Cost-benefit Analysis of RAP Incorporated Stone Matrix Asphalt Mixtures

Lekhaz Devulapalli, Saravanan Kothandaraman

***Abstract**: It is desirable to incorporate Reclaimed Asphalt Pavement into the asphalt mixtures, which provides several benefits i.e. economic, environmental and performance. It is necessary to study, the economic analysis of the RAP since that incur several contingencies to the asphalt mixtures. In this study, a simple approach is used to evaluate the production cost of the asphalt and RAP incorporated asphalt mixtures. Apart from that Waste Vegetable Oil (WVO) is used as a rejuvenator to enhance the properties of the mixture. In this study, asphalt mixture production cost is evaluated and cost of each material is taken from the Public Works Department Standard Scheduled of Rates (PWD – SSR) and the market survey techniques are followed. From the cost-benefit ratio, it is observed that the reduction in the Optimum Binder Content (OBC) provides great economic savings to the production cost. The incorporation of the RAP reduced the asphalt content and reduced the production cost of the asphalt mixtures. The addition of the WVO further reduced the OBC but increased the production cost compared to the non-rejuvenated mixture. The increase in the production cost is due to the extra cost invested on the WVO and other contingencies.*

***Keywords**: Economic Analysis, Reclaimed Asphalt Pavement, Rejuvenator, Waste Vegetable Oil.*

I. INTRODUCTION

The construction of the asphalt pavements required a large quantity of the aggregates and asphalt. The aggregates are naturally consisting of crushed rock and gravel, whereas, asphalt is a petroleum product. The asphalt mixtures comprised of about 95 % aggregates and 5 % asphalt that act as a binder material. However, the quantity of the asphalt is very little but it will sum around 60 % of the total cost. It is estimated that around 1.36 trillion tons of asphalt are used in the pavement construction annually [1]. Therefore, the increase in the demand and the scarcity of these materials increased the construction cost of the asphalt pavements [2]. The pavement industries are searching for possible ways to reduce the construction cost, and one such process is the reusing the existing deteriorated pavement materials. These materials are known as Reclaimed Asphalt Pavement (RAP), which contains aggregates coated with asphalt [3]. The successful usage of the RAP will reduce the quantity of the natural aggregates and asphalt in the asphalt mixtures and ultimately reduces the cost. Apart from the economic benefit, the usage of RAP will reduce landfill and environmental pollution. The RAP usage is foreshortened, due to inconsistent performance and increase in the stiffness, which will reduce the RAP content in the asphalt mixtures. Therefore, wide-ranging research is going on to develop and adopt RAP incorporation in the asphalt mixtures [4]. To reduce the stiffness of the mix, a softer virgin binder may be added, and that increases the mixture cost. Whereas, rejuvenators provide a viable option to reduce the stiffness and are economical. Rejuvenators is an additive which restores the chemical structure of the aged binder and, increases the workability of the RAP mixture and brings the viscosity to an accepted range. The dosage of the rejuvenator should be selected properly. So, the flexural properties of the RAP materials are improved without compromising the rutting resistance [5]. Subsequently, the rejuvenators increase the cracking resistance of the RAP incorporated asphalt mixtures [1]. Careful choice of rejuvenator and its dosage helps to avoid the bleeding, cracking and other problems in the mixture [5,6,7]. Several researchers concluded that the rejuvenators improve the overall performance of the RAP incorporated asphalt mixtures. It is seen from several studies that there are many commercial rejuvenators are available in the market which showed promising results. However, the cost of the commercial products is very high and that will increase the overall pavement construction cost, which will confront the usage of RAP [8]. To overcome those issues in this study, non-commercial rejuvenator is used. Economic analysis is also performed to study the cost-benefits ratio of the RAP incorporated asphalt mixtures with rejuvenator [9]. The main objective of the study is to evaluate the influence of RAP content and rejuvenator dosage on the cost-benefit ratio of the Stone Matrix Asphalt mixtures (SMA). SMA is a gap graded pavement which consists 70% of coarse aggregate which forms an aggregate skeleton and a fair amount of fine aggregate helps to fill the voids present in the coarse aggregate and give better stone-on-stone contact and gives strength to the mixture [10,11].

