LITERATURE REVIEW
The Use of Waste Plastics in Asphalt Mixtures

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Asphalt is a combination of aggregate and bitumen, a by-product of crude oil refining. Traditional asphalt mixtures included unmodified bitumen (White & Reid, 2018); however, studies have shown that the service life of asphalt pavements has decreased over the past decades, likely in response to the increase in heavy vehicle traffic. Asphalt is also affected by fluctuations in temperature, with high temperatures leading to rutting, and low temperatures promoting cracking (Jan, Aman, Khan, & Karim, 2017). Modifying asphalt mixtures using the addition of polymers and fibers has been shown to prolong service life and reduce maintenance, as well as provide improved bonding to aggregate particles (Ghuzlan, Al-Khateeb, & Qasem, 2015).

Plastic is a polymer, and in recent years, researchers have explored the use of waste plastic products as an additive in asphalt mixtures, both as a means of reducing the amount of waste material in landfills and other facilities, as well as providing a potential cost savings over the use of more expensive modifiers ("On the Plastic Highway," 2018). Two basic methods were used in the studies; a wet process introduced plastic as a bitumen modifier, while a dry process substituted plastic for a portion of the aggregate (Costa, Peralta, Oliveira, & Silva, 2017). Tests were done using different percentages of plastic in the asphalt mixtures, with optimum quantities varying from 1.5% (Aschuri & Woodward, 2010) to 6% (White & Reid, 2018). The plastic used was processed differently depending on how it was to be added to the mixture. Mir (2015) found that grinding the plastic to a powder and mixing the powder with the bitumen allowed for a homogenous mixture. MacRebur, a company from the UK, has created custom combinations of pelletized plastics for various applications. This company feels that, while current formulas use 5 – 10% replacement of bitumen by the plastic additives, that it could eventually be increased to 25% ("On the Plastic Highway," 2018).

Some of the studies combined other substances with the plastic. Ashuri & Woodward (2010) found that a combination of recycled asphalt pavements (RAP) and waste high-density polyethylene (HDPE) improved the performance of asphalt concrete exposed to heavy traffic use in higher temperatures. Jafar (2016) treated the plastic with an oxidizing mixture of dichromate and sulphuric acid before using it as a replacement for a portion of the aggregates.

The costs of cleaning and processing waste plastic for re-use is expensive, but several of the reports indicated that the technique could represent a cost savings for the overall project. MacRebur, mentioned earlier, stated that a tonne (1.1 US ton) of bitumen cost around £400 ($521 US) in Great Britain. Processed waste plastic for road use averages £300 - £350 ($398 - $464 US) per tonne, representing a cost savings for the percentage of bitumen replaced by plastic additives ("On the Plastic Highway," 2018). An Indian study claimed that, while the cost of plastic-modified asphalt may be slightly higher than conventional mixtures, the reduced maintenance constituted a savings of Rs. 1,080,000 ($15,248 US) per km. This figure was based on their assertion that plastic-modified bitumen doubled the life of the roadway in their test – a claim not made in any of the other studies.

All of the reports reviewed indicated that a positive result could be achieved by adding waste plastics to asphalt mixtures, particularly in areas subjected to high ambient temperatures. However, nearly all of them indicated that results are preliminary, and that further research is needed. Several also cautioned that the cost effectiveness would need to be considered. The literature search did not find any indication that this process is being used – or even considered – by any DOT in the US.

Discussion:

It should to be noted that the papers examined in this literature review represent research done in the laboratory with very little mention of long-term field testing. Laboratory testing represents steps 3-5 of the nine point scale developed by FHWA in their Technology Readiness Level (TRL) Assessment , indicating that years of research are needed to show the viability and effectiveness of this technology. Dr. Richard Willis of the National Center for Asphalt Technology at Auburn University responded to an inquiry, stating that he knew of research on this topic being conducted in the US, but was not aware of any published work from US institutions (the research represented in the literature review was done abroad). Dr. Willis also confirmed the fact that no state DOT has developed specifications for the use of plastics in asphalt mixtures – and raised the following questions regarding gaps in the current state of the knowledge:

1. Does it work? How does it impact the binder/mixture properties?
2. How does it impact environmental permitting? If this is added like an aggregate, how does it impact fumes and emissions coming out of the plant?
3. Does it impact the recyclability of asphalt mixtures? Can I recycle a mixture that contains plastic? Does that impact performance or EH&S?
4. Are there human health concerns with the use of this product? If I am adding it dry, are there respiratory concerns? If I am milling an old pavement, are microplastics getting into the air and could they be ingested by milling crews?
5. Is this economically viable? Am I replacing binder or polymer? There seems to be some confusion regarding this idea.

