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Strength and Rutting Characteristics of WBM with Partial Replacement of Aggregates by Steel Slag

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Abstract: *Water Bound Macadam (WBM) is widely used as sub-base or base course for National and State highways and also as a wearing course for low volume roads. WBM consists of mixture of conventional aggregates, a binder and screenings (fines). Usually moorum is used as screenings and quarry dust as binder.*
The present paper, brings out the results of experimental investigation of strength and rutting characteristics of two WBM mix consisting of expansive soil as binder, steel slag as fines and conventional aggregates with and without steel slag.
An indigenously built (patent pending) equipment Roller Compactor cum Rut Analyzer (RCRA) was used to perform rutting tests on both WBM combinations. Results indicated that Partial replacement of conventional aggregates by steel slag resulted in 10% rise in MDD, 52% increase in CBR value and 18% improvement in resistance against rutting.

Keywords: *CBR, RCRA, Rut depth, Steel Slag, WBM.*

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I. Introduction

As per the Indian census of 2010-11, 68% of population resides in rural areas. An uninterrupted connectivity by means of all weather roads is necessary for socio-economic development of rural masses. Among various types of highways: NH, SH, MDR, ODR and VR; it is ODRs and VRs which provide comprehensive and extensive connectivity to rural areas and are accordingly termed as rural roads. Type of pavement for construction of low volume roads is based on cumulative ESAL applications over design period. When ESAL applications are less than 10000, an earthen road is preferred, for 10000-100000 gravel road is opted and when ESAL applications are above 100000 but less than 1000000 WBM road with or without thin bituminous dressing is chosen or a rigid pavement is opted for.

As like any other pavement layer WBM layer is also prone to various distresses/deformations due to pumping action of pneumatic tyre vehicles along with abrasion and grinding effect of solid iron wheeled bullock carts. Rutting is one such permanent deformation which degrades riding quality and leads to failure of layer when becomes severe. In the present study, strength characteristics of WBM are evaluated by CBR test and the rutting characteristics by Roller Compactor cum Rut Analyzer (RCRA). Steel slag, an industrial waste is utilized as an alternative material for WBM. Steel slag fines are used as screenings. The coarser fraction of steel slag was used as partial replacement to conventional mineral aggregates. RCRA is indigenous equipment capable of compacting as well as performing rutting tests on pavement layers at different tyre pressures.

Figure 1: roller compactor cum rut analyzer (RCRA)

II. Literature Review

Non-Bituminous surface courses are more susceptible to permanent deformation (Rutting) than Bituminous surface courses because of unsealed surface texture. Various researchers have studied non bituminous courses while making use of different materials as reinforcements and additives.

Earlier Studies:

Madhavi Latha, et al., (2010)(1) carried out rutting studies on unpaved roads. They constructed a 2m long and 1m wide unpaved road over a subgrade prepared by in situ natural soil in the IISc campus. A scooter weighing 106kg was moved on it at an average speed of 20kmph. Different reinforcements used in the study were geotextiles, biaxial geogrid, uniaxial geogrid, geocell layer and tyre shreds. They noticed that for same thickness, geocell layer outperformed all others in terms of Traffic Benefit Ratio (TBR).

Kiran Kumar, et al., (2012)(2) indigenously built an equipment called Roller Compactor cum Rut Analyzer (RCRA) which is capable of performing both compaction and rutting on a layer. Its outstanding feature is that, it simulates field conditions of compaction and rutting in laboratory. It has a set of vertical and horizontal transducers which are capable of measuring movements and consists of a Programmable Logical Circuit with control screen for monitoring, recording and operating. Bituminous Concrete (BC) grade-2 specimens were prepared using Marshall Hammer, Superpave Gyratory compactor (SGC) and Roller Compactor cum Rut Analyzer (RCRA). SGC specimens resulted in lowest OBC followed by RCRA for the same binder and air voids. Also, SGC specimens had the highest stability, and those by RCRA were close to SGC.

Erol Tutumluer, et al., (2016)(3) conducted cyclic loading test on non bituminous layer to evaluate effectiveness of geo-synthetic fibre reinforcement in case of unpaved roads. Steel mould measuring 2x2x2m was fabricated to house pavement material to be tested. It was noted that as the thickness of granular layer increases permanent deformation decreases, where as with increase in number of cycles they noticed severe deformation. In case of geogrid reinforced layer, it was observed that nearer the geogrid from surface lesser was the permanent deformation. In both cases it was clearly evident that for initial loading cycles rate deformation is high and which decreases at later stages of loading.

