Utilisation of Recycled Concrete Aggregate in Bituminous Paving Mixes: An Economic Evaluation

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ABSTRACT: The present paper presents economic evaluation of dense bituminous macadam (DBM) mixes containing recycled concrete aggregate (RCA) modified by waste polyethylene, using net present value (NPV) method. The important findings including procedure for pre-treatment of RCA have been presented. The value of initial investment along with rehabilitation and extra widening for 30 years of bituminous pavement construction has been considered for determination of whole-life construction cost. This varies mostly due to the costs related to manufacturing, production, transportation and mixture preparation. The guidelines on the structural design of bituminous pavements by Indian Roads Congress (IRC) involving elastic layer analysis have been followed. Considering a hypothetical example of a pavement for economic implication of using the above two waste materials, it was observed that there is 8-10% reduction in total cost by using RCA/PRCA with or without waste polyethylene for modification of mixes as compared with the conventional one.

Keywords: *Pre-treated recycled concrete aggregate, waste polyethylene, economic evaluation, Net present value method.*

1. INTRODUCTION

Aggregates in the form of crushed stone are one of the basic raw materials used in construction industry, occupying about 70% to 90% of the total volume of the mixtures. Therefore, administrators, engineers and researchers are more concerned about the availability of natural aggregates to meet the future demands for sustainable growth. These concerns include economic issues, such as transportation costs as well as environmental issues. Hence, incorporation and reuse of recycled concrete aggregate (RCA) in the production of new bituminous mixtures justify themselves in both environmental and economic benefits. However, the physical, chemical and mechanical properties of RCA are quite different from natural or virgin aggregates (Lee et al., 2012; Perez et al., 2012, Giri et al., 2018a and 2018b). Generally, RCA has higher water absorption and lower specific gravity values compared to natural aggregate (NA) due to the attached cement mortar over its surface. To overcome this problem many researchers have tried various pre-treatment techniques. But it appears that these processes are cumbersome, need careful handling and also, some are expensive. In similar manner, it is a known fact that polymer modification of the bituminous mixtures offers greater resistance to pavement failures such as rutting, thermal cracking, fatigue damage and stripping. Many researches contributed on plastic based polymer for modification of bitumen (Panda and Mazumdar, 1997 & 1999; Kalantar et al., 2012; Hasan et al., 2016). One of the waste polymers is mostly from low density polyethylene (LDPE) which is in the form of carry bags. This waste material constitutes as the major contributor of waste plastics in India, and therefore, the potential utilization of such waste product has a great relevance in the country, particularly to reduce environmental pollution and other issues related to its disposal (Punith and Veeraragavan, 2007; Kalantar et al., 2012; Vasudevan et al., 2012).

These above facts motivate the author to explore a simple and user friendly procedure to pre-treat the RCA and utilize it with the waste polyethylene from milk packaging (WPMP) as an additive in bituminous mixtures to improve the stiffness, temperature susceptibility and other engineering properties for a comparative study with respect to the conventional bituminous mix. Further, for any study related to development of new materials specifically waste materials, it is imperative to explore the economic implications in respect of the whole pavement. As a part of the main objective, it was planned in the present study to consider typical example of a conventional bituminous pavement through a conceptual design, in which DBM layer is proposed to have RCA/PRCA in place of conventional natural aggregates in coarse fraction and also to have above mixes modified by waste polyethylene. For comparison of cost of the pavement with DBM layer with aforesaid non-conventional mixes, the economic evaluation was made using the net present value (NPV) method.