Manuscript published on 30 September 2019
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II. METHODOLOGY AND MATERIALS

A. Methodology

In this study SMA mixtures are prepared with four RAP content levels i.e. 10, 20, 30 and 40 % at each level the rejuvenator dosages varied at 0%, 3%, 6%, and 9%.

A conventional mixture without RAP and rejuvenator is also prepared and the same is considered as the Control Mixture (CM). Total 17 combinations of the SMA mixtures are prepared including CM. The Waste Vegetable Oil (WVO) is used as rejuvenator.

This study is divided to two stages: firstly, the materials cost are arrived from Publics Works Department Standard Scheduled of Rates (PWD – SSR), Government of Tamilnadu, India and market survey. The Optimum Binder Content (OBC) for all the mixtures is taken from the published report (Devulapalli et al., 2019b). In the second stage the production cost of the asphalt mixture, and the RAP incorporated asphalt mixtures with rejuvenator are evaluated. The RAP is obtained from the local dumping ward, and the PWD – SSR rates is used to calculate the cost of the removal, transportation and processing of the RAP material. WVO rates are fetched from the local buyers and then rate analysis is carried out. Whereas, the rate of the virgin aggregates and bitumen are taken from the PWD-SSR. In this study, the production cost for one cubic meter of the asphalt mixtures is carried out for all the mixtures and same is considered for the cost-benefit ratio analysis.

B. Materials Used

RAP is obtained through milling the various pavement layers and locations in Chennai, Tamil Nadu State, India. Predominantly, RAP has a relative bitumen coated to the aggregates that will reduce the virgin Bitumen Content (BC). To use the RAP in the bituminous mixtures, the milled RAP is crushed in the asphalt production plant and screened to Nominal Maximum Aggregate Size (NMAS) [12]. The screening helps in removing the impurities and the aggregates can be graded as per specifications. Crushed stone aggregate is chosen and the virgin aggregate, and VG – 30-grade asphalt taken in this study purpose. Pelletized cellulose fibre is used as a drain down inhibitor. WVO is a used oil which is not suitable for the original purpose. Mostly, WVO is obtained from the oil refining industries, restaurants, hotels, food processing industries, which consists of residues such as food particles, water, and nasties. Therefore, the WVO needs to be filtered to remove waste products [13,14] The WVO can be obtained at a minimal price; however, the refining process of oil for biofuels will increase the cost [6].

III. EXPERIMENT ANALYIS AND RESULTS

A. Methodology

To perform the cost-benefit analysis of the RAP incorporated asphalt mixtures, a study on the virgin asphalt mixtures and RAP mixtures are conducted. Several factors which are involved in the asphalt mixture production process are considered as per Indian Road Congress (IRC) specifications. It is to be noted that the study is limited to the production of the asphalt mixtures. The sequential order of the production of the asphalt mixtures is evaluated by the data obtained from the local asphalt plants and PWD-SSR [15]. This will provide the information about the parameters which will incur the cost to the production. Eq.1 is used to calculate the production cost of the conventional asphalt mixture. The production process of RAP incorporated asphalt mixtures is same as the conventional mixtures; however, the RAP incorporation reduces virgin aggregate and asphalt usage and some extra contingencies (RAP incorporation and rejuvenator application cost) and Eq.2 is used to calculate the production cost of the RAP incorporated asphalt mixtures. On the other hand, WVO is added to improve the performance of the asphalt mixtures and it will slightly increase the production cost and Eq.3. gives the production cost of the RAP incorporated asphalt mixtures with WVO. The virgin aggregate and RAP aggregate gradation, and the OBC for all the mixtures are taken from the published work [10] and same is used in the cost calculation for each mixture. Since the price of the WVO and cellulose fibre are not available in the PWD-SSR, then the rate is taken based on the local market survey. The economic savings of the RAP are analysed thorough the cost-benefit ratio. Eq.4 presents the cost-benefit ratio of the mixtures and is used to evaluate the most economical mixture [9]. Table 1. presents the materials price used in the production of the asphalt mixtures.