Shalabi, et al., (2016)(4) evaluated the efficiency of steel slag in improving performance of local clayey soil of Saudi Arabia. Steel slag aggregates from various steel industries were collected and basic tests were performed. Clayey soil was mixed with varying percentages of steel slag, Atterberg limits, free swell index, shear parameters, compaction characteristics and CBR were obtained by experimental study. It was observed that with increase in steel slag content the treated clayed soil was observed to have a lower plasticity index and free swell index, where as Maximum Dry Density (MDD) and California Bearing Ratio (CBR) values increased.

Ramulu, et al., (2012)(5) studied influence of gradation of mix, moisture content of subgrade, field density, California Bearing Ratio (CBR) and traffic volume on rutting behaviour of Water Bound Macadam (WBM). The authors selected a total of fifteen 500m stretches spread across three districts of Andra Pradesh having different geological and climatic conditions for field studies using various destructive and non destructive methods and post data analysis using appropriate software tools they developed response models. It was noticed that closer the gradation curve to upper limit lower was the rut depth. Moisture content of subgrade was observed to have a direct relationship with rut depth where as field density had an inverse relationship.

III. Experimental Investigations

3.1 Materials: In the present study, the following materials along with notations mentioned therein are used.

Table 1: Different WBM Combinations

WBM Mix	Coarse aggregates	Screenings	Binder
WBM-A	Conventional aggregates	Steel slag fines	Expansive Soil
WBM-B	Conventional aggregates with partial replacement by steel slag	Steel slag fines	Expansive Soil

3.2 Methodology: Basic properties of conventional aggregates, steel slag and soil are evaluated followed by gradation of coarse aggregates and screenings. Modified proctor compaction test and California Bearing Ratio test are conducted for both combinations of WBM. Further, the two WBM combinations are subjected to Rutting tests at two different tyre pressures of 5.6kg/cm^2 and 6.2 kg/cm^2, in each test minimum 3 samples are tested and average value is presented.

3.3 Rutting test using RCRA: RCRA mould is properly cleaned and it's inside surface is properly lubricated. RCRA has provision to mount either compacting wheel or rutting wheel to the same frame. Initially for compacting purpose compacting wheel is mounted. Coarse aggregates are placed and spread uniformly in the mould, followed by rolling. After a certain period of time rolling is stopped, screenings are applied over this coarse aggregate layer with light application of water and rolling is resumed. Rolling continued till thickness achieved is in excess by around 5mm of required 75mm thickness. Rolling is stopped, with aid of water binder (soil) is uniformly applied over the surface and compacted to required 75mm thickness. This compacted surface is left for few hours to set/dry properly.

Compacting wheel is dismounted from frame and rutting wheel is fixed to carry out rutting test on the surface. The level of the finished surface is accurately marked and noted, rutting wheel is made to operate on the surface with application of required pressure. Rut depth is measured at regular intervals of 5 passes of rutting wheel with finished surface after compaction as datum. This is continued until a rut depth of 20mm is reached.

Properties of Conventional Aggregates: Various tests on conventional mineral aggregates were carried out as per 'Specifications for Rural Roads' by Ministry of Rural Development (MoRD) (2014) and IRC:19-2005. The values are tabulated below along with their corresponding limits.

Table 2: Properties of Conventional Aggregates

Sl.No	Parameter	IS code	Obtained Value	Prescribed limits as per MoRD & IRC:19-2005
1	Impact value of aggregate	IS:2386 Part 4	21%	< 30%
2	Los Angeles abrasion value	IS:2386 Part 4	22%	< 40 %
3	Flakiness index	IS:2386 Part 1	2%	< 15%
4	Water absorption	IS:2386 Part 3	2%	<10%
5	Crushing value of aggregates	IS:2386 Part 4	24%	<30%
6	Specific Gravity	IS:2386 Part 3	2.9	
7	Angularity number	IS:2386 Part 1	9	
8	Bulk Density	IS:2386 Part 1	15.21 kN/m^3	>11.2 kN/m^3

Properties of Steel Slag: Steel slag was obtained from Kalyani Steel Industries, Koppal, Karnataka. After separating the fines, the coarser fraction was tested in similitude with conventional aggregates as per IRC:19 guidelines for WBM. Also as per code material passing 11.2mm IS sieve is considered as fines/screenings and fraction retained on 11.2mm IS sieve is coarse fraction.

