K4D Knowledge, evidence and learning for development

Using waste plastics in road construction

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Question

Please provide evidence about the use of waste plastics in road construction to inform road infrastructure investments in the Horn of Africa and to enable DFID to better understand the latest innovations and possible future use in road construction and maintenance.

Contents

1. Executive summary

The idea of using waste plastics in road construction is relatively new. Laboratory tests have shown positive results when a small amount (5-10% by weight) of plastic is incorporated in bituminous mixes (asphalt), resulting in improved pavement stability, strength, and durability. However, international field experience using plastics in actual road construction is quite limited. In this review, we found examples of waste plastics being used in road construction in a few case studies in India, UK, Netherlands, Ghana, Ethiopia and South Africa. While roads constructed using waste plastics have shown good longevity and pavement performance to date, the first roads constructed using this technology are only about ten years old, so long-term outcomes are not yet clear. This review did not find any evidence discussing the maintenance of roads constructed using waste plastics.

2. International experience using waste plastics in road construction

Using waste plastics in road construction is a relatively new idea and no roads have been constructed entirely from plastics. However, a review by Huang *et al.* (2007) suggested that recycled plastics can either replace aggregates or serve as a binder modifier. Waste plastic has potential for use in bituminous road construction as its addition in small doses (about 5-10% by weight of bitumen) helps in substantially improving the stability, strength, fatigue life and other desirable properties of bituminous mixes, leading to improved longevity and pavement performance (Kalantar *et al.*, 2012; Vasudevan *et al.*, 2012; Indian Road Congress, 2013). Laboratory and field performance studies report that using waste plastic in bituminous mixes increases durability and results in higher resistance to deformation and water induced damage, indirectly contributing to user satisfaction and accident reduction (Bale, 2011; Behl *et al.*, 2012; Bhoot *et al.*, 2012; Khursheed and Singh, 2017; Manju *et al.*, 2017). The addition of waste plastic in the bituminous mix results in a reduction of bitumen consumption, thereby resulting in reduction of costs (Vasudevan and Rajasekaran, 2006; Rashid *et al.*, 2009; Behl *et al.*, 2012; Vasudevan *et al.*, 2012). Using waste plastic for road construction also contributes to longer road service life (Sojobi *et al.*, 2016).

A technical summary of laboratory studies on the use of waste plastics in road construction have been conducted around the world is included in Appendix A.

India

India is the country where there appears to be the most experience with using waste plastics in road construction. India has promoted the use of waste plastic in bituminous mixes for the construction of its national highways and rural roads, and has approved it as a default mode of periodic renewal with hot mixes for roads within 50 km periphery of urban areas with more than 500,000 population (Government of India, 2015; National Rural Roads Development Agency, 2019). The Indian Road Congress (2013) has published guidelines for the use of waste plastic in hot bituminous mixes while the National Rural Roads Development Agency (2019) provides guidance on the use of waste plastic specific to rural roads construction.

Since 2002, waste plastic has been used to construct more than 2500 km of roads which were reportedly functioning well without potholes, ravelling and rutting up to ten years later (Vasudevan *et al.*, 2010; Indian Road Congress, 2013) (Table 1). Poor binding between the aggregates and bitumen is one of the reasons for such defects in standard road construction, but binding between plastic coated aggregate and bitumen is stronger in comparison to standard construction techniques (Vasudevan *et al.*, 2012; Mishra and Gupta, 2018).

According to Vasudevan *et al.* (2012) a tonne of waste plastic was used for every 1 km of road constructed, which reduced carbon dioxide emissions by 3 tonnes/km in comparison to standard construction techniques.

Table 1: Roads constructed in India using waste plastic and their condition

Road		*Year laid*	*Unevenness (mm/km)*	*Skid number*	*Texture depth (mm)*	*Field density (kg/m^3)*	*Rebound deflection (mm)*
Design standard (acceptable values)		–	<4000	<65	0.6–0.8		0.5–1
Typical construction method: plain bitumen road		2002	5200*	76*	0.83*	2.86	1.55*
Roads constructed using waste plastics	Jumbulingam Street	2002	2700	41	0.63	2.55	0.85
	Veerabadhra Street	2003	3785	45	0.70	2.62	0.60
	Vandiyur Road	2004	3005	41	0.66	2.75	0.84
	Vilachery Road, Mai	2005	3891	45	0.50	2.89	0.86
	Canteen Road, TCE	2006	3100	45	0.65	2.86	0.86

*Values outside acceptable design parameters shown in red
Traffic data was not available
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Some data on the costs associated with the use of waste plastic for the construction of roads in India are presented in Table 2.