$$PC = VAC + AC + LC + EC \quad (1)$$

$$RPC = VAC + AC + LC + EC + RAPC + C \quad (2)$$

$$WPC = VAC + AC + LC + EC + RAPC + RC + C \quad (3)$$

$$C/B = \frac{RPC/WPC}{PC} \quad (4)$$

Whereas, PC – Production cost of control mix, RPC –Production cost of RAP mix, WPC –Production cost of RAP mix with WVO, C/B – Cost-Benefit Ratio, VA – Virgin Aggregate Cost, AC – Asphalt Cost, LC – Labour Cost, EC – Energy Cost, C – contingencies, RAPC – RAP Cost, RC – Rejuvenator cost

Table.1. Cost of the materials

Materials	Price	Source
Virgin Aggregate	₹ 800/cum	PWD-SSR [15]
Virgin Asphalt	₹52,000/ tonne	PWD-SSR [15]
RAP	₹ 253/cum	PWD-SSR [15]
WVO	₹20,000/tonne	Market survey
Filler	₹ 200/cum	Market survey
Pelletized cellulose fibre	₹ 300/kg	Market survey

Fig.1. presents the OBC value of all the mixtures and the same is used to calculate the production cost of the mixture. The OBC value of the control mixture is 6.24 %. Although the asphalt content is only 5 – 7 % in the asphalt mixtures it will make up to 50-60 % of the production cost. So, it is significant to reduce the asphalt content in the asphalt mixture, which will eventually reduce the overall cost. Therefore, even a slight reduction in the asphalt content will give high savings. It is observed that the addition of the RAP and WVO reduced the OBC. The addition of the 40 % RAP and 9 % WVO has a higher reduction in the OBC and gives higher savings. Fig.2. shows the production cost per cum of the asphalt mixtures. From Fig.2, it can be seen that the addition of the RAP reduced the production cost. The production cost of the control mixture is ₹5203/cum and, for the 10 – 40 % RAP content mixtures it is in between ₹5082 – 4765/cum, which shows that the addition of the RAP reduced the production cost and, is due to a decrease in the asphalt content and virgin aggregate. Therefore, it will confirm that the addition of the RAP reduces the production cost.

The production of the 3 % WVO mixtures is in the range of the ₹5072 – 4804/cum, which shows the addition of the WVO slightly increased the production cost because the incorporation of the WVO incurs some extra contingencies cost. The production cost of the 6 % and 9 % WVO dosage mixtures is in between ₹5075 - 4800/cum and ₹5098 – 4796/cum respectively. The increase in the WVO dosage moderately increased the production cost when compared to the non-rejuvenated mixture, however, it is less than the control mixture.

