

UPCYCLING PLASTIC WASTE FOR RURAL ROAD CONSTRUCTION IN INDIA

AN ALTERNATIVE SOLUTION TO TECHNICAL CHALLENGES

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ABBREVIATIONS

ADB	– Asian Development Bank
BS	– British Standard
EN	– European Norm
GSB	– granular subbase
IRC	– Indian Road Congress
km	– kilometer
m ²	– square meter
MORD	– Ministry of Rural Development
NRIDA	– National Rural Infrastructure Development Agency
OGPC	– open-graded premix carpet
OGPC+P	– open-graded premix carpet with plastic waste
PCC	– Portland cement concrete
PCCBP	– plastic cell-filled concrete block pavement
PMGSY	– Pradhan Mantri Gram Sadhak Yojana (Prime Minister's Rural Road Program)
WBM	– water-bound macadam

ABSTRACT

One of the innovative ways by which the Government of India is addressing the challenges of rural road development is the use of plastic waste as an alternative material for road construction. Under the Pradhan Mantri Gram Sadhak Yojana (PMGSY), or the Prime Minister's Rural Road Program, several implementing state-level agencies have utilized plastic waste as alternative road construction materials in various ways, even though still on a pilot basis. It is expected that India will not only reduce the amount of plastic waste that goes to its landfills or incinerators, but also benefit from more efficient rural road development. This study examines the two most common innovations that use plastic waste in rural road construction and discusses their implementation and measures taken to improve their performance. It also makes recommendations for possible adoption by other states looking into the use of plastic waste in their own rural road projects.

I. INTRODUCTION

A. General

1. India's road network consists of about 114,158 kilometers (km) of national highways, 761,217 km of state highways and district roads, and 4.2 million km of rural roads.¹ Sustained underinvestment in the country's road infrastructure has resulted in a road network that, although extensive, is of low quality and capacity. Only 50% of the entire network is surfaced roads. Many of the villages in the rural areas, where 70% of India's population lives, can only be accessed via dirt roads that cannot accommodate motor vehicles and become impassable during the rainy season.

2. All-weather rural roads are essential for last mile connectivity to enhance access to markets, health centers, education facilities, and other socioeconomic opportunities. Recognizing this, the Government of India, through the Ministry of Rural Development (MORD), seeks to improve rural connectivity through the Prime Minister's Rural Road Program or Pradhan Mantri Gram Sadhak Yojana (PMGSY). The PMGSY's main goals are to (i) reduce poverty faster for more inclusive growth; (ii) expand rural infrastructure to accelerate agricultural growth and the rural economy; (iii) create more jobs; and (iv) enable social development to improve education, health, and social indicators. As of August 2019, a total of about 600,000 km of all-weather rural roads have been constructed.²

3. The National Rural Infrastructure Development Agency (NRIDA) was established under MORD to manage and monitor the implementation of the PMGSY and more importantly, to provide guidance and technical support to the implementing agencies at the state level.

4. In support of the PMGSY, the Asian Development Bank (ADB) has provided assistance to the Government of India through loans totaling \$2.31 billion and is on track to construct over 22,000 km of all-weather rural roads in the states of Assam, Chhattisgarh, Madhya Pradesh, Odisha, and West Bengal (the investment program states). Under the ongoing multitranche financing facility for the Second Rural Connectivity Investment Program, ADB has provided technical assistance to support the state rural road development agencies evaluate new technologies used in rural road construction and explore possibilities for alternative innovations.

5. The overall implementation of the PMGSY has faced a number of challenges which may vary between states, but are mostly associated with cost, materials availability, technology readiness, and restricted specifications.

- (i) **Cost.** The design and build of all-weather roads carry substantial cost implications. Furthermore, many federal states in India are prone to natural disasters which can cause damage to road infrastructures. This means an allowance should be made for post-disaster remedial works.
- (ii) **Materials availability.** Premium construction materials can be expensive and may not be available locally. On the other hand, secondary and waste materials are available and offer an opportunity for exploitation, but they may require diligent processing methods.

¹ Government of India, Ministry of Road Transport and Highways. 2017. *Basic Road Statistics, 2016–2017*. New Delhi.

² Pradhan Mantri Gram Sadhak Yojana (PMGSY) Online Management, Monitoring and Accounting System (OMMAS).

- (iii) **Technology readiness.** Road construction is one of the most conservative industries, where technology tends to be old, inefficient, and often outdated. Upscaling the technology is warranted to improve the quality of finished roads and maintain their serviceability.
- (iv) **Restricted specifications.** Rural road projects usually adopt generic specifications which have been historically sufficient in providing long-lasting roads. However, they are often subject to value engineering, mostly due to financial restrictions.

B. Objective

6. This working paper was produced under the ongoing ADB assistance to the PMGSY under the Second Rural Connectivity Investment Program, to highlight how the investment program states have addressed the above challenges through innovative approaches, in particular through the use of plastic waste in rural road construction. It discusses key aspects of using plastic waste in the construction of rural roads and explores measures to improve current practices and procedures.

7. This working paper also develops and recommends a scenario based on the two most common plastic waste innovations used in the PMGSY roads, which can be further tested by a rural connectivity training and research center in the investment program states.

II. INNOVATIVE APPROACHES IN THE PMGSY ROADS

8. In 2013, all the states implementing the PMGSY were required to pilot the use of innovative approaches on at least 15% of the length of rural roads proposed for PMGSY funding. This initiative was intended to (i) reduce construction costs; (ii) conserve nonrenewable natural resources by using alternative, environmentally-friendly materials; and (iii) utilize waste materials in rural road construction by maximizing the use of locally-available marginal materials, industrial wastes, new materials, and environment-friendly (“green”) technologies in road construction.

