatures but also to ageing.

In fact, the technique consists of setting up a mixture of shredded recycled plastic and asphalt binder, at relatively high temperature, prior to mixing with mineral aggregates. The asphalt mix produced exhibits improved performance with respect to conventional asphalt mixes. The results of an experimental research on asphalt mix specimens, introducing recycled LDPE in the asphalt binder, illustrate an excellent performance (stability, flow) [5]. It seems that a successful polymerization of the bitumen takes place at high mixing temperatures. All characteristics of asphalt mixes improve when recycled plastic waste (LDPE) replaces conventional asphalt at a rate of 10%.

A method of production of prefabricated pavement slabs from recycled plastic has been developed in the Netherlands, where lack of raw materials, especially, of aggregates for roads, is a persistent problem. Plastic waste was assessed as a very promising construction material for various reasons: resistant to disintegration and to extreme weather conditions, friendly to wheel tires and noiseless under traffic. Moreover, the life cycle of a plastic road is believed to be much longer than the respective of a conventional one. The PlasticRoad concept consists of placing prefabricated, modular and hollow road structures, made from recycled plastic, on the pavement subgrade (Figure 1). The hollow space can be used to temporarily store water (preventing flooding), power cables, and pipes (preventing excavation damages), with numerous other conceivable applications - sensors for charging EV's [6].



Figure 1: The Plastic Slab Pavement [6]

An alternative concept for utilization of plastic waste in road construction was developed in California, USA (2018). In the frame of a pilot project, the first highway in the country paved in part with recycled plastic (PET) was constructed. It took place on a 300 m stretch of a state highway, introducing a specific in-situ asphalt recycling process. A "recycling train," scoops up the top 3 inches of asphalt on a lane, grinds them on a mill and mixes them with a G5 asphalt binder (Technisoil), containing from 2%-20% of liquefied plastic (PET). It seems that the new pavement exhibits high strength, mainly due to the matrix of the plastic binder while rock aggregates play a minor role. This new type of asphalt pavement is believed to resist potholes and cracking and to last two to three times longer than standard asphalt [7].

Use of polymers from plastic waste in asphalt pavements, whether by hot or cold mix technique, aims at improving resistance to stripping and rutting, thermal cracking and fatigue damage. Polymers are used when enhanced durability and performance are needed. They are often chosen to decrease life cycle maintenance costs of asphalt [8].

Although, plastic roads are still at the beginning of a long itinerary in the road construction industry, it may prove that these road structures resist effectively traffic loads and weather aggressiveness, which means that they need less frequent maintenance. In a street network of heavy traffic, this is a significant advantage, since, due to the improved performance of plastic roads, traffic closures for maintenance are rarely needed.

The Alternative Concept

In the Aristotle University (AUTH), a different concept of recycling plastic waste in pavements has been developed. The triggering factor was the identification of some flaws in all three abovementioned techniques:

- The binder modification method seems effective but it is hardly a waste consuming method. The content of plastic waste is 5-10% by weight of asphalt, which means 1%, by weight of aggregates. No surfacing is needed whenever this method is applied in pavement construction.
- The plastic slab method for pavements is a very interesting technique which may be combined with different applications (thermal energy, subsurface water drainage) but requires accuracy in slab production and construction (evenness). It is questionable if the flexural strength of slabs is capable of carrying truck loads and it is certain that some conventional surfacing is needed as a wearing course, as well as, some

slab reinforcement.

- The on-site recycling method is a promising technique with multiple benefits, since it recycles asphalt pavement layers and plastic waste at a single stage. The rate of plastic waste recycled is limited but the benefits are considerable. Adequacy of current equipment for asphalt pavement recycling is a concern. Surfacing by conventional asphalt layers is certainly needed, in the case of main transport corridors.

The method developed and presented hereafter was based on several key directions: be simple in material processing and mix preparation, absorb significant quantities of waste material and require conventional equipment for construction. In brief, the method consists of designing a mixture of plastic waste (PET) aggregates, coarse and fine, bound by epoxy resins which serve as a special binder. Reasonably, the mix is intended for construction of stabilized base courses in semi-rigid pavements (Figure 2). These stabilized base courses can resist low and high temperatures, provided that the fundamental strength characteristics, in short-term, are satisfactory. By contrast to the traditional cement-treated base courses, the plastics/resin courses are supposed to exhibit better performance with regard to fatigue cracking under traffic loads.