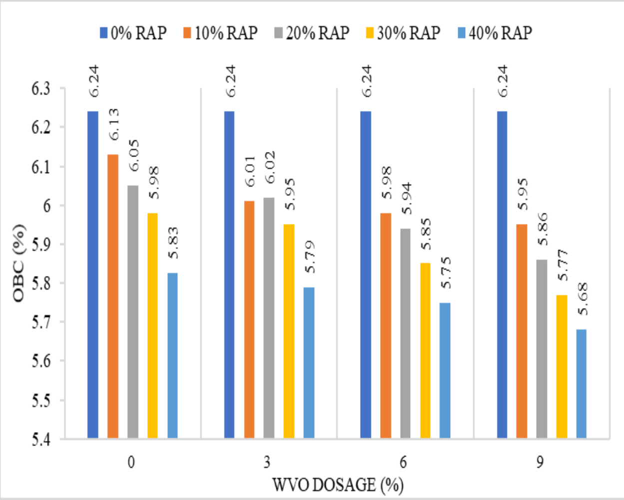

Fig.1. Optimum Binder Content

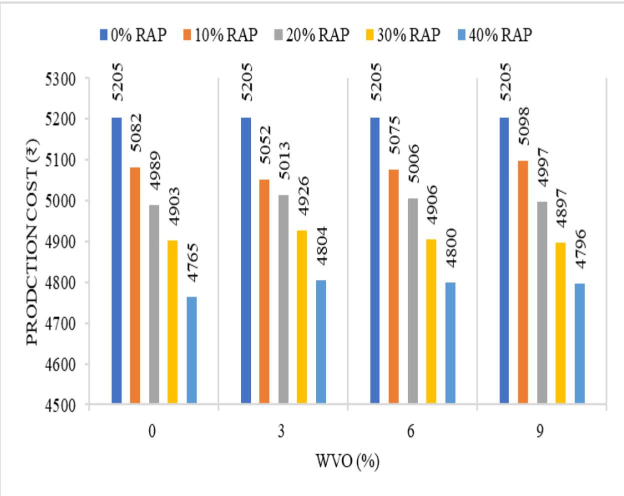

Fig.2. Production Cost per cum

The cost-benefit ratio shows that the incorporation of 10 % RAP gives a total saving of 2.36 %. The high savings are observed for the non-rejuvenated 40 % RAP content mixture i.e. 8.45 %. The high RAP content mixtures showed high savings compared with the control mixtures. It is observed that the addition of the WVO slightly reduced the production cost. On the other hand, the increase in the dosage increased the cost-benefit ratio, which is due to an increase in the cost of the WVO. However, the increase is depended on the RAP content. The 40 % RAP content with 9 % WVO dosage mixture showed a high increase in the cost-benefit ratio when compared to the other WVO mixture. Overall it is observed that the incorporation of the RAP provided great economic savings. The addition of WVO reduced the savings when compared to the non-rejuvenated mixtures, however, savings are higher than the control mixture. Other important advantages of RAP incorporation are reducing landfills stress and a serious environmental concern.

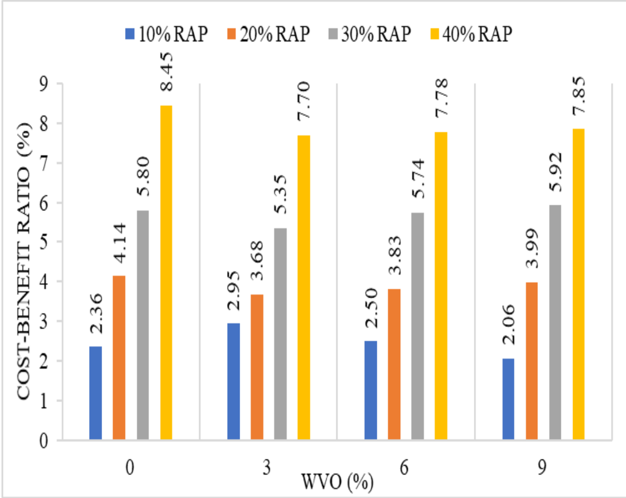

Fig.3. Cost-Benefit Ratio per cum

IV. CONCLUSION

The present study aimed to study the cost-benefit analysis of the RAP incorporated SMA mixtures with WVO as a rejuvenator. All parameters which will incur a cost in the production process are evaluated and the rates are chosen based upon the PWD-SSR and market rate. From the study, it is observed that the incorporation of the RAP increased the cost-benefit of the asphalt mixtures. The 40 % RAP mixtures provided higher savings when compared to the other mixtures. The addition of the WVO decreased the OBC value, which gives economic savings. However, due to the increase in the contingences with the addition of WVO slightly increased the production cost when compared to the non-rejuvenated mixtures.

- The study confirms that the RAP provides up to 9 % of the economic saving
- It is observed that even the slight reduction in the asphalt content will give high economic savings.
- The WVO increased the production cost, when compared to the non-rejuvenated mixtures, however, WVO increases the mixtures quality, which gives indirect cost saving viz. maintenance cost, high service life.
- Overall the study is focused only on the material production cost, and the paving cost and life cycle analysis of the actual pavement surface can be evaluated as future studies.

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