2. EARLIER STUDY ON USE OF RCA AND WASTE POLYETHYLENE

The experimental works presented under this heading are exactly as per the studies made by the same authors (Giri et al. 2018a, 2018b, 2018c, 2019 and 2020). The experimental works embodied in these works are divided into two parts. The salient features of these works are only presented in this paper to enable a reader to proceed with the economic evaluation of the DBM mixes containing these two waste materials namely, RCA and waste polyethylene. In part A, the methodology was developed to improve the properties of RCA by pretreating its surface with bitumen emulsion, which is known as pretreated RCA (PRCA). After several trials, the pretreatment procedure was finalized and recommended. As per that, a solution was prepared by mixing 40% medium setting (MS) bitumen emulsion and 60% water (each by weight of total solution) and 8% by weight of this solution was used to mix with dried RCA and mixed uniformly till a homogenous mixture was obtained (Giri et al., 2018a). The mixture was allowed to cure for a day and the resultant pretreated RCA (PRCA) was developed for preparation of bituminous mixtures. In part B, the design of DBM mixes was conducted which comprised of both conventional and non-conventional materials modified by waste polyethylene from milk packaging (WPMP). Specifically, the coarse aggregate fraction of the mix comprised of RCA, PRCA or NA. The important engineering properties of these DBM mixes such as tensile strength ratio, resilient modulus and rutting resistance were studied for evaluation of the same prepared at their respective optimum bitumen and polyethylene contents.

2.1 *Tensile strength ratio (TSR)*

The tensile strength ratio of bituminous mixtures is an indicator of their resistance to moisture susceptibility and the test was conducted as per AASHTO T 283 (2014). The TSR values of different DBM mixes considered are presented in figure 1. It may be observed from this figure that, the samples prepared with PRCA and waste polyethylene resulted in higher TSR value followed by the same with NA and waste polyethylene. Similarly, cement as filler resulted in somewhat higher TSR values compared to stone dust. However, all DBM mixes considered in the study satisfied the MoRTH (2013) requirement as TSR value in each mix was greater than 80%.

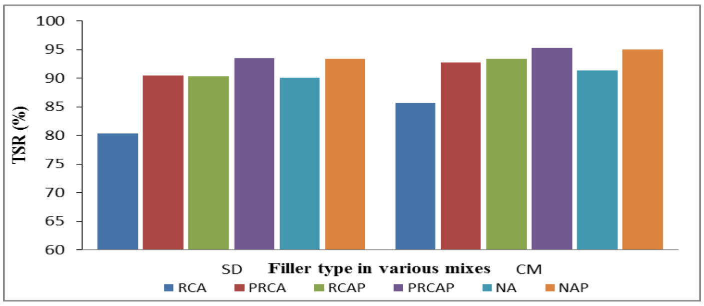

Figure 1. Tensile strength ratio

2.2 *Resilient Modulus*

The resilient moduli of the bituminous mixtures and other materials in various layers are critical inputs for the analysis and design of flexible pavements as per elastic layer analysis. As the bituminous layer under consideration in this study was proposed to be made of DBM mixes prepared with RCA, modified or unmodified with WPMP, it was essential to determine these two properties. The repeated load indirect tensile test was conducted to determine these two parameters at most prevailing test temperature of 35ºC as per ASTM D4123-82 (1995). The results are presented in figure 2.

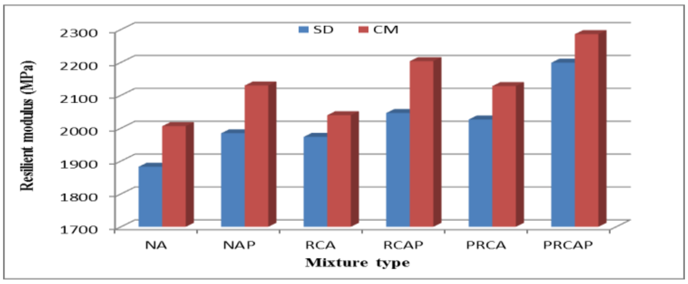

Figure 2. Resilient modulus values of different DBM mixes

It may be seen that the mixes prepared with PRCA and cement as filler, and modified by WPMP resulted in higher moduli followed by the mixes with RCA and cement as filler, modified by WPMP at each test temperature. On the other hand, the mixes with NA resulted in lowest resilient modulus compared to the mixes with RCA/PRCA at each test temperature. Hence, it may be concluded that there are definite benefits of utilisation of RCA in bituminous paving mixtures and modification of such mixtures by waste polyethylene, in terms of development of stiffer bituminous mixtures.