Table 3: Properties of Steel slag Aggregates

Sl.No.	Parameter	IS code	Obtained value	Prescribed limits as per MoRD & IRC:19-2005
1	Impact value of aggregate	IS:2386 Part 4	25%	< 30%
2	Los Angeles abrasion value	IS:2386 Part 4	14%	< 40 %
3	Flakiness index	IS:2386 Part 1	1%	< 15%
4	Water absorption	IS:2386 Part 3	1.12%	<10%
5	Crushing value of aggregates	IS:2386 Part 4	26.93%	<30%
6	Specific Gravity	IS:2386 Part 3	3.52	
7	Angularity number	IS:2386 Part 1	13	
8	Bulk density	IS:2386 Part 1	17.55 kN/m^3	>11.20 kN/m^3
9	Soundness	IS:2386 Part 5	0.8%	< 18% ($MgSO_4$)

Properties of Soil: Soil for present study was collected from Davangere, Karnataka. Since clayey soil is being used as a binder it was ensured that it satisfies the liquid limit and plasticity index values prescribed in IRC SP:20 Rural Roads Manual.

Table 4: Properties of Binder (Soil)

Sl.No	Property	IS code	Obtained value	Prescribed limits for Binder of WBM as per IRC SP:20
1	Specific gravity	IS:2720 Part 3	2.43	
2	Natural water content	IS:2720 Part 2	5.13%	
3	Particle size analysis Cu Cc	IS:2720 Part 4	 6.07 0.71	
4	Liquid limit	IS:2720 Part 5	40.50%	<55%
5	Plasticity Index	IS:2720 Part 5	16.36%	<30%
6	Maximum Dry Density	IS:2720 Part 8	15.40 kN/m^3	
7	Optimum Moisture content	IS:2720 Part 8	24.3%	
8	CBR	IS:2720 Part 16	3%	
9	Colour		Black	

The particle size distribution curve and modified proctor curve for the binder are shown in Fig. 2 & 3 respectively.

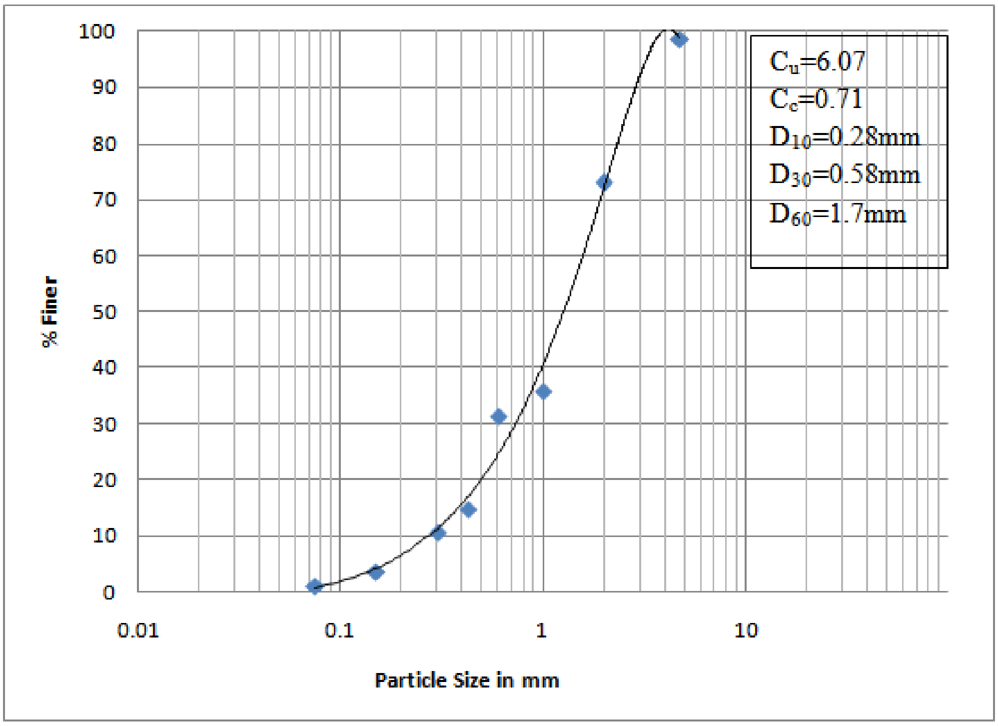

Figure 2: particle size distribution curve for soil (binder)