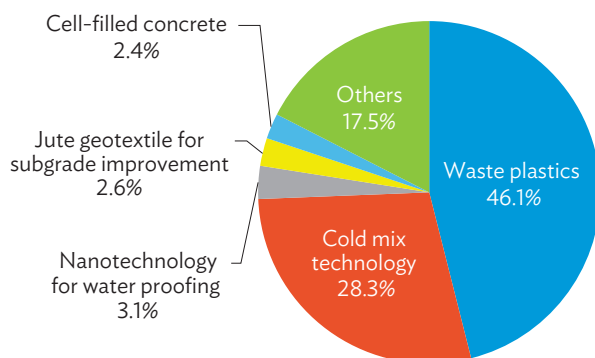
9. In order to facilitate and encourage such innovations, NRIDA referred to the practice of accreditation of materials and technologies adopted by the Indian Road Congress (IRC).³ In 2013, MORD, through the NRIDA, published *Technology Initiatives under PMGSY*, which contains a list of technology initiatives in road materials and construction techniques.⁴ These can be grouped into distinct categories based on their usage and application and placement in pavement layers:

- (i) **Additives and/or technologies for soil stabilization.** Lime, cement, fly ash, enzymes, nanotechnologies, and fibers.
- (ii) **Technologies for slope stabilization.** Geotextiles and bioengineering.
- (iii) **Use of waste and secondary aggregates.** Crusher run, quarry waste, industry byproducts, soft aggregates, and reclaimed bricks/concrete.
- (iv) **Additives and/or technologies in cementitious materials.** Fly ash, cell-filled concrete, paneled concrete, interlocking blocks, and roller compacted concrete.
- (v) **Additives and/or technologies in bituminous materials.** Bitumen emulsion, half-warm mixtures, waste plastics, and asphalt preservatives.

³ A list of such accredited materials and technologies is available on both the *Indian Road Congress (IRC)* and NRIDA websites.

⁴ PMGSY OMMAS. 2013. *Technology Initiatives under PMGSY*. India.

Figure 1: New Technologies and Innovative Approaches Used in Building Rural Roads in India Under the PMGSY, January 2019



PMGSY = Pradhan Mantri Gram Sadhak Yojana (Prime Minister's Rural Road Program).
Source: PMGSY Online Management, Monitoring and Accounting System.

10. As of January 2019, the MORD has approved the construction of about 36,000 km of roads using new technologies, of which about 23,000 km have been completed.⁵ Figure 1 shows the amount of materials used, based on to the proportion of completed roads in India for each technology. This figure shows that under the PMGSY, waste plastics are the most used (46.1%) followed by cold mix technology (28.3%). Together, these two comprise about 75% of the new technologies and innovative approaches used for rural road construction under the program.

III. DEALING WITH PLASTIC FOR RURAL ROAD CONSTRUCTION

11. In 2019, the Times of India reported that 25,940 tons of plastic waste are generated in India every day, a substantial portion of which remains uncollected and has become huge human health and environmental issues.⁶ Recently, a restriction has been applied on importing plastic waste from overseas; however, the accumulation of domestic waste remains a serious concern.

12. India has been in the forefront of using plastic waste in road construction. In the early 2000s, it initiated studies on using mixed plastic waste streams for incorporation into construction materials. These studies offer an alternative solution to plastic materials ending up in landfills or incinerators. Nonetheless, the potential human health and environmental impacts during production, as well as the impact of the use of plastics in construction materials on the recyclability of a pavement at its end of life should be considered.

13. Per the PMGSY guidelines, rigid pavements such as cement concrete should be used for any sections of rural roads passing along inhabited areas. In such cases, plastic waste is used in different forms: (i) dry-processed plastic as aggregate coating in asphalt for flexible pavement, or (ii) post-

⁵ Government of India, Ministry of Rural Development. 2019. *Green Technology in PMGSY*. Press release. 7 January.

⁶ V. Mohan. 2019. India Has a 26,000-tonne Plastic Waste Problem. *Times of India*. 23 January.

processed reclaimed plastic as interconnected cells to contain cement concrete mix for rigid pavement. These two forms will be further explored in this working paper.

A. Dry-Processed Plastic Waste in Asphalt Mix

14. The simplest process to utilize plastic in road construction is by using the “dry-processed” approach, where the plastic element is added to the bitumen before it is mixed into the aggregate. This has become the norm adopted in rural road construction under the PMGSY. Tamil Nadu was the first state that initiated trials on this material in the early 2000s. The experience and track records collected from these trials led to the development of a national guideline and standard protocol.⁷ Further discussion regarding this standard protocol can be found in Appendix 1.

15. **Production control.** The information gathered to date shows that the dry-processed approach appears to be an effective way to add plastic waste to asphalt mix.

16. At the production stage, the following aspects need to be met:

- (i) A consistent and uniform distribution through the aggregate should be ensured to control the performance of the asphalt mixes.
- (ii) The effectiveness of plastic waste to coat the aggregate should be verified to ascertain the claimed benefit, as well as to assess the required bitumen replacement. The durability of an asphalt mix might be compromised if effective coating does not take place.
- (iii) The requirements to control the properties of the plastic shreds, which include the source of plastic material, acceptable dimensions, maximum impurity, and melt-flow value, should be in accordance with the IRC guidelines.⁸ At a minimum, these control requirements should clearly be stated in the project specifications to ensure that they are properly implemented.
- (iv) Better controls should be required to ensure that the correct dosage of plastic has been added. For this, the use of calibrated containers is recommended.

17. At the construction stage, subsamples of open-graded premix carpet (OGPC) must be taken during each batch of the work to assess any variation in mixture compositions (such as those prescribed in the British Standard (BS) European Norm (EN) 12697-2 for combined aggregate grading and BS EN 12697-1 for binder content). For bigger projects, it is recommended that additional subsamples recovered from the mixing plant be subject to tests such as, but not limited to:

- (i) mixture volumetric analysis, such as for air voids and density (BS EN 12697-5, 6, and 8);
- (ii) coated aggregate stripping test, such as by static immersion, boiling, or rolling bottle (BS EN 12697-11);
- (iii) simulative stripping test of asphalt mixtures (i.e., OGPC and/or seal coat), such as by immersion wheel tracking (BS EN 12697-22); and
- (iv) indirect tensile strength test, with and/or without moisture conditioning (such as that prescribed in the American Association of State Highways and Transport Officials (AASHTO) T-283 documents).

