Characteristics of Polymer Modified Reclaimed Bitumen and Aggregate as a Sustainable Pavement Material

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Abstract. Infrastructure development in a country depends on the development of road network. In a developing country like India construction of pavements forms the integral part of infrastructure development. The most common material used for the construction of pavements is hot mix asphalt (HMA). The demand for this material is very high and at the same time due to maintenance of pavements lot of used paving material is wasted. This paper deals with the characteristics of reusing the reclaimed materials as construction materials in the construction of pavements. Experimental investigations were conducted to study the properties of aggregate and bitumen that are reclaimed. The test results on the reclaimed material were conducted and it was found to be suitable to be reused for the pavement construction. Systematic proportioning of the reclaimed material with the virgin material was investigated and the results show that the reclaimed materials performed equally well as the virgin material. The cost analysis for using these recycled materials is also calculated, in order to highlight the advantage of using the recycled material.

Key words— Binder content, stability, gradation, ductility, penetration

1. Introduction:
The concept of using sustainable materials in construction is the recent research focus. In this aspect materials that are considered waste and some by-products from Industry like fly ash, slag, crusher dust and bottom ash, which are generated in enormous quantities are finding use as construction materials. Many experimental results are available by the use of these materials in construction field. Apart from these industrial by products, many materials that are demolished are reused as building materials. In that way reclaimed asphalt is one of material that can be potentially used as a paving material. Reclaimed bituminous mix is the material obtained from pavement surface removed for maintenance or repair. It can be separated into bitumen and aggregates. These materials are obtained when the pavement surface is digged for burying pipes or other underground utilities. The quantity of reclaimed bitumen is enormous and is wasted by piling it up along road sides. If these materials can be reused then we can conserve the virgin material for future use thereby preventing the source from depleting. Many researchers have given exceptionally good results using the reclaimed asphalt as a paving material which has proved that this material can be used advantageously. A recent study that was published by National Asphalt Pavement Association (NAPA) has stated that about 99% of the reclaimed asphalt has been reused. As a result of reusing reclaimed asphalt 20.5 million barrels of asphalt binder has been conserved in 2010 [1]. Many countries allow the use of reclaimed asphalt in the base course and surface course as much as 10 to 25% [2]. Use of reclaimed asphalt has both economic and environmental benefits.
The need for the use of virgin material will get reduced thereby proving it to be an economical solution [3], [4], [5]. Also use of reclaimed material will avoid dumping of waste material resulting in reduction in landfill [4]. Use of reclaimed asphalt mixes has also proved to improve the performance of pavement characteristics like rutting resistance, fatigue life, moisture resistance and overall pavement performance compared to the virgin material [6], [7], [8]. The behavior of pavement materials with high content of recycled asphalt in the pavement was also reported [9]. The effect of dynamic modulus on mixes with higher recycled asphalt shingles (RAS) was studied and it proved to be stiffer compared to conventional virgin mixes. Similarly the dynamic modulus, cracking and rutting of HMA with RAS was reported [10], [11]. It was proved that by the addition of RAS to HMA there was improvement in the stiffness of the mix and resistance to rutting. A laboratory study was conducted to investigate the use of HMA with 0 to 30% of RAP and reported that increase in RAP content improved rut resistance, fatigue life and increased the tensile strength[12]. The durability characteristics of asphalt mixes with different percentages of recycled asphalt pavement (RAP) was studied using various laboratory tests [13]. Recent research has also focused on a mechanics-based approach for quantification of damage of asphalt mixes caused due to accumulation of moisture [14], [15], [16]. Recycling of wiped out pavement surface has been successfully practiced in a number of the developed nations and therefore the research remains under reach analyze various properties of the combination. This work presents some detailed material properties of reclaimed asphalt and reused aggregate as pavement material and the relative economic benefits in using these recycled materials.

2. Materials and Methodology
The materials used in this study are grade II aggregate and virgin VG-30 bitumen for conventional mix design. Reclaimed bitumen that was dugged out from a NH and dumped along the road side was used as recycled material and bitumen was extracted using the equipment given in figure-1. The waste material and the processed aggregate after removal of bitumen is shown in figure-2. The normal bitumen design is done and the properties of the normal bitumen with that of the reclaimed bitumen are compared. The bituminous mix is designed with the help of grade II aggregate and VG-30 bitumen. The properties of the bitumen are found by the tests such as ductility, penetration and softening point. The properties of the aggregate are found by the specific gravity test and gradation test results for the conventional VG-30 bitumen are given in Table-1. Marshal mix design was adopted for the design mix and the test results of the bitumen mix are given in table-2.