2.3 *Rutting*

A laboratory wheel-tracking device is used to simulate to the road tests that measure the rutting behaviour. The test was conducted as per European Committee for Standardization (CEN 12697-22, 2003) and the results are presented in figure 3.

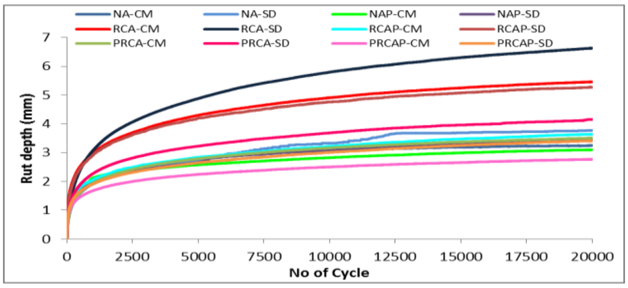

Figure 3. Relationship between rut depth and number of cycles

From figure 3, it is observed that, all the mixes satisfied the criteria of maximum rut depth i.e. < 12 mm after 20,000 cycles. The PRCA mixes with cement as filler, modified by WPMP resulted in the lowest rut depth followed by the mixes prepared with NA and cement as filler, modified by WPMP. On the other hand, the maximum rut depth was found for the mixes containing RCA as coarse aggregate and stone dust as filler without WPMP modification.

From the above earlier observations, as a filler cement was found to perform better than stone dust in the DBM mixes considered. This was attributed to larger surface area of cement.

3. ECONOMIC IMPLICATIONS ON USE OF RCA AND WASTE POLYETHYLENE IN DBM MIXES

It may be observed from above mentioned experimental studies (Giri et al. 2018a, 2018b, 2018c, 2019 and 2020) that, there is a definite benefit in utilization of RCA, preferably with appropriate pre-treatment along with the waste polyethylene in bituminous paving mixtures. Hence the present study was extended to observe the economic benefits of using the wastes in the binder course of a bituminous pavement through a conceptual analytical design of a conventional flexible pavement for a period of 30 years. In this conceptual design, a conventional flexible pavement (bituminous) is to be designed for a National Highway (with four lane divided carriageway) in the state of Odisha, India with a design life of 15 years. RCA and waste polyethylene have been proposed to be used in the binder course with different combinations of ingredient materials as discussed earlier, each one with either of two different fillers, namely cement or stone dust. The presumed inputs such as initial traffic in the year of opening as 1500 commercial vehicles per day, annual traffic growth rate as 6% and vehicle damage factor as 5.2, lead to an estimated design traffic of about 50 million standard axles (msa) at the end of 15 years considered as per IRC: 37:2012. Further, after 15 years, the pavement needs to be widened with one lane on each side and existing one strengthened to carry traffic up to 30 years (estimated design traffic resulting to about 170 msa as per IRC:37:2012). The maintenance and rehabilitation of the hypothetical pavement considered is to be carried out as per the plan given in figure 4. The maintenance to be carried out in every five years includes a thin layer (25 mm) of bituminous concrete to improve the functional performance of the pavement.

Figure 4. Maintenance and rehabilitation programme for 30 years

The material properties in the form of elastic modulus and Poisson's ratio for all the constitutive layers considered in the present analysis like bituminous concrete (BC), wet mix macadam (WMM), granular sub-base (GSB) and subgrade are presented in Table 1. The input material properties as per the table except the elastic modulus of DBM mixes are as per IRC 37 (2012). The elastic moduli of various DBM mixes specified are as per the actual ones as determined in the laboratory and presented in figure 2.