The asphalt industry currently recycles nearly all of the asphalt that is used, so it would be important to determine whether or not asphalt using waste plastic products can be recycled in an economical and environmentally-friendly manner. If not, the use of such product would be detrimental to our current asphalt program.

Reviewed Papers with Abstracts:

Aschuri, I., & Woodward, D. (2010). Modification of a 14mm Asphalt Concrete Surfacing Using RAP and Waste HDPE Plastic. *International Journal of Pavements, 9*(1-2-3), pp 70-78.

This paper reports the findings of a laboratory investigation to assess the use of waste high-density polyethylene (HDPE) plastic and recycled asphalt pavements (RAP) to improve the performance of a 14mm asphalt concrete (AC) surfacing. Waste HDPE plastic obtained from plastic milk cartons was blended with 60/70 penetration grade bitumen and its addition evaluated using the Softening Point test and modified Penetration test at 25°C, 30°C, 35°C and 40°C. This found the addition of waste HDPE plastic to increase softening point and lower penetration value. Deformation and fatigue testing of a 14mm asphalt concrete mix surfacing mix incorporating a blend of waste HDPE plastic and RAP was carried out at a range of test temperatures. This found that modification using waste HDPE plastic and RAP improved both deformation and fatigue properties. The laboratory investigation has shown that the use of waste HDPE plastic derived from milk containers combined with RAP could improve the performance of asphalt concrete subjected to heavy trafficking at higher ambient temperatures.

Costa, L. M. B., Peralta, J., Oliveira, J. R. M., & Silva, H. M. R. D. (2017). A New Life for Cross-Linked Plastic Waste as Aggregates and Binder Modifier for Asphalt Mixtures. *Applied Sciences, 7*. doi:doi:10.3390/app7060603

Every year, millions of tons of plastic waste, with potential to be reused, are wasted in landfills. Based on a literature review and in a local market analysis, cross-linked polyethylene (PEX) waste arose as the material with the greatest potential to be tested for incorporation in asphalt mixtures due to the difficulty in its recycling and the lack of solutions for its reuse. Thus, in the present work, mixtures produced with and without PEX were tested in order to compare their performance, aiming at understanding if this waste could successfully be used as an alternative material for this type of application. Thus, water sensitivity, rutting resistance, stiffness modulus and fatigue cracking resistance tests were carried out on asphalt mixtures with up to 5% PEX. Based on the results obtained, it can be concluded that the incorporation of PEX in asphalt mixtures is a viable solution for paving works, especially when high service temperatures are expected. It also decreases the density of the mixture, which can be attractive to lighten structures. Thus, this technology contributes to give new life to cross-linked polyethylene plastic waste. The possibility of using this thermoset plastic waste in asphalt mixtures as a partial substitute of the aggregates would promote the use of higher amounts of this waste material, increasing its value, while saving landfill space and reducing the extraction of mineral aggregates. Thus, this work intended to replace part of the mineral aggregates with recycled PEX and improve the performance of the asphalt mixtures, which was obtained by using 5% of PEX, by volume of mixture. Almost all PEX material is made from high-density polyethylene, containing cross-linked bonds in the polymer structure that change the thermoplastic to a thermoset nature.

The main objective of this work is to incorporate a significant amount of PEX in an asphalt mixture for a road pavement surface layer and compare its performance with a conventional mixture without PEX. Thus, two comparable asphalt mixtures were defined in this work to carry out the study: (i) a conventional mixture with only mineral aggregates; (ii) a new mixture incorporating PEX, with 5% of PEX by volume of the aggregates used in the mixture.

Ghuzlan, K. A., Al-Khateeb, G. G., & Qasem, Y. (2015). Rheological Properties of Polyethylene-Modified Asphalt Binder. *Athens Journal of Technology & Engineering, 2*(2), 75-88.
https://www.athensjournals.gr/technology/2015-2-2-1-Ghuzlan.pdf
Polyethylene (PE) is the most common type of plastic. In daily life, plastic bags, plastic bottles, and many other PE products are seen everywhere. Significant amount of plastics are not disposed properly and therefore present as waste material in the environment. Using polyethylene as an additive to asphalt binders may be considered a good way to utilize this material. However, modified asphalt binder properties should be investigated. Rheological properties at higher temperatures of asphalt binders modified with PE are investigated in this study. PE was added to asphalt binder at different percentages by volume of asphalt binder. These percentages were: 3, 4, 5, 6, and 7%. The rheological properties included: the rotational viscosity (RV), asphalt binders complex shear modulus (G*), and the phase angle (δ). It was found that the increase of PE to asphalt binder (PE/A) ratio increased the complex shear modulus (G*) and the rotational viscosity (RV) of asphalt binders. Furthermore, the rutting parameter (G*/sin δ) was improved. However, the PE/A ratio have no significant effect on the phase angle.