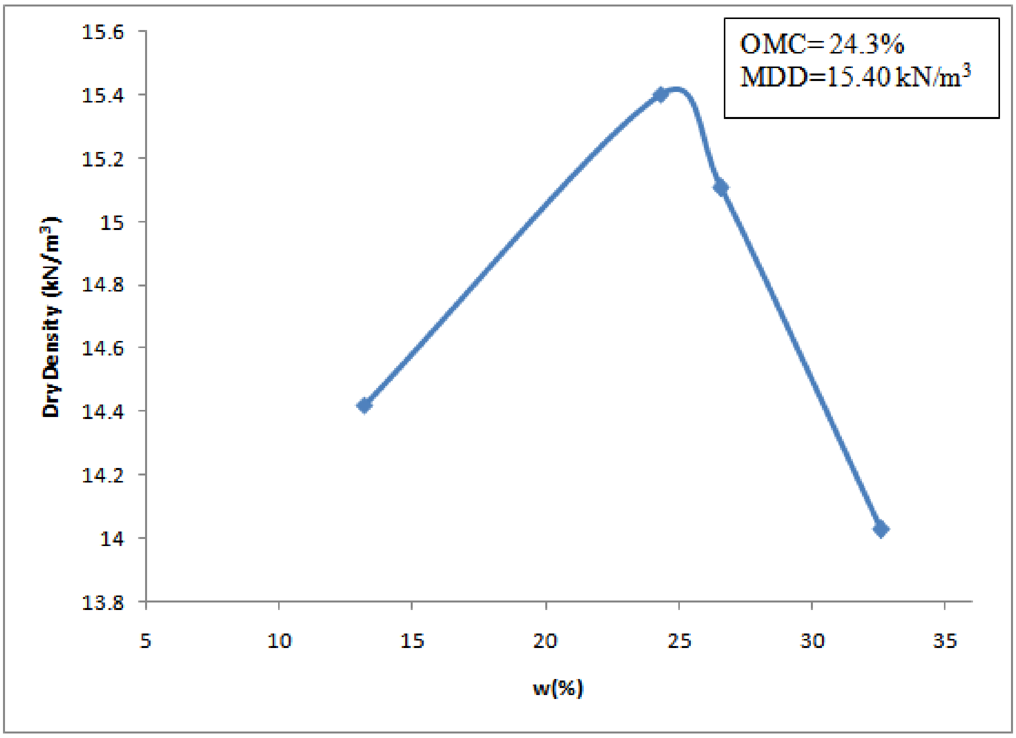

Figure 3: Modified proctor compaction curve for the soil

Gradation: gradation of coarse aggregates and screenings is shown in following figures. The upper and lower limits are as per IRC:19.