Table 2: Road construction cost data using waste plastic in India

Cost of Bitumen*	~$670/ton
Cost of Waste Plastic*	~$230/ton
Cost of Shredding Machine and other equipment	~$955
Optimum amount of waste plastic in the mix	~11%
Cost saved by using waste plastic in road construction (per km)*	~$670/km

*The exchange rate at 2012 of 1 Indian Rupee = $ 0.01909 was used for this calculation (https://www.xe.com/)
Source: *Vasudevan et al. (2010); Bale (2011); Vasudevan et al. (2012)*

United Kingdom

MacRebur, a UK based company, has developed a solution to use waste plastic within asphalt for road construction and surfacing (White and Reid, 2017; White and Reid, 2018; White, 2019). MacRebur's recycled waste plastic was incorporated into asphalt instead of traditional bitumen and used by Durham County Council in the UK for resurfacing a section of A689 near Sedgefield and for resurfacing runways and taxiways at Carlisle Airport in the UK. MacRebur was also involved in the construction of plastic roads in the **United States** and **Australia** (UCSD Guardian, 2018) and is currently constructing **South Africa**'s first plastic road (in Kouga Muncipality). MacRebur products are the only technology for road construction using waste plastic which has made it to global commercial use (see Appendix A for product specifications and costs).

The UK government recently announced the investment of £23 million into plastic road technologies by setting up real-world tests across eight local authorities (Buckinghamshire, Bedfordshire, Cumbria, Staffordshire, Kent, Reading, Suffolk, Solihull and Birmingham) (Department for Transport, 2019). A portion of this funding, approximately £1.6 million, will be used to extend an existing road in Cumbria that is built from recycled plastic mixed with asphalt. This project also aims to produce a guidance document for the design and specifications of plastic asphalt (Department for Transport, 2019).

Ghana

A Ghana based plastic recycling company, NelPlast Ghana Ltd, produces pavement blocks from waste plastic. These pavement blocks have been approved by Ghana's Ministry of Environment, Science, Technology and Innovation, and have been used to construct a road in Accra (AfrikaTech, 2018).

Ethiopia

Some data on the costs associated with the use of waste plastic for the construction of roads in Ethiopia are presented in Table 3.

Table 3: Road construction cost data using waste plastic in Ethiopia

Cost of Shredding Machine*	~$1,545
Cost of Plastic*	$0.15/kg
Optimum amount of waste plastic in the mix	11.5%
Cost saved by using waste plastic in road construction (per km)	10.06%

*The exchange rate at 2014 of 1 Ethiopian Birr = $ 0.05151 was used for this calculation (https://www.xe.com/)

Source: Welegabir et al. *(2014)*

The Netherlands

A 30 metre cycle path entirely built from prefab, modular and hollow blocks manufactured from recycled plastic is operational in the Zwolle municipality in the Netherlands (PlasticRoad, 2018). A second such bicycle path is under construction in the Steenwijkerland municipality (PlasticRoad, 2018). The concept was developed by a consortium of KWS (a VolkerWessels company), Wavin and Total, who are currently working on the development of plastic roads for wider applications (PlasticRoad, 2018).

3. Construction methods

Bituminous hot mixes using waste plastic for road construction are manufactured using either a 'dry' process or a 'wet' process (see Figure 1 and Figure 2). The dry process is considered to be simple, economical and environmentally friendly, while the wet process requires more investment and machinery, and hence is not commonly used (Mishra and Gupta, 2018).

Figure 1: Road construction process using waste plastic, See: Centre for Innovations in Public Systems (2014: 8), http://www.cips.org.in/documents/Published_Documents/e-Books/2015/Urban-Governance/Use-of-Plastics/Use-of_Plastics.pdf

Dry process

In the dry process, the processed waste plastic is shredded and added to the hot aggregate (in Figure 2, when lines *a*, *b* and *d* are opened, keeping *c* and *e* closed). The Indian Road Congress (2013) and National Rural Roads Development Agency (2019) indicates that the shredded waste plastic size should preferably be 2-3 mm for better spread and coating on the aggregate. Dust and other impurities should not exceed 1%. The shredded waste plastic is then added to the aggregates that are heated to 170ºC. The shredded waste plastic softens and melts to form a coating around the aggregates (Sahu and Singh, 2016). The bitumen is also heated to 160ºC and the plastic-coated aggregates are then mixed with bitumen and used for road construction.

Laboratory tests indicate that the percentage of shredded waste plastic in bituminous mixes to be between 5% to 10% of the weight of bitumen, with 8% recommended to be the optimum percentage (Vasudevan *et al.*, 2012; Indian Road Congress, 2013; Mishra and Gupta, 2018; National Rural Roads Development Agency, 2019).