Table 1. Material properties considered for analysis

Layer type	Elastic modulus (MPa)	Poisson's ratio
BC	3000 (with VG 40 grade bitumen)	0.35
DBM	1800 – 2400 (Refer figure 2)	0.35
WMM	450	0.40
GSB	250	0.40

Subgrade	61	0.45

3.1 *Conceptual design of a conventional flexible pavement*

In the present study, the layer thicknesses of the bituminous pavement have been decided based on the analysis carried out using IITPAVE software (IRC: 37, 2012), a linear elastic layered analysis program followed in India. The input parameters for this software are elastic moduli and Poisson's ratios of pavement component materials, wheel load and tire pressure. Using the IITPAVE software, the strains at the critical locations which are horizontal tensile strain below the bituminous layer and vertical compressive strain on the top of the subgrade are estimated and compared with the critical strain values obtained from the fatigue (Eq. 1 and 2) and rutting performance criteria (Eq. 3 and 4) according to IRC: 37 (2012). This is to be noted that the thicknesses of GSB, WMM and BC layers have been considered for 15 years' design life as 150 mm, 200 mm and 40 mm respectively and the thickness of DBM layer has only been altered in the hypothetical pavement. The same for 30 years' design life as 200 mm, 200 mm and 50 mm respectively, and again the DBM layer thickness has only been altered in the hypothetical pavement as before.

The fatigue criteria developed using the performance data collected from Indian roads are given by Eq.1 and 2 for 80% and 90% reliability level respectively.

$N_f = 2.21 \times 10^{-04} \times [1/\epsilon_t]^{3.89} \times [1/M_R]^{0.854}$ (1)
(80% reliability)

$N_f = 0.711 \times 10^{-04} \times [1/\epsilon_t]^{3.89} \times [1/M_R]^{0.854}$ (2)
(90% reliability)

Where, N_f = Fatigue life in number of standard axles

ϵ_t = Maximum tensile strain at the bottom of the bituminous layer

M_R = Resilient modulus of the bituminous layer

Whereas, the rutting criteria suggested by IRC: 37 (2012) for 80% and 90% reliability are given by Eq. 3 and Eq. 4 respectively.

$N = 4.1656 \times 10^{-08} [1/\epsilon_v]^{4.5337}$ (3)
(80% reliability)

$N = 1.41 \times 10^{-08} [1/\epsilon_v]^{4.5337}$ (4)
(90% reliability)

Where, N = Number of cumulative standard axles (units of ESALs)

ϵ_v = Vertical strain on the subgrade

N_r = Number of repetitions causing rutting

$k_1 = 2.1 \times 10^{-2}$ for 85% confidence limits

1.8×10^{-2} for 95% confidence limits

3.2 *Optimum thickness design using IITPAVE*

The computed strains such as ϵ_t and ϵ_v using IITPAVE software, for 50 msa (for 15 years traffic) and for 170 msa (for 30 years traffic) are presented in Tables 2 and 3. The design thicknesses of BC, DBM, WMM and GSB layers are chosen in such a way that the strains at critical locations remain closer to, but within the limiting values obtained from the fatigue and rutting criteria given in IRC:37 (2012).

Table 2. Thickness of pavement layers for design traffic of 50 msa

DBM Mix type	**Design DBM thickness (mm)**	**Calculated strain (From IITPAVE, (x10^{-6})**		**Maximum allowable strain (ϵ_t and ϵ_v)**
		ϵ_v	**ϵ_t**	
NA-CM	110	335.8	170.7	ϵ_t=175.9 x10^{-6} ϵ_v=371.7 x10^{-6}
NA-SD	110	338.4	174.6	
NAP-CM	110	333.4	166.9	
NAP-SD	110	336.2	171.2	
RCA-CM	110	335.4	170.0	
RCA-SD	110	337.2	172.8	
RCAP-CM	110	348.9	174.8	
RCAP-SD	110	334.9	169.3	
PRCA-CM	110	333.3	166.7	
PRCA-SD	110	335.3	170.3	
PRCAP-CM	100	347.0	171.4	
PRCAP-SD	100	349.3	174.4	

Table 3. Thickness of pavement layers for design traffic of 170 msa

DBM Mix type	**Design DBM thickness (mm)**	**Calculated strain (From IITPAVE, (x10^{-6})**		**Maximum allowable strain (ϵ_t and ϵ_v)**
		ϵ_v	**ϵ_t**	
NA-CM	150	237.7	127.8	ϵ_t=128.4 x10^{-6}
NA-SD	160	230.7	125.4	