Jafar, J. J. (2016). Utilisation of Waste Plastic in Bituminous Mix for Improved Performance of Roads. *KSCE Journal of Civil Engineering, 20*(1), pp 243-249.
http://dx.doi.org/10.1007/s12205-015-0511-0
The use of waste plastic as a partial aggregate replacement in bituminous mix products often suffers from weak bonding between the plastic surface and the bitumen. This work reports on the use of plastic waste and chemical additives in order to improve the performance of the volumetric and mechanical properties of bituminous mixtures. The selected recycled waste plastics were used as partial aggregate replacement in bituminous mix product. The plastics were treated using a strong oxidising mixture of dichromate and sulphuric acid while the bitumen was treated with a cross linking agent, polyethyleneimine. Three modified bituminous mixtures were prepared and the stiffness results (from Retained Stiffness after Water Immersion Test) were compared with the control bituminous mixture. Over the ten measurement cycles it was observed that the stiffness increased by 10% for the chemically modified bituminous mixtures. This improvement is attributed to an increase in the bonding forces between the aggregates and the bitumen. Furthermore, a mechanism is proposed in order to explain the effect of the chemical additives on the increase in the stiffness of the bituminous mixture.

Jan, H., Aman, M. Y., Khan, S., & Karim, F. (2017). *Performance of Hot Asphalt Mixtures Containing Plastic Bottles as Additive*. Paper presented at the ISCEE 2016 : 2016 International Symposium on Civil and Environmental Engineering.
https://www.matec-conferences.org/articles/matecconf/pdf/2017/17/matecconf_iscee2017_09006.pdf
This study focuses on evaluating the resistance of polymer modified asphalt mixes and the role played by asphalt in the realm of construction is undeniably important. Addition of polymers(PB) as additives to asphalt helps to improve the strength and water repellent property of the mix and as well as helps environment in various ways andat the same time, analyzing its lower maintenance activities and service life is most important.

The use of inexpensive polymers, in this case, waste polymers has without any doubt proven to be the most convenient way of reducing the cost of construction and at the same time maintaining quality. The main resolve for this research was to establish the effects of the use of plastic bottles on hot asphalt and its mixtures. In order to put this into perspective, varying percentages of asphalt mixtures were calculated and subjected to laboratory tests. The two-factor variance analysis (ANOVA) was conducted to determine the significance at various confidence limits. The results indicate that the inclusion of Polyethylene Terephthalate (PET) had a particularly substantial effect on the properties of asphalt. Consequently, it can encourage the re-utilization of waste in the manufacturing industry in an ecologically friendly and cost-effective way.

Mir, A. H. (2015). Use of Plastic Waste in Pavement Construction: An Example of Creative Waste management. *IOSR Journal of Engineering, 5*(2), 57-67.
http://www.iosrjen.org/Papers/vol5_issue2%20(part-1)/H05215767.pdf
Plastic which is toxic in nature is found to be nearly 5% in Municipal Solid Waste (MSW). A major problem nowadays is the disposal of plastic wastes. These wastes are non biodegradable in nature causing environmental pollution and hygiene problems. The experimentation at several institutes indicated that waste plastic can be utilized in Asphalting of roads. The use of these wastes in road construction is based on Economic, Technical and Ecological criteria. Taking an example of INDIA (Authors native land) several million metric tons plastic wastes are produced every year. If these wastes can be suitably utilized in road construction, the disposal and pollution problems can be minimized to a large extent. In road making process bitumen is used as binder. The bitumen can be modified with plastic waste pieces forming a mix which can be used as a top layer of flexible pavement, showing better binding property, stability, density and which is more resistant to water.