Mishra and Gupta (2018) reported a marked improvement in various parameters such as Marshall stability and indirect tensile strength for the outputs from dry process in comparison with that of wet process. This shows higher resistance to withstand at higher loads and to resist deformation.

Prof R. Vasudevan has obtained a patent (PCT Classification Number C08L95/00) in 2006 for the dry process of mixing waste plastics with aggregate and bitumen for flexible pavements (Vasudevan, 2004; Vasudevan *et al.*, 2012). This process was adapted for the construction of the roads presented in Table 2.

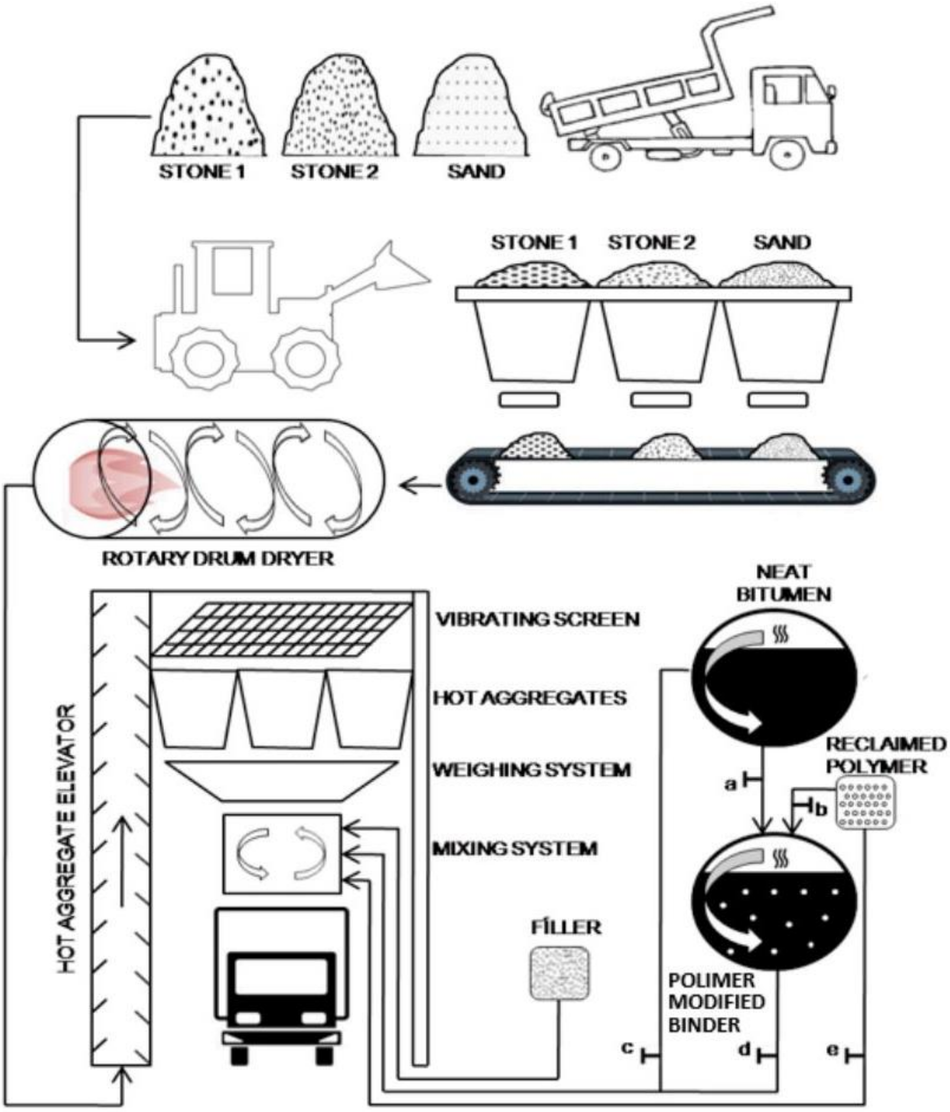
The UK company MacRebur converts waste plastics into pellets and adds them to an asphalt or bitumen mix before heating the mix to between 160ºC and 180ºC. The waste plastic pellets melt fully and homogenise to form part of the bitumen mix.

Wet process

In the wet process, the processed waste plastic in powder form is added to the hot bitumen (in Figure 3, when lines *c* and *e* are opened, and *a*, *b* and *d* are closed).

The powdered waste plastic is directly mixed with bitumen before adding them to the aggregates. It has to be ensured that there is an even mix of plastic and bitumen, and the temperature range for this method is 155ºC to 165ºC (Asare *et al.*, 2019). Sahu and Singh (2016) and Asare *et al.* (2019) suggests a 6-8% of waste plastic powder within the bitumen mix.