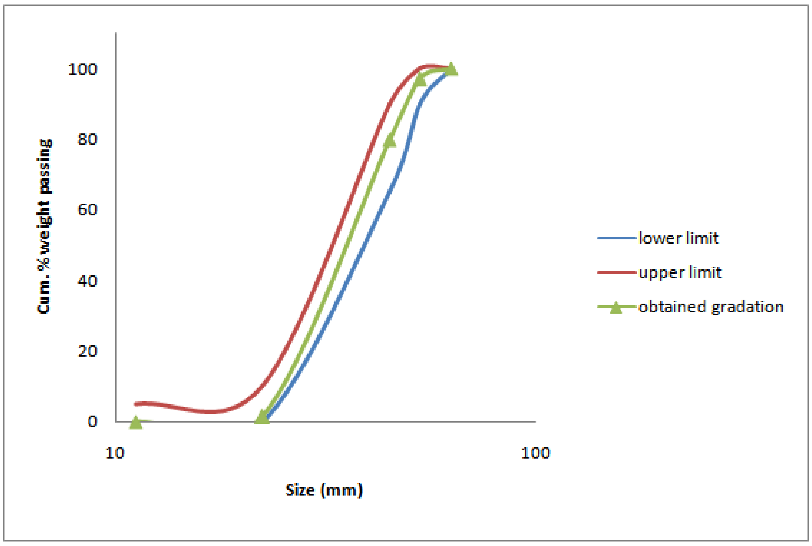

Figure 4: gradation of coarse aggregates for WBM-A

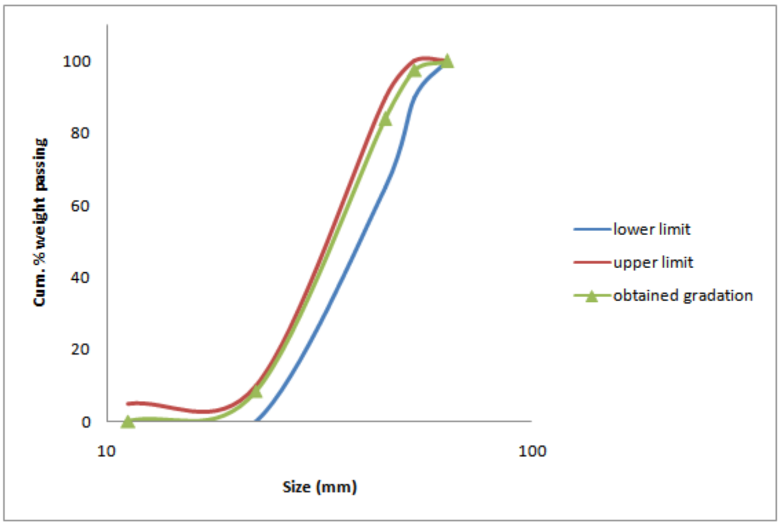

Figure 5: gradation of coarse aggregates for WBM-B

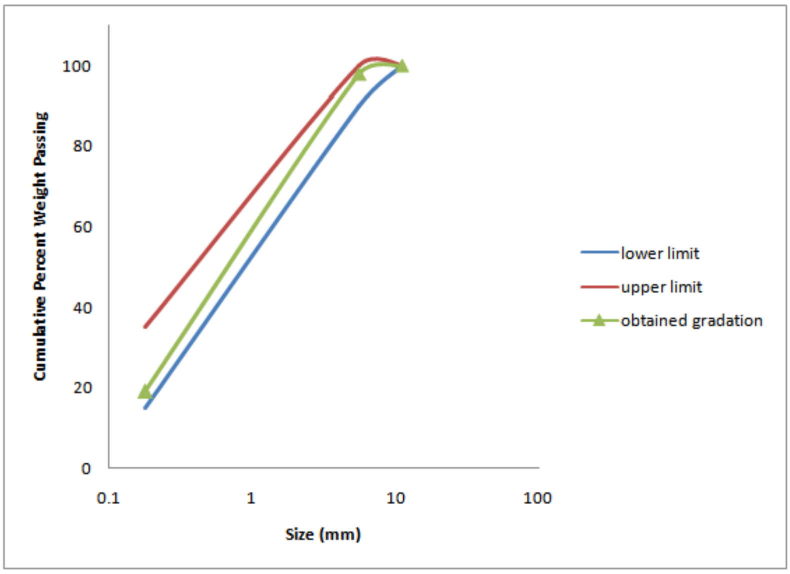

Figure 6: gradation of screening/fines

IV. Results And Discussions

The effect of partial replacement of aggregates by steel slag in a WBM course is discussed in this section under three headings, a) Its effect on MDD. b) Effect on CBR value. c) Effect on rutting characteristics.

4.1. Effect on Maximum Dry Density (MDD): it is observed that WBM-A exhibited MDD of 20.60kN/m^3 and WBM-B exhibited MDD of 22.66kN/m^3, indicating 10% increase in MDD for WBM –B after partial replacement by steel slag, specific gravity of steel slag is higher compared to conventional aggregates. Fig. 7 & 8 show modified proctor compaction curve for WBM-A and WBM-B respectively. Fig. 9 presents the comparison of MDD.

