A Study on using Plastic Coated Aggregate for evaluation of modified Bituminous Concrete Mix

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Abstract - Road network system of India is deteriorating day by day due to rapid increase in traffic and improper maintenance. This paper aims to shed light on the use of plastic coated aggregate (PCA) in bituminous concrete (BC) and analyze PCA's efficiency using various tests in eco-friendly way to achieve efficiency in economical manner. The major advantage of using PCA to construct pavement in sustainable way is by reduction in usages of bitumen and also improve the properties of aggregate. Dry mix (DM) method was adopted to mixed the waste plastic by utilizing shredded waste plastic bottles made of Polyethylene Terephthalate (PET) in bituminous mixes. The physical properties of traditional aggregate and PCA were also compared. The Marshall blend was prepared by using bitumen grade 80/100, PCA, stone dust and cement as a filler to make BC Grade -2. The aggregates used for prepared total mix coated with PET content of 3%, 5%, 7%, 9% and 11% by weight of optimum binder content. To find out its suitability in field, Marshall stability, flow value and volumetric characteristics of mix were determined and compared to traditional bituminous concrete mixtures (without plastic). PCA had better binding property, less water absorption, and higher Marshall Stability value was also shown in the results, and is a better option to solve environment pollution due to plastic waste.

Keywords - Dry Mix, Flexible Pavement, Flow value, Marshall Test, Plastic Coated Aggregate (PCA), Plastic waste.

1. INTRODUCTION

India's rapid population growth has the world's second-largest population, and India's estimated total population amounted to around 1.37 billion people[1]. This massive crowd and industrial sector development adds an immense amount of non-biodegradable solid wastes to the environment. This growth involves not only livelihoods but also requires a broad network of mobility. Economic and social growth has a close connection in every nation's economy to the creation of its transport sector[2]. The nation has an overall road length of 5,603,293 km; of which 142,126 km are paved roads, as reported by the Transportation Ministry in 2013[3].

Road network is one of the most widely used by people across all modes of transport. Hence keeping the roads in good order is important. Road performance is dependent upon the materials used. At the top layer of flexible pavement, the highest stress resistance occurs, which is why they are made primarily of superior bitumen material. Bitumen has acted as a binding material for constructing roads and pavements for many years. Demand for bitumen has increased as a result of rapid urbanisation. Bitumen is commonly used in constructing road, mainly due to its excellent binding and waterproofing properties. The appealing properties of bitumen depend on the form and composition of the mixture. Bitumen is a visco-elastic material; hence, its strength and adhesion mechanisms are determined by loading rate and temperature. If insufficient binder is used in the mix then premature failure in the pavement can occur, such as cracks and rutting, potholes, etc. Due to insufficient
maintenance to the pavement the situation is getting worse. The bitumen thus needs to be modified along with innovative sustainable pavement design techniques. The possible solution to this problem could be to improve the quality of bituminous mixtures. There are many binders available on the market to improve bituminous mix properties but the use of these binders raises overall project cost. The escalating costs of bitumen and the lack of resources motivated highway engineers to explore alternatives for road construction [4].

To solve this problem there are two choices to modifying bituminous mix i.e. first to add polymer directly in bitumen mix secondly by coating shredded thin waste plastic on aggregates and then applying hot bitumen to the plastic-coated aggregate (PCA). The process of applying PCA on hot bitumen is known as dry process. Modification of bituminous blends by PCA has many benefits such as reduced thermal sensitivity and rutting, reducing cracking at low temperatures, better overall adhesion, improved tire friction etc. The use of recycled plastic bottles polythene, Polyethylene Terephthalate (PET) in bituminous pavement has been shown to be responsible for its decreased rutting and low temperature cracking of durable pavement base. PET is an contraction for polyethylene terephthalate, which is a long-chain polymer belonging to the semi-crystalline, thermoplastic polyester [5]. PET is derived by a polymerization reaction between an acid and alcohol [6]. PET is a widely used due to its easy handling and durability properties. [7].