⁷ IRC. 2013. Guidelines for the Use of Waste Plastic in Hot Bituminous Mixes (Dry Process) in Wearing Courses. IRC: SP: 98-2013. Delhi.

⁸ IRC Guidelines. 2013. Clauses 4.4 and 8.

18. **On-site performance.** The pictures below illustrate the overall process for the production and application of asphalt incorporating plastic waste, as seen from a production site in Sehore, Madhya Pradesh. The road project, which comprises a road measuring 1.67 km from Sehore to Thuna in Madhya Pradesh, was one of the earliest applications of asphalt that incorporated waste plastic under the PMGSY program in the investment program states. The road was opened for traffic in December 2013.



Incorporating plastic waste into a road asphalt mixture using the dry process in Sehore (photos by ADB).

19. The road surfacing comprised a seal coat, overlaying a 20 millimeter (mm) thick OGPC which incorporates plastic waste. A site visit in February 2019 revealed that even after the end of the 5-year warranty period, no defects had been reported on this road, in contrast to the experience with conventional materials, where around 25% of the work would have typically required some repairs within the same period.



Using plastic waste to improve interconnectivity. This 1.67 km road from Sehore to Thuna in Madhya Pradesh, India was built using a mixture of asphalt and plastic waste and has held up well under an inspection conducted 5 years after it was first built (photos by ADB).

20. **Monitoring service performance.** The current monitoring regime is based on visual assessment and, where required, some site tests (e.g., Merlin's regularity/riding quality, texture depth, skid resistance, and Bengkelman beam's deflection). However, these assessment methods may not be effective enough to pick up the impact of using plastic waste in road building, particularly since most applications have been to modify relatively thin-layer OGPC (around 20 mm), which will then be covered by a seal coat or surface dressing.

21. Each assessment method has its own particular benefits and limitations:

- (i) **Merlin's regularity/riding quality.** A good measure to assess the overall performance of the road pavement. However, it is not effective for assessing very thin asphalt layers such as OGPC and seal coat, since the results are likely to be influenced by the thicker substrate layer.
- (ii) **Texture depth.** Considered appropriate for assessing very thin asphalt layers, but test results are likely to be heavily influenced by the performance of the seal coat.
- (iii) **Skid resistance.** Not considered appropriate for assessing the performance of OGPC layer since test results are likely to be influenced by the performance of the seal coat.
- (iv) **Bengkelman beam's deflection.** A good measure to assess the overall performance of the road pavement. However, it is not effective for assessing very thin asphalt layers such as OGPC and seal coat, since the results are likely to be influenced by the thicker substrate layer.
- (v) **Visual condition survey.** A good measure to assess the overall performance of the road pavement, including the OGPC layer, but the presence of seal coat may hinder detection of any defect within the OGPC layer.

22. Therefore, considering these limitations, it is recommended that performance monitoring of OGPC incorporating plastic waste should focus on assessments on texture depth and visual condition surveys, as well as improvements to tighten production control. The visual condition survey should include a recording of any sign of material loss (fretting/raveling), surface depressions/rutting, and cracking.

B. Plastic Cell-Filled Concrete Block Pavement

23. In several investment program states, rigid pavement such as cement concrete is used for any sections of rural roads passing along inhabited areas, or in any areas where the soil condition does not allow flexible pavements to be constructed. In such cases, plastic waste is used in different forms.

24. The second most common PMGSY innovation using plastic waste is the plastic cell-filled concrete block pavement (PCCBP). Originally developed in South Africa, the concept involves filling interconnected diamond-shaped plastic cells with granular materials. These plastic cells can be made of recycled low-density polyethylene (LDPE) or high-density polyethylene (HDPE) and are typically 0.2 mm–0.5 mm thick. These cells are then manually welded together using a paddle sealer. For the rigid pavements of PMGSY roads, the granular materials are replaced with cement concrete materials, as shown in the pictures below.



Pre-construction processing of plastic cells. (Left) Processed low-density polyethylene ready for welding into plastic cells. (Right) A paddle sealer welds polyethylene sheets to create the plastic cells (photos by ADB).



Application of plastic cell during road construction. (Left) Plastic cells filled with granular materials. (Right) Plastic cells filled with cement concrete (photos by ADB).

25. In PCCBP, diamond-shaped heat-welded plastic cells (pictures below) are used to encase concrete blocks, each of which measures 150 mm x 150 mm with a depth of 100 mm–150 mm. During compaction, cell walls get deformed and provide interlocking among the blocks; some practices use plastic pipe as formwork to assist in the installation of the cementitious material.⁹ After compaction, the curing process starts as per regular concrete cement.¹⁰

26. The use of plastic cells allows small movement and flexibility in the pavement layer. For this reason, this type of pavement is also called a “flexible–rigid” pavement.¹¹



Road construction using plastic waste. Plastic cell-filled concrete block pavement under construction (top left); compaction by plate vibrator (top right); and use of plastic pipe formwork to assist installation (bottom) (photos by ADB).

⁹ Y. A. Singh, T. L. Ryantathiang, and K. D. Singh. 2012. Structural Performance of Plastic Cell-filled Concrete Block Pavement for Low Volume Roads. Paper for the 10th International Conference on Concrete Block Paving. Shanghai, People's Republic of China. 24–26 November.

¹⁰ B. B. Pandey. n.d. Cell-filled Concrete Pavement (Flexible–Concrete Pavement). Published under Ministry of Rural Development, Government of India. for PMGSY roads.

¹¹ P. Madke and S. Harle. 2016. Plastic Cell Filled Concrete Road: A Review. *Journal of Structural and Transportation Studies*. 1 (3). pp. 1–15.

27. **Advantages and limitations.** The performance of PCCBP is broadly similar to that of conventional cement concrete.

28. The main benefits of using PCCBP are as follows:

- (i) It is durable and long-lasting and therefore, has low maintenance requirements.
- (ii) Its rough surface texture does not deform in hot weather.
- (iii) It has low sensitivity against moisture damage.
- (iv) Its initial cost is lower than conventional concrete pavement.
- (v) Expansion or contraction joints are not required.
- (vi) It uses less aggregate due to having a thinner layer than conventional concrete.
- (vii) It acts similar to modular or block concrete pavement, which makes it easier to do localized repair in case of failure on individual blocks.