MOGHADDAM, T. B., KARIM, M. R., & SOLTANI, M. (2013). UTILIZATION OF WASTE PLASTIC BOTTLES IN ASPHALT MIXTURE. *Journal of Engineering Science and Technology, 8*(3), 264-271.
Nowadays, large amounts of waste materials are being produced in the world. One of the waste materials is plastic bottle. Generating disposable plastic bottles is becoming a major problem in many countries. Using waste plastic as a secondary material in construction projects would be a solution to overcome the crisis of producing large amount of waste plastics in one hand and improving the structure's characteristics such as resistance against cracking on the other hand. This study aimed to investigate the effects of adding plastic bottles in road pavement. Marshall properties as well as specific gravity of asphalt mixture containing different percentages of plastic bottles were evaluated. Besides, Optimum Asphalt Content (OAC) was calculated for each percentages of plastic bottles used in the mix. The stiffness and fatigue characteristics of mixture were assessed at OAC value. Results showed that the stability and flow values of asphalt mixture increased by adding waste crushed plastic bottle into the asphalt mixture. Further, it was shown that the bulk specific gravity and stiffness of mixtures increased by adding lower amount of plastic bottles; however, adding higher amounts of plastic resulted in lower specific gravity and mix stiffness. In addition, it was concluded that the mixtures containing waste plastic bottles have lower OAC values compared to the conventional mixture, and this may reduce the amount of asphalt binder can be used in road construction projects. Besides, the mixtures containing waste plastic showed significantly greater fatigue resistance than the conventional mixture.

On the Plastic Highway. (2018, Sept. 13th, 2018). *The Economist*.
https://www.economist.com/science-and-technology/2018/09/13/road-makers-turn-to-recycled-plastic-for-tougher-surfaces

Vootukuri, V. R. R. (2018). *REPORT ON THE UTILIZATION OF WASTE PLASTIC MATERIALS IN ASPHALT PAVEMENTS*.
https://il-asphalt.org/files/5115/1742/3750/Venkat_Vootukuri_2017_Cdale.pdf
This paper is the study of some of the waste plastic materials which could be reused by some processing methods and it can be mixed with the asphalt while construction of road. These waste plastics are used as the partial replacement of aggregate in asphalt mix product. Plastic is a toxic and persistent material, the quantity of plastic it is getting increased day by day due the population, urbanization, development activities and frequent changes in the life style which is leading to increase the junk on the land. For example, the usage of water

bottles, containers, plastic carry bags and packing strips etc. is increasing day by day as a result the amount of plastic is getting increased. Even though was have been recycling the plastic but 20% of the plastic is not getting recycled and due to their non-biodegradability, it is hazardous to human's health and has negative impact on the environment; consequently, rivers, gutters and roadsides are choked and filled with waste plastics. There are so many researches going on in the institutes and some of them have come to conclusion that waste plastic can be used in the construction of roads using asphalt. There are two main procedures in which we can mix plastic with asphalt they are Dry process and another one is Wet process. To prepare a plastic modified asphalt concrete mix, dry process involves direct incorporation of waste plastic, which is blended with aggregate before adding it with the bitumen and in the Wet Process involves the simultaneous blending of bitumen and waste plastic. If we use the waste plastics in the construction of the asphalt road, we can reduce the cost of the road construction and the pollution index of the environment to an appreciable extent. This plastic can be used as a binder along with the bitumen. It may also result in better finish ability, stability, resistant to water, durability and binding property.

White, G., & Reid, G. (2018). *Recycled waste plastic for extending and modifying asphalt binders*.

Plastic drink bottles, single-use plastic bags and other waste plastics have a significant impact on the environment. Consequently, there is global interest in recycling and reuse of waste plastics. Significant progress has been made towards the incorporation of waste plastics into building and construction materials, although this has focussed mainly on cement and concrete applications. This paper assesses the use of three commercially available recycled plastic products for bituminous binder extension and modification in asphalt mixtures. Using a dry-mixing process, shredded and pelletised recycled waste plastics replace 6% of the binder volume. Comparative laboratory testing of two typical UK asphalt mixtures indicated that asphalt containing the recycled waste plastic products showed improved deformation resistance and fracture resistance compared to conventional 40/60 penetration grade binder. The viability of imported recycled plastic waste use in Australian asphalt mixtures was also evaluated. One of the three recycled plastic products is expected to be a cost effective alternate to M1000 or A35P and another is expected to be a viable alternate to A20E, at a significant cost saving. Partial replacement, without performance enhancement, of C320 bitumen is not viable due to the high cost of recycled waste plastic importation. However, partial C320 replacement may become viable with the introduction of local recycled plastic processing in the future. The findings of this research require validation by objective comparison to Australian asphalt mixtures produced with common Australian asphalt binders, as well as confirmation of likely importation costs. Verification of consistent product digestion and distribution through drum-based asphalt production plants is also required.