PET is broadly used to coat the aggregates in bituminous concrete (BC) mix among all the polymers. Coating ensures a proper bond between aggregates and improving its surface roughness for a good relationship thus makes superior engineering properties to asphalt mixtures [8, 9]. Plastics consisting mainly of polythene and low-density polyethylene (LDPE) in bituminous mixtures, resulting in improved durability and fatigue life [10]. A doubling of the fatigue life of modified bituminous concrete mixes observed as compared to standard ones. Increase in durability, tensile strength and moisture tolerance of Asphalt blends by incorporating 8% waste plastic (by bitumen weight)[11]. The mixture is provided greater strength by coating plastics over hot aggregates in dry phase than by mixing it with asphalt in wet method [12]. In addition, bitumen properties are substantially improved when combined additives are used in bitumen mixtures as opposed to unmodified bitumen [13],[14]. Waste plastic bottles have been used in this study to coating the aggregate. Recycling this waste material for the development of new roads and highways will help solve environmental problems by discarding those waste materials in dumpsites. Plastics remain on site for a long time as non-biodegradable materials and cause pollution for the environment [15]. Old methods of disposing of plastic waste, such as burning and land-filling, produce different types of air, water and soil pollution[16]. A recent survey by the Central Pollution Control Board in India estimated that about 33.7 million pounds of plastic waste are generated daily, around 13.2 million pounds of which remain uncollected and pollute environment [17]. Polymer use in modified bitumen improves the efficiency of funnel asphalt paving [18],[19]. The use of recycled plastic waste polythene bags enhanced the engineering properties of bituminous concrete mix, such as toughness or fatigue life. [20]. This technique helps to develop green flexible flooring for future generations by using solid waste as a modifier to improve the engineering properties of bituminous concrete mixtures[21],[22],[23],[24]. In this way. An effort is being made to test the properties of Bituminous Concrete (BC) blends Grading-1 Indian Roads Congress (IRC: 111-2009) using dry plant waste plastics [25].

In this research, PET which is a type of plastomer was used to modify the properties of the BC mix. It is used to coat the aggregate instead of changing the properties of bituminous. The primary objectives of this research are to study the effect on the hot mix bitumen when PCA was added and to determine the optimum bitumen content and excellent PET content in the BC mixture. In this study, economic mix developed with proper PCA gradation and sufficient bitumen ratio to meet the desired mix properties of stability, toughness, resilience, skid resistance and workability. Using the Marshall Stability Mix design process on traditional bitumen mix samples, the optimum bitumen content is determined and modified samples are prepared by incorporating PCA into the mix in different percentages. The main objective of the study is to examine the behaviour of PCA as a modifier to
determine stability, flow and volumetric characteristics. These experimental findings have shown that overall performance of modified mixtures is more favourable than traditional mixtures.

2. EXPERIMENTAL MATERIALS USED AND METHODOLOGY:

This research aims at achieving an environmentally friendly Bitumen Mix contained PCA. This section deals with the methods used to measure the research work. The technique followed for carrying out the experimental program was demonstrated with the aid of a flow chart in Fig. 1 and the interpretation below is endorsed [26].

![Flow chart](image)

**Figure-1. Flow chart portray overall methodology**

The materials used for experimental research include bitumen, aggregate, stone dust and plastic bottles such as PET. Aggregate measurements were taken in compliance with specifications of the Ministry of Road Transport and Highways (MORTH). The bitumen used was degree 80/100 and was bought from a local contractor of Moga, Punjab. For this research, plastic bottle were used which made by PET. The bottles were collected from municipal and residential waste and shred into small pieces about 2 mm to 5mm. The BC grade-2 was selected as it provides the aggregate mixture gradation shown in Table 1. [27],[28].

| Sieve Size (mm) | % Passing | % Passing Blending Ratio | MORT & H Requirement |
|----------------|-----------|--------------------------|----------------------|
|                | 13.2      | 11.2                     | SD       | Cement | 0.10 | 0.35 | 0.53 | 0.02 | 100.0 | 100 |
| 19.00          | 100       | 100                      | 100      | 100    |      |      |      |      |       |     |
| 13.20          | 97        | 100                      | 100      | 100    | 99.7 | 90-100 |
| 9.50           | 15        | 75.2                     | 100      | 100    | 82.8 | 70-88  |
| 4.75           | 0.2       | 0.4                      | 98.6     | 100    | 54.4 | 53-71  |
In order to examine the mechanical properties of conventional and plastic coated aggregates like strength, durability, hardness, water absorption ability etc., various physical test such as Impact value, Abrasion value, Crushing test, specific gravity, Flakiness and elongation were performed. All the obtained results lie within the acceptable limits which were shown in table no.2.

Table-2 Physical properties of conventional aggregates (0 % plastic) and plastic coated aggregate(PCA)

| Description of tests | Test Method | Percentage of Plastic/ additive by weight of OBC | MORT& H (Fifth Revision-2013 Specifications) |
|----------------------|-------------|-----------------------------------------------|---------------------------------------------|
| Aggregate Crushing strength | IS:2386-PartIV | 17.9% 16.2% 14.9% 12.5% 11.5% 12.2% Max 30% | | |
| Impact value | IS:2386-PartIV | 15.7% 14.35 13.6% 12.5% 10.9% 11.7% Max 24% | | |
| Specific gravity | IS:2386-PartIII | 2.73% 2.76% 2.78% 2.82% 2.84% 2.87% 2-3 | | |
| Los Angles abrasion value | IS:2386-PartIV | 21.8% 20.6% 19.4% 17.6% 15.3% 16.2% Max 30% | | |
| Combined Flakiness & Elongation index value | IS:2386-PartI | 31.7 29.6 29.6 29.6 29.6 29.6 Max 35% | | |
| Water absorption value | IS:2386-PartIII | 0.68% Nil Nil Nil Nil Nil 2% | | |
| Soundness value | IS:2386-PartV | 7% Nil Nil Nil Nil Nil Max 12% | | |
| Stripping value | IS:6241 | 5% Nil Nil Nil Nil 5% | | |