29. It has, however, some limitations, as noted below:

- (i) When placing the PCCBP directly on the compacted in-situ soil, the equivalent elastic modulus of cell slab tends to reduce with a decrease in slab thickness.¹²
- (ii) A 100 mm thick PCCBP layer can be structurally adequate for ultra-heavy traffic conditions of up to 100-ton axle loads, although a 150 mm layer is preferable.¹³
- (iii) It is only suitable for low-volume traffic and is not suitable for heavy-load traffic to avoid foundation failure.¹⁴
- (iv) When used as surface course, its regularity and riding quality may not be as good as asphalt surfacing.

30. **On-site performance.** In February 2019, the project team visited Odisha to inspect the project implementation in Bhagatpur, Kanpur, Chhagaria Road, where PCCBP was installed in 2018.

¹² A. T. Visser. 1994. A Cast In-Situ Block Pavement for Labour-Enhanced Construction. *Concrete Beton, Journal of the Concrete Society of South Africa*. 76 (71). pp. 1–8.

¹³ A. T. Visser. 1999. The Response of Flexible Portland Cement Concrete Pavements Under Ultra Heavy Loading. *Concrete Beton, Journal of the Concrete Society of South Africa*. 94. pp. 11–18.

¹⁴ S. Roy, K. S. Reddy, and B. B. Pandey. 2010. An Investigation on Cell-Filled Pavement. *International Journal of Pavement Engineering*. 12 (3). pp. 229–37.



Road with plastic cell-filled concrete block pavement. Physical appearance of the finished PCCBP on Bhagatpur, Kanpur, Chhagaria Road, Odisha, 2019 (photos by ADB).

31. The use of PCCBP on this road has been favorable for the following considerations:
 - (i) the substrate has a high risk of being saturated by flood or the high-water table, therefore flexible pavements cannot be used, and
 - (ii) the road is situated in inhabited areas where there was not enough space to operate the asphalt paver.
32. In addition, PCCBP was also chosen due to its perceived improved durability against cracking. The cell is shaped like a diamond, and is 150 mm squares by 100 mm deep. M30 concrete mix was poured into the cell and compacted using a vibratory tamping machine. This system allows microcracks to develop along the perimeter of each cell. Also, repairs were deemed to be easily managed as damage tends to be localized within each cell and remedial work could be done on the isolated cell.
33. **Production control.** The process for installing PCCBP generally takes a longer time and is more labor-intensive. There must be a continuous feed of fresh concrete to ensure a good quality finish at the end of each day shift. However, PCCBP can be seen as more economical for regions where the cost of labor is more affordable than investing in construction plants. Furthermore, the labor skill sets required for PCCBP installation are similar as those needed for conventional cement concrete works.
34. The pictures on page 11 illustrate the risks that can happen if the cement concrete feeding or the work is stopped or delayed, before the finish level is completed. If the cementitious grout cures before the filling process is completed, the grout will set and harden, and it will be very difficult to rectify and/or correct the finished profile. The irregular finished profile can lead to poor surface quality and may accelerate damage to both the pavement and vehicles due to the rough surface.
35. The quality control requirements of PCCBP are similar to conventional concrete, such as the use of the vertical slump test for the concrete mix, and the compression strength test for cube specimens cast on site during each day of production. When used as surface course, a suite of assessments should be performed to determine texture depth, skid resistance, and regularity of the pavement.



Production control. Implementation of plastic cell-filled concrete block pavement should not be delayed or stopped to maintain a good finish quality of roads. Delays in cement concrete feeding can result in an irregular finish (photos by ADB).

36. PCCBP construction and maintenance represent an economical solution compared to conventional concrete and flexible pavements. The reduction in layer thickness from 150 mm in regular pavement quality concrete to 100 mm in PCCBP contributes to reduced production costs. The life cycle cost of PCCBP is also comparatively less than conventional flexible and rigid pavement constructions, as discussed later in this paper.

37. Interlocking between concrete blocks results in good bearing capacity of the pavement. Concrete compressive strength of 15 megapascal was found adequate for traffic operation. The road can be opened within 24 hours for light traffic, while for heavier traffic, there must be a wait of at least 14 days to ensure that the materials have reached sufficient strength.

38. Overall, PCCBP is considered suitable for low-volume village roads and is not recommended for very heavy traffic. PCCBP can also be used as an overlay over existing pavement surface and can be recommended for use in place of flexible pavement on weak base and subbase layers.

IV. MAXIMIZING THE IMPACT OF REDUCED PLASTIC WASTE

39. Plastic waste has been used in many states in India to improve the durability of asphalt surfacing. Similarly, it has been more economical to use recycled plastic in PCCBP, rather than conventional cement concrete for the weather resilience layer. The same impact can be expected by using plastic waste in PMGSY roads.

40. The project team explored the possibility of enhancing the use of plastic waste in rural road construction, based on the team's observations on the use of plastic in OGPC mix and PCCBP roads.

41. Hypothetically, a combination of asphalt layers that incorporate plastic waste (i.e., OGPC layer and PCCBP) can offer multiple benefits:

- (i) roads with good serviceability, durability, and riding quality provided by the asphalt surfacing;
- (ii) improved sustainability as a result of incorporating plastic waste in the seal coat and OGPC layers, and recycled plastic in PCCBP to help minimize the amount of plastic waste ending up in landfills;
- (iii) an economic advantage from the reduction of bitumen content, improved durability, and reduced layer thickness; and
- (iv) a positive socioeconomic impact from the opening of new markets for plastic waste and opportunities for small business units.

42. Details of the hypothetical pavement structure are illustrated in Figure 2.

43. This working paper will further assess the hypothetical flexible–rigid pavement in terms of road serviceability, sustainability objectives, and costs.

A. Road Serviceability

44. Generally, road serviceability depends on a robust design, well-executed installation, and sustained maintenance activities. An asphalt surface course provides good riding quality and protection of the substrate from vertical moisture or rainwater ingress. A conventional asphalt surface course such as an OGPC layer plus seal coat would typically require resurfacing after the initial 5 years of service. Anecdotal information suggests that around 25% of rural roads required localized repairs during the first 5 years. On the other hand, using plastic waste in the OGPC layer seems to have improved the performance of the surface course during the same period.