| S. No | Property                          | Criteria as per MORTH Revision | Test Results at Optimum Binder Content |
|-------|----------------------------------|--------------------------------|---------------------------------------|
| 1     | Stability in Kgs                 | 921                            | 2081                                  |
| 2     | Flow in mm                       | 2-4                            | 3.02                                  |
| 3     | Voids in mix (%)                 | 3-5                            | 4.12                                  |
| 4     | Voids in aggregate filled with bitumen | 65-75                   | 75.23                                  |
| 5     | VMA                              | 14 minimum                     | 15.81                                  |
| 6     | Binder content by wt of Mix (%)  | Sp. Gr 2.61                    | 5.41% 5.3                             |
| 7     | Binder content by wt of Agg. (%) | -                              | 5.42                                  |
Then the reclaimed bituminous mix is separated into bitumen and aggregate using the Ignition Type Binder content Tester. A mix design with hundred percentage of reclaimed aggregate and small amount of virgin bitumen was made and its optimum binder content was noted. Similarly a mix design with fifty percentage of reclaimed aggregate and small amount of virgin bitumen was studied. Finally the reclaimed bitumen modified with polymer was made and its optimum binder content was noted. Reclaimed polyethylene of 2.5 % was found to be optimum to improve the bitumen properties. The comparison between the normal and reclaimed bituminous mix was done and results were evaluated. The gradation of aggregate with 50 % reclaimed aggregate and 100 % reclaimed aggregate are shown in Figure-3.

The resistance to plastic deformation was investigated using Marshal method of mix design in which the compacted cylindrical specimens were subjected to loading at the rate of 50 mm /min. Marshal method is used to analyze the relationship between density-void ratio and stability - flow test. The maximum load that the specimen can withstand at 60°C is defined as the Marshal stability and the deformation of the specimen is taken as the flow value. This method is used to find the optimum binder content for the type of aggregate gradation used. A particular aggregate grading is to be selected and the proportion of each aggregate size required to produce the design grading is to be found. The specific gravity of the aggregate in combination with the bitumen content is determined. The trial
specimens are prepared with varying bitumen content and the specific gravity of the compacted specimen is determined.

![Figure-3 Gradation of aggregate](image)

**Figure-3 Gradation of aggregate**

3. Results and Discussions

Marshall stability and flow test are the performance indices of the bituminous mix. The aggregate and filler of 1200 gm are heated to 175°C. About 5% of bitumen is heated to 125°C. The bitumen and aggregate are mixed at 160°C and placed in a preheated mould of size 10 cm diameter and 7.5 cm height fitted and compacted with 50 blows on either side to achieve a compacted thickness of 63.5 mm. Similarly the specimens were prepared with various bitumen contents of 5.5%, 6 % and 6.5%. The percentage of voids and the voids filled with bitumen are calculated by conducting stability tests. Optimum binder content is selected from these trials. The design is evaluated from the obtained data. The prepared specimen is placed in a water bath at 60°C for about 30 minutes. Then the specimen is placed in the Marshal Stability testing machine and the rate of loading applied is constant so that the deformation is 5 mm per minute before failure. The load at which the specimen fails is taken as the Marshal stability value.

![Figure-4 Void content with 50% reclaimed aggregate](image)

**Figure-4 Void content with 50% reclaimed aggregate**
The deformation that occurs at the failure load is taken as the flow value. The test should be completed within 30 seconds after the specimen is removed from the water bath. The percentage of voids between the aggregates including the air voids are calculated as the percent voids. The voids % as shown in Figure-4 is found to gradually decrease as the binder content was increased from 5 to 6 %. But further increase in the binder content increased the void % from 2 to 5 %. The % of voids filled with bitumen as shown in figure-5 was found to increase from 58 % to 79 % as the binder content was increased from 5 % to 6.5 %. When 100 % reclaimed aggregate was used the % voids as in figure-6 was found to decrease from 8.5 % to 4 % with increase in binder content from 5 % to 6.5 %. Similarly figure-7 shows that the % voids filled with bitumen was found to increase from 55 % to 78 % with increase in binder content when 100 % reclaimed aggregate was used.

![Figure-5 Void content after filling with bitumen with 50 % reclaimed aggregate](image1)

![Figure-6 Void content with 100 % reclaimed aggregate](image2)
The next set of experiments is involved with using reclaimed bitumen and using polyethylene in different percentages to improve the properties of reclaimed bitumen. The amounts of polyethylene bags are enormous in a country like India which is the main source as a packaging material. The disposal of polyethylene bags poses a great threat to the environment because it causes pollution of land and water bodies and also burning these polyethylene bags poses a threat to the environment causing air pollution. Hence, it finds a great use in the construction of bitumen pavements. Many researchers have worked on the use of plastics in bituminous road pavements and also have proved that it offers better properties. An attempt has been made in this work to improve the properties of reclaimed bitumen using polyethylene in various dosages to improve the properties.