NAP-CM	150	235.4	125.0	ϵ_v=283.7 x10^{-6}
NAP-SD	160	228.3	122.8	
RCA-CM	150	237.3	127.5	
RCA-SD	160	229.3	124	
RCAP-CM	150	233.9	123.1	
RCAP-SD	150	236.9	126.9	
PRCA-CM	150	235.3	124.9	
PRCA-SD	150	237.7	127.8	
PRCAP-CM	160	230.7	125.4	
PRCAP-SD	150	235.4	125.0	

3.3 *Life cycle cost analysis (LCCA) using NPV*

The LCCA is used to evaluate the cost-efficiency of alternatives based on the Net Present Value (NPV) concept (Babashamsi et al. 2016). LCCA attempts to identify the best value (the lowest long-term cost that satisfies the performance of pavement) for investment expenditures. The LCCA analysis period should be sufficiently long to reflect long-term cost differences between alternatives. Basically, the selected analysis period should include at least one rehabilitation activity for each alternative. For this, the most widely used economic valuation technique is the NPV approach. The main principle of NPV approach is that a risky tomorrow is less valuable then a certain today, which means future cash flows are discounted in each year. The discount rate reflects the chance cost of the investment mobilized, which increases with the projected riskiness of the modernization opportunity (Zizlavsky 2014). Hence, NPV is calculated by discounting all project costs to the present time (time of construction). Thus, the entire project can be expressed as a single present time cost. Alternatives are then compared by comparing these costs. NPV is a common economic calculation for roadways and is expressed by Eq. 5.

$$\text{NPV} = \text{initial cost} + \sum_{k=1}^{N} \text{Rehab cost}_k \times \left[\frac{1}{(1+i)^{n_k}}\right] \qquad [5]$$

Where,

i = Discount rate

n = Year of expenditure

The necessary components for the cost analysis require an evaluation of cost due to labour, equipment, materials, processing of material (if any) and delivery for the construction purpose. These costs were combined to decide the unit price. The construction costs were estimated as per existing analysis of rates in practice by the Govt. of Odisha, India. Based upon this constructional cost, the whole-life construction cost of the pavement containing different materials in DBM layer is presented in Table 4. These values were calculated based on net present value method with discount rate of 10% and inflated rate of 5%.

Table 4. Comparison of whole-life construction cost of pavement

DBM type	Total cost (Rs.) per Km	% of cost reduction
NA-CM	65052163	-
NA-SD	64629454	0.66
NAP-CM	62082869	4.66
NAP-SD	61668768	5.31
RCA-CM	61561941	5.47
RCA-SD	61130462	6.15
RCAP-CM	58981512	9.52
RCAP-SD	59574970	8.59
PRCA-CM	60883269	6.54
PRCA-SD	60178775	7.64
PRCAP-CM	59259965	9.08
PRCAP-SD	58802441	9.80

From Table 4, it is observed that, with use of RCA and WPMP in DBM layer there is significant saving in the whole life cost, if these two waste materials in selected combinations are used in bituminous mixtures. Compared to all twelve different mixes considered, PRCAP-SD in DBM layer resulted in highest cost benefit.

4. CONCLUSIONS

This research work attempts to explore the economic benefits of using bituminous mixtures made with RCA and WPMP. From the review of various previous studies undertaken by the same authors, it was concluded that the DBM mixes made with PRCA and modified by waste polyethylene, can be used in hot bituminous paving applications with the scope of best performances. Even, RCA can be recommended to be used in lower bituminous layers. Further, it is observed from the economic evaluation of such mixtures having waste materials such as RCA and waste polyethylene that, a significant cost saving in the whole life cost of around 8-10% can be observed with nonconventional bituminous mixtures as compared with similar mixtures prepared with conventional natural aggregates. Hence, use of WPMP and RCA waste may provide sustainable construction benefits in terms of reduction in cost as well as addressing the fast depleting natural stone resources. These benefits produce positive impacts on engineering, economic, social and environmental aspects that help to alleviate many of the challenges that are currently being encountered, and also can conserve the natural stone resources for use in many other more important infrastructure activities.

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