Figure 2: Hypothetical Flexible–Rigid Pavement Structure for Rural Roads

Surface course	Seal coat incorporating plastic waste
20 mm thickness of OGPC incorporating plastic waste	
Binder course	100 mm thickness of plastic cell-filled concrete block pavement
100 mm–200 mm thickness of WBM/DLC/stabilized layer /GSB	
Subgrade	

DLC = dry lean concrete, GSB = granular subbase, mm = millimeter, OGPC = open-graded premix course, WBM = water-bound macadam.

Source: Asian Development Bank estimates.

45. A cement concrete surface course, including one that uses PCCBP, can be a durable long-lasting layer. The predicted service life of a well installed cement concrete surface course can be 3 to 5 times longer than the asphalt alternative (i.e., can be in excess of 25 years); however, the riding quality tends to be poorer.

46. A base course or subbase materials—such as water-bound macadam (WBM), a stabilized layer, and granular subbase (GSB)—are expected to last up to 10 years, if these materials are well protected from moisture and excessive loading. The life expectancy of these layers might be shorter when they are overlaid with asphalt layers (such as OGPC and seal coat) than with cement concrete (such as PCCBP).

47. Considering the above, it is possible that the hypothetical pavement structure as shown in Figure 2 can offer good riding quality with a longer service life and less maintenance requirement. This said, there should always be available and adequate drainage to protect both the embankment and the unbound or weakly bound substrates.

B. Sustainability Objectives

48. The Bruntland Report introduced the term “sustainable development” as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs.”¹⁵ This definition was later translated by the Department of the Environment, Transport and the Regions in the United Kingdom into four specific objectives:¹⁶

- (i) social progress which recognizes the needs of everyone,
- (ii) effective protection of the environment,
- (iii) prudent use of natural resources, and
- (iv) maintenance of high and stable levels of economic growth and employment.

49. For construction industries, the concept of sustainable development implies a commitment to several activities, including:

- (i) minimization of waste,
- (ii) maximization of recycling,
- (iii) use of recycled and secondary materials,
- (iv) minimization of the use of virgin materials through improved design efficiency,
- (v) energy and water efficiency, and
- (vi) the use of tools such as whole life costing, life cycle analysis, and ecological footprints.

50. The above contributes to the sustainability objectives of protection of the environment and sensible use of natural resources. This is consistent with the waste hierarchy adopted by the United Kingdom and Europe, well known as 3-R (reduce, reuse, and recycle):

- (i) The most effective environmental solution is to reduce the generation of waste.
- (ii) Where further reduction is not practicable, products and materials can sometimes be reused, either for the same or a different purpose.

¹⁵ World Commission on Environment and Development (WCED). 1987. *Our Common Future: The Brundtland Report*. WCED. Oxford: Oxford University Press.

¹⁶ Government of the United Kingdom, Department of the Environment, Transport and the Regions (DETR). 2000. *Building a Better Quality of Life: A Strategy for More Sustainable Development*. DETR. London.

- (iii) Failing that, value should be recovered from waste, through recycling, composting, or energy recovery from waste.
- (iv) Only if none of these solutions is appropriate should waste be disposed of, using the best practical environmental option.

51. The green technologies presented in this working paper clearly tick several of the sustainability objectives, specifically through:

- (i) reuse of reclaimed plastic waste as an additive to asphalts (i.e., OGPC layer and seal coat);
- (ii) maximization of recycling plastic waste into a new product (i.e., PCCBP);
- (iii) minimization of the use of virgin materials through improved design efficiency, such as
 - a. using plastic waste to replace a portion of bitumen;
 - b. using less material for repair or rehabilitation due to the more durable, longer service life of the product;
- (iv) attainment of product lower whole life cost due to the incorporation of plastic waste; and
- (v) the opening up of new markets and opportunities for small enterprises engaged in the collection and processing of plastic waste, which then helps facilitate the regional economy and promote employment.

52. Despite the above positive marks, the future of these green technologies is yet uncertain. Regular asphalt pavement removed during most road resurfacing and reconstruction projects can be economically recycled into good quality asphalt materials.¹⁷ However, the question remains whether at the end of their service life, asphalt or concrete materials incorporating plastic waste can be reused or recycled back into the same application.

53. In general, asphalt material is reusable and recyclable.¹⁸ Recycling OGPC layers incorporating plastic waste can be done, provided that a good quality management plan is in place to screen the reclaimed material and separate the good material from any possible contaminant. On the other hand, recycling of reclaimed PCCBP could be more challenging. It will require further research to explore the best way to recover or extract the PCCBP, and to process the remaining reclaimed materials. Nonetheless, this material is expected to be durable and long-lasting and, therefore, the risk with future recycling is not imminent and there is ample of time to explore feasible options.

C. Cost Comparisons

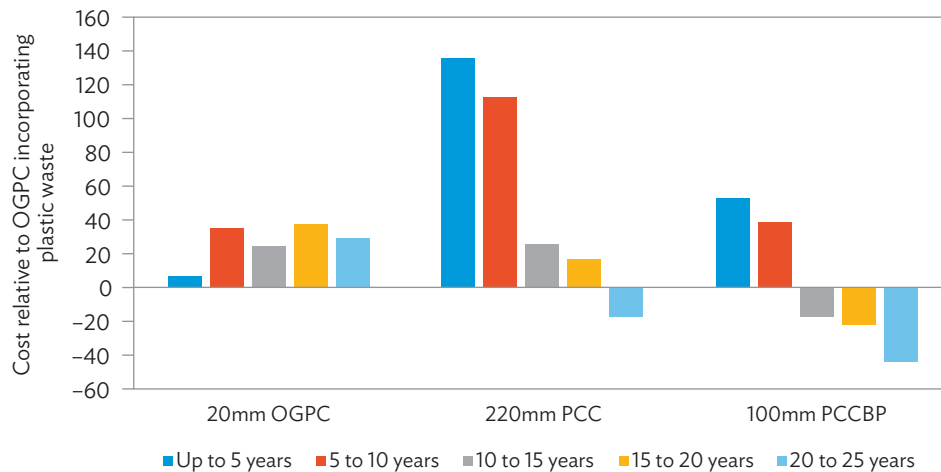
54. An assessment of the cost benefits associated with different materials is mainly based on the cost of materials, installation, routine maintenance, and resurfacing plan. While carbon footprint reduction and other environmental costs could be relevant, these aspects are not currently considered in this paper due to the complexity in assigning different assumptions.