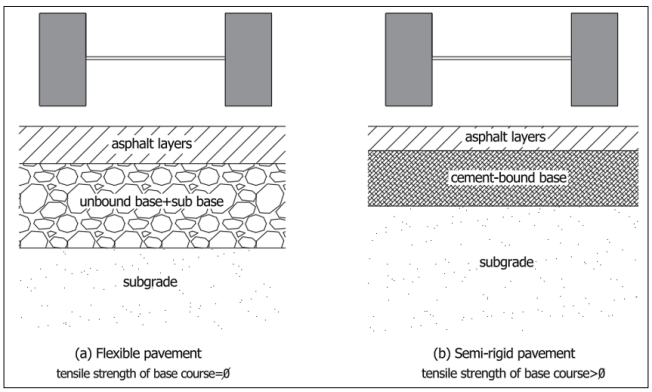

Figure 2: Flexible and Semi-Rigid Pavements

Properties and Advantages of PET Material

A major innovative accomplishment of the present research is that recycled PET material was used as the main aggregate skeleton of the mixes over the experimental stage. The idea was born because some types of plastics, especially, PET and PVC plastics, exhibit high strength properties and significant durability. While in most plastic recycling experiences, LDPE waste, at limited content percentage has been used, the main idea of the present research was to introduce PET waste in base courses as full replacement of mineral aggregates.

PET, or polyethylene terephthalate, is a common plastic material, used in the manufacturing of products such as water bottles, food packaging, and textiles. Due to its lightweight, durability, strength and resistance to chemical alteration, PET has become an essential material in modern-day society [9]. However, the increasing use of PET has also led to a global crisis in waste management, as the improper disposal of PET products seems to have caused significant environmental damage [10].

PET waste is retrieved from municipal solid waste after paper and litter removal. Recycling consists of heating, melting, cooling and breaking into coarse particles. PET is the most recyclable plastic material worldwide because it is very strong and stiff, lightweight, transportable, stable, owing to its minimal water absorption, and has excellent heat resistance [11].

By contrast to cement and concrete, but also, to bitumen at low temperatures, PET waste exhibits high resistance to cracking [12]. This characteristic is the basis of the hereafter presented research introducing plastic waste in alternative pavement construction. The processed plastic is meant for total replacement of aggregates in stabilized base courses of semi-rigid pavements, according to a concept, totally different from the current practice, where plastic waste (LDPE) is used as a polymer in asphalt mixes.

PET Processing and Testing in Laboratory

The raw material processed in the recycling batch plant was provided in aggregates with a coarse and uniform gradation (d= 20-30mm). Recycled PET aggregates had an angular shape and the grain-size distribution matched that of coarse aggregates (Curve 1, Figure 3). A grain-size refining process, mainly by milling, was undertaken to improve the PET aggregate gradation. Accordingly, throughout the experimental stage of the research, a PET material of finer and more continuous gradation (0/20) was used (Curve 2, Figure 3).

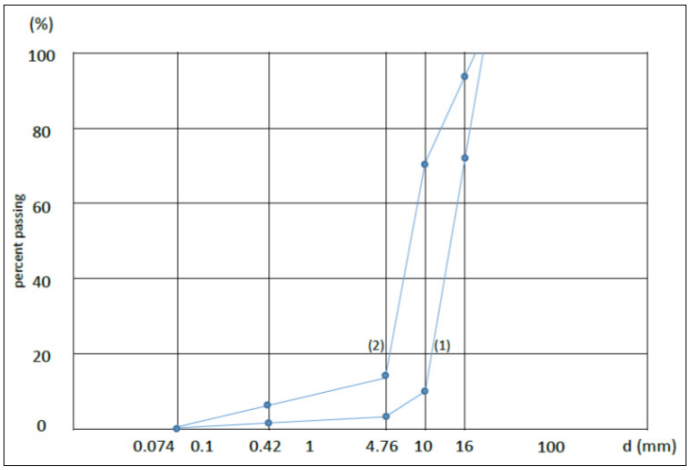

Figure 3: Gradation Curves of Unprocessed and Processed Pet Material

Resin-Stabilized Base Courses

Epoxy resins are polymers of low shrinkage, high tensile strength, excellent adhesion to several substrates and high thermal and chemical resistance.