2.1. Marshall Specimen preparation for traditional mix:

The bituminous concrete mixture has been formulated according to the standard Marshall Stability test. To find out optimum binder content of the developed mix, Marshall Specimens are casted with virgin bitumen and aggregate mix. First of all all aggregates and filler material were heated in a pan in required proportions and held for 2 hours in an oven at a temperature of 160°C. Bitumen (5.0 % by weight of total aggregate) is heated to 150–160 °C and thoroughly mixed with heated aggregates at 154°C to 160 °C temperatures. The mix is put in a preheated mould and compacted at a temperature of 138°C to 149°C by a rammer with 75 blows at either side A filter paper is placed on top of the sample and under the sample. After sample compaction, moulds are held at 60°C for 30 minutes in temperature controlled water bath after 24 hours. In the next trial vary the bitumen content by ± 0.5 % up to 7 % and repeat the procedure above. In the Marshall test setup the prepared mould is loaded. The optimum bitumen content for the unmodified bitumen mixes was found to be 5.5 % by weight of the total mix. The Marshall Stability and Flow test provides the measure of output.
prediction for the Marshall Mix design process. The test’s portion of stability tests the average load that the test specimen bears at a load rate of 50.8 mm / minute. Load shall be added to the specimen before failure, and the full load shall be known as stability.

2.2. Modified Marshall Sample preparation:

Modified Marshall Samples were developed as per Marshall Samples the standard procedure after deciding Optimum Binder Content. After determining the optimum bituminous material content (5.5% by weight of total mix), five different proportion of PET (3%, 5%, 7%, 9% and 11% by weight of binder content) has been used to coat the aggregate. The aggregate of each specimen is heated until it reached 170º C before adding the PET. The duration and heating temperature were chosen based on literature review from reference [29]. This temperature is sufficiently hot to melt the PET with a particular size of 2 mm-10 mm to such an extent that it would stick to the aggregate surfaces and leave a textured PET surface with a bond between the coated aggregates. A comparative analysis on BC mixes containing PCA using PET. For each aggregate gradation and content of bitumen at least three specimens are needed. The physical properties of modified mixtures such as Air voids (Va), Voids of mineral aggregate filled by bitumen (VFB), Voids in mineral aggregate (VMA), and flow values are calculated.

3. RESULTS AND DISCUSSIONS

The study results showed a higher stability and VMA percentage of the modified mixture relative to the traditional mixtures. This would have a positive influence on these Mixtures’ rutting resistance. Each compacted test specimen is subjected to the following tests and obtained results are shown in Table 3. As a result, it can be inferred that applying PET to coat the aggregate will play a significant role in enhancing mechanical properties of pavements in terms of reduced rutting and cracking susceptibility. Marshall Stability was also found to be higher for a changed mix than an traditional one.

Table-3 Marshall stability-flow and volumetric characteristics results of Traditional and modified BC mix

| Composition | Marshall Stability (kN) | Marshall Flow (mm) | Bulk Density (g/cc) | % Air Voids | VMA(%) | VFB (%) |
|-------------|-------------------------|--------------------|---------------------|-------------|--------|---------|
| Testing Method | Asphalt Manual MS-2 Seventh Edition | | | |
| 'TM | 100% B | 10.2 | 3.5 | 2.362 | 3.6 | 15.8 | 74.90 |
| BM1 | 97% B + 3% P | 9.3 | 2.7 | 2.347 | 3.2 | 16.3 | 86.70 |
| BM2 | 95% B + 5% P | 9.7 | 2.9 | 2.356 | 3.3 | 16.4 | 80.00 |
| BM3 | 93% B + 7% P | 10.4 | 3.3 | 2.369 | 3.7 | 16.5 | 77.20 |
| BM4 | 91% B + 9% P | 9.2 | 3.4 | 2.351 | 3.8 | 16.6 | 77.00 |
| BM5 | 89% B + 11% P | 9.1 | 3.7 | 2.364 | 3.7 | 16.2 | 76.90 |
| 'MORT H (V Revision-2013 Specificatio ns) | BC Grade-2 | >9 | 2–4 | – | 3–6 | >12 | 65-75 |

