Sustainable materials in the production of pavement base and subbase courses

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Abstract. The use of sustainable materials in construction is the need of the hour amidst the depletion of natural resources at a rapid rate. The significance of green roads is increasing day by day and green approach for road construction can be only achieved by the use of sustainable construction materials. In the present study, an effort has been made to make base and subbase courses sustainable using Reclaimed Asphalt Pavement (RAP) and Ground Granulated Blast Furnace Slag (GGBS) along with a very less quantity of cement. RAP used in the present study was obtained from the in situ milling of NH-16 at Srikakulam. To meet the gradation requirements as per IRC Ground Granulated Blast Furnace Slag (GGBS) was used along with RAP. Upon initial trial tests, it was concluded that unbound specimens made with RAP and GGBS have failed to meet the minimum unconfined compressive strength (UCS) requirements as per IRC: SP-89:2010 due to which cement by weight of 2% of total mix was added to meet the UCS requirement of 4.5 MPa at seven days. The optimum proportion of RAP that can be used to replace virgin aggregate (VA) was found to be 30% based on UCS test results. The durability studies of GGBS stabilized RAP/VA mixes were found to be satisfactory. The retained strength of the samples after durability studies is 91.43% which is greater than 80% as specified by IRC: SP-89:2010.

1. Introduction
Reducing the damage caused during the extraction and manufacturing of conventional construction materials and conserving them for future generations without compromising the present needs is the key to sustainable development. The damage reduction due to the extraction and manufacturing of conventional construction materials can only be achieved after an extent by reducing their usage in construction. For reducing the use of conventional construction materials and thereby reducing their implications on environment recycling is one of the ways forward. The use of recycled materials in construction is not a new development but solutions for overcoming the ill effects due to the use of recycled materials as a partial substitution for conventional materials is certainly an area where significant research is required. This kind of research will promote the use of recycled materials in construction thereby contributing to less use of conventional materials thereby reducing pollution created by extraction and manufacture of conventional construction materials, saving cost, giving an answer to their disposal problems, etc. RAP is the material obtained during the process of milling an old pavement surface. It consists of aggregates coated with bitumen fragmented by the process of milling. The major challenge for using RAP as a construction material is the presence of an aged and oxidized bitumen layer over the RAP aggregates. This layer prevents establishing a bond between RAP and any other material. GGBS, on the other hand, is an industrial by-product generated during
the manufacture of steel in the blast furnace at steel plants. RAP can be an excellent pavement construction material when properly blended with suitable material for its application in various courses of flexible pavements [3]. RAP is an inferior material compared to VA and can be only used and partial replacement for VA or has to be used besides binders like cement [8]. If cement is not an economically viable solution mineral admixtures like Fly ash and other slags can also be used along with RAP for improving its properties [11]. Utilization of RAP and its extraction not only saves the economy but also keeps in limit the rise in height of the pavement over years due to resurfacing on the old pavement [1]. Durability is a property that defines the resistance offered by material for damage caused by the surrounding environment [5].

2. Materials used

2.1. Reclaimed Asphalt Pavement material

RAP used in the present study was obtained from in situ-controlled milling of 50 mm thick surface course NH-16 at Srikakulam where the existing four lanes are being upgraded to six lanes national highway. RAP consists of aggregates both coarse and fine coated with bitumen which in most cases is aged and oxidized. The major challenge in using RAP is this oxidized and aged layer of bitumen which prevents bonding. Both fine and coarse fractions of RAP are used in the present study for casting the specimens. Sieve analysis of RAP was performed to check its suitability as per the gradation requirements of base and subbase courses of pavements specified in MORTH Section-400. It was observed from the grain size distribution of RAP that certain fractions specified in MORTH gradation for base and subbase courses were missing in the RAP collected. The grain size analysis is presented in the following table 1.