Figure 2: Sketch of the wet and dry processes in an asphalt plant



Source: Brasileiro, Luzana; Moreno-Navarro, Fernando; Tauste, Raúl and Rubio-Gámez, *Maria*. 2019. **Reclaimed Polymers as Asphalt Binder Modifiers for More Sustainable Roads: A Review**. *© 2019 by the authors.* https://www.researchgate.net/publication/330706261_Reclaimed_Polymers_as_Asphalt_Binder_Modifiers_for_More_Sustainable_Roads_A_Review. *Licensee MDPI, Basel, Switzerland. License http://creativecommons.org/licenses/by/4.0/*

4. Maintenance

This review did not find any evidence discussing the maintenance of plastic roads. This might be due to the relatively short life of the technology and the existing roads that have been constructed (Table 1). The Centre for Innovations in Public Systems (2014) noted that roads constructed with plastic modified bitumen required maintenance after 10 years in service compared with 5 years for normal roads, however the impact of road traffic and associated loads were not reported in this estimation. We also found no studies examining the use of plastic for maintaining roads, rather than resurfacing. MacRebur's recycled waste plastic products were used for resurfacing A7 (a major trunk road) in the UK's Lake District (Dickinson, 2018).

5. Challenges

Health and environmental hazards

Chakraborty and Mehta (2017) identified two chemical hazards associated with the application of waste plastic within road construction:

- Leaching of toxic components during the cleaning process
- Generating hazardous chlorine based gases during the road construction process

White (2019) reported that both leachate and toxic fume generation were negligible and did not have any adverse effects.

Collecting and sorting waste plastics

The use of waste plastics in road construction depends on good quality systems for collecting, sorting, and cleaning waste plastic. Separation of waste is important because only the following types of waste plastic can be used for road construction (Centre for Innovations in Public Systems, 2014):

- Films (carrier bags, disposable cups) of thickness up to 60 microns (PE, PP, PS)
- Hard foams (PS) of any thickness
- Soft foams (PE and PP) of any thickness
- Laminated plastics of thickness up to 60 microns

Training for construction workers

Training of the workers is mandatory for health and safety of the workers concerned. They should also be provided with an understanding of the type of waste and methods of handling. Similarly, mandatory training for the contractors, workers and engineers should involve awareness of both plastic waste management and its use in road construction. Technical manuals and handbooks pertaining to the same may be drafted.

Regulatory framework

An adequate regulatory framework for the use of waste plastics in road construction, drawing on evidence-based standards, is important to establish the legal as well as technical basis for the use of this technology (Mogadishu Municipality, 2018). Governments could consider providing the highways/road authorities with the mandate to oversee the use of waste plastics in road construction. The authorities could also be responsible for the technical monitoring involving the checking of temperature of the mix, quantity and type of waste plastic and bitumen and run quality assurance regimes.

6. References

Abdullah, M.E., S.A. Abd Kader, R. Putra Jaya, H. Yaacob, N. Abdul Hassan and C.N. Che Wan (2017). Effect of Waste Plastic as Bitumen Modified in Asphalt Mixture. **ISCEE 2016 : 2016 International Symposium on Civil and Environmental Engineering**. Wuhan, China, MATEC Web of Conferences. **103**.

Ahmadinia, E., M. Zargar, M.R. Karim, M. Abdelaziz and E. Ahmadinia (2012). "Performance evaluation of utilization of waste Polyethylene Terephthalate (PET) in stone mastic asphalt." **Construction and Building Materials 36**: 984-989.

Asare, P.N.A., F.A. Kuranchie, E.A. Ofosu and F. Verones (2019). "Evaluation of incorporating plastic wastes into asphalt materials for road construction in Ghana." **Cogent Environmental Science 5**(1).

Awwad, M.T. and L. Shbeeb (2007). "The use of polyethylene in hot asphalt mixtures." **American Journal of Applied Sciences 4**(6): 390-396.

Bale, A.S. (2011). "Potential reuse of plastic waste in road construction: a review." **International Journal of Advances in Engineering & Technology (IJAET) 2**: 233-236.

Behl, A., P. Jain and G. Sharma (2012). **Study on waste polyvinyl chloride modified bitumen for paving applications**. ARRB Conference, 25th, 2012, Perth, Western Australia, Australia.

Bhoot, K., K. Malviya and T.K. Prajapat (2012). "Potential reuse of plastic waste in road construction: A review." **International Journal of Scientific Research in Engineering 1**(9): 1-5.

Brasileiro, L., F. Moreno-Navarro, R. Tauste-Martínez, J. Matos and M.d.C. Rubio-Gámez (2019). "Reclaimed Polymers as Asphalt Binder Modifiers for More Sustainable Roads: A Review." **Sustainability 11**(3): 646.