Epoxy resin, a material in liquid form, is particularly useful in various applications since it can be easily mixed with aggregates, as a binder. The resin binding material, used in the experiments, consists of two components, a virgin resin and a hardener. After mixing for 3 minutes, at a rate of virgin resin/ hardener = 63/ 37 by weight, the product remains workable for 30-60 minutes, depending on the environmental conditions. Thereafter, the mix is properly preserved to enable curing. The resin binder, thus produced, does not shrink, unlike hydraulic binders, and is impermeable to liquids, which is important since it is intended for application in road pavements. Of interest are the extreme temperatures, at which the material maintains its properties without deforming or cracking (-30 ° to +50 ° C).

The Experimental Stage

The basic idea of preparing and testing PET-resin mix specimens was to experiment on different mix formulas and test them by evaluating their strength characteristics in laboratory. For each mix formula, specimens were prepared for unconfined compression and for indirect tensile tests.

Preparation of specimens started from properly setting up the resin binder in a metallic container where, the virgin resin and the hardener (component A and component B), are poured. Their ratio is strictly defined and must be thoroughly observed: virgin resin/hardener = 63/ 37 by weight. The two components are mixed mechanically with a glass rod, at slow rate for 3 minutes. At the end of the mixing procedure, the resin mix is just left to rest and the curing stage starts.

On the other hand, the recycled PET material (Figure 4) is placed in metallic and plastic bowls. While the resin is still workable, it is poured into the bowls containing the PET material, and is properly mixed to provide a uniform mixture. The resin binder must cover the entire surface of grains, to enhance stability of the mixture. Mixing is performed by a glass rod. The composite material produced is placed in molds before it cures and hardens [13].



Figure 4: Plastic Waste Material Before Mixing

It is worth mentioning that the composite material begins to cure shortly after mixing and stabilizes in less than 30 minutes, depending on the state of the resin.

Laboratory tests on the constitutive materials and the mix samples were performed to define their density. Tests on the recycled PET material gave low value of porosity (4%), while the bulk density was found 1.27 t/m3.Test results are summarized in Table 1:

Table 1: Density of Constitutive Materials

Material	Mass Density (t/m³)	Porosity (%)	Bulk Density (t/m³)
PET (raw)	1.32	4.1	1.27
PET (granules)	1.32	38.0	0.95
Epoxy Resin	1.12	0	1.12
Mix Samples	–	31.0	0.82–0.87

Strength Testing and Results

Laboratory experimentation consisted of unconfined compression and indirect tensile testson cylindrical specimens (Figure 5). Tests were conducted on specimens of different composition to provide evidence of the contribution of the resin content to strength properties [13].

The aggregate gradation is a factor strongly affecting strength properties of the mixes. Judging from the structure of the mixes produced, there are significant discontinuities in the PET aggregate skeleton. Reasonably, the gradation needs further improvement. A grain-size distribution without discontinuities would certainly lead to higher values of strength parameters.



Figure 5: Resin-Pet Mix Specimens

Laboratory tests were performed on cylindrical specimens of 5.1 cm (diameter) × 10.2 cm (height) for compressive strength testing. Specimens for indirect tensile tests were also cylindrical of 10.2 cm (diameter) x 5.1 cm (height). PET-resin specimens were subject to external loading and driven to failure (Figure 6). The rate of load application was 0.2 MPa/s. Strength test results are shown in Table 2.

Table 2: Strength Test Results

Resin Content	Unconfined Compression		Indirect Tensile	
	Specimens R/H (cm)	Strength (MPa)	Specimens R/H (cm)	Strength (MPa)
r = 5%	5.1 / 10.2	1.53 – 1.91	10.2 / 5.1	0.39 – 0.47
r = 6.5%	5.3 / 10.2	2.61 – 3.15	10.2 / 5.3	0.49 – 0.51
r = 8.5%	5.1 / 10.2	2.82 – 3.34	10.2 / 5.1	0.69 – 0.79



Figure 6: Specimens After Cracking

Compressive strength of specimens with 6.5% and 8.5% of resin was found similar to the strength of hydraulically bound aggregates with 4% of Portland cement [14]. The ratio of the tensile strength to the compressive strength is higher in resin-stabilized PET mixtures, exhibiting higher ductility. This leads to a design of a semi-rigid pavement with a 20-25 cm stabilized base, in either case, thickness depending on traffic load figures and on the subgrade bearing capacity. Taking into consideration current prices of materials, it seems that a stabilized base course

using the resin-PET mixture has a cost by 20-30% higher than the base from cement bound aggregates. However, further processing of the PET material with respect to gradation, may bring to light an improved performance of the resin-PET mixtures, especially in fatigue resistance, and lead to different design and economic considerations.