| Sieve size | Retained weight | % of retained | Cumulative % of retained | % of passing |
|------------|----------------|---------------|--------------------------|--------------|
| 26.4       | 0.9            | 2.3           | 2.3                      | 97.7         |
| 20.0       | 1.2            | 3.0           | 5.3                      | 94.7         |
| 4.8        | 31.0           | 76.8          | 82.2                     | 17.8         |
| 600.0      | 6.0            | 14.7          | 96.9                     | 3.1          |
| 75.0       | 1.3            | 3.1           | 100.0                    | 3.6          |

2.2 Cement

Ordinary Portland cement of grade 43 in compliance to IS 8112 was used in the study. Basic tests like initial setting time, final setting time, soundness, consistency, fineness are determined to ensure that it qualifies for the specified limits as per IS 4031. The results were presented in the following table 2.

| Sl. No. | Name of test            | Value Obtained | Specified Limit |
|---------|-------------------------|----------------|-----------------|
| 1.      | Initial Setting Time    | 42 min         | >30 min         |
| 2.      | Final Setting Time      | 290 min        | <10 hrs         |
| 3.      | Consistency of Cement   | 30%            | 27% – 32%       |
| 4.      | Specific Gravity of Cement | 3.1          | 3.0 -3.2        |
| 5.      | Soundness of Cement     | 3 mm           | <10 mm          |
| 6.      | Fineness of Cement      | 2%             | <10%            |

2.3 Virgin Aggregates

The natural aggregates used in the present study were collected from a quarry near Palakonda, Andhra Pradesh of maximum nominal size 26.5mm as specified in MORTH Section-400 for base and subbase courses. Aggregates were tested for abrasion, impact, crushing and specific gravity as per IS 2386 PART IV-1963 and were presented below in the following table 3.
Table 3. Test results for virgin aggregate and RAP.

| Sl. No. | Name of Test                  | Virgin Aggregate | RAP     |
|--------|-------------------------------|------------------|---------|
| 1      | Aggregate impact test         | 28.19%           | 16.94%  |
| 2      | Aggregate crushing test       | 20.3%            | 16.65%  |
| 3      | Los Angeles abrasion test     | 23.68%           | 26.12%  |
| 4      | Aggregate specific gravity test| 1.96             | 1.97    |
| 5      | Aggregate Water Absorption    | 1.01%            | 0.39%   |

Figure 1 shows the reclaimed asphalt pavement material.

Figure 1. Reclaimed Asphalt Pavement Material.

It can be observed from the test results that except abrasion value RAP perform better than virgin aggregates in terms of mechanical properties which can be attributed to the presence of hard oxidized and aged bitumen coating on the aggregate surface. Water absorption of RAP also was observed to be less than of the conventional aggregate because of the same reason.

2.4 GGBS

GGBS collected from Auto Nagar, Visakhapatnam with the source of steel plant located at Vishakhapatnam is used in the study. GGBS is a by-product of iron ore mixed with limestone and coke and burned in the blast furnace. The slag is then quenched from blast furnace and results in the formation of granules which are then ground to granules to a desired fineness and then used in concrete. Some properties of GGBS and Cement are similar. So, it was used to replace some percentage of cement in construction. It acts as a sustainable material and decreases pollution. GGBS reduces the heat of hydration and also the formation of early aged cracks. It also reduces chlorine and sulfate attacks. In this study, we tested the mix of GGBS, RAP by adding 2% to 4% of cement for using in base and subbase courses of pavements. Grain size analysis was performed for GGBS and is presented in figure 2 and table 4.

Figure 2. Ground Granulated Blast Furnace Slag at the site.
### Table 4. The grain size distribution of GGBS.

| Sieve size | Retained weight | % retained | Cumulative % retained | % passing |
|------------|----------------|------------|-----------------------|-----------|
| 4.75mm     | 0.00           | 0.00       | 0.00                  | 100.00    |
| 2.36mm     | 0.00           | 0.00       | 0.00                  | 100.00    |
| 1.18mm     | 0.00           | 0.00       | 0.00                  | 100.00    |
| 600microns | 0.06           | 6.02       | 6.02                  | 93.98     |
| 425microns | 0.20           | 20.08      | 26.10                 | 73.90     |
| 300microns | 0.27           | 27.11      | 53.21                 | 46.79     |
| 150microns | 0.12           | 11.65      | 64.86                 | 35.14     |
| 90microns  | 0.28           | 27.91      | 92.77                 | 7.23      |
| 75microns  | 0.07           | 7.23       | 100.00                | 0.00      |

**Figure 3.** Ground Granulated Blast Furnace Slag gradation curve

### 2.5 Research Objectives
To determine the optimum proportion of RAP to replace with virgin aggregate for base and subbase course of pavements.