55. Figure 3 shows this cost comparison by benchmarking the costs of OGPC with plastic waste (OGPC+P), against those of regular OGPC, regular Portland cement concrete (PCC) pavement, and PCCBP. Similarly, Figure 4 shows this cost comparison by benchmarking the costs of PCCBP against those of regular OGPC, OGPC+P, and PCC. The positive figures denote higher costs (more expensive),

¹⁷ I. Widyatmoko and R. C. Elliott. 2002. Asphalt Pavement Recycling for Hong Kong. *Proceedings of the Road Pavement Recycling Seminar*. Warsaw. 10–11 October.

¹⁸ I. Widyatmoko. 2016. Sustainability of Bituminous Materials. In J. Khatib, ed. *Sustainability of Construction Materials*. 2nd ed. Elsevier.

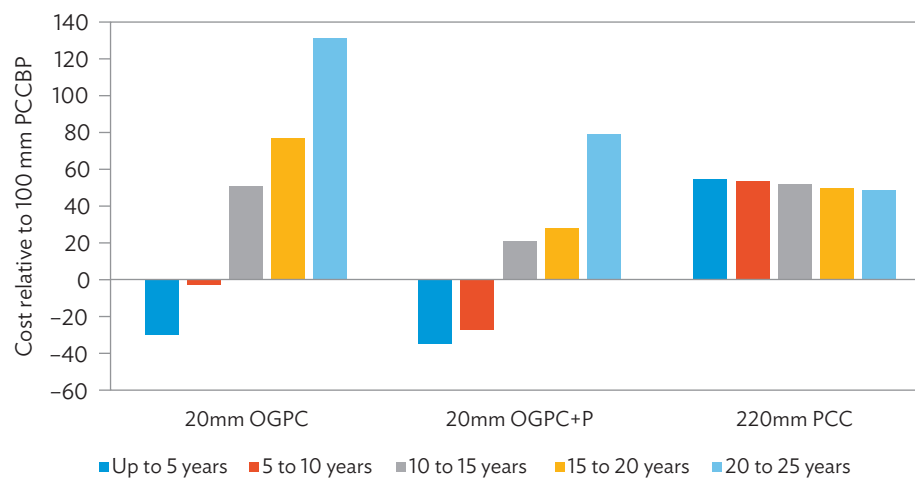
Figure 3: Cost Analysis Relative to Road Surfacing with OGPC Incorporating Plastic Waste (%)



mm = millimeter, OGPC = open-graded premix carpet, OGPC+P = open-graded premix carpet with plastic waste, PCC = Portland cement concrete, PCCBP = plastic cell-filled concrete block pavement.

Source: Asian Development Bank estimates.

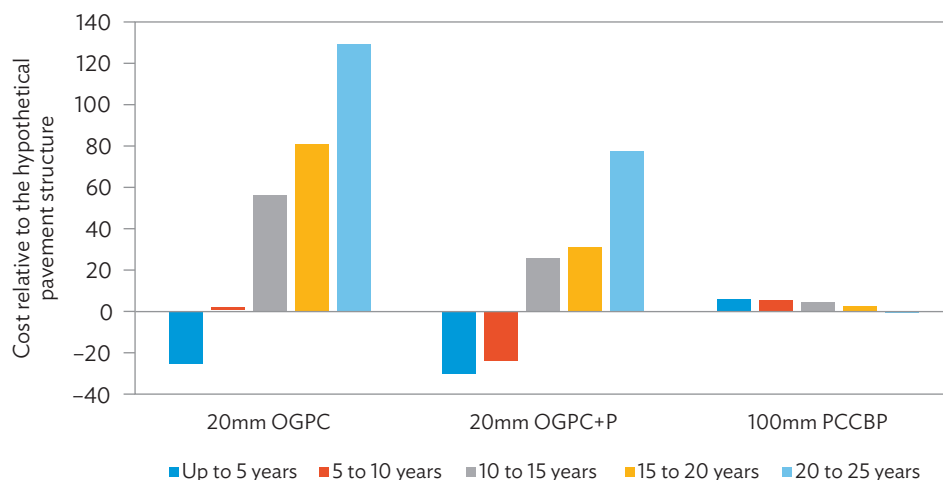
Figure 4: Cost Analysis Relative to Road Surfacing with PCCBP (%)



mm = millimeter, OGPC = open-graded premix carpet, OGPC+P = open-graded premix carpet with plastic waste, PCC = Portland cement concrete, PCCBP = plastic cell-filled concrete block pavement.

Source: Asian Development Bank estimates.

Figure 5: Cost Analysis Relative to the Hypothetical Flexible–Rigid Pavement Structure (%)



mm = millimeter, OGPC = open-graded premix carpet, OGPC+P = open-graded premix carpet with plastic waste, PCC = Portland cement concrete, PCCBP = plastic cell-filled concrete block pavement.

Source: Asian Development Bank estimates.

and the negative ones denote lower costs (cheaper). Appendix 2 provides a detailed calculation of these comparisons.

56. The results suggest that pavements that incorporate OGPC+P are expected to provide cost savings immediately after construction is completed, although after 10 years in service, PCCBP pavements appear to provide better cost savings. On the other hand, PCCBP pavements appear to offer cost savings immediately after construction compared to conventional PCC pavements, or after 10 years in service when compared against OGPC and OGPC+P pavements.

57. For the hypothetical pavement with a similar structure as that shown in Figure 2 and with a 150 mm moorum subbase, Figure 5 provides a comparative cost analysis against the different pavement options.