Centre for Innovations in Public Systems (2014). Use of Plastics in Road Construction; Implementation of Technology and Roll out.Retrieve from http://www.cips.org.in/documents/Published_Documents/e-Books/2015/Urban-Governance/Use-of-Plastics/Use-of_Plastics.pdf

Chakraborty, A. and S. Mehta (2017). "Utilization & Minimization of Waste Plastic in Construction of Pavement: A Review." **International Journal of Engineering Technology Science and Research 4**(8): 2394-3386.

Chavan, M.A.J. (2013). "Use of plastic waste in flexible pavements." **International Journal of Application or Innovation in Engineering and Management 2**(4): 540-552.

Costa, L.M.B., H.M.R.D. Silva, J. Peralta and J.R.M. Oliveira (2019). "Using waste polymers as a reliable alternative for asphalt binder modification – Performance and morphological assessment." **Construction and Building Materials 198**: 237-244.

Department for Transport. (2019). "Technological trials to help future proof roads." Retrieved 24/04/2019, from https://www.gov.uk/government/news/technological-trials-to-help-future-proof-roads.

Dickinson, K. (2018). "Recycled Plastic Road Surface Trialled by Enfield Council." Retrieved 02/05/2019, from https://resource.co/article/recycled-plastic-road-surface-trialled-enfield-council-12444.

Essawy, A., A. Saleh, M.T. Zaky, R.K. Farag and A. Ragab (2013). "Environmentally friendly road construction." **Egyptian Journal of petroleum 22**(1): 189-198.

Fang, C., X. Liu, R. Yu, P. Liu and W. Lei (2014). "Preparation and properties of asphalt modified with a composite composed of waste package poly (vinyl chloride) and organic montmorillonite." **Journal of Materials Science & Technology 30**(12): 1304-1310.

Government of India (2015). Use of plastic waste in bituminous mixes in construction of National Highways. M.o.R.T. Highway, Ministry of Road Transport & Highway.

Huang, Y., R.N. Bird and O. Heidrich (2007). "A review of the use of recycled solid waste materials in asphalt pavements." **Resources, Conservation and Recycling 52**(1): 58-73.

Indian Road Congress (2013). Guidelines for the Use of Waste Plastic in Hot Bituminous Mixes (Dry Process) In Wearing Courses. India.

Jan, H., M.Y. Aman and F. Karim (2017). **Plastic Bottles Waste Utilization as Modifier for Asphalt Mixture Production**. MATEC Web of Conferences, EDP Sciences.

Kalantar, Z.N., M.R. Karim and A. Mahrez (2012). "A review of using waste and virgin polymer in pavement." **Construction and Building Materials 33**: 55-62.

Khursheed, T. and B.K. Singh (2017). "Road construction from solid waste in jaipur." **International Journal For Technological Research In Engineering 4**(9): 1711-1714.

Manju, R., S. Sathya and K. Sheema (2017). "Use of plastic waste in bituminous pavement." **Int J ChemTech Res 10**(08): 804-811.

Mishra, B. and M.K. Gupta (2018). "Use of plastic waste in bituminous mixes by wet and dry methods." **Proceedings of the Institution of Civil Engineers - Municipal Engineer**: 1-11.

Mogadishu Municipality (2018). Somali Urban Resilience Project; Environmental & Social Management Framework (ESMF).

Moghaddam, T.B., M.R. Karim and M. Soltani (2013). "Utilization of waste plastic bottles in asphalt mixture." **Journal of Engineering Science and Technology 8**(3): 264-271.

Nasr, D. and A.H. Pakshir (2017). "Rheology and storage stability of modified binders with waste polymers composites." **Road Materials and Pavement Design 20**(4): 773-792.

National Rural Roads Development Agency (2019). Guidelines for the use of Plastic Waste in Rural Roads Construction, Ministry of Rural Development, Government of India.

PlasticRoad. (2018). "A revolution in building roads." 29/4/2019, from https://www.plasticroad.eu/en/.

Punith, V. and A. Veeraragavan (2007). "Behavior of asphalt concrete mixtures with reclaimed polyethylene as additive." **Journal of materials in civil engineering 19**(6): 500-507.

Rahman, W.M.N.W.A. and A.F.A. Wahab (2013). "Green pavement using recycled polyethylene terephthalate (PET) as partial fine aggregate replacement in modified asphalt." **Procedia Engineering 53**: 124-128.

Rashid, S., T.A. Khan, Sangita, S. Mb and D. Sharma (2009). "Performance evaluation of waste plastic/polymer modified bituminous concrete mixes." **Journal of scientific and industrial research 68**(11): 975-979.