Conclusions

Incorporation of recycled PET aggregates in resin-stabilized mixes for semi-rigid pavements seems a promising and realistic technique. This innovative concept of recycling plastic waste on construction projects may prove effective and beneficial, since it defines a construction process engaging big quantities of waste material. Stabilization of PET aggregates, by use of epoxy resins as a binder, attributes significant tensile strength to the bound base and satisfactory performance at low temperatures.

Compressive and indirect tensile tests on resin-PET specimens, driven to failure, provided moderate values of yield strength, as expected. At a resin content of 6.5% and 8.5%, per weight of aggregates, the resin-PET mixes exhibit a performance quite similar to cement stabilized aggregates for base courses of semi-rigid pavements. Nevertheless, it seems that the cost of the PET-resin option is higher that the cement stabilization option.

Further research must effectively address the gradation issue of the PET aggregates and evaluate the effect of a more continuous grain-size distribution on strength values. Furthermore, a comparative laboratory study on the fatigue performance of both, resin-PET and cement-rock aggregate mixes, is necessary to assess the long-term stress-strain relationship of these techniques and to lead to proper design of semi-rigid pavement structures. A prospective wide application of this alternative technique in road construction projects will be possible if it combines the engineering advantages with a reasonable cost, while compared to the conventional cement/mineral aggregate technique for stabilized pavement courses.

References

1. Statista Research Department (2024) Annual production of plastics worldwide from 1950 to 2023.
2. European Parliament (2024) How to reduce plastic waste: EU measures explained. Guidelines.
3. European Council (2018) Waste management and recycling: Council adopts new rules, Press Release https://www.consilium.europa.eu/en/press/press-releases/2018/05/22/waste-management-and-recycling-council-adopts-new-rules/.
4. Vasudevan R, Ramalinga ARC, Sundarakannan B (2012) A technique to dispose waste plastics in an ecofriendly way—Application in construction of flexible pavements. Construction and Building Materials 28: 311-320.
5. Mouratidis A, Manthos E (2024) Plastic waste in dense asphalt mixes for road pavements. Insight-Civil Engineering 7: 658.
6. Moore S (2016) Plastic roads under development, Plastics Today. Report.
7. Caltrans (2020) Caltrans Repaves Roadway with Recycled Plastic Bottles. Report https://dot.ca.gov/news-releases/news-release-2020-024.
8. Yuonne B, Yajaira MP (2001) Polymer modified asphalt. Vision Technologica 9: 39-48.
9. Sarda P, Hanan JC, Lawrence JG, Allahkarami M (2022) Sustainability performance of polyethylene terephthalate, clarifying challenges and opportunities. Journal of Polymer Science 60: 7-31
10. Joseph TM, Azat S, Ahmadi Z, Jazani OM, Esmaeli A, et al. (2024) Polyethylene terephthalate (PET) recycling: A review. Case Studies in Chemical and Environmental Engineering 9: 2-16.
11. Bhanderi KK, Joshi JR, Patel JV (2022) Recycling of polyethylene terephthalate (PET Or PETE) plastics – An alternative to obtain value added products: review. Journal of the Indian Chemical Society 100: 100843.
12. Ahmad F, Razali AR, Razelan ISM (2016) Utilization of polyethylene terephthalate (PET) in asphalt pavement: A review. IOP Conf. Series: Materials Science and Engineering 203: 1-7.
13. Efraimidis A (2019) Experimental Investigation of Introducing Plastic Waste Aggregates in pavement Bases. M.Sc. Dissertation Thesis, AUTH.
14. Barišić I, Dokšanović T, Draganić H (2015) Characterization of hydraulically bound base materials through digital image correlation. Construction and Building Materials 83: 299-307.

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