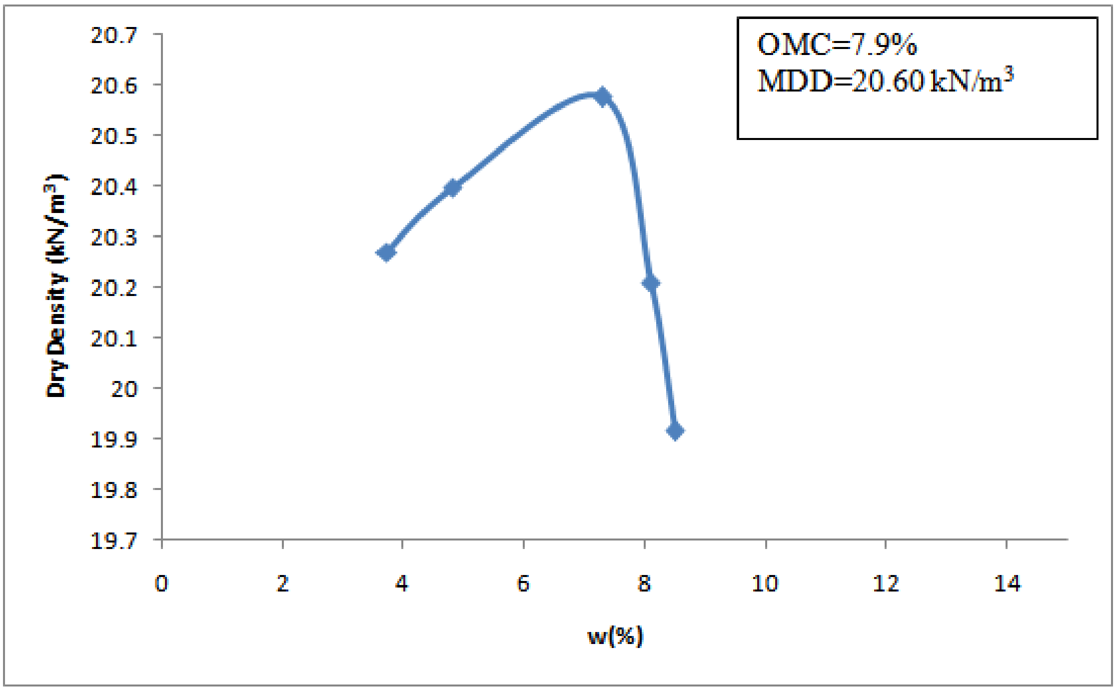

Figure 7: modified proctor compaction curve: WBM-A

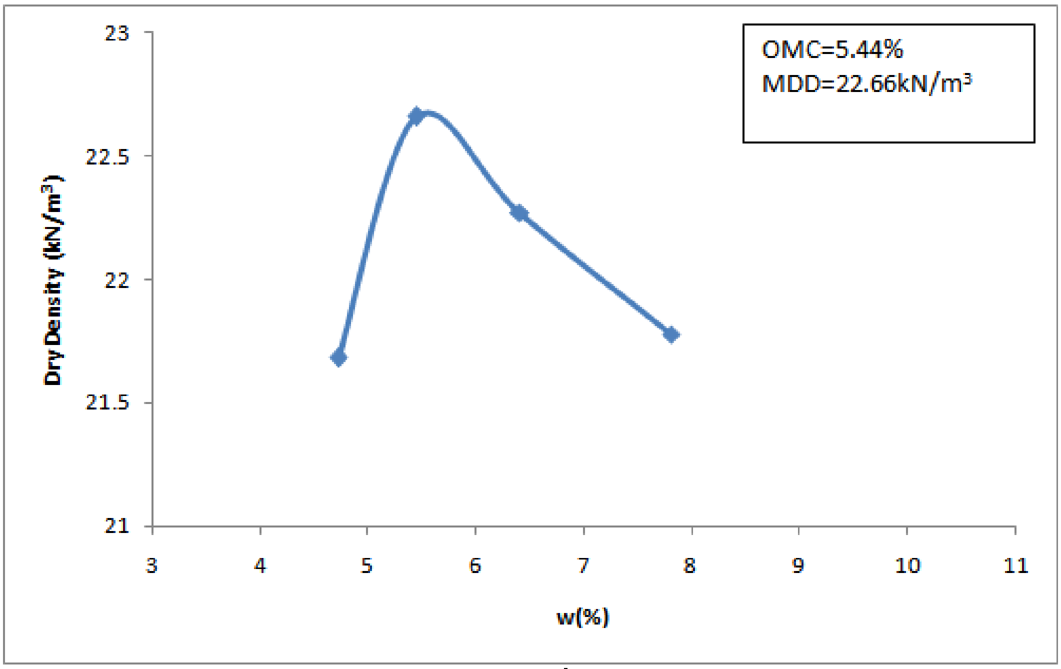

Figure 8 : modified proctor compaction curve: WBM-B

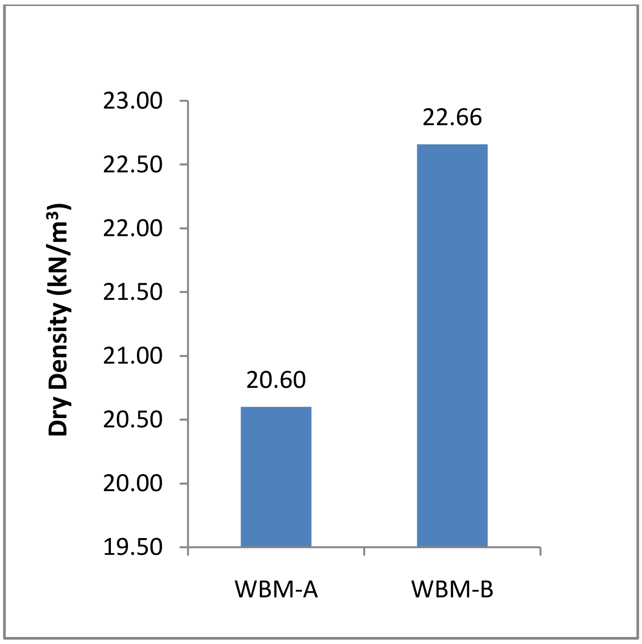

Figure 9: comparison of maximum dry densities

4.2. Effect on CBR value: Average 4 days soaked CBR values are compared in Fig. 10. It can be observed that partial replacement by steel slag resulted in about 52% improvement in CBR value.

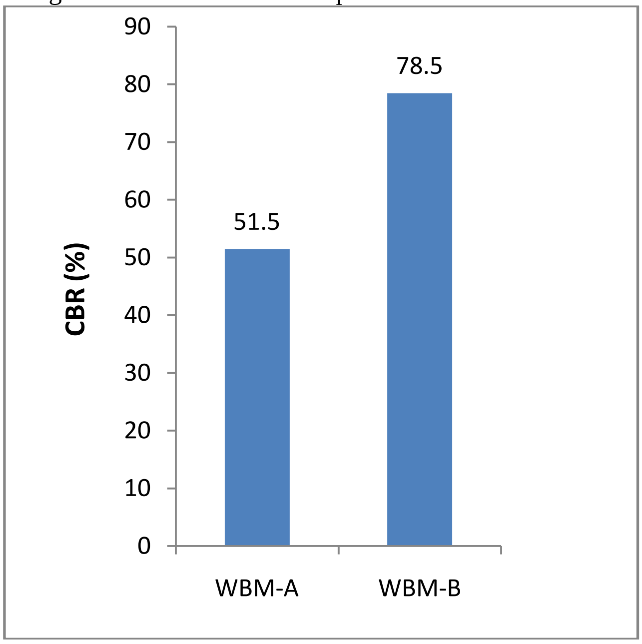

Figure 10: comparison of CBR values

4.3 Effect on rutting characteristics:

As per IRC: 37, limiting value of rut depth is 20mm owing to serviceability requirement of pavement. Two tyre pressures 5.6 kg/cm^2 and 6.2 kg/cm^2 were considered as per IRC:006 and taking into account the overloading goods vehicles for Indian conditions.

It can be seen from the Fig. 11 that for tyre pressure of 5.2kg/cm^2 WBM-A sustained 82 passes where as WBM-B stood 97 and from Fig. 12 it is clearly evident that for 6.2 kg/cm^2 tyre pressure WBM-A sustained 72 passes where as WBM-B took 78 passes.

It can be observed that at 5.6 kg/cm^2 tyre pressure there is 18% increase in resistance against rutting in case of WBM-B compared to WBM-A and 8% increase at 6.2 kg/cm^2 tyre pressure.