Sahu, A.K. and R. Singh (2016). **Application of waste plastic materials in road construction**. 2nd International Seminar On—Utilization of Non-Conventional Energy Sources for Sustainable Development of Rural Areas ISNCESR '1617th & 18th March.

Shankar, A., K. Koushik and G. Sarang (2013). "Performance studies on bituminous concrete mixes using waste plastics." **Highway Research Journal 6**(1).

Sojobi, A.O., S.E. Nwobodo and O.J. Aladegboye (2016). "Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete." **Cogent engineering 3**(1): 1133480.

UCSD Guardian. (2018). "First Road in U.S. Made With Recycled Plastic Paved on Campus." Retrieved 25/04/2019, from http://ucsdguardian.org/2018/11/04/first-road-u-s-made-recycled-plastic-paved-campus/.

Vasudevan, R. (2004). "Use of plastic waste in construction of tar road." **Environmental information system (Envis), Indian Centre for Plastics in the Environment 2**: 1-4.

Vasudevan, R. and S. Rajasekaran (2006). **Study on the construction of flexible road using plastic coated aggregate**. Global Plastics Environmental Conference (GPEC), Atlanta, USA.

Vasudevan, R., A. Ramalinga Chandra Sekar, B. Sundarakannan and R. Velkennedy (2012). "A technique to dispose waste plastics in an ecofriendly way – Application in construction of flexible pavements." **Construction and Building Materials 28**(1): 311-320.

Vasudevan, R.N.S.K., R. Velkennedy, A.R.C. Sekar and B. Sundarakannan (2010). "Utilization of waste polymers for flexible pavement and easy disposal of waste polymers." **International Journal of Pavement Research and Technology 3**(1): 34-42.

Welegabir, A., B. Fisshaye, G. G/Korkos, K. Debissa, M. Demmissie and A. Kalayu (2014). **Partially Replacement of Waste Plastics in Bituminous Mixes as Road Construction Material**. B.Sc Degree in Civil Engineering, Ethiopian Institute of Technology- Mekelle.

White, G. (2019). **Evaluating recycled waste plastic modification and extension of bituminous binder for asphalt**. Eighteenth Annual International Conference on Pavement Engineering, Asphalt Technology and Infrastructure, Liverpool, England, United Kingdom.

White, G. and G. Reid. (2017). Recycled waste plastic for extending and modifying asphalt binders. 26/04/2019, from https://www.researchgate.net/publication/324908837_RECYCLED_WASTE_PLASTIC_FOR_EXTENDING_AND_MODIFYING_ASPHALT_BINDERS

White, G. and G. Reid (2018). **Recycled waste plastic for extending and modifying asphalt binders**. Symposium on Pavement Surface Characteristics (SURF), 8th, 2018, Brisbane, Queensland, Australia.

Appendix A: Technical specifications and costs of MacRebur products

The following MacRebur products are commercially used as binder extenders and /or modifiers to reduce the volume of bitumen required in an asphalt mix (MacRebur, 2018):

- **MR6**
  - MR6 is a complex arrangement of polymers designed for the extension and enhancement of bituminous binder for asphalt used in road surfaces.
  - Selected to increase the stiffness and deformation (rutting) resistance of asphalt mixtures without compromising flexibility (crack resistance).
  - Suited to all asphalt types to be used in all layers of road construction. Ideally suited to surfacing intersections, roundabouts and slow moving, heavy vehicle areas, where deformation resistance is critical.
  - Suited to increase the stiffness of binder and base course layers to reduce the overall thickness of pavement required
- **MR8**
  - MR8 is a blend of polymers designed for the extension of bituminous binder for asphalt used in road surfaces.
  - Selected to extend unmodified bitumen, to maximise environmental and economic benefits without adversely impacting asphalt performance.
  - Suited to all asphalt types to be used in all layers of road construction. Ideally suited to surfacing car parks, driveways and local roads, where sustainability and economics are the primary drivers.
- **MR10**
  - MR10 contains a block co-polymer designed for the extension and enhancement of bituminous binder for asphalt used in road surfaces.
  - Selected to increase fracture and cracking resistance without compromising deformation (rutting) resistance of asphalt mixtures.
  - Suited to all asphalt types to be used in all layers of road construction. Ideally suited to surfacing general trunk roads where stiffness and crack resistance is critical. Ideal for producing highly crack resistant, but very stiff course layers for overall pavement thickness reduction, similar to EME and other high modulus asphalt mixtures.