To assess the durability of cement-treated RAP and GGBS for base and subbase courses.

### 3. Methodology
The specimens of size 100 mm × 200 mm cylinders were cast and cured through moist curing for 7, 14 and 28 days and were tested for UCS are shown in the following figure 4. The flow chart shown in figure 5 depicts how this experimental study is conducted. As per the guidelines formulated for base and subbase courses in IRC 37-2012 the specimens should attain a minimum unconfined compressive strength of 4.5 MPa after curing for 28 days.

**Figure 4.** Moist curing of UCS samples by wet cloth wrapping
For blending RAP and GGBS to achieve the gradation specified in the MoRTH section -400 trial and error method was employed and a ratio of 70:30 for RAP to GGBS is fixed in this study. This trail and error method also satisfied with the 80:20 ratio of RAP to GGBS and results of the trial and error method of gradation are given in the following table 5. Initially, the trial test has been made for unbound base courses and subbase courses without cement using 70:30 ratio of RAP and GGBS but
they failed to reach the minimum UCS of 4.5MPa so cement was added starting with 2% in increments of 1% up to 4% by weight of the total mix. The UCS values for 2% addition of cement itself have satisfied the minimum UCS value hence it was adopted for further study. Initially, a compaction test was conducted for virgin aggregates and GGBS mix to determine optimum moisture content. Later RAP was used to replace virgin aggregates in the mix starting with 100% in decrements of 10% up to 60%.

Table 5. Gradation of RAP and GGBS.

| SI No. | Sieve Size | Grad. % as per MORTH | RAP Gradation % | GGBS Gradation % | 70% virgin Aggregate | Combined Gradation % | 80% RAP | 20% Virgin Aggregate | Combined Gradation % |
|-------|------------|-----------------------|-----------------|------------------|----------------------|---------------------|--------|----------------------|---------------------|
| 1.    | 26.5 mm    | 100                   | 97.7            | 100              | 68.3                 | 30                  | 98.3   | 78.1                 | 20                  | 98.2               |
| 2.    | 22.4 mm    | 50-100                | 94.6            | 100              | 66.2                 | 30                  | 96.2   | 75.7                 | 20                  | 95.7               |
| 3.    | 4.75 mm    | 35-55                 | 17.8            | 100              | 12.4                 | 30                  | 42.4   | 14.2                 | 20                  | 34.3               |
| 4.    | 600µm      | 10-30                 | 3.1             | 93.97            | 2.1                  | 28.1                | 30.3   | 2.4                  | 18.7                | 21.3               |
| 5.    | 75µm       | 2-5                   | 3.6             | 3.11             | 2.5                  | 0.9                 | 3.4    | 2.8                  | 0.622               | 3.5                |

4. Results and discussion

4.1 Durability Test

The durability of specimens was calculated based on the procedure outlined in IRC SP 89-2010. There are two methods outlined for assessing the durability of base and subbase courses in which method 1 was adopted in this study. Two sets of specimens each set coning three UCS samples were considered for durability testing. Initially, both sets of specimens were cured at constant moisture content for 7 days after which one set was continued to cure at constant moisture content and another set was submerged in water till 14 days. At the end of 14 days both sets were tested for UCS and the percentage of unconfined compressive strength of set submerged in water to that of constant moisture curing is calculated and this parameter is treated as a measure of the durability of that respective mix. The test results of durability for different proportions of RAP replacing VA were presented in table 6. The resistance to water on strength was determined by calculating the percentage of strength achieved by constant moisture curing to that of immersion curing. As per the recommendations of IRC SP 89-2010, this percentage should be greater than 80% and the mix with only 80% RAP and 20% VA exhibited slightly less than 80% and other mixes exhibited good durability.
### Table 6. Durability test results.