The properties were compared with reclaimed bitumen without addition of polyethylene in terms of marshal stability value and flow value. LDPE (low density polyethylene bags) were cut into pieces of approximately 300 to 350 mm size. The density of the material was 0.95 gm/cc. Aggregates gradation conforming to grading I as suggested by IRC was used in this study. The size of the aggregate ranged from 20 mm to 0.6 mm. The polyethylene fibres were mixed for 20 minutes at 2500 rpm and to get a homogenous mix. Depending upon the percentage of polyethylene binder the temperature of binder formation was increased from 160 to 200°C. Marshal stability was conducted for the specimens as...
discussed and the results are given in figure-8. The marshal stability was found for specimens with conventional bitumen without any additive and the polyethylene content was increased from 2.5 % to 10 %. The % void was found to decrease with increase in PE % to the reclaimed bitumen (figure-9).

From Table-3 the Marshall Properties values for the specimen of BC Grade-II vary with the variation in percentage of RAP content. The stability value for the mix at 50 % RAP was 17.87 kN, 100 % RAP was 17.82 kN which are within limit. Addition of RAP content decreases the stability values. The 50 % RAP shows good result compared to fresh mix with decreased air voids than the fresh mix which had virgin bitumen alone. Increase in binder content decreases the air voids. The voids filled with asphalt (VFA) are increased with increase in the binder content. From the table it is noted that optimum bitumen content obtained for RAP mix and fresh mix for BC grade-II was different at different percentage of RAP content. From the table-3 it is also noted that both the RAP mix can be used for road construction, but the main difference is that the amount of Bitumen used in the 50 % mix is greater than the 100 % mix.

**Table-3 Comparison of properties**

| Properties                      | Requirements | Test Results of 0% RAP | Test Results of 50% RAP | Test Results of 100% RAP |
|---------------------------------|--------------|------------------------|-------------------------|--------------------------|
| Optimum Binder Content          | Min 5.4%     | 5.58                   | 5.70                    | 5.90                     |
| Compaction Level                | 75 blows     | 75 blows               | 75 blows                | 75 blows                 |
| Minimum Stability(KN)           | 9            | 20.57                  | 17.87                   | 17.82                    |
| Marshall flow (mm)              | 2-4          | 3.05                   | 2.92                    | 3.21                     |
| %Air voids                      | 3-5          | 4.15                   | 3.97                    | 4.16                     |
| %voids filled with bitumen      | 65-75        | 74.94                  | 76.02                   | 75.70                    |
### Table-4 Cost analysis report for the 0, 50, 100 % RAP

| Materials            | Vol. in m³ | Cost of 0% RAP | Cost of 50% RAP | Cost of 100% RAP |
|----------------------|------------|----------------|-----------------|------------------|
| 19mm And down size aggregate | 0.063      | 105            | 52.5            | 20               |
| 13.2mm And down size aggregate | 0.072      | 84             | 42              | 15               |
| 6.7mm And down size aggregate | 0.107      | 100            | 50              | 15               |
| 2.36mm And down size aggregate | 0.244      | 216            | 108             | 30               |
| VG30 Grade bitumen   | 50.364 (kg)| 1648           | 1648            | 1648             |
| **Total cost**       |            | **2153**       | **1900**        | **1728**         |

RAP being cost effective also does not decrease the pavement performance. Surface distresses will not occur because of the use of RAP. Based on the cost analysis described in this paper, when RAP was included in the Mix, it offered a good amount of savings in the road application. For every 10 m² of road, Rs.425 was saved when 100% RAP was used and Rs.253 when 50% RAP was used. This analysis shows that regardless of the construction, use of RAP will give an economic solution.

### 4. Conclusions:

The results obtained from the study have been used to derive the following conclusions:

(i) Based on recycled aggregate properties result, it shows all test result for both 50 and 100% RAP are within specification limits and it can be used for further tests.

(ii) The Marshall Stability Values for mixes prepared with RAP material of 0%, 50% and 100% shows all the Marshall Test values of the mixes are well and within the specified limit.

(iii) It has also been seen that there was very less difference in the Marshall Properties values of different percentage of RAP mixes. The Laboratory prepared mixtures containing RAP tend to have slightly lower Stability than those from control mixtures without RAP.

(iv) Specimen prepared with Fresh Mix (0% of RAP) sample has less Air Void value than specimen prepared with RAP mixes, thus it indicates that Air Voids value goes on increased while increasing the RAP content.

(v) PE modified reclaimed binder has a potential use as a paving material with improved performance.

(vi) Use of recycled material can reduce the cost of construction without compromising the strength properties.

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