58. The above analysis suggests that the hypothetical flexible–rigid pavement option, which uses a combination of asphalt layers that incorporates plastic waste and PCCBP layers in between, could potentially offer cost savings over the PCCBP pavement (which also infers savings against the PCC pavement). Cost savings as compared to OGPC and OGPC+P can only be expected after 5 and 10 years in service, respectively.

59. Considering the other benefits offered by the hypothetical flexible-rigid pavements, this innovation could be considered as having the best balance between cost, performance, and environmental benefits, in comparison to the other pavement structures presented in this analysis.

60. Nonetheless, further work will be required to test and validate the hypothesis. This work should include the installation and monitoring of the service performance of trial sections in low-volume traffic rural roads.

V. CONCLUSION

61. Due to the expected increase in road construction and its impact on the environment, the requirement for more sustainable and low-maintenance road infrastructures has become very important. This working paper presents a summary of practices and recent developments in the use of plastic waste on rural road projects under PMGSY in the investment program states in India.

62. Compared to conventional materials, using road materials that include plastic waste has the following benefits:

- (i) reduces whole life cost,
- (ii) longer service life,
- (iii) preserves natural resources, and
- (iv) reduces plastic waste in landfills.

63. The hypothetical flexible-rigid pavement structure incorporating plastic waste elements, specifically OGPC with plastic waste and PCCBP, has been theoretically assessed for its potential to offer:

- (i) good serviceability (durability, weather resilience, and riding quality),
- (ii) improved sustainability (higher recyclability and waste contents),
- (iii) cost savings, and
- (iv) positive socioeconomic impacts.

64. The findings are very encouraging as the hypothetical flexible-rigid pavement scores the overall best balance of these points.

VI. LIMITATIONS AND RECOMMENDATIONS

65. The site observations and associated discussions presented in this working paper have been based on experience gathered from low-volume rural road applications.

- (i) The characteristics of the users and traffics are expected to be different from those on major highways. Therefore, care must be taken when considering the findings presented in this document for applications other than rural roads.
- (ii) Furthermore, in-service performance of road pavements can be affected by local conditions such as topography, climate, and environment. These factors should also be considered.
- (iii) Cost analyses have been based upon information provided from recent literatures which are not necessarily up to date. The data, including the associated assumptions, should be validated against current practices.

66. It is recommended that trial sections incorporating the proposed hypothetical flexible-rigid pavement structure be installed on rural roads. These trial sections could be used to assess the in-service performance of the structure and to validate the assumptions and findings presented in this working paper. Successful trials can provide a good foundation to develop a new design guide incorporating this pavement structure.

67. Future recycling has not been covered during this study. As discussed in this working paper, there is a need to consider what process and/or procedure will be required to recycle layers incorporating PCCBP.

APPENDIX 1: INDIA'S NATIONAL GUIDELINES AND STANDARD PROTOCOL FOR THE USE OF PLASTIC

1. India's national guidelines and standard protocol (IRC: SP: 98-2013)¹ for the use of plastic allows the addition of plastic waste into the following pavement layers:

- (i) Dense grade bituminous mixtures (IRC: 111-2009)
- (ii) Open graded premix carpet (OGPC) (IRC: 14-2004)
- (iii) Slurry seal surfacing (IRC: SP: 78-2008)
- (iv) Surface dressing (IRC: 110-2005)

2. In addition to the above protocols, IRC: SP: 98-2013 protocol specifies some restrictions and recommendations:

- (i) Only plastic waste containing the following polymers is permitted: low-density polyethylene (LDPE) and high-density polyethylene (HDPE), polyurethane (if small quantities), or polyethylene terephthalate. Black colored plastic waste and PVC are not permitted.
- (ii) Production temperature must be maintained below 180°C to prevent the risk of releasing harmful gases into the atmosphere.
- (iii) Allowable replacement of bitumen (by weight) with plastic waste has been specified at 6%–8%. In practice, the target has been set at 8%.

3. Upon implementation, the first challenge in controlling the mixture consistency is ensuring that the addition of waste plastic remains between 6% and 8% of the total bitumen weight.

4. Section (iv)(d) of Appendix 2 of the IRC: SP: 98-2018 on processing details states that

“The aggregate mix is heated to 140/175°C in central mixing plant. The requisite percentage of waste plastic to the weight of bitumen is injected with a pipe under compressed air in the drum of a drum mix plant through a pipe at 2/3 length of the drum or through an opening over the pugmill in the case of batch mix plant....”

5. However, variations in the adopted protocols were observed in the different asphalt production plants in the investment program states. Generally, there are two kinds of variations (photos on page 19).

- (i) Plastic shreds are manually added at the front end of the conveyor belt. Subsequently aggregate materials are added on top of the plastic shreds (e.g., via the cold bin). Both materials are then transferred into the heated drum; or
- (ii) Plastic shreds are manually added at a pre-determined rate to the aggregate conveyor belt at the immediate point of the entry to the heated drum.

¹ Indian Road Congress. 2013. Guidelines for the Use of Waste Plastic in Hot Bituminous Mixes (Dry Process) in Wearing Courses. IRC: SP: 98-2013. Delhi.



Upcycling plastic waste to build roads through India's rural areas. There are two ways to add plastic waste into material meant for road building. (Left) Plastic shreds are added at the front end of the conveyor belt; (right) plastic shreds are added to the cold aggregate prior to entering the heated drum (photos by ADB).

6. The above practices are clearly different from that specified in the IRC protocol. However, these are done for logical reasons:

- (i) Injecting waste plastic to the pugmill has apparently resulted in issues with clogging since the plastic shreds tend to melt on the pipe and much of these do not mix with the heated aggregates.
- (ii) Plastic shreds are lightweight and could easily be blown away by the wind. Placing aggregates as weight can help minimize the loss of plastic shreds, as long as the wind remains calm. As an additional measure to account for the loss of material, an additional 20% of plastic waste would be added to the target dosage.