B-Bitumen, P-Plastic, Optimum mix in bold

3.1. Marshall Stability and flow value

Analysis of Marshall Stability on both unmodified and modified mixes was carried out. Stability value obtained from average of three samples prepared for each mix. Stability-Flow and Volumetric
analysis was performed on Traditional Mix and modified mixes of Bituminous Concrete. Traditional Mix Stability value (5.5 per cent by weight of total mix) is 10.2 kN, which meets the minimum BC mix stability requirement. The maximum stability value was obtained for by BM 3 (10.4) is considerably higher than the unmodified mix. These result values indicate that modified binder mix with plastic waste provides better stability than traditional bituminous mix. For almost all the adjusted blends, the stability values obtained are higher than unmodified mix. The stability and flow tests are conducted after evaluating the bulk-specific gravity of the test specimens. In each sequence, the flow value of bituminous mixes is observed to grow with an increase in percentage replacement by waste additives. Unmodified mix flow value is 3.5 mm, while adjusted mix flow value i.e. BM3 is 3.3 mm within the specified limit of 2–4 mm. Also within defined limit is the flow value of the optimum adjusted mix.

3.2. Density and voids analysis

After the stability and flow check has been completed, a density and voids study for each collection of specimens is carried out. For each bitumen material, average the determinations of the bulk density. Unmodified mix bulk density is 2.362 g / cc. The maximum value of bulk density was obtaining 2.369 g / cc for BM3. Density values of the modified mix found to be higher than unmodified mix. Air voids were found to be 3.6% in the unmodified BC mix, well within the acceptable limits as per MORTH, 2013. In modified mixes, the percentage of total air voids increased. In the unmodified mix, VMA are found to be 15.8% that is within specified limits that depend on the aggregate size. The cumulative VMA increased with the partial percentage of waste additives.

It can be found that the stability value always increases up to certain limits with the addition of modifiers, and further addition reduces the stability. This may be due to excessive quantities of additive which cannot be properly dissolved in bitumen. Thus it was found that maximum stability at 7% of PET at optimum bitumen content, varying content of modifiers. It is observed that with the rise in the flow value of the binder material but with the addition of modifier flow value decreases than that of traditional mixes. The experimental results from this analysis illustrate the benefit of using PET for coating the aggregate. It has been determined that PET exhibited reduced temperature sensitivity with increased additive content, according to traditional bitumen studies. Significant differences were found above 7% PET in the modified mixes. Such values can be seen as thresholds for the transition to higher performance properties.

4. COST ANALYSIS

Cost analysis of the modified and unmodified bituminous concrete mix was conducted on a pavement section as per IRC37:2012 and findings are presented in Tables 4 and 5.

Table 4 The cost analysis data for the concept.

| Sr. No. | Design data               | Values   |
|---------|---------------------------|----------|
| 1.      | Collective no. of standard axles | 150 msa |
| 2.      | No. of lane               | 1 (one)  |
| 3.      | Length of pavement        | 1 Km     |
| 4.      | Width of pavement         | 3.5 m    |
| 5.      | Thickness of pavement     | 40mm     |
Table 5 Cost reduction of Traditional and Modified mix developed

| Composition | Bitumen Cost | BC layer thickness/length | Cost Reduction |
|-------------|--------------|----------------------------|----------------|
| Units       | lakhs        | 40 mm/1 km                 |                |
| CM          | 6.39         |                            |                |
| BM1         | 6.20         |                            | 2.97           |
| BM2         | 6.07         |                            | 5.07           |
| BM3         | 5.95         |                            | 6.66           |
| BM4         | 5.82         |                            | 9.04           |
| BM5         | 5.69         |                            | 11.11          |

The results showed that partial replacement of bitumen by PET to coat the aggregates contributes to improving strength, density of the mix itself. Higher value of density mixing gives better efficiency for build pavements. However, the estimated mix cost analysis revealed that the use of PET as additives in BC mix provide better solution to construct roads and makes them more economical than unmodified mixes.

5. CONCLUSIONS

The following conclusions are drawn on the basis of the experimental investigation:

- The results indicate that PET can be used as modifier to coat the aggregate to improve the binding property of the mix and reduce porosity.
- The use of waste plastic bottles, PET by providing suitable plastic coating over it by Dry Method in roads can solve the problem of environmental pollution that their dumping can cause.
- The Optimum Bitumen Content (OBC) for traditional mix was found to be 5.5% (by weight of total mix) and the Optimum Plastic Content (OPC) for PET to be added as a modifier of bituminous concrete mix was found to be 7% weight OBC of BC mix.
- Bituminous concrete mix modified with PET coated aggregates showed considerable higher Marshall Stability and flow value as compared to traditional BC mix.
- Various products that become waste after their single use as polythene bags and plastic wrapper and bottles, can be used as partial substitutes in bituminous concrete mixtures that can help meet the increasing demand for bitumen in road construction.
- Physical properties of PCA were improved noticeably as compared to conventional aggregates, so that way plastic road is economical and having less maintenance as compared to traditional roads.

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