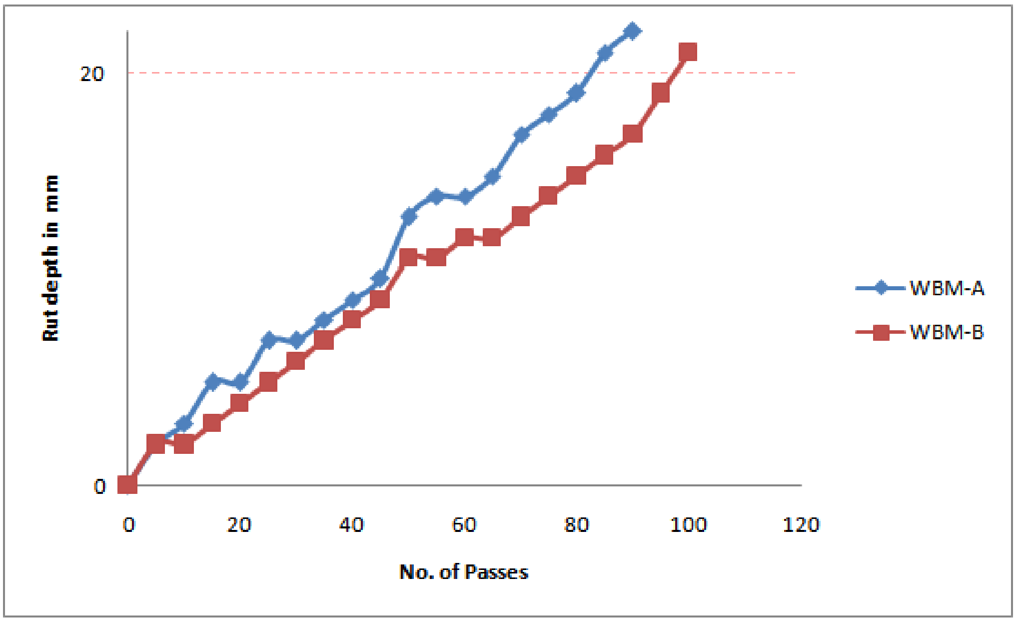

Figure 11: rutting characteristics at 5.6kg/cm^2 tyre pressure

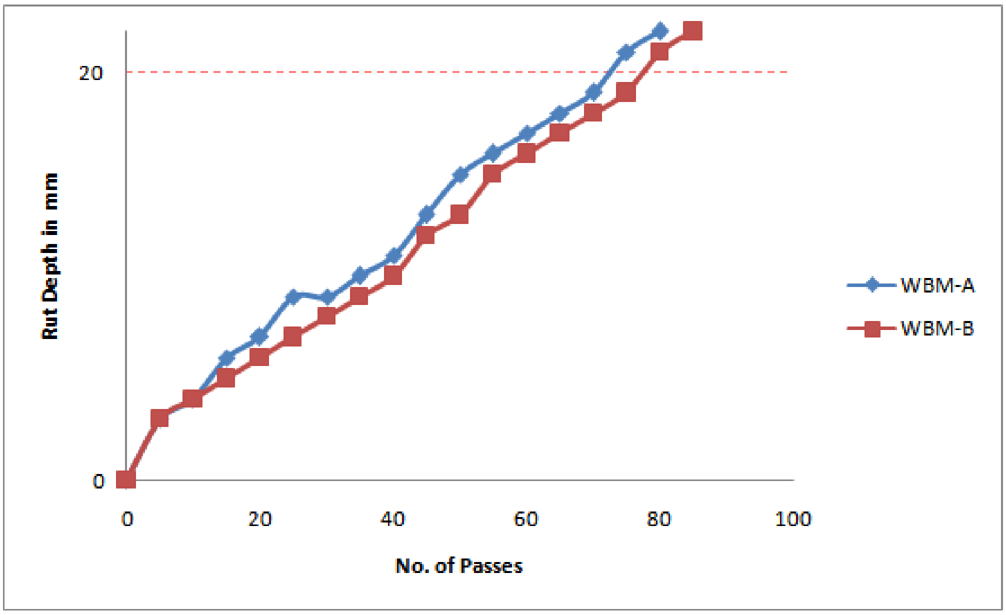

Figure 12: rutting characteristics at 6.2kg/cm^2 tyre pressure

V. Conclusions

Tests on WBM course with conventional aggregates (WBM-A) and partial replacement by steel slag (WBM-B) yielded the following results.

1. Specific gravity of steel slag 3.52 is higher than conventional aggregates 2.9.
2. Water Absorption for steel slag (1.1%) is less compared to conventional aggregates (2%) indicating comparatively lower affinity towards water.
3. Soil used as binder had LL = 40% and PI = 16% well within specified limits as per IRC SP:20, hence found suitable for arid climatic regions.
4. Partial replacement (20%) of conventional aggregates by Steel slag reduces OMC and increases MDD of the WBM.
5. CBR value of the WBM improves by 52% with partial replacement by steel slag.
6. Partial replacement by steel slag also enhances resistance against rutting by 18% at 5.6kg/cm^2 tyre pressure and by 8% at 6.2kg/cm^2 tyre pressure.

Steel slag an industrial waste product can be utilised for road construction in lieu of aggregates thereby promoting sustainability in construction.

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