7. While the modified protocols seem to have worked, there are also some uncertainties such as those associated with lack of control or verification whether the correct dosage has been used. Initially, the amount of plastic shreds are determined for the target volume of asphalt mix in a dumper (transfer lorry). Typically, 62 kilograms of waste plastic will be added for a 14 cubic feet dumper (approximately 0.4 cubic meter), enough to cover 500 square kilometer area. However, the rate of addition seems to be controlled either by volume per minute (i.e., plastic shreds are placed into a basket of known volume) or by intuition of experienced technicians (i.e., simply grabbing a heap of plastic shreds by both hands). This can increase the risk for either an excess or deficiency in the actual dosage of plastic shreds. Ultimately, this will have a knock-on effect on the dosage of added bitumen since the added bitumen will be compensated by the target dosage of plastic shreds.

8. The above practices can lead to variations in the finish quality, such as bleeding due to excessive dosage of plastic shreds. During one visit to an ongoing construction site, the project team observed evidence of bleeding or binder richness on the surface of OGPC containing waste plastic.

9. Improvements to the quality of the installation must also work in tandem with promoting safety during construction. The use of personal protective equipment during the installation is warranted to safeguard the health and safety of laborers (e.g., site engineers, technicians, and operators) during construction works. Below is a non-exhaustive list of examples of these practices:

- (i) dust and eye masks as protection from airborne dust and fine plastic particles,
- (ii) heat resistant gloves for handling very hot materials,
- (iii) safety shoes as protection against chemicals, heat, and crushing,
- (iv) safe zone for workers and passersby as traffic and passersby must be separated from the construction site, and
- (v) reflective clothing to add visibility to the laborers on site.

APPENDIX 2: COST RATES USED IN THIS STUDY

1. For this working paper, conventional materials, specifically Portland cement concrete (PCC) and open-graded premix carpet (OGPC), were used for benchmarking purposes. For the calculations, the following cost rates (Rs/m²) as reported by Madke and Harle² and Sutar, Patil, and Tashmare³ were used, specifically:

- (i) Construction of 150 mm granular subbase (GSB) = Rs 169/m²
- (ii) Construction of 150 mm moorum subbase = Rs 60/m²
- (iii) Supply and laying of 150mm water-bound macadam (WBM) = Rs 237/m²
- (iv) Cost for 20 mm OGPC = Rs 200/m²
- (v) Cost for 20 mm OGPC incorporating plastic waste (OGPC+P) = Rs 188/m²
- (vi) Cost for 220 mm PCC = Rs 1190 /m²
- (vii) Cost of plastic cell formwork = Rs 70 /m²
- (viii) Cost of cement concrete for 100 mm PCCBP = Rs 550/m²

2. In addition to the above, the following assumptions were considered:

- (i) Pavement structure is assumed as illustrated in Table A2.1.
- (ii) Materials and installation costs increase by 15% during a 5-year period.
- (iii) For OGPC, resurfacing will take place every 5 years.
- (iv) For OGPC+P, experience suggested no defects took place within the first 5 years and it is assumed that 25% of the area will require major repairs during the 5–10 years in service. Resurfacing will take place every 10 years.
- (v) Cost analysis will be done for a period of 25 years, with a 5-year interval between analysis.
- (vi) WBM layers may need replacement every 10–15 years.
- (vii) The service life of PCC and PCCBP is assumed to be more than 25 years.

Table A2.1: Assumed Pavement Structures

Pavement 1	Pavement 2	Pavement 3	Pavement 4
20 mm OGPC	20 mm OGPC+P	220 mm PCC	100 mm PCCBP
150 mm WBM	150 mm WBM	150 mm WBM	150 mm WBM
150 mm GSB	150 mm GSB		150 mm Moorum Subbase

GSB = granular subbase, mm = millimeter, OGPC = open-graded premix carpet, OGPC+P = open-graded premix carpet with plastic waste, PCC = Portland cement concrete, PCCBP = plastic cell-filled concrete block pavement, WBM = water-bound macadam.

Source: Asian Development Bank.

² R. M. Madke and S. Harle. 2016. Plastic Cell Filled Concrete Road: A Review. *Journal of Transportation Studies*. 1 (3). pp. 1–15.

³ D. M. Sutar, S. Patil, and A. P. Waghmare. 2016. Feasibility of Plastic Coat Road with respect to Cost and Their Performance. *International Research Journal of Engineering and Technology (IRJET)*. 3: 12. pp.1513–1518.

3. Results from the cost analysis of different surfacing options are summarized in Table A2.2.

Table A2.2: Cost Analysis of Different Road Surfacing Options

Timeline	Description	Surfacing Material			
		20 mm OGPC	20 mm OGPC+P	220 mm PCC	100 mm PCCBP
Year 0	Construction of 150 mm GSB	169	169		
	Construction of 150 mm moorum Subbase				60
	Supply and laying 150 mm WBM	237	237	237	237
	Installation of surfacing	200	188	1,190	620
	Total construction cost	606	594	1,427	917
0 to 5 years	Routine maintenance cost for 5 years	45	16	16	16
5 to 10 years	Renewal cost of OGPC after 5 years	230	55		
	Routine maintenance cost for 5 years	52	24	30	26
10 to 15 years	Renewal cost of OGPC + WBM after 10 years	503	472		
	Routine maintenance cost for 5 years	60	40	35	30
15 to 20 years	Renewal cost of OGPC after 15 years	265	63		
	Routine maintenance cost for 5 years	68	60	40	34
20 to 25 years	Renewal cost of OGPC + WBM after 20 years	578	543		
	Routine maintenance cost for 5 years	79	52	46	40

GSB = granular subbase; OGPC = open-graded premix course; P = plastic waste; PCC = Portland cement concrete, PCCBP = plastic cell-filled concrete block pavement; WBM = water-bound macadam.

Source: Asian Development Bank estimates.

Upcycling Plastic Waste for Rural Road Construction in India

An Alternative Solution to Technical Challenges

The Government of India seeks to improve rural connectivity through the Rural Road Program or Pradhan Mantri Gram Sadhak Yojana (PMGSY). The overall implementation of the program has faced several challenges mostly associated with cost, availability of materials, technology readiness, and restricted specifications. One innovative way by which the Government of India is addressing these challenges is through the use of plastic waste as an alternative material for rural road construction. This working paper highlights how the investment program has addressed these challenges through such innovative approaches.

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