| Mix ID | % of RAP | % of conventional aggregate | Compressive Strength for Moisture Curing (N/mm²) | Compressive Strength for Water Curing (N/mm²) | Percentage of UCS immersed in water to that cured at constant moisture content |
|--------|----------|----------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------------------------------------------------|
| 1.     | 80       | 20                         | 7.32                                          | 5.72                                          | 78.14                                                                         |
| 2.     | 70       | 30                         | 9.12                                          | 7.64                                          | 83.77                                                                         |
| 3.     | 60       | 40                         | 10.33                                         | 9.22                                          | 89.25                                                                         |

**Figure 7.** Bar chart showing durability test results.

**Figure 8.** Line showing percentage of UCS immersed in water to that cured at constant moisture content.
4.2 Unconfined compressive strength test
UCS test was performed on cylindrical specimens of size 100mm×200 mm following the procedure outlined in IRC SP 89-2010. The results of the UCS test were presented in the following Table 7. ALL the mixes after the addition of cement have exhibited the minimum UCS value of 4.5MPa at 28 days but unbound mixes have failed to reach the minimum UCS value. Although cement addition was done up to 4% in the bound mixes, the mixes with 2% cement addition itself have satisfied the minimum UCS requirement and hence that was adopted as an optimum percentage of cement in the mix. With a decrease in the percentage of RAP used for replacing VA unconfined compressive strength has increased which can be observed in the results presented in table 7. The maximum percentage of RAP that can replace VA is found to be 80% since the UCS value exhibited by this proportion of RAP has crossed the minimum UCS value of 4.5 MPa needed for base and subbase courses.

| SL. No. | % of RAP | % of conventional aggregate | % of cement added | UCS (MPa) |
|---------|----------|-----------------------------|-------------------|-----------|
|         |          |                             |                   | 7 days    | 14 days | 28 days |
| 1.      | -        | 100                         | 0                 | 3.12     | 3.73    | 4.12    |
| 2.      | -        | 100                         | 4                 | 10.72    | 14.1    | 20.56   |
| 3.      | -        | 100                         | 3                 | 10.59    | 13.33   | 16.82   |
| 4.      | 100      | -                           | 0                 | 2.41     | 2.82    | 3.21    |
| 5.      | 100      | -                           | 2                 | 3.40     | 3.92    | 4.32    |
| 6.      | 80       | 20                          | 2                 | 4.72     | 5.34    | 7.32    |
| 7.      | 70       | 30                          | 2                 | 5.79     | 8.32    | 9.12    |
| 8.      | 60       | 40                          | 2                 | 6.32     | 8.56    | 10.33   |

Table 7. UCS test results.

5. Conclusions
1. The mechanical properties of RAP like crushing value, impact value are better than Virgin Aggregate (VA) due to the presence of a layer of oxidized and aged bitumen on the aggregate surface.
2. Based on initial trial test results it was found that unbound RAP and GGBS samples did not meet...
the minimum UCS of 4.5 MPa at 28 days and this made cement addition mandatory for RAP-GGBS mixes to attain the required UCS as per IRC SP 89:2010.

3. The durability studies of GGBS stabilized RAP/VA mixes performed satisfactorily except the mix with 80% RAP and 20% VA. The retained strength of other mixes after durability studies is greater than 80% as specified by IRC: SP-89:2010.

4. The maximum proportion of replacement of RAP with Virgin Aggregate is 80% since the mix at this percentage of replacement attained the minimum UCS required for base and subbase courses.

5. Overall, it was observed that GGBS treated RAP and Virgin Aggregate with 2% addition of cement can be utilized effectively for base and sub-base courses of pavements for making them economical as well as sustainable.

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