Table A.1 Recycled plastic products and replacement percentages

MacRebur Product	Binder Replacement
MR6	6-10%, with 6% recommended as optimal
MR8	6-10%, with 6% recommended as optimal
MR10	6-10%, with 6% recommended as optimal

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White et al (2017) conducted laboratory tests on two asphalt mixtures - with and without recycled plastic as a partial binder replacement (see Table A.2). The mixtures were designed to be typical base course (dense graded 20 mm mix) and Stone Mastic Asphalt (SMA) surface course (10 mm SMA) in the UK. The 20 mm base course (AC 20) was produced with unmodified 40/60 binder (similar to C320) and with 6% of the binder replaced by MR6. The 10 mm surface course (SMA 10) was produced with the three recycled plastic waste products (MR6, MR8 and MR10) replacing 6% of the 40/60 bitumen.

Source: White and Reid (2017)

Table A.2 Asphalt mixture properties

Property	AC20 Mixture	SMA10 Mixture
Binder content (by mass)	4.8%	6.3%
Maximum density	2,524 kg/m^3	2,440 kg/m^3
Bulk density	2,411 kg/m^3	2,350 kg/m^3
Combined aggregate grading (percentage passing the sieve (mm)		
31.5	100	-
20	99	-
14	77	100
10	66	97
8	60	76
6.3	46	45
4	36	38
2	26	24
1	18	17
0.500	14	14
0.250	12	13
0.125	11	11
0.063	9	9.8

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Each mixture was evaluated under the associated British specifications for AC20 (BS EN 13108-1:2016) and SMA10 (BS EN 13108-5:2016) mixtures (see Tables A.3 and A.4).

Table A.3 Comparison of AC20 asphalt mixture result

Property	Straight 40/60	6% MR6	Limits	Units
Air Voids at Refusal Density	1.1	1.2	> 0.5	%
Stiffness Modulus	7,827	11,600	> 1,800	MPa
Moisture Damage	95.6	>100.0	Report Only	%
Wheel Track Rut Depth	1.8	1.5	Report Only	mm
Wheel Track Rate	0.046	0.039	< 1.00	mm/10^3 cycles

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Table A.4 Comparison of SMA10 asphalt mixture results

Property	Straight 40/60	6% MR6	6% MR8	6% MR10	Limits	Units
Stiffness Modulus	1,823	5,438	4,032	6,451	Report only	MPa
Moisture Damage	94.8	> 100.0	85.0	86.0	Report only	%
Rut Depth	3.1	1.3	2.6	2.0	Report only	mm
Rut Rate	0.11	0.03	0.07	0.05	< 1.00	mm/10^3 cycles
Fracture toughness	23.8	29.1	25.8	27.6	Report only	N/mm$^{3/2}$

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Table A.6 summarises the effects of plastic modification on the asphalt properties for the three MacRebur products

Table A.6 Summary of effect of recycled plastic on asphalt performance

Performance requirement	MR 6	MR 8	MR 10
Resistance to deformation	Greatest improvement	Modest improvement	Significant improvement
Resistance to fracture	Greatest improvement	Depends on stress/strain level	Significant improvement
Resistance to moisture damage	Improvement	Moderate reduction	Moderate reduction
Structural contribution	Significant improvement	Moderate improvement	Greater improvement
Toxic fume generation	No effect	No effect	No effect
Hazardous leachate	No effect	No effect	No effect

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Appendix B: Summary of the literature review of recycled plastic in bituminous compositions conducted by Sojobi *et al.* (2016)

Authors	Materials	*Optimum Bitumen Content (OBC)*	*Optimum Plastic Content (%)*	*Remarks*
Fang *et al.* (2014)	Waste package PVC and organic montmorillonite (OMMT)	-	-	Improved high- and low-temperature performance/stability of the modified asphalt. Better dispersion of PVC. OMMT should be added in small quantity for improved performance
Chavan (2013)	Polypropylene	4% by weight of total mix	-	Reduction in aggregate impact value and crushing values and increase in specific gravity. Plastic coating can be used to improve performance of poor quality aggregate.
Essawy *et al.* (2013)	Polypropylene (PP) and polyester fibres	-	5	Increase in hardness, specific gravity, dynamic viscosities, and decrease in penetration with increase in polymer contents. The better modifies is PP waste, although both are suitable for paving road. Also, reduced temperature susceptibility. Modifiers lowered the asphalt content required. However, polyester waste was found very tough
Moghaddam *et al.* (2013)	Plastic bottle wastes	6%	0.5	Lower OBC results with plastic addition. Other benefits include improved fatigue life, improved flexibility of mixture, and postponement of crack creation and propagation
Rahman and Wahab (2013)	3-mm pellet granules of plastic bottle wastes	5% Asphalt Mixture	5	Improved permanent deformation resistance which leads to increased service life of road

Authors	Materials	*Optimum Bitumen Content (OBC)*	*Optimum Plastic Content (%)*	*Remarks*
Ahmadinia *et al.* (2012)	Plastics bottle wastes	-	4-6 by weight of OBC	Higher resilient modulus, higher rutting resistance, prevention of excessive draindown, reduction in tensile strength, and tensile strength ratio
Awwad and Shbeeb (2007)	High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) (Ground and unground)	5.4%	12 by weight of OBC	Ground HDPE performed better than LDPE. Ground HDPE had the maximum stability. The plastic contents reduced the density and slightly increased the air voids and voids of mineral aggregates which will increase rutting resistance of asphalt mixture and provide better adhesion between asphalt and aggregates

Source: Sojobi, Adebayo Olatunbosun; Nwobodo, Stephen Emeka and Aladegboye, Oluwasegun James. 2016. **Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete.** *https://www.cogentoa.com/article/10.1080/23311916.2015.1133480*. *License http://creativecommons.org/licenses/by/4.0/*

Appendix C: Laboratory experiments on the use of waste plastics in road construction

Author(s)	**Types of Plastic**	*Type of asphalt*	*Optimum Waste Plastic Content by weight of bitumen (%)*	*Tested temperature (ºC)*	*Improved properties comparted to the traditional method (%)*	*Notes*
Costa *et al.* (2019)	Ethylene vinyl acetate (EVA)	35/50 penetration grade bitumen	5	NA	Softening point temperature (25)	i,ii
				25	Reduced penetration value (43)	iii
				180	Dynamic viscosity (280)	iv
	High-density polyethylene (HDPE)				Softening point temperature (19)	i,ii
				25	Reduced penetration value (46)	iii
				180	Dynamic viscosity (370)	iv
Nasr and Pakshir (2017)	Polyethylene terephthalate (PET) & Crum rubber (CR) (CR/PET 60/40)	60/70 pen grade bitumen	15	165	Rotational viscosity (78)	
		85/100 pen grade bitumen			Rotational viscosity (121)	
		60/70 pen grade bitumen		64	Rutting parameter (171)	v
		85/100 pen grade bitumen		70	Rutting parameter (270)	
		60/70 pen grade bitumen		NA	Fatigue life (300)	vi
		85/100 pen grade bitumen		NA	Fatigue life (372)	
Abdullah *et al.* (2017)	PET	60/70 PEN bitumen	4	60	Marshall stability test (700)	
			8	25	Resilient modulus (86)	
				40	Resilient modulus (-5)	
				40	Creep Modulus (184)	
			0	25	Indirect tensile strength test (-4)	Vii

Author(s)	Types of Plastic	*Type of asphalt*	*Optimum Waste Plastic Content by weight of bitumen (%)*	*Tested temperature (ºC)*	*Improved properties comparted to the traditional method (%)*	*Notes*
Jan *et al.* (2017)	PET	60/70 penetration grade bitumen	15		Marshall stability (13.8)	Viii
					Marshall flow (16.5)	
Shankar *et al.* (2013)	low density polyethylene (LDPE)		6		Marshall Stability (12)	
					Bulk Density (0.5)	
Behl *et al.* (2012)	polyvinylchloride (PVC)	80/100 pen bitumen	5	155-160	Marshall Stability (97)	ix
				60	Tensile strength ratio (10)	
				50	Rut depth (37)	x
				60	Avg. retained stability(9.3)	xi
Punith and Veeraragavan (2007)	Polyethylene (PE)	80/100-grade	7.5	-	Gyratory shear index (26.6)	
			5	5	Resilient Modulus (23.6)	
				25	Resilient Modulus (28.9)	
			10	30	Creep strain rate (58.9)	
			10	60	Creep strain rate (68.4)	
			5	45	Stripping Inflection Point (300)	

Notes

i) The results were compared with virgin polymer (i.e. styrene-butadienestyrene)
ii) Base bitumen softening point test was conducted to check rutting resistance properties
iii) Reduced penetration value was suggested to be associated with a higher stiffness modulus and lower fatigue cracking resistance, therefore it seems that waste polymer reduced overall fatigue resistance properties of the asphalt
iv) Workability indicator
v) Dynamic shear rheometer test (G/ sin δ)*
vi) Linear amplitude sweep (LAS) 5% strain amplitude
vii) The result for sample with zero plastic content compared with 8% plastic content (the optimum plastic content for this test) associated with resistance of asphalt to thermal cracking viii)tested for three different types of aggregate, for one type an 3.6 % decrease was observed
ix) Temperature is related to mixing and compaction
x) Wheel tracking results
xi) Testing resistance to moisture induced instability

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